An Ontology-Based System for Knowledge Management and Learning in Neuropediatric Physiotherapy

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Abstract. This chapter first presents an extensive review of the current state of art in knowledge management and ontologies. Next, we propose a methodology for modeling and building an ontology-based system for knowledge management in the domain of Neuropediatric Physiotherapy and its application to supporting learning. This area of Physiotherapy includes diagnosis, treatment and evaluation of patients with neurological injuries. The domain knowledge in Physiotherapy is, by nature, complex, ambiguous and non-standardized. In this work knowledge was elicited from domain experts and complemented with information from reference textbooks. The acquired knowledge was represented as an ontology. The formal procedures allowed the development of a knowledge-base for further use in an educational tool. The completeness and consistency of formal model was verified. Overall, the main contribution of the work are a domain ontology based on consensus vocabulary for an important area of health sciences, and the possibility of using it as a tool for supporting the learning of undergraduate students. In particular, the application of the ontology for learning in Physiotherapy is of great importance, since it includes multimedia resources as well as active learning concepts, together with traditional instructional methods.

Keywords: ontology, knowledge management, neuropediatric physiotherapy, learning.

1 Introduction

Similarly to Medicine, Physiotherapy also has different areas of specialization. One of them is the Neuropediatric Physiotherapy that includes diagnosis, technical procedures and continuous evaluation of patients that have motor or postural diseases due to lesions in the central nervous system [1].

There are many reference publications focusing all aspects of diagnosis and clinical treatment in Neuropediatric Physiotherapy. However, not all physiotherapists have extensive knowledge of such domain [1].

Recent developments of information technology and the widespread availability of the internet have lead to huge amounts of data in all segments of human knowledge, including those related with health sciences [2]. Physiotherapy in general, and, more

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specifically, Neuropediatric Physiotherapy, is a domain where knowledge is subjective by nature and concepts are poorly systematisized. This has been the main drawback for creating a consensus vocabulary and, consequently, sharing and reuse of data, information and knowledge. Efforts towards this issue would allow efficient management of technical knowledge in this area, by organizing, validating, maintaining and spreading the available expert knowledge. As side effect, both teaching and learning could be enhanced, by introducing formalized concepts and vocabulary.

Modeling and developing a formal structure for representing knowledge in the domain of Neuropediatric Physiotherapy can be of great interest and an important contribution not only for Physiotherapy, but also, for other health-related areas. Such areas are frequently characterized by subjectiveness and the use of non-standardized information. Therefore, they could benefit from the use of knowledge management methodologies.

An ontology is a formal description of a given knowledge domain based on concepts and relationships. Recent literature has demonstrated that such approach is an efficient way to structure knowledge in many areas. This is the formal approach used in this work, which methodology can be extended to other similar areas.

Besides the importance of ontologies for knowledge management, we will show that a developed ontology can be also useful for the teaching-learning process in the related area. Ontologies are frequently used for the development of consensus vocabulary. However, the use of ontologies for learning is poorly explored, especially in the health-related areas.

The objectives of this work are: (1) apply formal procedures for knowledge management in the specific domain of Neuropediatric Physiotherapy; (2) develop a reusable and extensible ontology for representing knowledge in that domain; (3) propose a methodology for using the developed ontology as an educational tool in Neuropediatric Physiotherapy.

2 Knowledge Acquisition and Representation

In the Artificial Intelligence (AI) area, the word "knowledge" means the information that a computer program needs to solve problems in such a way considered intelligent [3].

Knowledge is made up of data and information [4] Data are raw, isolated facts. Information is a set of organized facts. The term information is defined in a more generic sense as knowledge obtained from investigation, study, or instruction. Finally, knowledge is information within a context [5]. Knowledge leverages experience and interpretation to make sense out of information and data. In other words, knowledge is a set (information) of facts (data) and relationships (context) used or needed to obtain insight or to solve a problem [6].

Knowledge can be of two types: explicit and tacit (or implicit) [7]. Explicit knowledge is the one that is available in concrete media (such as books or CD-ROMs) and can be easily shared among people. The tacit knowledge refers to the individual knowledge that aggregates the experience and intuition of each one. Tacit knowledge is implied or understood from the context without being actually stated. It is accepted that people knows much more than they can speak about or transmit [8]. Therefore, the knowledge acquisition process from a given expert domain may be quite difficult, if tacit knowledge is wanted to acquire.

Overall, the knowledge acquisition and representations can be considered as a linear and hierarchical progression, in which data are converted into information, and information is converted into knowledge [4].

2.1 Knowledge Acquisition

The Knowledge Acquisition (KA) process includes elicitation, transformation and transfer of information from a knowledge source to a computer program. The objective of KA is to obtain specialized knowledge from an expert to solve problems [9].

The KA process is usually divided into two stages: initial analysis, when it is decided which knowledge is necessary; and knowledge elicitation and interpretation, when the knowledge itself is acquired from the expert [3].

The main potential knowledge sources are the human experts. Also, other sources of explicit knowledge are considered as complimentary, such as textbooks, data bases, experimental reports, as well the personal experience of the knowledge engineer [10].

There are several techniques for KA, such as text analysis, behavioral analysis, analysis of scenarios and interviews.

In the text analysis, knowledge is extracted by means of a careful analysis of textbooks accepted as reference in the corresponding area. This is an indirect way by which the knowledge engineer tries to assimilate knowledge from the expert (who wrote the textbook). This method has the advantage of being possible without the need of a human expert. However, this is also its main drawback, since the direct contact with the expert is much more efficient for explaining terminology and clarifying possible doubts.

Behavioral analysis is a technique that consists in a systematic observation of the tasks that an expert executes during his/her professional activity. The observer, although passive most time, is allowed to interrupt the expert requesting further explanations of specific points not understood. Obviously, questioning has to be done with parsimony so as to avoid excessive disturbance.

In the analysis of scenarios, the knowledge engineer submits selected cases (tasks), either real or hypothetic, to the expert and observes their resolution. The selection of cases should be based on the premise that they reflect relevant problems that cover a considerable portion of the domain, as well as problems that include different levels of uncertainty. This technique emphasizes the case-based reasoning, where a solution of the problem is based on the adaptation of a known solution for a similar problem.

Interview is an interactive activity between the knowledge engineer and expert. It is based on an answer-reply strategy and, usually, several sessions are necessary according to the depth and complexity of the knowledge to be elicited. Interviews can be directed, structured and semi-structured, as follows:

- A direct interview is similar to a habitual conversation in which the expert talks with the knowledge engineer about specific subjects of his/her domain. The interview usually follows a predefined agenda, focusing selected topics of the domain. Such agenda is previously sent to the expert to allow the familiarization with the subjects. The main objective of the interview is to acquire a broad overview of the area of expertise as well as the tasks involved.

- The semi-structured interview is similar to a questioning. The information required is more specific and at a deeper level than that focused in the directed interview. The objective here is to acquire a better understanding of the issues involved in the solution of a given problem. The strategy is to divide the most general tasks into subtasks. The order of questioning is changeable so as to allow the knowledge engineer to adopt a terminology according to the progress of the interview and the appropriation of knowledge. This kind of interview combines open and closed questions.
- Structured interviews have some characteristics that make them useful in KA. They require a careful previous planning of the questions to be done and the order of questioning, besides the actions expected from the knowledge engineer. This kind of interview should take place after the interviewer has already acquired enough knowledge about the domain, so as to explore specific issues. The interview is based on closed questions, previously elaborated with the objective of extracting information that was missing in previous semi-structured interviews.

There are many obstacles to be considered during the KA process, for instance: experts have extensive and specialized knowledge, usually tacit (that is, they are not aware of all they know, but use such knowledge to solve problems); frequently, experts are very busy and difficult to approach; due to the level of specialization, experts do not know everything about the domain. Consequently, to achieve success in the KA process, it is necessary to devise ways to circumvent the obstacles previously mentioned.

To illustrate in a general sense the KA process, it is presented an example proposed by Milton [11]. This method starts with a simple approach and then proceeds with more elaborated techniques, as follows:

- The first step is to conduct an initial interview with the expert, aiming at establishing the objectives and the scope of the knowledge to be acquired. Also, it is important to make clear how and for what purposes the knowledge will be used. Establishing a communication channel with the expert, allows the basic terminology of the area to be acquired, as well as facilitate further approaches. This interview (as well as all remaining ones) should be recorded to preserve information.
- Next, the initial interview should be transcribed and the resulting document analyzed. From this analysis, a hierarchy of concepts about the knowledge is constructed, thus obtaining a general overview of the domain. The hierarchy can be further used for producing a set of questions about the main topics of the domain, as well as serving as guide for the KA process.
- In the third step, a semi-structured interview with the expert is conducted, using the questions previously planned. The objective here is to enhance structure and improve focus.

- The expected result of the previous step is a documented protocol with the main concepts of the domain, their attributes, typical and limit values, relationships and explicit rules.
- In the fifth step it is suggested the representation of the knowledge acquired to date using appropriate analytical models (rules, diagrams, hypertexts and others).
- Based on the previous models, a questionnaire is elaborated for a structured interview, so as to complement and extend the information modeled.

The steps described above should be repeated until the formal model generated meets the expectations of both expert and knowledge engineer. After finishing the KA process with an expert, it is desirable to validate the knowledge with other experts, who may require changes. In this stage, the knowledge engineer must to have a strategy for managing possible conflicts.

2.2 Knowledge Representation

One of the main concerns of AI researchers is how to represent knowledge. The question is how to capture, in a formal language suitable for being processed by a computer, knowledge in its full extension, so as to enable its use to simulate intelligent behavior [9].

Therefore, Knowledge Representation – KR, is the method used by the knowledge engineer to model expert knowledge in a given domain. The representation should be efficient enough for using by a computer, thus, it may include a combination of data structures and interpretative procedures. KR is always related with the ways by which humans express information. Although there is much research towards the development of general languages and systems for KR, still different types of knowledge require different representation methods.

Sowa [3] points that KR is the application of logics in the task of constructing computational models in a given domain. Frequently, KR is referred as "knowledge representation and reasoning" because KR formalisms are useless without the possibility of reasoning and inference with them.

KR is closely related to the KA process. Actually, as the knowledge engineer conducts the KA process he/she has to record the acquired knowledge using formalism and so, KR takes place. This is the way by which real-world facts and events, human convictions and expertise are computationally modeled and used [10].

Amongst the many methods for KR proposed in the literature, possibly the most frequently used are logics, rules, semantic nets and frames [9]. Fig. 1 shows the methods for knowledge representation.

- Logics: the logical representations are based on Mathematics and Philosophy, trying to characterize the principles of correct reasoning. It concerns about the development of formal representation languages with consistent and complete deduction inference rules (deduction).
- Rules: production rules consist of propositions, usually in the form "IF *A* THEN *C*". The antecedent (*A*) is a logical conjunction of conditions, and the consequent (*C*) is a given class. The conditions of the antecedent are *t*-uplets

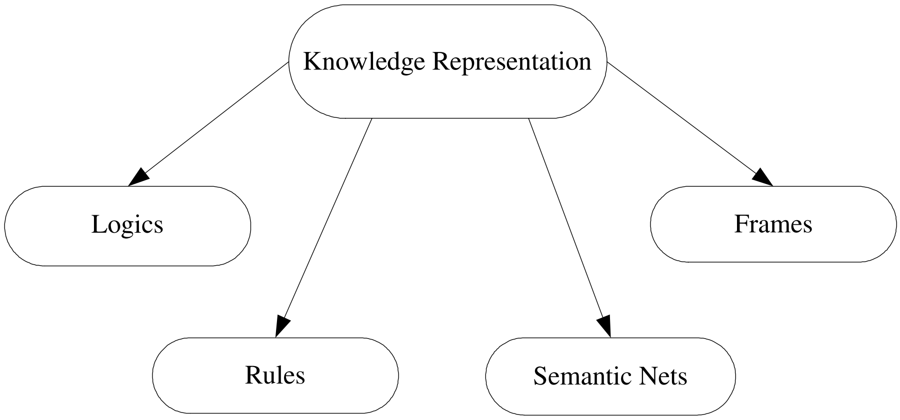

Fig. 1. Main methods for Knowledge Representation

in the form <A_i *Op* V_{ij}>, where A_i is the *i*-th attribute, *Op* is a relational operator, and V_{ij} is the *j*-th possible value of the corresponding *i*-th attribute. The combination of several conditions in the antecedent is accomplished by means of the logical operators. The consequent of the rule consists of a simple condition in the form <$M_i = V_{ij}$>, where M_i is one of the possible target attributes and V_{ij} is the same as above.

- Semantic nets: represents knowledge explicitly as a graph, where vertices correspond to facts or concepts and edges correspond to relationships or associations between concepts.
- Frames: are data structures that group elements into classes, subclasses, down to instances. Each frame is composed by slots that contain features and properties of a class or instance. Frames connect each other to build a compete idea.

Therefore, a knowledge base can be defined as a mapping between objects and relationships of a given domain, and the computational objects and structures within a computer program. Results of inferences in the knowledge base should correspond to results of actions or observations of real-world facts. The objects, the relationships and the inferences are all mediated by the knowledge representation language.

3 Knowledge Management

Knowledge Management (KM) includes the procedures for creating, maintaining, applying, sharing and updating of knowledge, aiming at to increase the organizational performance and aggregate value to the established knowledge [12]. According to Keeling [13], the main objective of KM is to use the experience and comprehension of people in an organized way so as to enrich the intellectual property. A more significant definition of KM is an innovative practice that allows collaboration and communication between knowledge developers of the same or different domains [5].

Smith and Farquhar [14] summarize KM as a procedure that improves the organizational performance, because allows capture, sharing and application of the collective knowledge to take correct decisions. To accomplish this, organizational knowledge has to be constantly updated and reviewed.

KM, in its basic form, exists since long ago, and can be identified in many professions and areas, such as, philosophy, religion, education, and politics. However, the concept of KM, as a subject or specific branch of knowledge, has developed only from a decade ago. KM has become more technical and formal as the necessity and value of knowledge has increased in large organizations, to be competitive with the growing technological advancements.

3.1 Knowledge Life Cycle

According to the Merriam-Webster dictionary [15], life cycle is a series of stages by which something (such as individual, a culture or a manufactured product) undergoes during its lifetime. Many researchers describe the life cycle of knowledge. For instance, Birkinshaw and Sheehan [16] described four stages: creation, mobilization, diffusion and commoditization. Staab et al [17] described the knowledge life cycle as a circular process that includes: creation and/or importation, capture, access and use. Also, Bhatt [18] described a cycle composed by four stages: creation, revision, distribution and adoption. However, independently of the terms describing the life cycle of knowledge, attention should be paid to each stage of Knowledge Management, otherwise, knowledge can become invalid, outdated and unreliable.

3.2 Knowledge Management in Healthcare

The widespread use of informatics in health areas has fostered the need for information systems, diagnosis support systems, and teaching/learning support systems. Consequently, an underlying problem that emerges is the acquisition, representation and management of knowledge in such systems [13]. Knowledge Management (KM), in particular, is essential for supporting and improving the efficiency of health professionals in their daily activities [7].

Davenport and Glaser [19] report that KM helps health professionals to avoid errors, to learn with other colleague's experience, and to access updated and specialized information, when necessary. There are, also, other circumstances that contribute to popularize KM in this area: the health professional can give support to the system so as to create, extend or improve the knowledge-base and, more importantly, he/she still will have control over the situation, being the only responsible for the final decision about a diagnosis or treatment.

During decades, health professionals have seen the exponential growth of knowledge in their areas of expertise, and the growing difficulty in accessing, manipulating and sharing information. Nowadays, the access to information is essential to provide a satisfactory clinical and therapeutic support to patients. It is a matter of fact that, in the near future, health professionals will need complimentary education to deal with the ubiquitous information technology and manage knowledge in the respective area [20]. Information technology is a critical issue that establishes a clear division between past and future for health professionals and the way they manage patients.

4 Ontologies

Several data structures can be used for organizing and formalizing knowledge, as mentioned before. Recently, an emerging approach that has drawn the attention of researchers is the ontologies. Based on a set of concepts and their relationships, an ontology establishes concisely a formal descriptions of a given knowledge domain.

The origin of the word "ontology" relies in the Philosophy, and was introduced by Aristotle. In this context, philosophers try to answer the questions: "What is a being?" and "What are the common characteristics of all beings?" [21]. More recently, both the AI and KM communities have adopted this term to express concepts that can be used to describe a given area of knowledge or, else, to construct a representation of it.

A frequently used definition of ontology is provided by Gruber [22], who asserts that it is a formal and explicit specification of a conceptualization. Such definition requests further explanation of the meaning of words used [23]:

- Conceptualization is referred to an abstract model of a given phenomenon that identifies relevant concepts of such phenomenon;
- Explicit means that the type of concepts used and the limitations of their use must be clearly defined;
- Formal indicates that the ontology must be capable of being processed by a machine.

In fact, the literature about ontologies presents several different definitions, some of them are complimentary each other. Fig. 2 shows an schema with the main components of an ontology.

For instance, Guarino [24] presents a extensive discussion about the meaning of the term within the scope of Computer Science, as follows:

- In AI, an ontology is a theory about which entities can exist in the mind of a knowledge agent [25];
- From the point of view of a knowledge about a particular task or a domain, an ontology describes a taxonomy of concepts that define the semantic interpretation of the knowledge [26];
- Ontologies are consensus about shared conceptualizations. Shared reflects the notion that the ontology captures consensual knowledge. That is, this knowledge should not be restricted to a few number of individuals but, instead, accepted by a group of experts in the domain of the ontology [27];
- An ontology is an explicit, but partial conceptualization, a logic theory that restricts models into a logic language [28];
- An ontology is an explicit and partial specification of a conceptualization that is expressible, from the meta-level point of view, in a set of possible domain theories, with the objective of modular design, redesign and reuse of intensive knowledge [29];
- Ontology is an explicit specification of knowledge level of a conceptualization, which can be affected by a particular domain or task, for which it has been created [30].

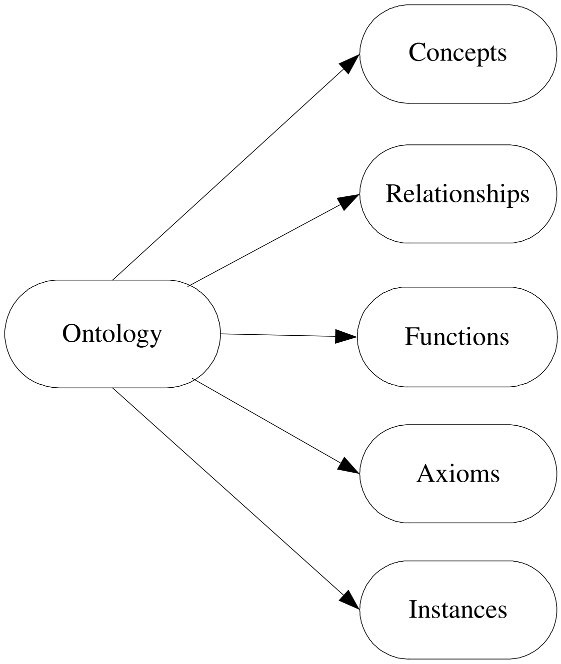

Fig. 2. Main components of an ontology

Another complimentary definition of ontology is proposed by Gómez-Pérez [31] who includes information about its structure: an ontology is a set of hierarchically ordered terms aimed at describing a domain that can be used as skeleton for a knowledge base. According to such description, an ontology groups a set of terms organized with a hierarchy or associated taxonomy. An important detail of this description is to present one of the main utilities of an ontology, which is to serve as the starting point of a knowledge base.

This definition makes an important distinction between ontology and knowledge base. Ontology creates the structure over which it is possible to construct a knowledge base. It provides a set of concepts and terms to describe knowledge in a given domain. On the other hand, the knowledge base uses those terms and concepts to describe a given reality. If this reality is modified, the knowledge base will be modified as well to reflect it, but, even so, the ontology remains unchanged, provided the domain is the same.

In general, there are some important benefits in using ontologies, as follows. Ontologies can provide a common vocabulary for representing knowledge among a group of professionals, thus decreasing ambiguities and interpretation errors. By using ontologies a formal representation of knowledge can be constructed, thus allowing information sharing. Differently from natural language, where words are subject to contextual semantics, ontologies offer an exact description of knowledge. Finally, the same conceptualization represented in an ontology can be expressed in several different languages and its reuse may extend a generic ontology to be suitable for specific domains.

4.1 Structure and Classification of Ontologies

According to Gómes-Pérez [31] and Maedche [21], ontologies are structured over several components:

- A set of concepts (also known as classes) and a hierarchy among concepts, that is, a taxonomy. A simple example of taxonomy is the concept of "man" being a sub-concept of "people";
- A set of relationships between concepts. An example of relationship between concepts "people" and "car" is "the owner of";
- A set of functions (also known as properties). A function is a special case of relationship in which a set of elements has a unique relationship with another element. An example of function is "to be parent", where the concepts "man" and "woman" are related to another concept "people";
- A set of axioms, that is, rules that are always valid. An example of axiom is the assertion "every people has a mother";
- A set of instances, or specialization of concepts. Gómez-Pérez [31] considers instances as part of the ontology, in opposition to the definition proposed by Maedche [21], where instances belong to the knowledge base.

There are several classifications of ontologies, provided by different authors. Mizoguchi, Vanwelkenhuysen and Ikeda [32] classify ontologies according to the function: domain ontologies, task ontologies and general ontologies. Uschold and Gruninger [33] classify ontologies according to their degree of formalism: highly informal, semi-formal and rigorously formal ontologies. Jasper and Uschold [34] classify ontologies according to their application: neutral authorship, as specification and common access to information. Haav and Lubi [35] classify ontologies according to the structure: high-level, domain, and task ontologies. Van-Heijist, Schreiber & Wielinga [30] classify ontologies according to their contents: terminological, information-based, knowledge modeling, application, domain, generic and representation ontologies.

Guarino [36], on the other hand, classifies ontologies in a simple and intuitive way, according to their level of generality, therefore having some overlapping with other previously mentioned classifications:

- High-level ontologies: they describe general concepts, such as space, time, event, and other. These concepts are usually independent of a given problem or domain;
- Domain ontologies: they describe a particular vocabulary related to a given domain, and can be a specialization of a high-level ontology;
- Task ontologies: they describe the vocabulary for a given task or generic activity;
- Application ontologies: they are more specific and particularize concepts from both the domain and the task ontologies.

In general, the high-level ontologies are those that have the largest capacity of reuse, and application ontologies, the smallest one. This is because high-level ontologies define generic concepts, and application ontologies define concepts regarding a specific application.

4.2 Applicability of Ontologies

Currently, there are many areas in which ontologies have been successfully applied, for instance: knowledge management, electronic commerce, natural language processing, web information retrieval, education, and other.

There are KM-related projects that include acquisition, representation, maintenance and access to knowledge within the scope of an organization. Ontologies can help to provide the basic structure over which enterprise knowledge bases are constructed.

In projects related to electronic commerce, it is possible to develop automated transaction systems. They require a formal description of products, beyond syntactic exchange formats. An ontology can provide a common description and understanding of terms, thus allowing interoperability and ways to accomplish an intelligent integration of information [21].

In natural language processing, domain knowledge is essential for a coherent comprehension of the text. Ontologies can play an important role for elucidating the ambiguities inherent to text interpretation, and to establish a dictionary of concepts within the text domain.

Due to the exponential expansion of the information available in the internet, much attention has been given to web information retrieval (or semantic web). The search engines available are not able to improve search and obtain precise results without discovering the precise meaning of the web pages searched. To circumvent this problem, Tim Berners-Lee [37] proposed the semantic web that includes semantics to the web pages by using three technologies: Extensible Markup Language (XML), Resource Description Framework (RDF), and ontologies. Basically, the role of ontologies is to provide a semantic structure in the annotations of web pages.

Ontologies are essential for the development of knowledge-based systems. Every knowledge-based model is, explicitly or implicitly, committed to some kind of conceptualization, which, in turn, is the basis for ontological models [38].

The most important KR projects are based on ontologies, such as CYC [39] and TOVE [33]. Specifically in the health sciences, there are important research projects that include ontologies and knowledge-base construction, for instance, SNOMED-CT [40] and GO [41].

In education-related projects, ontologies can become learning environments that describe a physical domain with rich details and standardization of terminology. Consequently, the formal representation of knowledge is accomplished with educational purposes [42].

4.3 Methodologies for the Development of Ontologies

It is important to adopt a methodology for modeling an ontology in order to avoid jumping from the KA process directly to the implementation phase. Such procedure may cause problems such as: difficulty or impossibility of reuse, since the ontology is implicit in the code, and difficulty in communication, because the domain expert usually does not understand computer languages in which the ontology was implemented.

Some methodologies for the systematic development and manipulation of ontologies are available [43]. Currently, the most widely known and cited in the literature are:

- Methodology of Uschold and King [44]: it is based on the construction of the Enterprise Ontology and comprehends four development stages: identification of the purpose of the ontology, construction, evaluation and documentation. However, this methodology does not describe in details the techniques for executing those activities. Data for the construction of the ontology are obtained by means of interviews with the domain experts, and also reusing existing ontologies;
- Methodology of Grüninger and Fox [45]: it is based on the experience of the authors in developing ontologies for small enterprises. The methodology has a formal procedure for identifying scenarios for using the ontology and includes questioning in natural language for establishing the scope of the ontology and for extracting the main concepts, properties, relationships and axioms. The methodology comprehends six steps: definition of motivational scenarios (problems demanding a new ontology and a set of possible solutions); informal definition of competencies (set of questions that require an ontology to being answered); specification of the terminology of the domain(using first-order logic); verification of completeness (matching of the ontology with the competence issues previously defined). Differently from the previous methodology, this one provides more than general principles. After KA, at the second step, a formal language is immediately required in the subsequent steps;
- Methodology of Fernández, Gómez-Péres and Jurino [46]: it is also known as Methontology and describes more deeply the steps to be followed and the artifacts to be generated for creating the conceptual model. It also proposes a life cycle based on the evolution of prototypes. The development process is divided in ten steps, as follows:
  - ✓ Identify the tasks of the ontology and plan the use of available resources;
  - ✓ Specify the purpose of the development and their potential users;
  - ✓ Acquire knowledge about the domain of the ontology;
  - ✓ Create a conceptual model that describes both the problem and the solution;
  - ✓ Create a formalization for transforming the conceptual model into a formal model;
  - ✓ Integrate, as far as possible, other existing ontologies to the new ontology;
  - ✓ Implement the ontology in a formal and computable language;
  - ✓ Evaluate the ontology;
  - ✓ Document the ontology so as to facilitate its reuse and maintenance;
  - ✓ Update the ontology, whenever necessary.
- Methodology of Noy and McGuiness [47]: it includes an interactive development through successive refinements. The development process is divided into six steps: define the domain and scope of the ontology; reuse existing ontologies; list terminology; define classes (concepts) and their hierarchy; define the priorities of classes or concepts, create instances of the concepts within the hierarchy;

- Methodology of Sure and Studer [48]: it is also known as On-To-Knowledge Methodology and is useful for the management of knowledge in organizations. This methodology is divided into five steps: Kick-off (identification of requirements and competence isssues); refinement (from the scratch to an application-oriented mature ontology); evaluation (focused on the technology, the user and the ontology); and maintenance (evolution and corrections, if necessary).

4.4 Software Tools for Developing Ontologies

In recent years, the number of computational tools for constructing ontologies has grown significantly. These tools aim at helping the knowledge engineer not only in building an ontology itself, but also, in reusing knowledge. Possibly, the most relevant tools available to date are [49]:

- Ontolingua Server, Ontosaurus and WebOnto: they were the first editors for ontologies.
- Protégé, WebODE and OntoEdit: they represent a new generation of development environments for ontologies.
- OILEd and DUET: tools especially suited for developing ontologies for semantic web.

In particular, Protégé was developed by the Medical Informatics group at Stanford University (USA) and is constantly updated. Its core is an ontology editor and has a large library of plug-ins that adds more functionality to the environment. Currently, there are plug-ins that allow to import/export contents in the format of ontology languages (such as FLogic, Jess, OIL, XML and Prolog), flexible access and manipulation of data bases, creation of restrictions and fusion of ontologies [38]. Besides, Protégé is open source and has a Graphic User Interface (GUI) that allows easy access to its resources. With Protégé it is possible to make explicit consensual knowledge, separate the knowledge domain from the operational knowledge, and analyze the domain at a high level [47]. All these features contribute to make Protégé an outstanding tool for KM, widely used by knowledge engineers, facilitating the development, sharing of structure and information, and reuse of knowledge.

5 The Use of Ontologies for Learning

Frequently, “seeing the big picture” is a key element in learning. Ontologies could play an important role in showing the big picture of a subject, allowing students to view knowledge in any sequence they wish and taking the time they need. Using ontologies, students are not forced to follow the order of the instructor; they may start at any location and follow the relationships in any order that is most beneficial to each individual student [50].

Ontologies have been used in colleges and universities for teaching. Milam [51] has described some uses: marketing to future students, describing academic disciplines, documenting data, providing metadata about learning management systems, describing the nature of higher education enterprise, and delineating online resources.

Wilson [52] provided a list of reasons why ontologies might be useful in a learning environment:

1. Students are provided with advanced browsing and searching support in their quest for relevant material on the Web. Especially where their understanding of a topic is low, students can be directed intelligently towards resources of relevance.
2. Syntactically different but semantically similar resources can more easily be located.
3. Information can be shared across educational applications, enabling reuse.
4. Distance learners can be provided with the intelligent and personalized support.

However, ontologies have been sparsely used for learning, although in the current applications very promising results can be observed. Examples are provided by Macris and Georgakellos [53] who developed an ontology for learning environmental education. Also, Hausmanns [54] created an ontology for illustrating contents of dynamical systems. Finally, a relevant reference is Wilkinson [50], who proposed an ontology for Physiotherapy undergraduate students learn anatomy. The work reported here is also focused on Physiotherapy.

6 A Case Study in Neuropediatric Physiotherapy

As mentioned before, Neuropediatric Physiotherapy is an area that includes diagnosis, treatment and evaluation of patients. Such patients, usually babies or young children, have to be frequently evaluated by the physiotherapist in order to observe the progress of treatment [1] [55].

When a child with neurological lesion is under diagnosis by a physiotherapist, its motricity and movement functionality is evaluated, regarding to the normal motor development. For instance, a normal child of 8 months old of *chronological age* is expected to have also 8 months old of *motor age*. On the other hand, a child affected by a neurological lesion can have 8 months old of chronological age, but 2 months old of motor age. This discrepancy is considered as a motor delay or abnormal condition. Starting from this presupposition, the physiotherapist is in charge of analyzing all the complex components of the normal motor development to be stimulated during the treatment of the patient. The objective is to foster motor development in such a way to make motor and chronological ages to match.

To treat children with neurological lesions, the physiotherapist must know the normal motor development (NMD) of a child, with all its peculiarities, so as to be able to recognize what would be abnormal. Therefore, the several steps of NMD are used as reference in the diagnosis procedure, as well as during treatment [56].

Understanding the underlying complexity, the extension, and non-standardization of terms in Neuropediatric Physiotherapy, it becomes clear the importance of correctly content learning and diagnosing to be able to carry out an effective treatment. It is in this scenery where the building an ontology takes place, establishing clear and definite concepts and relationships.

6.1 Knowledge Acquisition Procedure

Building an ontology is a labor-intensive activity and it becomes even more complex due to the absence of a standard vocabulary in the Neuropediatric Physiotherapy domain.

Uschold [57] emphasizes that there is no unified methodology capable of fulfilling all requirements for modeling any domain. In this work we followed the two steps associated with the development of an ontology, as proposed by Zhou et al [2]: (i) knowledge acquisition and management of the concepts between different sources of information (management of conflicting opinions), and (ii) implementation of the ontology itself using the represented knowledge.

The classical artificial intelligence suggests that the knowledge engineer should use a single knowledge source (expert) [10]. However, in this work we use an ontology for representing knowledge. The main authors in this area recommend that ontologies should be based by a consensus of a group of experts [22] [36]. Therefore, to cope with such contradiction, we decided to engage three expert physiotherapists. All of them had extensive expertise in Neuropediatric Physiotherapy, including educational (theoretical) and therapeutic (practical) experience.

Experts took part of several individual interviews. First, previously planned semi-structured interviews were used, and then, structured interviews for deepening specific subjects. To meet the requirements of the domain, on those interviews we adopted a six-phase questioning system proposed by LaFrance [58]:

1. Broad overview: a semi-structured interview was applied to the experts aiming at to understand the reasoning used during both diagnosis and therapy.
2. Categories cataloguing: all the classes (concepts) and subclasses relative to the domain were clearly defined.
3. Attribute detailing: structured interviews were carried out for analyzing how frequent was the use of each concept for different types of diagnostic outcomes.
4. Weight determination: weighting factors for each diagnostic class and subclass were obtained
5. Cross correlation: a consistency check was done after experts have exanimate all the information stored necessary for creating the ontology for Neuropediatric Physiotherapy.

Another important issue in the knowledge acquisition process is managing conflicts and divergence of opinions between experts. We used the methodology known as IBIS (Issue-Based Information System) [59] to manage conflicts between experts. This methodology helps to evolve a divergence of opinions to a convergence, thus emerging a consensus. When the knowledge engineer comes upon a question with different answers from the experts, he/she decides in favor of the one with better arguments. That is, the answer that is better supported by approval or justification. When two answers have justifications, one should choose the one with the large number of supporting arguments.

When finished the knowledge acquisition process with the experts, all information collected was checked against the main textbooks in Neuropediatric Physiotherapy [1] [55] [60].

As result of the knowledge acquisition process, the relevant information for diagnosis and learning was grouped into five main classes: reflexes, reactions, movement plans, movement patterns and motor skills. The divisions of these classes were also defined, as well as all relationships between the classes of the ontology.

6.2 Knowledge Representation in the Ontology

Acquired knowledge was represented in a hierarchical structure of an ontology. First, a taxonomy of terms was created with the main concepts (classes): *MotorAge* (corresponding to the diagnosis), *NormalMotorDevelopment* (NMD – set of characteristics belonging to a given diagnosis) and *Patients* (representing specific cases). This hierarchy was refined by creating subclasses from derived concepts: *MotorAge* included the 12 first months of life; *NormalMotorDevelopment* included the main components analyzed by the physiotherapist (reflexes, reactions, movement plans, movement patterns, motor skills and values); and *Patients* included some case-studies of real patients. Subclasses of NormalMotorDevelopment were later refined.

Next, the properties pertaining to each motor age (diagnosis) were represented, including their respective components of the NMD. An example is the property *has-Reflex* that connects individuals of the *Reflex* class with individuals of *MotorAge* class. For the full description of the domain, the definition axioms of each subclass of MotorAge were declared, thus fulfilling the components of NMD necessary to accomplish the diagnosis.

The tool chosen for knowledge representation was an ontology because it allows the formal representation of tacit knowledge (kept in mind of the experts, but not concretely expressed) usually found in the domain area.

During the development of the ontology, two methodologies were used: Methontology [46] and On-To-Knowledge Methodology [48]. To model the ontology, the following steps of the life cycle of Methontology were done: development, managing and support. In the development process the following activities were done: specification, conceptualization, formalization, implementation and maintenance. In the management process, the control and quality assurance activities were done. The support process was done in parallel to the previous mentioned processes, accomplishing knowledge acquisition, evaluation (analysis of competencies issues and coherence of the taxonomy) and documentation activities. It is important to note that in the specification activity, the principles of On-To-Knowledge Methodology were extensively used.

The implementation of the ontology was done using a computational tool for editing, Protégé[1], version 3.3.1. This tool has extensible architecture, allows good level of details, and its interface is user-friendly. The formal language for representation chosen was OWL-DL (Web Ontology Language – Description Logic), which is recommended by World Wide Web Consortium (W3C). Fig. 3 shows the high-level class hierarchy of the developed ontology.

The classes mentioned in the figure are those defined above. Notice that class *NormalMotorDevelopment* includes all components of the NMD (not expanded in the

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[1] http://protege.stanford.edu/

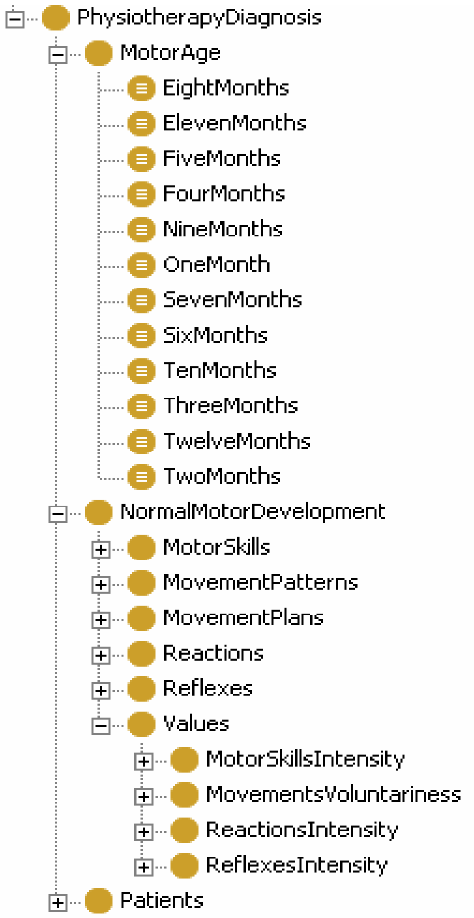

Fig. 3. High-level class hierarchy.

figure) necessary for the diagnosis of the patient in each class of *MotorAge*. Class Values includes the (relative) intensities of each component of the NMD.

6.3 Ontology Instantiation as a Learning Activity

The next step is the use of the ontology in the learning environment. This work explores the use of a computational tool for knowledge management for the education of Physiotherapy undergraduate students. These students are expected to use the ontology for developing and improving their own learning abilities. Therefore, using the ontology for studying includes the creation of specific instances, as an active learning process. Students use the preexisting class hierarchies to add contents to the ontology. They are instructed by the teacher to add a given patient profile and their associated features: reflexes, reactions, movement plans, movement patterns and motor skills.

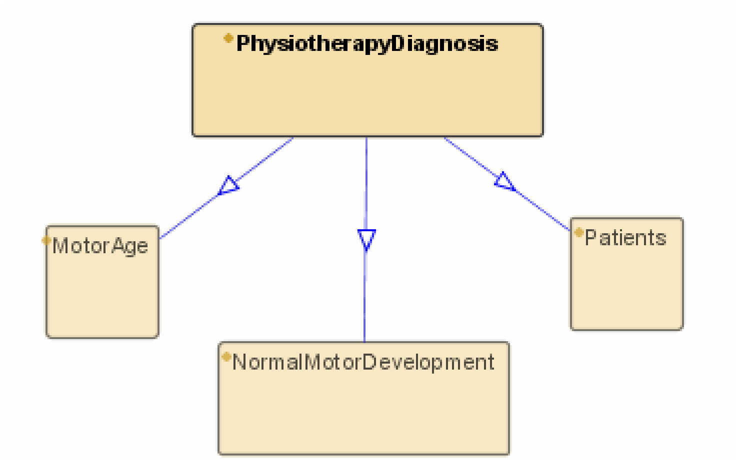

Fig. 4. SHriMP interface - arcs representing relationships

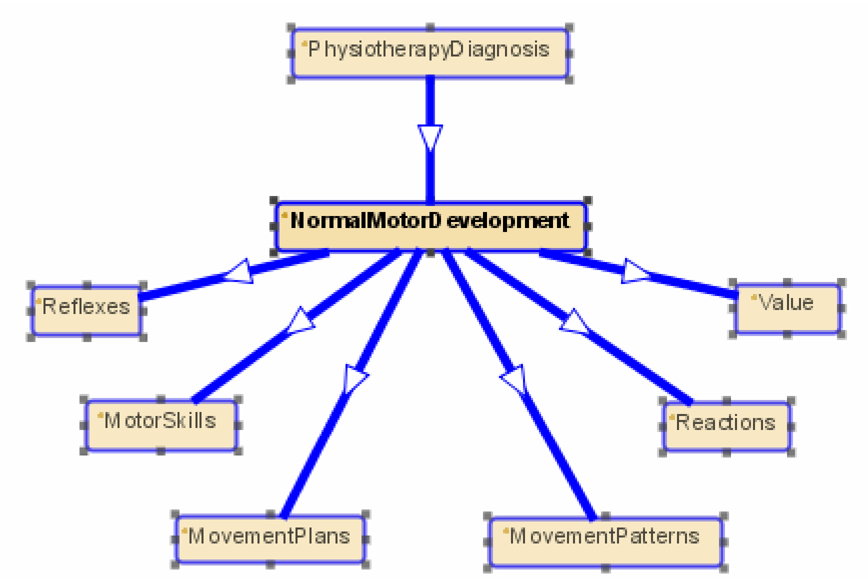

Fig. 5. SHriMP interface and navigation – class hierarchy notions.

The ontology for learning is presented to the student by means of a software known as Simple Hierarchical Multi-Perspective (SHriMP)[2]. Shrimp is both an application and a technique, designed for visualizing and exploring any information space. SHriMP is a domain-independent visualization technique designed to enhance how students browse, explore and understand complex knowledge-bases.

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[2] http://www.thechiselgroup.com/shrimp

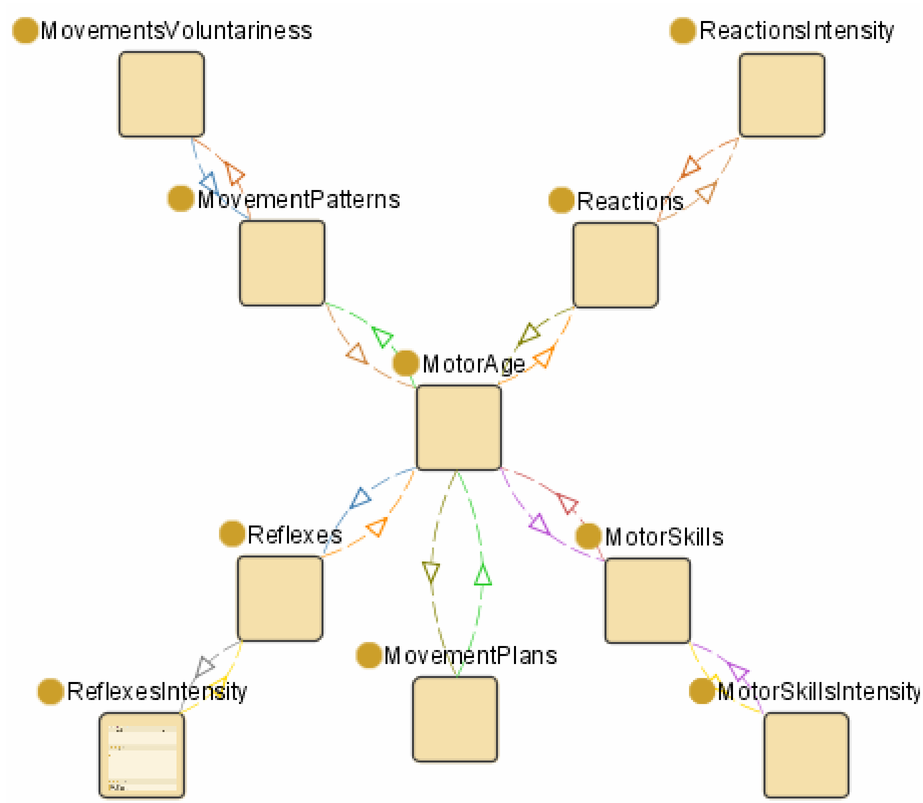

Fig. 6. SHriMP learning environment - edges represent domain and range between existing classes.

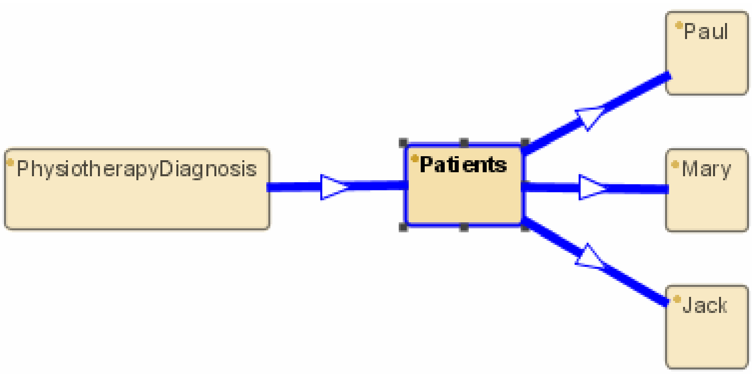

Fig. 7. SHriMP showing individuals (patients).

SHriMP allows a visual representation of the ontology, including edges that represent the relationships between existing classes (Fig. 4, Fig. 5 and Fig. 6) and given instances (Fig. 7). Each class and each instance are presented by a diagram shown in a separated square. Hierarchies, in turn, are fully included in a large square. Its content is represented by smaller squares. For instance, the generic class “patients” is represented by a large square that includes several squares concerning individual patients (Fig. 7). When clicking in each square, the student can visualize several other useful information, such as available subclasses, definition of concepts, and properties.

The ontology also has Uniform Resource Locators (URLs) capable of providing additional information to be available in the Internet. Such supplementary material can be web pages, Portable Document Format (PDF) files, video clips, pictures or drawings. Internet pages present specific subjects about the area of study. Pictures and drawings help to highlight anatomical points of interest or positions. Video clips demonstrate the normal motor development as well as cases of real-world patients.

6.4 Consistency Checking

Inference mechanisms are not explicitly defined in an ontology, although it is possible to reason about the properties of the domain represented by the ontology. Such inference mechanisms can be used to check the logical structure of the model and make inferences about the domain. Therefore, they can be used to crosscheck the consistency of the model and its generalization capability, as well as its relationships and instantiations.

Ontologies allow the distinction between intentional knowledge (general knowledge about the problem domain) and extensional knowledge (specific knowledge about a particular problem). Typically, in an ontology-based knowledge base, the Description Logic (DL) is composed by two components: a *TBox* and an *ABox* [61]. The *TBox* contains the intentional knowledge in the form of a terminology and it is constructed by declarations that describe general properties of concepts. The basic form of a declaration in a *TBox* is a concept definition. That is, the definition of a new concept based on other previously defined.

For checking the consistency of the developed ontology, we used a tool, named RACER (*Renamed ABox and Concept Expression Reasoner Profissional*[3]), together with the other tools available in the Protégé system. RACER implements the *Tableau* algorithm, with which the following checking were done in a *TBox*:

- Subordination or subclassification: starting from the declared constraints in each class, try to infer if a class is subclass of another one;
- Satisfability or concept consistence: analyze if there is some interpretation capable of satisfying the axiom such that the concept denotes a non-empty set in the interpretation;
- Equivalence: verify if two concepts are equivalent;
- Disjunction: determine if two disjoint concepts share the same instance;.

[3] http://www.racer-systems.com/

6.5 Results of the Case Study and Discussion

This section presents the main results and acquired experience during the development of the ontology for the Physiotherapy domain.

In the knowledge acquisition phase, during the structured interviews with the three domain experts, 12 questionnaires were requested to be filled in by them. These questionnaires had 49 items each, making up a total of 588 items evaluated.

It is important to note that, in Neuropediatric Physiotherapy, as well as in many health sciences, there are different schools of though that directs the professional practice, giving different approaches to the diagnosis problem. Due to the difference of approaches between schools of though, it could be quite difficult to establish consensual knowledge, thus making impracticable to build an ontology. As consequence of the lack of consensus, the created knowledge base could be inconsistent, thus making it useless for decision-support. Therefore, this work is directed towards the most widely spread school, created by Karel and Bertha Bobath [1] [55] [60], usually referred to as Neurodevelopment Treatment. As mentioned in section 4.1, knowledge acquisition was carried out with three expert physiotherapists. All of them belonged to the same school of though, thus taking more consistency and reliability to the resulting ontology and the knowledge-base. Even so, considering the large number of items to be evaluated by the experts, some divergences of opinions occurred. The occurrence of conflicts was relatively low, corresponding to only 7% of the items (that is, 41 out of 588). Such level of divergence between experts of the same school is promptly manageable and the IBIS methodology was adequate and efficient for this task.

Knowledge representation was carried out using Protégé. This hierarchical structure gives as result the full organization and formalization of diagnostic knowledge in Neuropediatric Physiotherapy. The current version of the developed ontology is composed by 100 classes and subclasses, 30 properties and 200 axioms. This ontology allowed the creation of vast consensus vocabulary for the domain, including concepts with full definitions through their relationships and axioms.

We believe that the application of the created ontology for supporting learning in Physiotherapy is of great importance, since it includes multimedia resources as well as active learning concepts, together with traditional instructional methods. Consequently, with this complimentary and illustrated resource, the learning of students can be more effective. Also, it promotes the approximation of health sciences with informatics.

7 Conclusions

In this work knowledge was elicited from domain experts and complemented from reference textbooks. Knowledge was formally represented as an ontology, using well-defined methodological procedures, thus enabling efficient management of knowledge during the whole process.

The formalism inherent to the methodology allowed the development of a knowledge-base which completeness and consistency were verified. Such ontology represents a consensus vocabulary in the domain of Neuropediatric Physiotherapy diagnosis, allowing knowledge reuse, sharing and maintenance, accomplishing the Knowledge Management life cycle.

It is important to recall the integration of different artificial intelligence-based methodologies, such as the LaFrance's questioning technique, the IBIS methodology for managing opinion conflicts, the Methontology and On-To-Knowledge Methodology for developing the ontology.

The use of an ontology for structuring knowledge was helpful not only for categorizing the collected information into hierarchies of concepts, but also, to comprehend the relationships between concepts, and, mainly, allowed full definition of concepts using axioms.

The use of this ontology for learning, by means of SHriMP, makes concepts more clearly defined to the student. Also, it facilitates the understanding of the hierarchy of concepts in Neuropediatric Physiotherapy, mainly the dependency relationship between them. Overall, the proposed approach gives the necessary broad view to the students, giving them a solid starting point to deepen the study.

Overall, the main contribution of this work is establishing a complete and effective methodology for knowledge management in the area of Neuropediatric Physiotherapy, an area with many unstructured and non-standardized information that lacks computational approaches for support. Also, the proposed methodology can be extended to other areas of health sciences.

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