PBLOntology: A Domain Ontology with Context Elements for Problem-based Learning

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Abstract: In education, ontologies have been proved useful for structuring intelligent tutors, collaborative learning, creation of learning models, semantic search for recommendation of learning material, personification and adaption of educational content based on the student's context. Problem-Based Learning (PBL) is a pedagogical methodology that is regarded as an alternative to traditional learning for skills development. However, the use of web-based technologies to support learning in the PBL methodology is still recent. A systematic review was conducted and it has shown the lack of formal representation of the PBL concepts based on ontology language. Thus, this paper proposes a reference ontology for PBL called PBLOntology, which uses context elements of the methodology. For conception of the ontology, a research was conducted in a computer-engineering course that adopts the PBL methodology. To assess the PBLOntology, we defined relevant criteria regarded as fundamental for ontologies: testing activities and evaluation with experts. Although most of the experts stated that the definitions satisfied or partially satisfied, their feedback allowed us adjust some definitions, improving the ontology.

1 INTRODUCTION

In the era of information, it is imperative that students develop mechanisms to build their own knowledge in an autonomous way, by developing multiple abilities and skills (Álvarez et. al, 2005). A pedagogical methodology suitable to this scenario is the Problem-Based Learning (PBL). It aims to encourage students to develop critical thinking, problem solving skills, self-learning, collaboration and communication skills, among others, by means of problem solving, which may not have a unique solution and are often complex (Ribeiro, 2005).

The Semantic Web has enabled the development of personalized learning environments and new forms of collaborative and interactive learning, contributing to a more active and dynamic process of teaching and learning (Kasimati and Zamani, 2011). In this scenario, ontologies have been proposed for learning environments in order to promote semantic interoperability, sharing, and learning customization (Gaeta et. al, 2009).

The student learning behavior can change according to the environment in which he/she interacts. This learning context includes for instance, the style and speed of learning, the time available, the location, personal interests, among others that can contribute to semantically enrich the process of teaching and learning (Medeiros et. al, 2010).

The student context is useful to define the student profile, recommend learning objects, personalize and customize content. Context-sensitive learning environments have also applied ontologies to model context (Barbosa, 2009; Maran and Bernardi, 2014).

The use of web-based technologies to support learning in the PBL methodology is still recent (Brush, 2013; Sobocan, 2017). Souza et. al (2014) conducted a systematic review in order to search for evidences of semantic web technologies for PBL. It was not found in the literature a formal representation of the PBL concepts based on ontology language, which would result a common and shared understanding, available for reuse.

The development of an ontology for PBL process could be useful for: (i) interoperability among systems using PBL; (ii) developing of intelligent systems and agents to assist the tutoring stage of the methodology; (iii) to assist the recommendation and adaptation of content at the research phase of the

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process PBL; (iv) to assess the accomplishment of the PBL process in distance education systems; (v) inferences and analysis on the development of skills and abilities proposed by the methodology.

This paper proposes a reference ontology for PBL called PBLOntology, product of a shared and consensual knowledge, bringing contextual elements of the methodology into this ontology. For its conception, we conducted a case study based on observations, questionnaires and interviews within the course of Computer Engineering in the State University of Feira de Santana (UEFS), Brazil.

The PBLOntology was instantiated using actual data. Its concepts were assessed in two ways: through testing and by the evaluation with domain experts. Essentially this ontology consists of a computational artifact that can be shared, reused and enriched both by researchers and professionals willing to develop semantic-based applications for PBL.

The remainder of the paper is structured as follows: Section 2 presents the PBL methodology; Section 3 briefly describes some related works; Section 4 presents the PBLOntology and the development steps; Section 5 discusses the evaluation process and results; finally, Section 6 draws some conclusions and points out future works.

2 THE PBL METHODOLOGY

The PBL methodology emerged in the late 1960s in the medicine program at McMaster University in Canada, due to dissatisfaction and boredom of students exposed to a large volume of knowledge perceived as irrelevant to medical practice (Barrow, 1996). In Brazil, PBL has been adopted by medical courses and has been also employed in many other areas of higher education, such as pedagogy, business administration, and engineering (Ribeiro, 2005).

A popular reference for PBL systematization is the "seven steps" framework, proposed by the Maastricht University (Deelman and Hoeberigs, 2009): (1) presentation of the problem and enlightenment of unknown terms; (2) identification of the problem posed by the statement; (3) problem discussion and formulation of hypotheses to solve it; (4) summarization of hypotheses; (5) formulation of learning objectives. Based on prior knowledge, the subjects to be studied for solving the problem are identified; (6) self-study of the issues raised in the previous step; (7) return to tutorial group to discuss again the issue in the light of new knowledge acquired in the self-study phase.

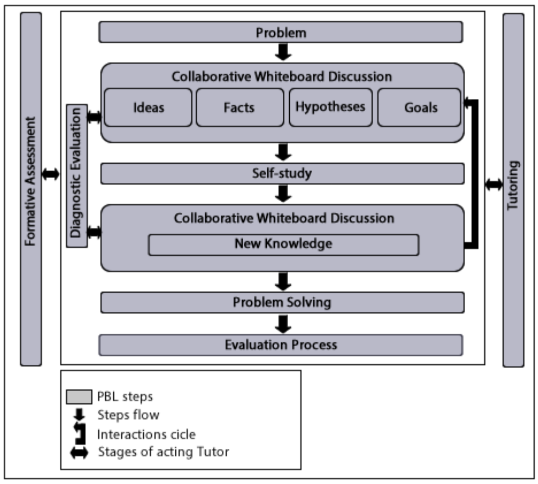

Figure 1: Conceptual Framework of the PBL Methodology.

The PBL session begins with the presentation of a problem to the group members, in which is raised the problem scenario. After that, students perform the collaborative whiteboard discussion. At this stage, students identify ideas and facts, formulate hypotheses, and define issues and learning goals. After the whiteboard discussion, students perform self-study to investigate the literature looking for solutions to the issues identified in the previous step. In the next step, students meet again in a tutorial session to perform a new collaborative whiteboard discussion, applying the new knowledge. New ideas, facts, questions and goals can be identified within a cycle of interactions until the problem resolution.

The Problem Solving stage consists of the submission of a solution by means of the delivery of a software, document, presentation, among other deliverables. At the end of each problem, the evaluation process is performed. Thus, the students have the opportunity to reflect on the knowledge built and to assess the problem, the tutor, the peers, and themselves.

For the methodology to be effective, it is necessary an active participation of the tutor responsible for the group. The tutor acts on three stages of the process: (i) Tutoring – monitors the group throughout the PBL process, (ii) Diagnostic evaluation – identifies students or tutorial group weakness during the session and (iii) Formative Assessment - evaluates the students development of skills and competencies during the PBL process, such as collaboration, communication, writing, leadership, self-study, among others.

3 RELATED WORKS

Jacinto and Oliveira (2008) present an architecture based on ontologies, where each component of the architecture is structured by an ontology, helping the understanding of the concepts of each component and consequently the promotion of interoperability between models of architecture.

Fontes et. al (2011) propose a domain ontology for PBL to facilitate an effective access to information about the area. It states that an important aspect to be considered in PBL is the lack of standardization and uniformity of the concepts related to PBL, hampering the common and shared understanding of the domain.

Our work differs from the related works in the following aspects: (1) our ontology considers the context of the PBL sessions in the formalization process; (2) the ontology presented in Fontes et. al (2011) can not be reused because the author has not shared the ontology in any repository and unfortunately it is no longer available, whereas our proposed ontology is available in a repository for reuse; (3) the ontology shown in Jacinto and Oliveira (2008) is not specific for PBL, besides the PBL formalized process does not conform to the classical references of the methodology: the 7 steps (Deelman and Hoeberigs, 2009) and the PBL cycle proposed in Hmelo-Silver (2004); and (4) these previous ontologies have not been evaluated.

Table 1: Comparison between PBLOntology and the ontologies that formalize the PBL process.

Ontology	Jacinto e Oliveira (2008)	Fontes et al. (2011)	PBL Ontology
Consider the PBL Cycle	-	X	X
Consider Reuse	X	-	X
Evaluation	-	-	X
Integrated within an Application	X	-	-

4 THE PBLOntology

PBLOntology is available for download in Ontohub (http://ontohub.org/repositories/pblontology), a web-based repository for ontologies based on open source software. The Protégé was chosen to develop the PBLOntology because it is an open source code tool and it provides a powerful editor of ontologies including semantic web standard languages. We use the language OWL (Web Ontology Language) due to the fact that it is a robust language, recommended by the W3C (World Wide Web Consortium) as a standard for representing ontologies. The rule language defined for the axioms creation is the SWRL, it allows the combination of the developed axioms with OWL. The query language is SPARQL, because it is also supported by Protégé and recommended by the W3C. The chosen inference engine is the *Pellet* for supports SWRL rules and it has a consistency check mechanism of ontology and good performance. The 101 Method (Noy and MCguiness, 2001) was adopted because it explicitly describes the steps comprising the development of an ontology.

To support the development of the PBLontology, it was performed a field research in the Computing Engineering course of the State University of Feira de Santana. The field research consisted of observations, questionnaires and interviews, during the tutorial sections and it has been performed in a period of six months.

4.1 The PBLOntology Development Steps

A systematic mapping conducted to verify if there was some ontology that could be reused. It has shown a lack of formal representation of the PBL concepts based on ontology language (Souza et. al, 2014).

The development of the PBLOntology comprises of two phases: first we formalized the knowledge of the essential elements that should be considered in PBL. The second phase focused on the formalization of contextual elements that emerged on the collaborative discussions of tutorial sessions.

The PBLOntology is structured as follows: (i) a classes and subclasses hierarchy representing the PBL taxonomy; (ii) Object properties that qualify or relate classes/individuals; (iii) data type properties, representing the attributes of the classes; (iv) instances, representing individuals of the classes; (v) SWRL axioms, which are rules to represent the knowledge domain; and; (vi) SPARQL queries.

During the PBLOntology development, 28 competency questions (CQ) were created. These questions indicate what our ontology must be able to answer and they are important to help testing the ontology, evaluating the constraints, semantic rules, and checking its consistency and competence. The following are some of our competency questions:

CQ1: Which students of a group have not been coordinators?

CQ2: What are the learning questions of a session?

CQ3: What is the problem solving ability of a student?

CQ4: What were the strategies created by the tutor in a tutorial session?

The above competency questions can be useful in many scenarios: the CQ1, for instance, can help the coordinator indicating which student would be the next coordinator. In a distance learning course that uses PBL, the system itself can suggest a coordinator. The CQ4 can help beginner tutors in the creation of strategies according situations other tutors had experienced.

4.2 Classes

To represent the PBL process twelve main classes were defined (*ActionPlan, Evaluation, Fact, Idea, LearningIssue, Person, Problem, Process, SelfStudy, TutorialGroup, TutorialSession* and *WhiteBoard*) and one main class (*Context*) to represent context of the collaborative discussions during sessions. Figure 2 shows the main classes of the PBLOntology.

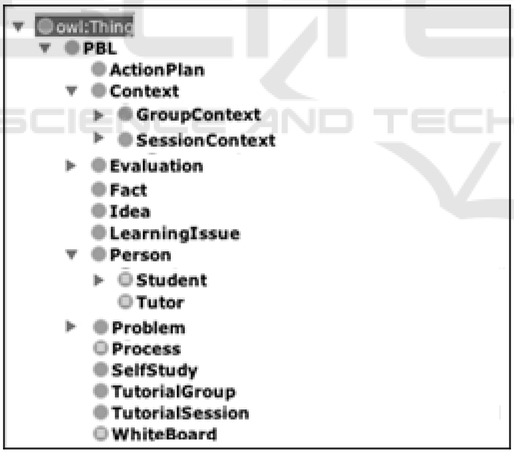

Figure 2. Main classes of the PBLOntology.

The *Process* class consists of the following stages: presentation of the problem; discussion of the problem by the group in the tutorial session; individual study phase that occurs after the tutorial sessions; and the evaluation phase. According to the PBL phases, the *Process* class was defined as a disjoint union of *Evaluation, Problem, SelfStudy, TutorialGroup* and *TutorialSession* classes.

The *Problem* class represents the problem addressed within the PBL process. This problem must be a real or potentially real situation. It is intended to cover a particular content, aiming at the construction of knowledge and the development of skills and competencies.

The *Evaluation* class represents the assessment of both the student and the methodology. It considers the following aspects: compliance with the targets; attendance; collaboration and behavior. These represent the properties of the class. It also includes assessing the assignments of the coordinator, whiteboard secretary, meeting secretary, and the evaluation concerning the delivery of the final product as well as the final report of the problem resolution.

The *TutorialSession* class represents the meeting with the group of students mediated by the tutor. It is intended to discuss the proposed problem, record the discussion progress on the whiteboard while the problem is being approached.

The *WhiteBoard* class represents the whiteboard where students record discussions about the problem during tutorial session. A whiteboard is, therefore, an aggregation of concepts ideas, facts, goals and learning issues. This class is a disjoint union of the following classes: *Idea*, *Fact*, *LearningIssue* and *ActionPlan*.

The *SelfStudy* class represents the individual study phase on the PBL process. Here students research the contents to respond to the learning issues and the achievement of the established objectives.

The *TutorialGroup* class represents the PBL tutorial group, which consists of a tutor and students. The *Tutor* class and the *Student* class are disjoint.

The *Context* class comprehends two main subclasses: *GroupContext* and *SessionContext.* The *GroupContext* class represents the group level and the people who form the group. To define the group's context we have considered the group structure representing the maximum and minimum number of students, and if the group had to be split into other groups or if it had to join another group. The context of people who are part of the tutorial group was also considered: i. e., skills of students in the group, areas of computing interest, previous experience in *PBL,* and reprobation or desertion of the student. The *SessionContext* class captures the context of tutorial sessions. This class considers the temporal context of the tutorial sessions, such as start time, end time, days of the week, the order of the session, the strategies to enable a productive tutorial session, and the interaction context yielded by the group of the tutorial session.

We consider as interaction context the student actions during a tutorial sessions, such as: the collaboration with the discussion, the achievement of the goals, the sharing of new knowledge, the questions formulated during the tutorial session, and the clarification of doubts raised by other students. The tutor interaction was also considered: the assistance in defining the whiteboard questions, the questions raised by the tutor, the clarification of pertinent questions, the assistance in defining the whiteboard functions, and the encouragement of student participation.

4.3 Properties

Aiming to represent relationships between individuals of classes, 37 *Object Properties* were defined in the first phase, whereas 23 *Object Properties* were established in the second phase. Table 2 shows two *Object Properties* defined in the PBLOntology.

Table 2: Object Properties.

Properties	Domain	Range	Inverse
hasPerson	TutorialGroup	Person	-
hasFact	WhiteBoard	Fact	isFactPartOf

The *hasPerson* property represents the relationship between the individuals of the *TutorialGroup* and the *Person* classes that are part of a tutorial group. The *TutorialGroup* class was, therefore, established as the domain of this property, and as the range the *Person* class. The *hasFact* property is the inverse of *isFactPartOf* property and represents the relationship between individuals of the class *WhiteBoard* and *Fact* defined in a tutorial session. The domain of this property is the *WhiteBoard* class and the range is the *Fact* class.

To the representation of *DataType Properties*, *26 properties* were established in the first stage of the PBLOntology development, and 29 properties in the second. As an example, Table 3 shows two *Datatype Properties* defined in the PBLOntology.

Table 3: Datatype Properties.

Properties	Domain	Range
learningQuestion	LearningIssue	string
actionStrategy	Strategy	string

The *DataType Properties learningQuestion* represents a learning question defined on the whiteboard during a tutorial session. The domain of this property is the *LearningIssue* class and the range is string. The *DataType Properties actionStrategy* property represents actions related to the strategies, in other words, what the tutor needs to do during the tutorial session for its proper functioning. The domain of this property is the class *Strategy* and the range is the string type.

4.4 Restrictors and Axioms

The semantics of the terms belonging to the ontology proposed in the first phase was defined with twelve restrictions. Those restrictions involve existential, universal,quantifiers and cardinality.

The restriction defined in the *Process* class, shown in Figure 3, establishes that the individuals of the *Process* class are formed by the union of the classes *Evaluation*, *Problem*, *SelfStudy*, *TutorialGroup* and *TutorialSession*. Besides, it states that this union is a sufficient and necessary condition to establish the *Process* class as an aggregation.

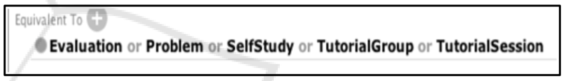

Figure 3: Restriction that determines the formation of the *Process* class.

We have specified five axioms in the language SWRL (Semantic Web Rule Language). The axiom shown in Figure 4 is designed to make inferences about the PBL experience of a student. The rule states that if there is a person within a tutorial group, within a PBL process, then this person has a context The context holds the PBL experience of a person. This axiom can be useful to recommend students as a tutor based on their PBL experience.

```
PBLExperience(?ex), Person(?pe), PersonContext(?perf),
Process(?pro), TutorialGroup(?g), hasExperience(?perf, ?ex),
 hasPerson(?g, ?pe), hasTutorialGroup(?pro, ?g),
isPersonContext(?perf, ?pe) -> hasPBLExperience(?ex, ?pro)
```

Figure 4: SWRL axiom that infers PBL experience of a student.

4.5 Instances

We have created a consistent database populated with actual instances suitable to support the development of future research. These instances Were collected during the field research. In the first stage, 266 individuals were instantiated and among the classes defined in ontologies. In the second stage, over 97 individuals were instantiated.

Figure 5 presents one instances of the *Fact* class where we can observe some data type properties (*PrirKnowledge*) instantiated in that class and an inferred object property (*isFactPartOf*).

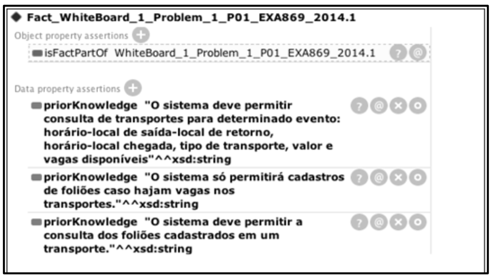

Figure 5: Instance defined in PBLOntology.

5 ONTOLOGY EVALUATION

In the literature, there are two evaluation methods for ontologies: test activities and evaluation with specialists (Santos, 2013; Silva, 2013). According to Vrandecic (2009) it is important to define some criteria to evaluate ontologies. Based on Vrandecic (2009), we defined the following criteria for evaluation of the PBLOntology: accuracy, adaptability, clarity, completeness and competence, consistency and coherence, and conciseness.

To evaluate the consistency, coherence and competence criteria, we carried out testing activities in both ontology development stages. These tests consisted of running the reasoner Pellet of protégé and observing the inferences made in the ontology, checking its behavior, consistency and formalization coherence.

The competency assessment was performed by the SPARQL queries that were created to answer competence questions.

For CQ1: Which students of a group have not been coordinators? The SPARQL query is presented below.

```
SELECT ?Group  ?Student WHERE{
?Grouppbl:hasPerson ?Student.
MINUS{?Sessionpbl:hasCoordinatorSession
?Student}}    ORDER    BY    (?Group)
(?Student)
```

For CQ4: What were the strategies created by the tutor in a tutorial session? The SPARQL query is presented below.

```
SELECT ?TutorialSession ?Event ?Action
WHERE{?SessionContextpbl:isSessionConte
xt ?TutorialSession.
?SessionContextpbl:hasStrategyContext
?Strategy.
  ?Strategypbl:eventStrategy
?Event.?Strategypbl:actionStrategy
?Action } ORDER BY (?TutorialSession)
```

SPARQL queries were designed to verify if the ontology was able to respond each of the defined competence questions.. The competence questions can support the systematization of the methodology and help in decision-making. The PBLOntology answered satisfactorily all defined competence questions, hence, it meets the competence criteria within the defined scope.

To verify if the ontology correctly captures and represents aspects of the real world, a questionnaire with 24 questions was developed. It was answered by 4 experts, who are lecturers with PBL experience in the course of Computer Engineering at the State University of Feira de Santana. The questions aimed to evaluate concepts and class names (conciseness and clarity), relationships and constraints defined in the ontology (accuracy), coverage and completeness. Figure 6 presents the evaluation of the concepts and class names.

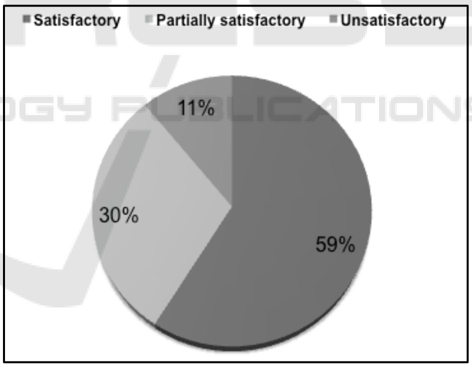

Figure 6: Evaluation of the concepts and class names.

Analyzing the experts' opinions, 59% of the answers stated that the concepts and names of the classes defined in the ontology are satisfactory, 30% partially satisfy and 11% do not satisfy. We also asked the experts to inform the most appropriate concept and name, when the answers were not totally satisfactory and this feedback was used to improve the ontology.

Regarding the evaluation of accuracy, in two questions the experts suggested changes in the ontology relationships and constraints, these changes were implemented. When assessing the coverage and completeness, it was not possible to draw any conclusions, since 50% evaluated the ontology as complete and 50% reported a lack of concepts.

The evaluation of the adaptability criterion was subjective, accomplished through the extension of the domain ontology incorporating context elements that had emerged during the tutorial sessions.

Table 4 presents a general overview of the questions and the evaluated criteria.

Table 4: Analysis and assessment of result.

Evaluation Approach	Results	Conclusion
Testing activities	Correction of inference errors and inconsistencies.	It complies with the coherence and consistency criteria.
	The executed queries brought the expected replies.	It satisfies the competence criteria.
Evaluation with experts	Concepts and names of classes: most questions satisfied or partially satisfied, and suggestions were accepted.	It meets the clarity criteria.
	Coverage: 50% said yes and 50% said no.	It is not possible to ensure that the completeness criteria is satisfied.
	Relationship and restrictions: the majority is correct.	It complies with the accuracy criteria.
Ontology expansion	It was possible to expand the domain ontology including contextual elements observed during tutorial sessions	It satisfies the adaptability criteria.

The assessment allowed us to make improvements to the ontology according to the defined evaluation criteria. A small number of inconclusive issues would have been further clarified had more experts participated in the evaluation.

6 CONCLUSION AND FUTURE WORS

This paper presented an ontology for Problem-Based Learning that provides a semantic formalization of the PBL process, as well as the contextual elements of collaborative discussions that appeared on tutorial sessions.

To mitigate potential problems, two approaches were defined for the evaluation: testing activities and expert evaluation. That approach towards the assessment of the results allowed us to improve the ontology. Thus, we provide strong evidence to conclude that PBLOntology meets the defined evaluation criteria satisfactorily, and displays pertinent applicability to the field of Computer Science.

The proposed ontology advances on current work by providing a formalization of the PBL domain based on ontology. It also establishes an innovative contribution by identifying contextual elements for the collaborative tutorial sessions.

Researchers and those who work with ontologies and development of semantic applications for the PBL domain can benefit from PBLOntology. This ontology can serve as a basis for the knowledge of the domain; It can also graphically illustrate the concepts and relationships of the PBL and therefore enable the understanding of the methodology for beginners in the subject. Besides, it can be reused for the creation of other ontologies or applications. Another advantage of PBLOntology is that it has a database with more than 300 instantiated individuals, which can facilitate the testing of new applications that use the ontology.

Although the ontology can be reused, shared and expanded, contributing to research and studies in the area, PBLOntology has some limitations: it was evaluated only in a computation course, the scope of contextual elements was very reduced and the amount of specialists was not enough to evaluate coverage and completeness of the ontology. Future works should address these limitations.

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