# Ontology-guided Problem-based Learning

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**Abstract.** Modern educators have agreed that deep and effective learning is best promoted by learning in authentic activities. Problem Based Learning (PBL) is a pedagogical method that challenges students to learn by creative thinking, by individualizing and sharing responsibility, and by developing problem solving skills. It was launched as an alternative to traditional professional education and has been widely spread all over world either in professional education programs or in general higher education practices. In PBL, students work in small groups with the guidance of facilitators, learning by solving problems while thinking about their own experience. The use of ontologies to represent domain knowledge improves information management in a Virtual Learning Environment because it allows automatic reasoning and facilitates the processes of knowledge search and retrieval. In this paper we show how a domain ontology can help students during the problem solving process.

## 1. Introduction

Problem-based Learning is inherently collaborative [1]. Collaboration allows learners to share ideas and develop new, authentic solutions to problems they are trying to solve, and while doing so, acquire useful knowledge of theories and concepts [2].

A Virtual Learning Environment (VLE) increases productivity in education because it provides access to learning materials at any time and at any place, and if in it implements a PBL facilitate an information transmission to knowledge construction.

Searching, discovering, exchanging and publishing information are important parts of PBL, because knowledge is constructed socially through joint effort towards common objectives. Although students who use these VLE also have access to tools of information retrieval in Internet (for example Google, Lycos and CiteSeer), a proliferation of superfluous data obtained under these conditions in the Web does not guarantee any form of validation or trustworthiness. In addition, the overabundance of the search results leads to the problem known as *cognitive overload*.

Applications of ontology to model related components of learning materials would contribute to effective reuse of knowledge. An organizational structure of generalized knowledge with pedagogical aspect can be helpful when knowledge repository is incorporated into comprehensive pedagogical design. However, in the broader litera-

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ture, there is a lack of formal ontology description of knowledge repository for pedagogical design.

In this paper we present a constructivist paradigm for VLE that includes automated mechanisms for searching and publishing of knowledge, based on the use of ontologies that describe a learning domain to help students in Problem-Based Learning. Students following a systematic procedure can discover and examine contents using pre-designed devices (Learning Objects, LO); to create, validate and publish new knowledge that can be used as learning objects, with a defined interface that allows and facilitates its reusability. The main contribution in this paper is in providing a content search in ontology-based repositories of educative materials.

The rest of paper is structure of the following way. In section 2 we describe foundations of this learning theory. In section 3 we analyze the ontologies concept and Learning Objects and ontologies use in a VLE. In section: 4 we show how to describe a problem domain in an ontology and how to use this representation to helping to students in a problem resolution strategy and we present a search and publish mechanism and expose study case. In section 5 we show the related work and in section 6 present some concluding remarks and comment about the future work.

## 2. Problem based Learning: A Learning Model from Problem Solving Activities

Problem-based learning was characterized as a collection of carefully crafted, ill-structured problems that reveal the underlying principles and concepts of a knowledge domain through the description of real life events and experiences, and serve as stimulus and focus for student activity [3].

It was originally defined as student-centered instruction method, which puts students in a real world situation and expects from them to find out the problems they are interested. Students discover the problem by themselves, trying to figure out at the same time tentative solutions and generating new learning needs through the process of problem inquiring. Comparing to the traditional instruction method, researches also show the students perform different ways of knowledge and processing in PBL [4].

In PBL, students collaborate on complex problems, thereby distributing the cognitive load among the members of the group and by taking advantage of the distributed expertise within the group. Collaboration is a social structure in which two or more people interact with each other and, some circumstances, some types of interaction occurs that have a positive effect [5].

PBL can be also applied to many kinds of curricula, such as business, law, education, engineering, science, among some more. The appropriate application depends on the characteristics and representation of the knowledge domain, which directs a problems complexity in PBL.

## 3. Learning Objects and Ontologies for Knowledge Management in a Virtual Learning Environment

Learning Objects [6] are elements of a new type of computer-based instruction grounded in the object-oriented paradigm of computer science that can be reused. Learning Objects paradigm is widely adopted in a VLE. Ontologies [7], or explicit representation of domain concepts, provide the basic structure around which knowledge bases can be built. The ontological model specifies a generic organizational structure of knowledge repository based on pedagogical design categories. An ontology that actualizes such a structure allows users of VLE to play an active role in pedagogical development through semantically relevant knowledge searching. The intention to represent concepts of any area in ontologies is to standardize and improve knowledge searching and discovery of mechanisms.

### 3.1. Learning Objects to Represent Knowledge

Learning Objects are a new way of thinking about learning material. A Learning Objects is a unit of digital resource that can be shared to support teaching and learning [8], [9]. A Learning Object is an independent and self-standing unit of learning content. Because knowledge can be displayed in many ways, for example a simulation, a text, figures, Learning Objects are suitable to represent them. Learning Objects are used for knowledge sharing in a Virtual Learning Environment [10], [11], [12], [13].

In VLE are emerging standards for describing learning resources, among them Learning Objects Metadata (LOM) [14]. LOM describes metadata for learning objects and is gradually becoming the reference standard for educational system managing learning objects.

### 3.2. Ontologies as Conceptual Model in Management Knowledge in a Virtual Learning Environment

Ontology is a science that studies the explicit formal specification about characteristic terms of a domain and the relations among them [15], [16]. Many different definitions of ontology have been proposed. One of most widely quoted and well-known definition of ontology is Gruber's: Ontology is an explicit specification of a conceptualization [17]. Each ontology is a system of concepts and their relations, in which concepts are defined and interpreted in a declarative way.

The use of ontologies in the educational environment design is not new. Bloom defines a taxonomy of educative goals, in which the category `contents' has a roll that specifies a concepts that were taught in a course [18]. Bloom's taxonomy of education objectives is a framework which has been widely used in all disciplines. The original Bloom's framework includes six levels of learning: knowledge, comprehension, application, analysis, synthesis and evaluation. Given the recent development in the knowledge management field, the term knowledge is no longer appropriate in this context.

Nevertheless, research on the use of ontology in a VLE has been focused in two fundamental aspects [19]:

a) Interoperability and classification of Learning Objects used in Learning Management Systems (LMS) [20]. The ontologies define a vocabulary that is shared by the applications.
b) Generation of adaptable Learning Environment [21], [22]. The ontologies describe roles and contents that allow personalizing a learning process.

Ontology has been receiving considerable attention in the learning research community. In the learning objects field, ontology is typically a network of semantically related knowledge for a specific instructional domain. The role of ontologies in a VLE is often underestimated. They can be useful for systems which have to interact (interoperability) and for the development process itself (reusability, reliability and specification process).

There has been moderate literature on ontologies associated with learning objects [22] [23]. However, few research reports have provided explicit generic structure of ontologies for knowledge sharing.

Learning objects metadata standards intend to generalize taxonomies and vocabularies for learning objects repositories for all discipline [24], [25], [26], [27], [28]. There is a tacit ontology behind a metadata standard. While learning objects metadata describe the artifacts of learning objects that are shared by diverse domain, ontology represent a knowledge domain that shares the relationships of learning objects within a specific context. The use of ontology does not exclude the use of metadata.

## 4. Use of Ontology in guided Problem Solving

In Problem-Based Learning (PBL), while students are identifying crucial parts of the problem, they are also conceiving possible solutions. These solutions can be characterized by the description along with the restrictions of the problem domain to guide the student to a good solution.

In all problem domains that are more susceptible than others of having a better formalization exist fundamental concepts that may be classified with the basic ontological relationships of *subclass of* and *part of*.

The ontologies involved in the guided solution of problems organize knowledge in two categories: Concepts and Solutions. The Concepts class describes the problem domain, whereas the Solutions class describes the existing algorithms. For example in a domain of graph algorithms used in computer science, the former class comprises concepts like graph, directed graph, shortest path and maximum flow subclasses, whereas the latter class comprises Bellman-Ford, Dijkstra, and Kruskal algorithms as subclasses.

The Concepts class organizes in subclasses concepts describing a problem domain and each subclass has the name and solvewith properties. The name property is used to identify class or subclass. The solvewith property associates concepts with solutions. The Solutions class organizes solutions that solve problems in this domain. Each subclass that belongs to this category has several properties. A description property has a brief narrative description of the solution to the students. The properties enlacePW and enlaceOA contain pointers to educative materials (Learning Objects) that describe solutions. The enlacePW property has a link to the main Learning Objects that describe a solution and it is normally elaborated by an expert. The enlaceOA property has more Learning Objects that further develop a solution description. These Learning Objects are elaborated by students and professors. This links allow navigation to review the educational material stored in a Learning Objects Repository. These materials are implementations of a solution and complement an exposed description solution in the main Learning Object.

### 4.1. Searching for Knowledge

Searching for the set of solutions to a problem given by a query consists on determining the set of Learning Objects that represents an appropriate set of solutions to the problem. Algorithm SEARCH shown in Figure 1 retrieves all the known solutions that can better solve the given problem.

Algorithm Search receives as inputs an ONTOLOGY and a QUERY (an abstract narrative description of the problem), and returns as outputs the set of SOLUTIONS that solves the QUERY according to the ONTOLOGY and the set of LEARNINGOBJECTS associated with the SOLUTIONS. As the ONTOLOGY has a hierarchical structure, the search starts in the top of the structure, descending by a breath-first traversal from the most general to the most specialized concept.

The algorithm begins by getting all the WORDS extracted from the QUERY (line 2). The algorithm iterates for each WORD in WORDS (lines 3 through 10) and for each CONCEPT of the ONTOLOGY (lines 5 trough 9) to find those concepts whose property NAME is the root of the discriminating WORD. In case that NAME identifies an abstract CONCEPT in the ONTOLOGY (lines 6 through 8), a new entry in the SOLUTION array is defined to associate the NAME to the SOLUTION obtained from property SOLVEWITH of CONCEPT (line 7). The set of all final SOLUTIONS are obtained by intersecting all partial solutions (lines 10 through 13) and the set of all LEARNINGOBJECTS are obtained by joining the sets of Learning Objects given by property ENLACEPW of each final solution (lines 14 through 16).

In this algorithm, function SPLIT(QUERY) returns the set of all WORDS (with no duplicates) that appear in QUERY, function GETSTEM(WORD) returns the root of WORD by using a LEXICON such as WordNet [29]. The algorithm uses dynamic associative arrays (like those found in JavaScript) in which a new entry is defined by assignment (as in line 7). There are no duplicated entries for this array. Associative arrays have an intrinsic function DOM() that returns the set of all elements for which an entry for the array is defined.

```
ALGORITHM Search
INPUT Ontology, Query
OUTPUT Solutions, LearningObjects
BEGIN
 Solutions, LearningObjects ← Ø
 Words ← Split(Query)) \ NonDiscriminantWords
 FORALL Word IN Words DO
   Name ← Lexicon.GetStem(Word)
   FORALL Concept IN Ontology
     IF Concept.Name=Name THEN
       Solution[Concept.Name] ← Concept.SolveWith
     END IF
   END FORALL
 END FORALL
 FORALL s IN dom(Solution) DO
   Solutions ← Solutions ∩ Solution[s]
 END FORALL
 FORALL s IN Solutions DO
   LearningObjects ← LearningObjects ∪ s.enlacePW
 END FORALL
END
```

**Fig. 1.** SEARCH Algorithm

Predefined set NONDISCRIMINANTINGWORDS contains frequently used words, among articles, pronouns, and verbs, which do not contribute to determine the problem domain. The operations of union (∪), intersection (∩) and difference (\) for generic sets have their usual meaning. The algorithm also uses high-level iterator FORALL that has the form FORALL ELEMENT IN SET DO ACTION END, meaning that variable ELEMENT is instantiated with each member of SET, if no empty, to perform the given ACTION upon ELEMENT. For the ONTOLOGY, the iterator traverses the hierarchy of nodes in a breath-first manner beginning by the top node, as explained before.

Because a problem generally involves concepts whose solutions may completely differ from others, the algorithm returns no solution when SOLUTIONS is empty. When no solution is found, it indicates that there is some inconsistency in the statement of the QUERY.

### 4.2. Publish of Knowledge

Publication consists on augmenting a centralized repository of Learning Objects with the known solutions for the problem. The publication process is lead by an instruction facilitator. In practice, Learning Objects can be either permanent or temporal, according to their duration in the repository. Permanent Learning Objects are elaborated by experts (generally the facilitators) to be used as reference in the subject matter and represents the most complete information available. Temporal Learning Objects are elaborated by students as incomplete, tentative, discardable solutions that arise during the problem solving.

### 4.3. Implementation

RIbONTOMidleware is a middleware [30] that we develop to provide high-level services for discovery, searching and publishing of knowledge. The knowledge level services facilitate a constructivist approach to education. Besides users can perform knowledge administration upon learning objects by means of a dedicated layer that manage a knowledge involved in solving problems by means of ontologies.

In addition, we develop a constructivist VLE EnEMoCi that provides the functionality of a learning management system to conduct the administrative tasks involved in teaching a course. A Constructivist VLE is an adaptable and contextual space that favors independent work from students with the purpose of offering non sequential approaches in order to foment the association of free ideas during problem solving. They are an additional complement to enrich the received education and foment practical ways of designing educational activities and organizing information according to the requirements of the constructivist approach.

### 4.4. Case of Study

In a course of Computational Algorithms it is asked to the students to solve the following problem: "A road map contains information about 20 cities and the roads that connect them have a length given in kilometers. There is always at least one route between any two cities of the map. The problem consists in finding an optimal route between any two cities that minimizes the distance covered by the route. "

Following the PBL methodology, the students start their activities by identifying the learning objectives they have. For this problem, the learning objective can be specified in abstract terms by the query "Finding the shortest path in a directed graph".

Documents related to the specified query were obtained from a search engine like Google [31] that comprises databases containing million of documents organized by classical information retrieval methods. Table 1 summarizes the first ten results the search engine returned to answer the query.

**Table 1.** Search results from Google.

| Links quantity | *Description* | *Average (%)* |
|---|---|---|
| 1 | *Dijkstra's Algorithm Description* | *10 (*)* |
| 2 | *Directed weighed Graph theory and Dijkstra's Algorithm Description* | *20 (*)* |
| 5 | *Data structure exercises* | *50* |
| 1 | *Floyd's Algorithm application paper* | *10* |
| 1 | *The link could not be shown* | *10* |

*(*) The link has information useful for students*

From the list of results, the students have to decide which information is most appropriate by examining each result. It was observed that only 30% from the retrieved information is useful for the students, because they contain enough information (theoretical explanations and algorithms) related to the purpose of the query, so that the students can satisfy their learning objectives.

Nevertheless, if the learning objective that the students have identified can be situated in an ontological domain of Computational Algorithms, then more precise results to that query could be obtained by using the RIbONTOMiddleware, a non-conventional search engine based on ontology containing those abstract terms. The results obtained by using the RIbONTOMiddleware to the same query are summarized in Table 2.

**Table 2.** Search results using RIbONTOMiddleware

| *Solutions* |
| --- |
| Bellman-Ford Algorithm |
| Floyd-Warshall Algorithm |
| Dijkstra Algorithm |

By using this search engine based on context ontology the following conclusions can be derived: (1) 100% of the retrieved information is useful for the students, and (2) the number of links was reduced significantly with respect to the results obtained from the Google search engine.

## 5. Related Work

Proposals that implement a constructivist approach and PBL [32], [33] in the educational process have made emphasis in the experimentation phase of knowledge generation. Nevertheless, its effectiveness is limited because it has insufficient mechanisms for reusability and integration of generated knowledge. It lacks of motivation in making a search of all known solutions and in publishing new knowledge as an integrated mechanism to VLE.

Snae propose the O-DEST system [22] that comprises ontology for e-learning process, such as course syllabus, teaching methods and learning activities. However the description only refers to pedagogical rolls and activities, and it does not approach the use of knowledge search mechanisms. In [34] a revision of the Learning Management System (LMS) concept is presented. It proposes ontology based on the most recent definitions that facilitate the evaluation, selection and implantation of a LMS, but it cannot be extended to other domains. In [35] is presented COFALE, a system to support flexible learning. The system supports the implementation of a problem-based learning that allows an adaptable use of: presentation of learning contents, pedagogical resources and generation of evaluations. Nevertheless, these systems do not include search and discovery knowledge mechanisms that allow the reusability of the generated knowledge. Hsiu-Ping [36] developed a Web-based Environment to support PBL, but this VLE is focused in improving team-working.

## 6. Conclusion

PBL is a constructivist learning process which requires of searching and discovery of information with semantic content for its implementation. Historically knowledge discovery has only recently captured the attention of the research community to use it in VLE design.

In this paper we have outlined a mechanism to guide the students in finding solutions to the given problem with the guidance of ontology in a VLE. It also shows how a semantic model can improve knowledge representation for pedagogical design (by means of Learning Objects). The ontology defines the vocabulary of the problem domain and a set of constraints on how terms can be combined to model the domain. The use of domain knowledge in a declarative form enables automatic ontological reasoning.

We have implemented the searching method which is now part of the RIbONTOMiddleware. The use of RIbONTOMiddleware has demonstrated that the retrieval mechanism based on context ontologies reduce the amount of links that students should navigate. In addition, we have developed the EnEMoCi Virtual Learning Environment that approaches problem-based learning, guides students through the problem solving activities, and implements a methodology for searching and publishing of knowledge.

We will continue our work on the Learning Objects Repository development, implement better user interface and incorporate more domain ontologies.

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