A Hierarchy of Ontologies for Didactics-Enhanced E-learning

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Abstract:

Ontologies are a fundamental concept of the Semantic Web envisioned by Tim Berners-Lee [1]. Together with explicit representation of the semantics of data for machine-accessibility such domain theories are the basis for intelligent next generation applications for the web and other areas of interest [2].
Their application for special aspects within the domain of e-learning is often proposed to support the increasing complexity ([3], [4], [5], [6]). So they can provide a better support for course generation or learning scenario description [7]. By the modelling of didactics-related expertise and their provision for the creators of courses many improvements like reuse, rapid development and of course increased learning performance become possible due to the separation from other aspects of e-learning platforms as already proposed in [8].

1   Introduction

Ontologies are a fundamental concept of the Semantic Web envisioned by Tim Berners-Lee [1]. Together with explicit representation of the semantics of data for machine-accessibility, such domain theories are the basis for intelligent next generation applications for the web and other areas of interest [2]. Top-level application areas identified by [9] are collaboration, interoperation, education and modelling.

Ontologies can be defined as a specification of a conceptualization [10], or in other words as the formal representation of an abstract view of the world.

The most useful features of ontologies are a vocabulary, a taxonomy, the interpretation as a content theory and the usage for knowledge sharing and reuse [2]. A vocabulary for the definition of terms with unambiguous meanings is one component of an ontology. Furthermore, logical statements for the description of terms and rules for their combination and relation are provided. A taxonomy is a part of the ontology concept for a hierarchical classification in a machine-processable form. Ontologies specify classes of objects, their relations and concept hierarchies. That qualifies them as content theories. The primary intentional usage is targeted toward knowledge sharing and reuse. The description of concepts and their relations can be used as the base for interaction and work of different agents or applications [11].

In general the technique described above can be applied for several e-learning aspects. According to [5] there are:

- **Didactical ontologies** for the categorization of learning goals,
- **Thematic ontologies** for the thematic categorization of learning material,
- **Rhetoric-semantic ontologies** for categorization of learning material for the creation of meaning contexts,
- **Relational ontologies** for the description of contextual dependencies and
- **Curricular ontologies** for the organisational categorization of learning material.

Didactics is a science targeting several directions, so it is the science of organized teaching and learning, the science of education or it is the application of psychological teaching and learning theories. Additionally it is seen as the theory of education contents and the theory of controlling learning processes [12]. This paper addresses the organisation and control of learning and teaching processes for e-learning. A taxonomy of didactical approaches is presented in figure 1.
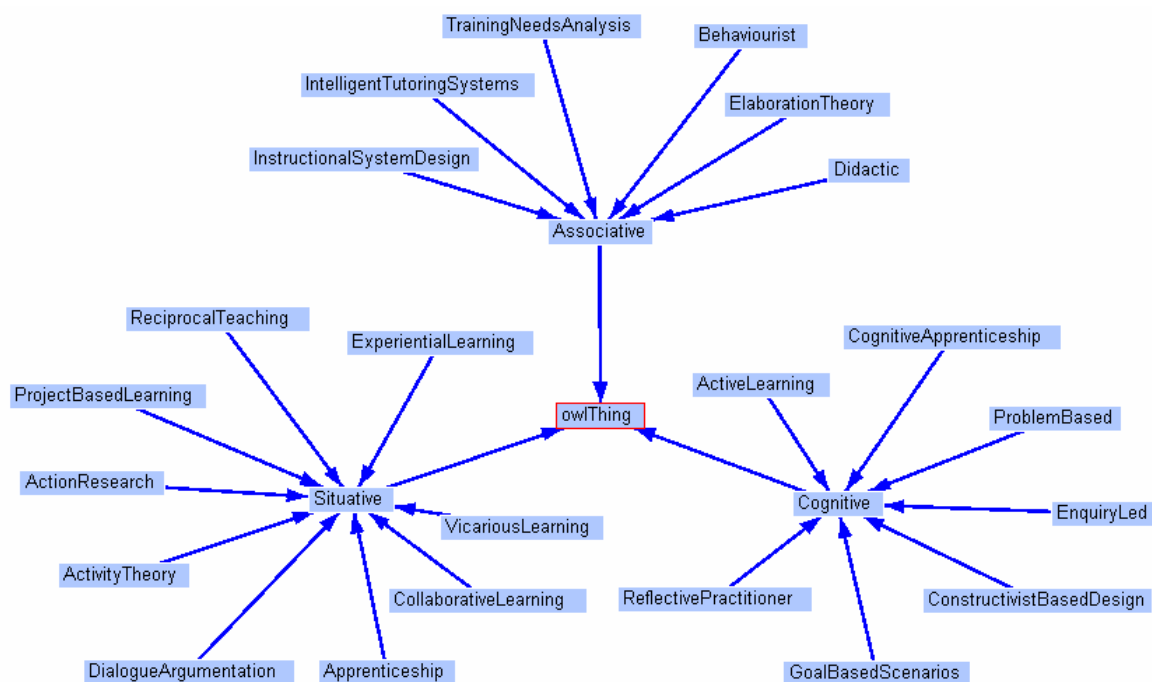

Figure 1: Learning/teaching approaches (cp. [13])

After these fundamental introductory notes about ontologies and their applicability for e-learning some related work and certain approaches that we base on, are described in section 2. Section 3 is dedicated to didactical ontologies and presents the core of this paper, with focus on the corresponding hierarchy. In section 4 we finish with a conclusion and some remarks about future work.

2   Related Work

Already established concepts to represent didactical expertise are Educational Modelling Languages. They shift the focus from a content-oriented design to process orientation (10). Chosen examples are listed below:

- **EML:** The Educational Modelling Language [14] is the basis for the IMS Learning Design Specification ([15], [16]). Its major implementation is an XML-based language and was developed to codify units of study, as e.g. courses, course substructures or

study programs. Therefore it provides structures for the content, roles, relations, interactions and activities of learners and students.

- **PALO:** PALO is a language to describe and design learning scenarios ([17], [18]). A corresponding reference framework provides five layers: management, sequencing, structure, activity and content, each identifying a group of related components of a learning resource. Different strategies can be created by defining special Document Type Definitions (DTD's).
- **TML:** The Tutorial Markup Language is limited to specific learning scenarios as e.g. for questioning and problem-solving. It is an ISO SGML language for the creation of HTML-based learning materials in a platform neutral manner. Thereby it separates delivery mechanism and content representation [19].
- **IMDL:** The Instructional Material Description Language is targeted towards instructional design and thereby limited to this special pedagogical design. It can be used to describe content, structure, assessments, user models and metadata in this context [20].
- **ELM:** The Essen Learning Model is a development model to support the creation of computer-supported learning environments ([21], [22]). Therefore it focuses on project management, quality assurance, process integration, curriculum development and learning sequence development. Another important aspect is the support for the specification of didactical models.

The relevance of ontologies to describe learning scenarios is motivated in [7], too. Here the authors propose an ontology-based configuration mechanism with the help of didactical sound information. They also describe their plan to integrate special ontology relations for the sequencing of teaching activities:

- Local to the learning scenario
    - Relations of didactical aspects to system features
- Global to the learning scenario
    - Temporal relations between activities (*is-preceded-by*, *is-followed-by*)
    - Structural relations to model compositions of activities (*part-of*)
    - Specialisations of activities (*kind-of*)

Another difference is that the authors to provide a specialised extension of their WBT-Master system instead of targeting the provision of general expert knowledge.

In [23] the author describes the Didactical Object Model (DIN DOM) developed within the German Standardization Body. It identifies the following major components to be important for the efficient exchange and reuse of didactical expertise:

- **Context:** to describe the (intended) environment for the scenario
- **Actors:** to model individuals, groups or agents within the scenario
- **Activities:** to describe the didactical concepts within an activity structure
- **Resource:** as the materials and services that are required for the scenario

Special needed sub-ontologies are already developed. As an example, there is a model of instructional objects in [4]. Each concept represents a particular instructional role of a learning resource. But these roles are only implicitly modelled. The following figure summarizes the instructional objects defined by the author.
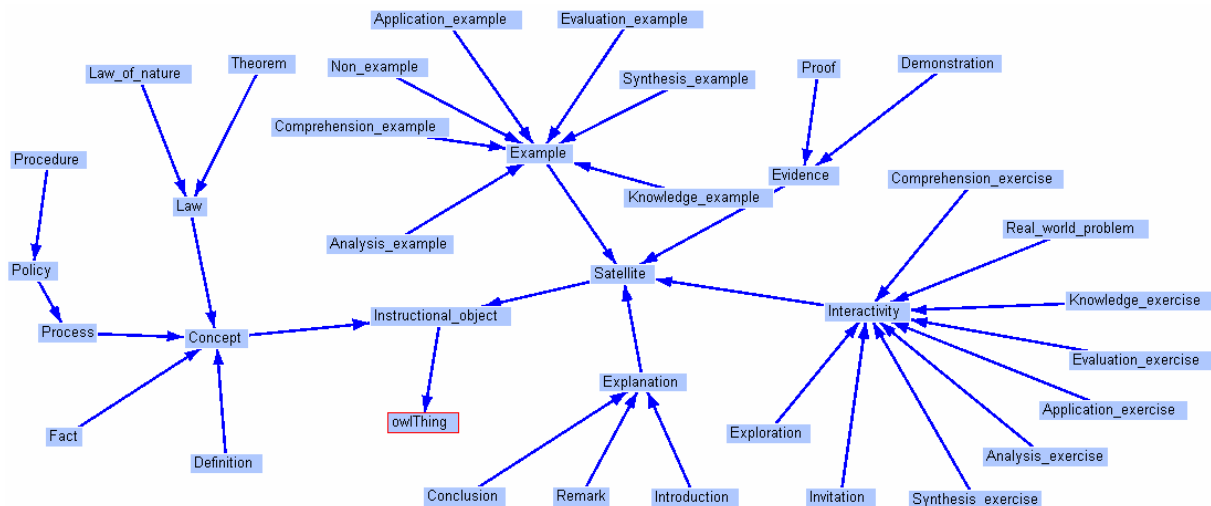
Figure 2: Class hierarchy of didactical objects (cp. [4])

Additional theoretical foundations are analysed by ([6], [24], [5]). There first taxonomies are described that can be usable for the authors' goal. They namely focus on knowledge types, presentation media, communication media, matter of fact relations, communication contribution cooperative objects as well as transactions/assignments.

3   Didactical Ontologies

"Design is that area of human experience, skill and knowledge which is concerned with man's ability to mould his environment to suit his material and spiritual needs." [25]
With our work we want to provide tools mould learning environments for improved and adapted learning experiences. The following paragraph presents our approach for an ontology-based provision of didactical expertise.
Meder [6] defines a didactical ontology as an approach to describe information for being able to structure cognitive learning processes. We go a step further and intend to use those information for the ontology-based modelling of didactical expertise – didactical ontologies.

3.1   Requirements for didactical ontologies

Reusability is very important because we want to provide expert knowledge. According to [23] following requirements need to be met:

- Formal representation, like a metadata model
- Widely accepted representation format
- Available repositories for search and retrieval
- Semantics need to be understandable in different contexts

Reuse of existing standards and ontologies is one of the most important aspects for ontology design. If everybody develops his own 'standard', the intention of ontologies to describe a certain semantic never can be achieved. Within this paper we base on the very valuable and widely accepted ontologies of Meder (cp. figure 3) to describe on knowledge types,

presentation media, communication media, matter of fact relations, communication contribution cooperative objects as well as transactions/assignments ([6], [24]). Another foundation is for example the Learning Objects Metadata standard (LOM) [26].
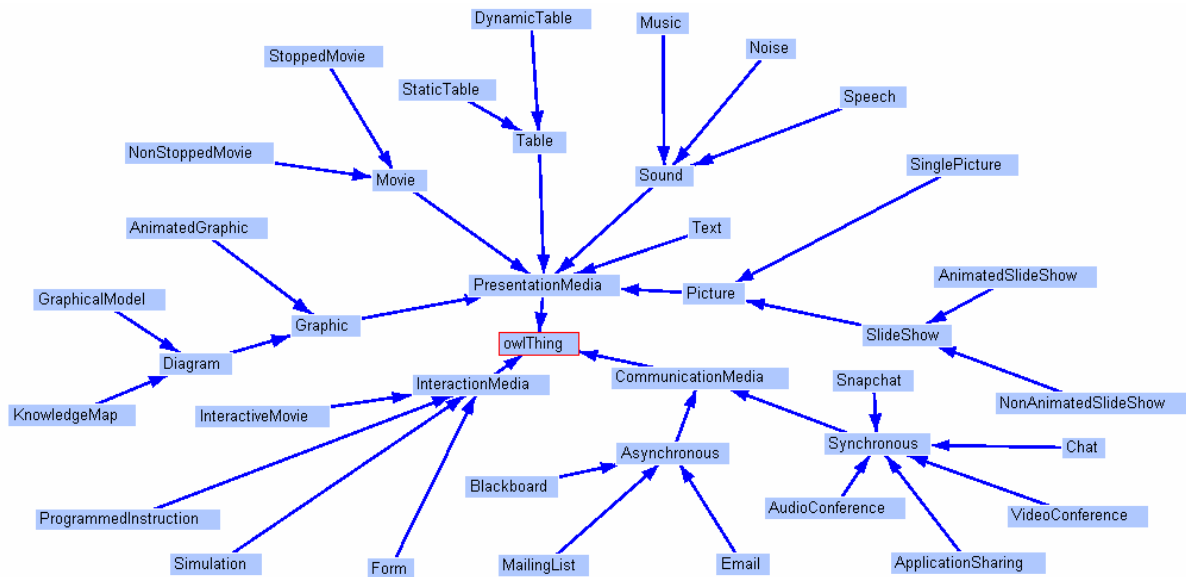

Figure 3: Example Ontology (cp. [24])

Applicability is another requirement. Therefore we present the architecture of a system that makes explicit and extensive use of the proposed ontologies. On the side of a centralized server the authorized sets of didactical approaches can be hosted and maintained (location A in figure 4) within a didactical repository.
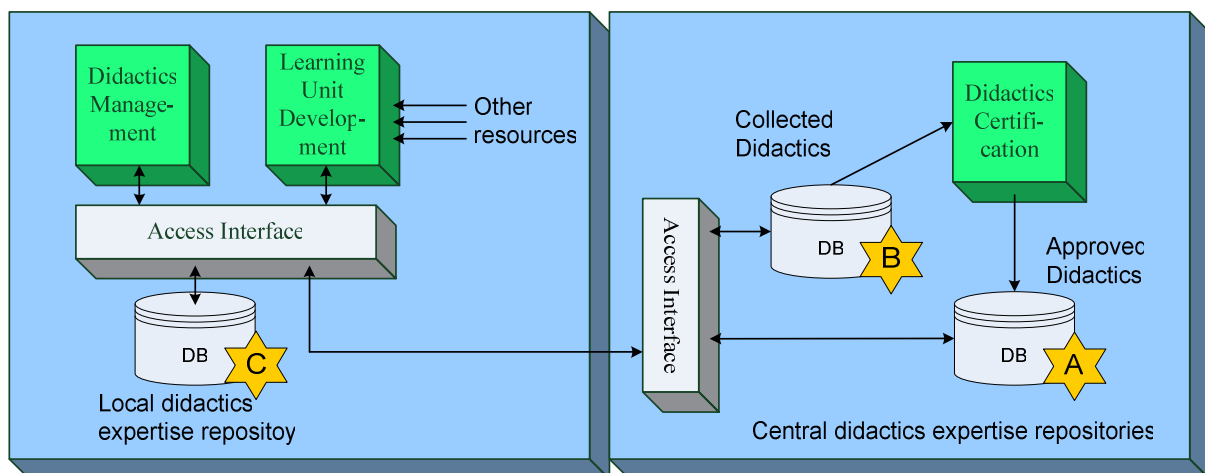

Figure 4: Possible architecture for using didactical ontologies

Of course there may exist other approaches that are (not yet) proved for being applicable, complete – in general sufficient – for the intention of providing didactical expertise. Therefore a collection pool is proposed (location B). This set serves as the basis of the work of a maintenance authority that analyses, re-models, annotates, categorizes and releases (in repository C) the proposed didactical approach, if it is found sufficient for approved usage.

The clients, that can benefit from (a hierarchy) of didactical ontologies, are e-learning systems. They need expertise for the didactically well founded creation of learning units (location C). Together with other resources like the content itself or curriculum specification these information are use to author high-quality e-learning courses. Another possible application is the storage of individual didactical approaches of the specific learning system vendor or operator. By this individual and group competencies can be collected, concentrated, further developed, maintained and made available.

At each location A, B and C the ontologies are used to store the didactical expertise as well as to serve as a directory representation for categorization and search mechanisms.

Extensibility is an integral part of the proposed approach. New expertise must be addable and new usage scenarios applicable. Flexibility is almost always a goal in modern sciences. Nevertheless openness must be restricted, otherwise the core of the approach is left and so usability and applicability are reduced. This can be achieved e.g. by defining new aspects as optional.

3.2   Design of the hierarchy of ontologies

For the hierarchy of ontologies we propose a 4-level structure to support the modelled architecture and to reach the intended advantages (cp. figure 5).
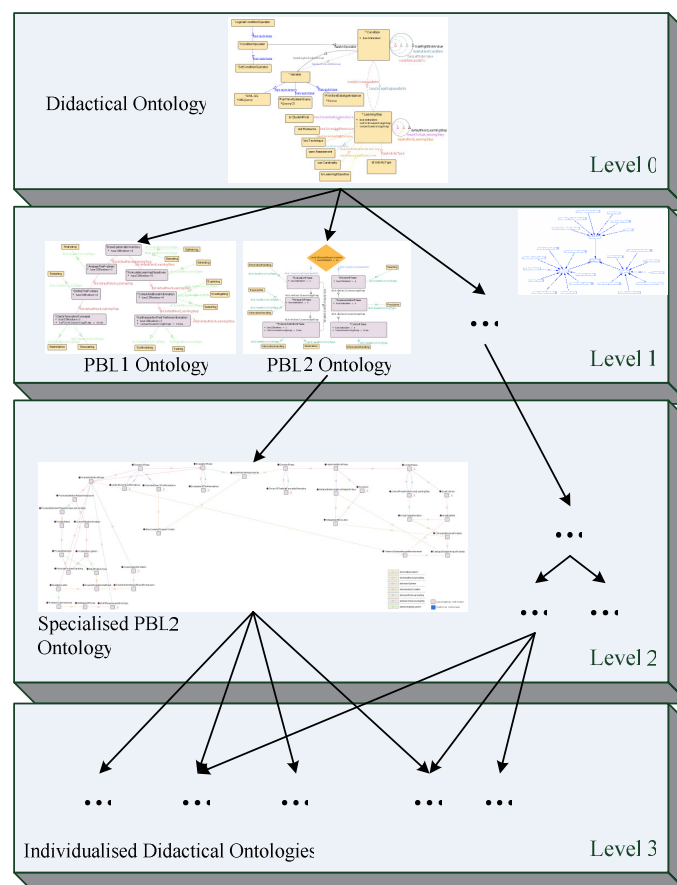

Figure 5: Hierarchy of didactical ontologies

Level 0 contains the most general ontology of the proposed set. It depicts a general description of a didactic strategy. Its purpose is to define the scheme for an ontology-based realisation of the order of learning content to achieve an optimal learning result. These timed strategic elements need to be adaptively chosen to fit certain context, learner or teacher-defined requirements:

- Abstract class for a learning step
- Definition of an order of learning steps
- Conditions for multiple learning paths
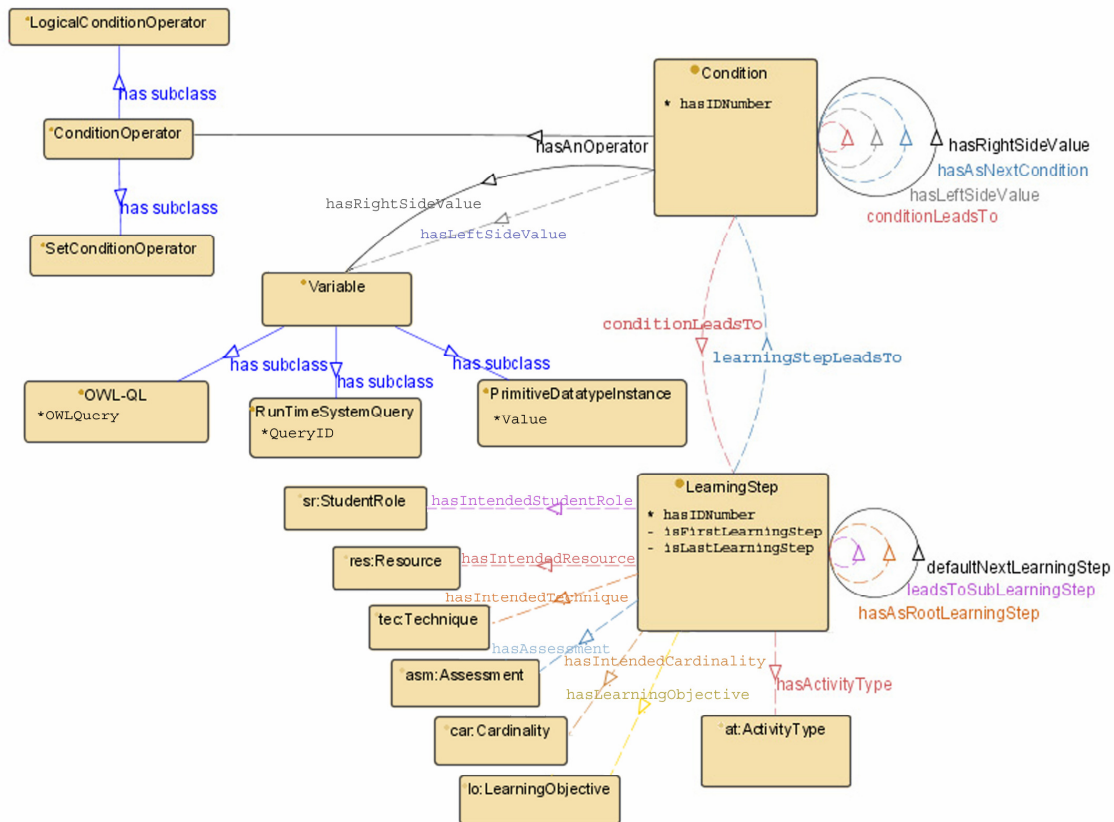- Metadata inclusion for runtime support

Figure 6: Ontology "Didactic"

Figure 6 presents the developed top-level ontology. The central concepts are the *LearningStep* and *Condition* class. A *LearningStep* is the reference to a part of a didactical approach. Further refinement is supported by the possibility to divide a learning step into several sub learning steps. Therefore the relation *leadsToSubLearningStep* was created to point recursively to the first *LearningStep* node that will compound the sub learning steps. The property *isFirstLearningStep* must be set true to mark this first node. According to this the property *isLastLearningStep* must be set true for the last node. To permit a return to the main didactical flow the sub nodes reference to their root node through the relation *hasAsRootLearningStep*. Additional relationships point to describing (sometimes taxonomic) ontologies:

- *hasActivityType* points to certain activities which the actual learning step should cover.
- *hasLearningObjective* points to a ontology describing learning objectives
- *hasIntendedStudentRole* points to a description where possible student roles a listed
- *hasIntendedResource* points (technical) resources that are intended to be used
- *hasIntendedTechnique* points special techniques/approaches for teaching
- *hasAssessment* points to suggestions for certain assessment types
- *hasIntendedCardinality* describes the type of interaction according to the number of participants

The *condition* concept is used to model restrictions to a path, permitting the runtime environment of an e-learning system to decide the next appropriate path through the learning content for the actual user in his actual context.

Both main concepts are used to model a didactic in this way:

- Identify the first LearningStep
- Follow the learning path for the first condition that delivers a true result

Therefore a *LearningStep* points to a *Condition* with a *learningStepLeadsTo* relationship. A *Condition* itself redirects the learning path to one other *LearningStep* with the *conditionLeadsTo* relationship, if its result is true. Multiple learning paths can be modelled by integrating multiple *Condition* individuals. To support those alternative ways through the e-learning course additional aspects are integrated into the ontology. A first one is a hierarchy of conditions. If one fails, the *conditionLeadsTo* relationship points to the next condition to be checked. Another one is a possibility to depict sequences of conditions by using the *hasAsNextCondition* relationship; the last condition of a sequence must point to a *LearningStep*. The default relationship *DefaultNextLearningStep* between two learning steps provides an alternative for the case when no condition is fulfilled and must appear only once. Figure 7 exemplary visualises some aspects described above.
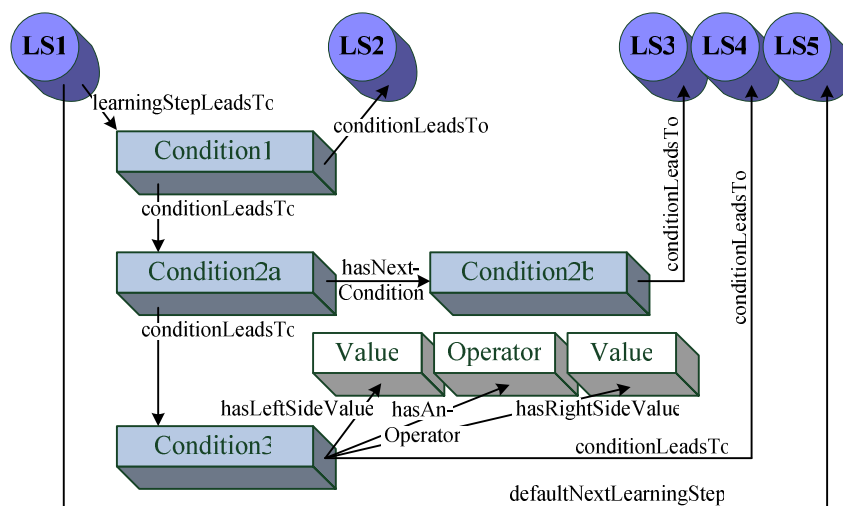

Figure 7: Hierarchical conditions for multiple learning paths

The conditions itself is described by three (two, if a unary operator is used) additional relationships. The relationships *hasLeftSideValue* and *hasRightSideValue* point either to another condition or to a *Variable* that can be of type *PrimitiveDatatypeInstance*, *OWL-QL* or *RuntimeSystemQuery*. The first type has the *anyType*-property *Value* and is used to model variables like the "5" within the following conditional expressions: "*If (NumberOfTries) isGreaterThan 5*". The *NumberOfTries*-variable is of type *OWLQL* and the query is stored as a string within the *OWLQuery* property. The *RuntimeSystemQuery* has a *string*-property, too. *QueryID* will be used by an e-learning runtime system to locate an internal condition. That is internally analysed and delivers back a Boolean value for the comparison. The ontology-intern condition must look like: "*If (runtimeCondition1) isEqual true*". The relationship *hasAnOperator* points to a *ConditionOperator* that defines the set and logical operators.

For conditions as well as for learning steps the mandatory property *hasIDNumber* was created. These IDs are for example used to provide the runtime environment a way to identify the path that the user has gone through.

Level 1 may reveal an inner hierarchical structure, too. It is directed towards to description of general didactical strategies, based on the level 0 ontology. According to the taxonomy of didactical approaches that are presented in figure 1, we chose the problem-based learning (PBL) approach for further implementation. PBL is a didactic that begins with a presented problem and is followed by a student-centred enquiry process [27]. Its fundamental principles base on the work of Barrows and Schmidt ([28] and [29]). Figure 8 visualises the ontology focussing on Schmidt's seven steps in problem-based learning.
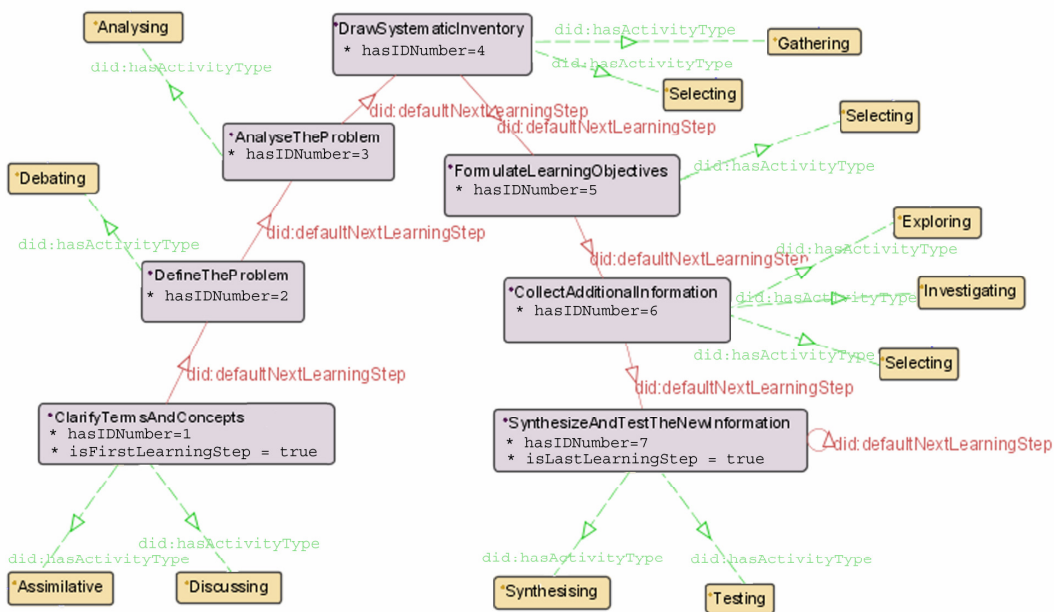

Figure 8: Problem-based learning didactic ontology

This implemented PBL ontology describes the seven basic steps that a PBL didactical approach should have according to [27], namely:

- Clarify terms and concepts
- Define the problem
- Analyse the problem
- Draw systematic inventory
- Formulate learning objectives
- Collect additional information
- Synthesize and test the new information

These steps are defined as individuals of a *LearningStep* and, as there is no special condition to the transition between them, only the *defaultNextLearningStep* relationship is used. The activity types for each *LearningStep* are chosen based on what should be performed, by the learner.

Level 2 contains the leaf nodes of the hierarchy, each describing an applicable didactical approach. Here for example the micro didactics of Meder [24] or the didactical models of [30] are integrated. Figure 9 defines an ontology for a special problem-based learning didactic. It is adopted from [31] and bases on [32].
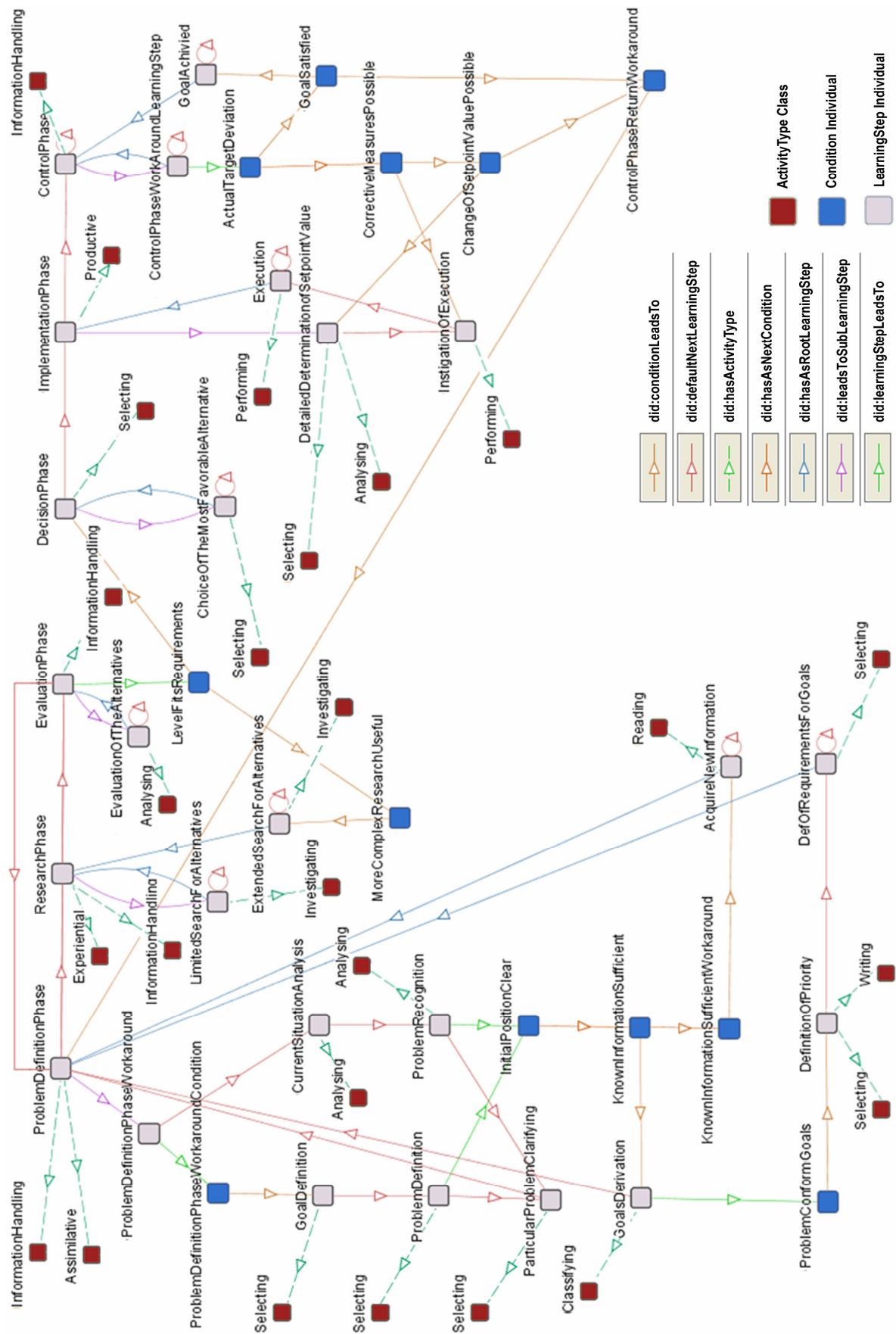
Figure 9: Problem-based learning didactic (cp. [31])

The presented didactical approach consists of six main steps, namely problem definition phase, research phase, evaluation phase, decision phase, implementation phase and control phase. These main learning steps are further refined into sub learning steps and related to appropriate activity types. The needed conditions are integrated as *RuntimeSystemQuery*, because this example was not developed according to a specific existing e-learning system. Exemplified conditions are specified below, based on the structure *ConditionName(did:hasAnOperator; did:hasLeftSideValue; did:hasRightSideValue; did:conditionLeadsTo):*

- *LevelFitsRequirements(did:EQUAL; RTSQ_LevelFitssRequirements; BooleanTrue; MoreComplexResearchUseful | DecisionPhase)*
- *ProblemDefinitionPhaseWorkaroundCondition(did:EQUAL; RTSQ_ProblemDefinitionPhaseWorkaroundCondition; BooleanTrue; GoalDefinition)*
- *CorrectiveMeasuresPossible(did:EQUAL; RTSQ_CorrectiveMeasuresPossible; BooleanTrue; InvestigationOfExecution | ChangeOfSetpointValuePossible)*

Level 3 is directed to the approach of individual (recombined) adapted didactics. The idea behind is, that individual approaches of specific teachers, tutors or scientists should be made available and usable, too. The trivial usage is to identify sub elements of the course that are didactically decoupled or only loosely coupled. These *LearningSteps* with their sub learning steps are affiliated with each other with the standard *defaultNextLearningStep* relationship or reusable relationships that e.g. point forward if the actual learning step was successfully completed. The more complex problem is the identification of inter-didactic relationships within certain contexts and their ontology-based modelling.

4   Conclusions and further work

In this paper we proposed a reusable mechanism to provide expert didactics knowledge. We used a formal, ontology-based representation to model those data. Next to the delivered expertise, we presented a shared vocabulary for teachers, course designers and experts for didactics. Partially we introduced features for repository-based search and retrieval mechanisms based on sufficient meta data. Thereby multiple, adaptable accessing and classification schemes become possible, according to different starting points for the initial information need as well as according to the differing points of view within the pedagogic science. Additional intentions are the minimization of duplications and the improvement of reuse.

Additionally we presented chosen examples of implemented didactical approaches to prove the applicability of our work. Other parts of our work will profit from these ontologies, as e.g. intelligent assistants or our autonomous data processing agents [33].

Next to the further refinement of our ontologies, a next step of our work in this context is the implementation of a didactic modelling tool that is based on the presented work. It will be part of the architecture for the collection and provision of didactical expertise. Therefore we will also complete an initial set of didactical approaches.

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