Semantically annotated learning paths

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Abstract

This paper shows an application of semantic lifting in the education domain. We present a metamodel for graphical representation of learning paths. This supports lecturers in the design of courses and learners to navigate through learning object to achieve their learning goals. The graphical models are semantically annotated with an ontology representing the content of the course and the learning objects. This enables reasoning for identifying learning objects dealing with specific topics and courses dealing with prerequisite knowledge. The approach is realized in ADOxx and validated with courses and lectures at a university of applied sciences in Switzerland.

Keywords

learning path, semantic lifting, teaching domain ontology, ADOxx, metamodel, ontology

1. Introduction

A learning path is a structured sequence of learning objects that are designed to organize the process by which learners acquire a specific skill or achieve a specific goal [1]. Visualizing this learning path can help both, lecturers and learners. In designing a course, lecturers can make explicit the structured sequence of learning activities that a learner can follow to achieve the learning goals. For the learners, a learning path provides a clear roadmap, indicating the order of courses they need to take and the skills they should acquire to progress in a subject or field.

The objective of this research is to extend learning paths with a representation of the learning content, i.e. the knowledge which the learner is supposed to learn. We use an ontology to provide a semantic meaning to this content. This makes it easier to reuse learning content, to identify learning material, which a learner should learn first as it is a prerequisite for a given course. We propose a metamodel for a learning path and show how it can be connected to an ontology representing the content of the course and its learning objects.

In Section 2, we describe the background for the development based on a literature review. Section 3 provides an overview of the research method. The requirements and challenges for the solution are described in Section 4. Section 5 is the core of the paper, in which the metamodel for the learning path and the connection to the domain ontology are presented. The artifact has been evaluated as described in Section 6.

2. Literature Review

Learning design is the activity that organizes the course content, like a choreography [2]. Nabizadeh et al. [3] propose to define the content of a course in four hierarchical levels (see Figure 1). The first level contains a single element which is the course itself and is composed of several lessons. Each lesson contains one or more topics. The complexity of the topic determines how many lessons are needed to cover it completely. Topics cover one and only one concept. Finally,

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there are learning objects, which represent the smallest units of content. These learning objects can be either learning *activities* or learning *material* [1,4,5]. The advantage of organizing educational content into learning objects is to have a highly structured representation of small content units that are self-contained, flexible, and reusable [6].

When designing a course, Premlatha and Geetha [6] distinguish two phases, identifying learning objects and then sequencing them. Al-Yahya et al. [4] split the first phase into two, which leads to three steps: first determining the semantics of the learning objects, then representing the learning object and finally presenting the learning objects in a specific order, which is determined by the prior knowledge of the learner, the learning goals and the information contained in the educational material [7].

A learning path is a sequence of activities with designated goals to help students build up their knowledge or skills in a subject area [1,4]. Learning paths can also be visually represented in different ways and they can be implemented in Learning Management Systems [8] where learning objects can be structured according to lessons – similar to the hierarchy of Nabizadeh et al. [3]. The eduWEAVER modeling environment [9] has a similar structure with an additional module level between course and lesson and it does not distinguish between various topics of a lesson.

The topics for the lessons and learning objects can be represented in the metadata of the learning objects like SCORM [10] and LOM [11], which are specialized for education material of the more general-purpose Dublin Core. While these standards specify metadata elements, encoding schemes are needed to describe the content of the learning objects. Ontologies can be the specification of the content [12].

In this research we combined the use of ontologies for content description with graphical modeling of learning path. It thus extends modeling of learning scenarios as done in eduWEAVER with a logic-based representation of the topic of a lesson. This allows more expressive reasoning and querying than metadata description like SCORM or LOM.

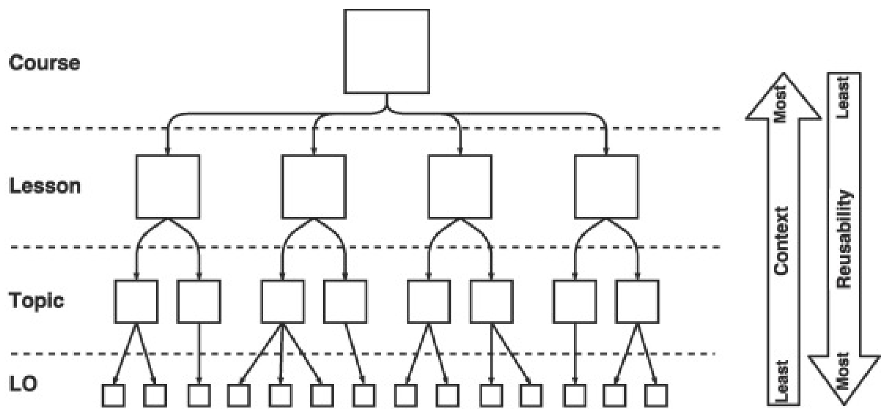

Figure 1 Content hierarchy of a course [3]

3. Research Method

We apply design science research strategy [13,14] following the process of Vaishnavi and Kuechler [15] to develop an artifact consisting of a metamodel for the learning path and its connection to a content ontology.

In the problem awareness phase, a course “Introduction to Programming” from Haute école de gestion Arc (HEG), which is taught by one of the authors, was analyzed and interviews with five teachers from HEG were conducted to better understand the challenges around the construction of the courses.

In the suggestion phase, the metamodel elements for the learning paths and the concepts for the learning objects were identified. This specification was represented using UML Class Diagrams. In the development phase, the focus was on the metamodel for the learning and the upper level of the content ontology. A solution was developed, how the two worlds of graphical modeling and ontology representation can be connected using semantic lifting [16].

Finally, the solution was evaluated by applying it to two courses, both in the domain of programming. In addition, a discussion is held with the course teacher to validate the models and gather feedback on their relevance and usefulness.

4. Challenges and Requirements for Learning Path Modeling

In the first phase of the projects, we analyzed the structure of the course "Introduction to Programming" from Haute école de gestion Arc (HEG), which is taught by one of the authors. Then we did interviews with five lecturers on how they prepare for a course and how they structure their courses. It turned out that all lecturers first structure their courses using spreadsheets. They determine the course topics and learning objects before representing them in the Learning Management System. The content of the Excel sheet corresponds to a simplified learning path and is the result of the first phase of course development according to [1,4]. Based on their experience with representing the learning path in Excel, the interviewees' requirements and challenges for modeling learning paths could be derived. These cover the modeling views, the modeling elements and the relations for the learning paths. These have been implemented in the meta-model (see Section 5).

We identified additional challenges that lecturers face when designing a learning path. These are related to the knowledge of the students and the content of the courses. Lecturers want to know what students already know in order to decide, what topics must be covered in the course. When students recognize a knowledge gap, they want to know, in which courses and lectures these topics are covered. From this analysis, the following questions are derived that should be answered with the solution:

- Which course covers which topics?
- Which exercises cover which topics?
- Which module(s) is/are prerequisite(s) for another?
- Which topic(s) is/are a prerequisite(s) for a module?

This shows the demand for a representation of the topic, which allows for reasoning – as it is possible with an ontology.

5. Metamodels for Learning Paths and Domain Ontology

The artifact consists of a metamodel for the graphical representation of the learning path, a metamodel for an ontology to represent the content and the connection between learning path and domain ontology. These are covered in the next three subsections.

5.1. A Metamodel for Learning Paths

The metamodel for the learning paths was implemented in ADOxx[2]. It consists of several model types representing different views on the courses. Figure 2 show the metamodel classes and relations that are represented in the ADOxx metamodel:

- The study program view (green box) shows the curriculum, in which the course is embedded.
- The semester program view (blue box) allows to present the structure of a single course. It corresponds to the top three levels of Nabizadeh's course hierarchy [3] (see Figure 1).
- The learning path view (yellow box) allows to represent the structure of the learning objects, i.e. the learning activities and the learning materials used in these activities.

[2] https://www.adoxx.org

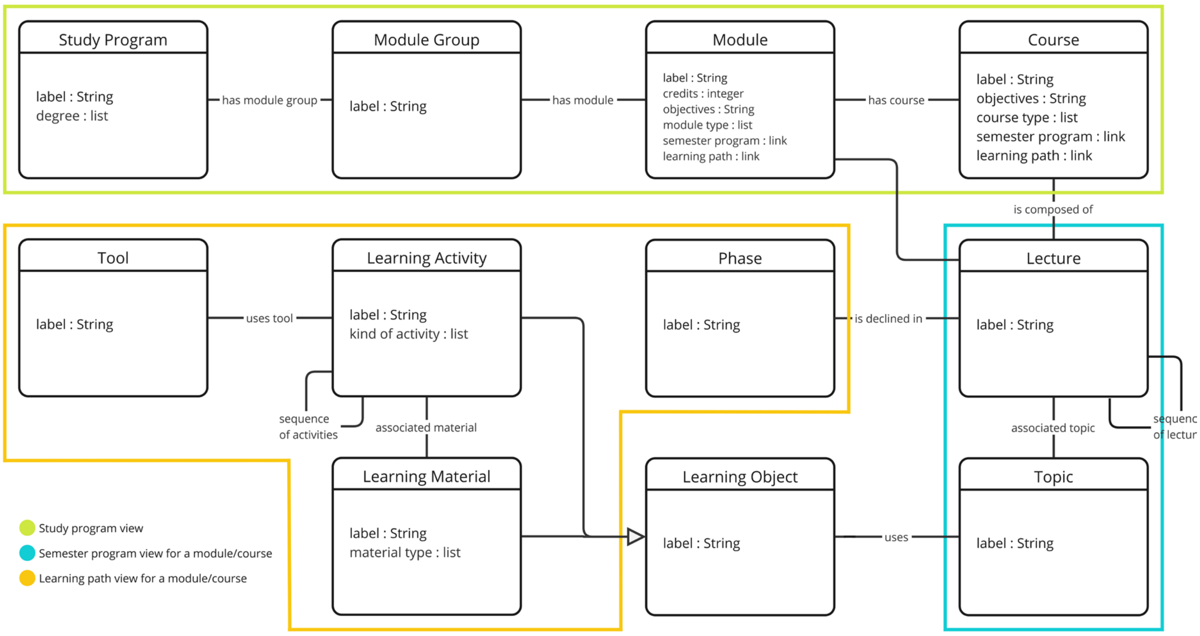

Figure 2 Learning Path Metamodel

Figure 3 shows the modeling elements for the study program view and the semester program view and how they can be used to create models.

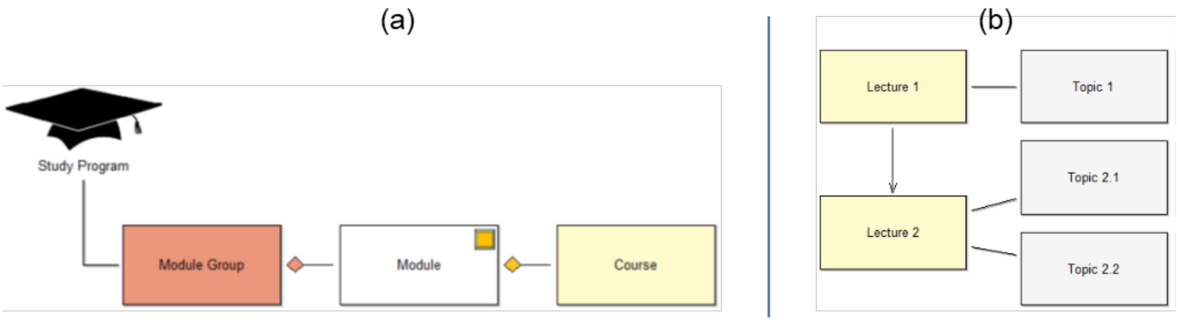

Figure 3 Visualizations of (a) study programm and (b) semester program views

Figure 4 shows an example of a learning path. It is designed for a flipped classroom lecture. On the left there is a preparation activity. The students shall read a literature. In the center there are the learning activities during the lecture. There is a teaching using some PowerPoint slides followed by an exercise, which is described in a document, In the consolidation phase the student do a group work using a software tool. The appearance of the learning objects depends on their type. The learning materials represent links. When students click on an item, the corresponding file opens or the software tool is started.

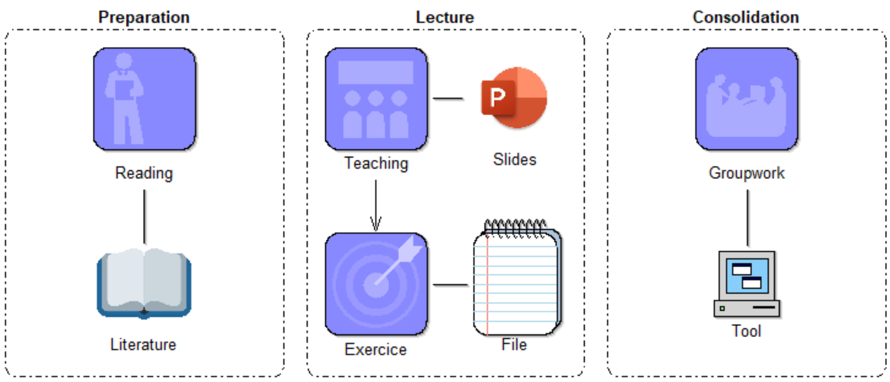

Figure 4 Example of a learning path for a single lecture.

5.2. Connection the Domain Ontology with the Learning Path Modeling

For connecting the learning paths and the domain ontology we applied semantic lifting [16,17]. The modeling and the ontology are managed in two separate environments: the learning path models are created in ADOxx and the ontology is created with Protégé[3]. Figure 5 shows the architecture, which is adapted from [18] where it is applied for Business Process as a Service (BPaaS).

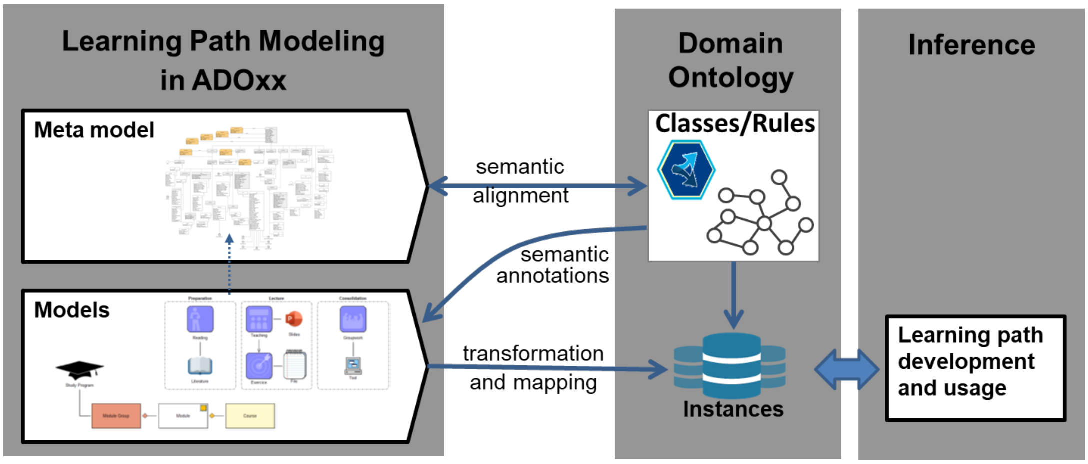

Figure 5 Semantic lifting approach, adapted from [18].

The ontology contains knowledge about the teaching domain. The top-level structure of a teaching domain ontology and the object properties were derived from the topic map of the course "Introduction to Programming" and the findings of the semi-structured interviews.

As can be seen in the class hierarchy in Figure 6, the ontology also contains knowledge about the learning path. This is necessary to allow reasoning about which topics are taught in which courses and thus to satisfy the requirements and challenges identified in the problem analysis (see Section 4). Ensuring that the classes in the ontology are consistent with the corresponding definitions of the modeling element in the modeling environment is called *semantic alignment*.

(a) Class Hierarchy (b) Object Property Hierarchy

Figure 6 Top-level domain ontology and properties

[3] https://protege.stanford.edu/

The *semantic annotation* realizes the connection of the models with the ontology about the teaching domain. All the information in the learning path that needs to be queried has a corresponding class in the domain ontology For semantic annotation, a web service is activated from the modeling environment, which queries the ontology according to the given context. The result is transmitted to ADOxx, which converts it so that the user can select the desired element via a selection box. The primary use for the semantic annotation is via the topic modeling element, which has an attribute that refers to an instance of the *Topic* concept in the domain ontology. The modeling element for learning activity has an attribute *activity type*, which can have as value instances of the subclasses of *Practice*.

The *transformation and mapping* is the third kind of interface between modeling environment and ontology. ADOxx offers an XML export function. Using an XSLT stylesheet, the XSLT processor produces a turtle file in which class instances and relationships between these instances are generated. This file can then be imported into the ontology, which is then populated with new data ready for querying.

5.3. Reasoning

After the data of the models are exported and mapped to the classes defined in the ontology, it is possible to do reasoning and ask queries about the models. Figure 7 shows some queries that allow to answer the questions derived from the problem analysis (see Section 4).

Prefixes required	PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> PREFIX owl: <http://www.w3.org/2002/07/owl#> PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#> PREFIX xsd: <http://www.w3.org/2001/XMLSchema#> PREFIX teaching: <http://www.semanticweb.org/charline.unternah/ontologies/2023/4/Teaching#>

List of prerequisited modules for a given module	SELECT *
	WHERE {
	  ?module teaching:hasModulePrerequisite ?previous_module .
	  FILTER regex(str(?module), "collaborative_programming", "i")
	}

List of example covering a given topic	SELECT *
	WHERE {
	  ?practise teaching:concerns ?topic .
	  ?practise rdf:type teaching:Example
	  FILTER regex(str(?topic), "Sequence")
	}

List of prerequisited topics for a given module	SELECT *
	WHERE {
	  ?topic teaching:isPrerequisiteForModule ?module .
	  FILTER regex(str(?module), "collaborative_programming", "i")
	}

List of modules covering a given topic	SELECT *
	WHERE {
	  ?topic teaching:isCoveredByModule ?module .
	  FILTER regex(str(?topic), "algorithm", "i")
	}

List of prerequisited topics needed for a given module and the previous module covering them	SELECT ?topic ?previous_module
	WHERE {
	  ?topic teaching:isPrerequisiteForModule ?module .
	  ?topic teaching:isCoveredByModule ?previous_module .
	  FILTER regex(str(?module), "collaborative_programming", "i") .
	  FILTER (?module != ?previous_module)
	}

Figure 7 Sample SPARQL Queries involving learning path and teaching domain knowledge

In this section we showed how the combination of learning paths and topic ontologies not only enables teachers to model their learning path with a nice graphical representation and students to navigate learning paths, but also to be able to take advantage of this modeling by automated reasoning.

6. Evaluation

The evaluation was done in two parts. First, the courses "Introduction to Programming" and "Advanced Data Structures" were represented in the modeling environment and the ontology for the teaching domain was represented in Protégé. Figure 8 shows the ontology and the instances for the first course after mapping the modeling elements of the first course to the classes of the ontology, with just the subclass-of and instance-of and composition relationships being visualized. Some sample queries are run to show that the representation and the reasoning is correct and appropriate.

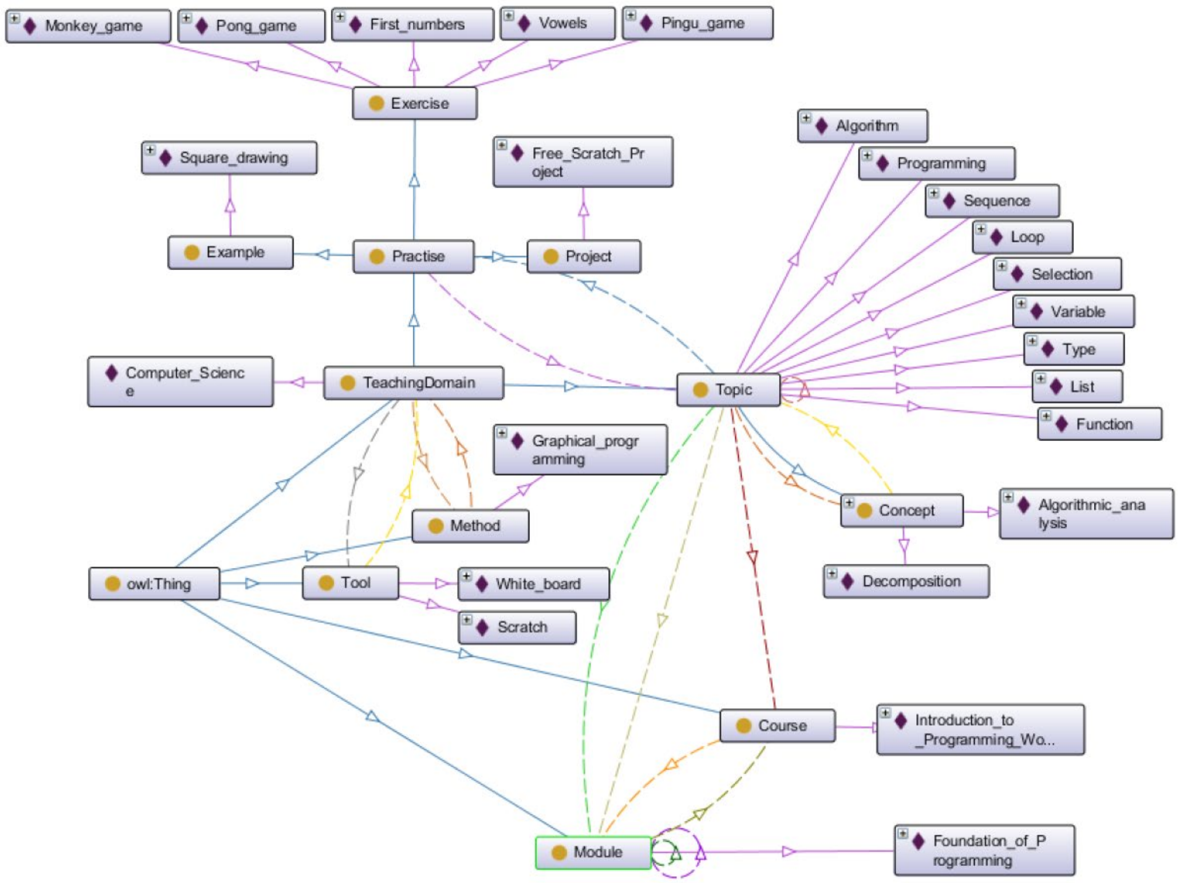

Figure 8 Ontology representation of the course "Introduction to Programming" at HEG

In the second part of the evaluation, the implementation carried out for the course "Advanced Data Structures" was validated with the lecturer of the course. Regarding the modeling, the teacher particularly appreciates is the freedom of abstraction: For the learning path, it is both possible to have a rather generic learning activity with several learning materials, or conversely, several learning activities, each associated with a single learning material. This does not restrict the teacher to a single way of implementing the learning path of his or her course.

The shared ontology is seen as a major added value, fostering inter-course transversality and enabling strong links to be established between the various elements. The lecturer listed a range of useful information that could be retrieved from the ontology using SPARQL queries:

- When preparing the course: adapting the course to the students' prior knowledge and avoiding repetition of the same topic in several courses.
- During the semester: Recommending learning material to the students to prepare a lecture.

Suggestions for improvement are mainly related to the user interface and the desire for a shared ontology covering all courses of a study program.

7. Conclusion

The learning process can be modelled as a learning path guided by learning objectives [1]. Using ADOxx for modeling the learning paths allows us to link learning material to the learning objects. Thus, the learning path can be used by the students as an interface to the content stored in a learning management system.

In this research, we enhance the modeling by using an ontology as an encoding scheme to represent the subject metadata for learning objects. Semantic lifting allows us to connect the ontology to the models of the learning paths enabling reasoning to support lecturers in the creation of a course and to support students in using finding appropriate learning objects.

A disadvantage of the semantic lifting approach is the separation of the modeling environment and ontologies in two separate environments. Using ontology-based modeling – as implemented in the Agile and Ontology-Aided Modeling Environment AOAME [19] – could overcome this drawback, but it does not yet have the opportunity to link external sources to the learning modeling objects.

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