MODELING EDUCATIONAL KNOWLEDGE
Supporting the Collaboration of Computer Science Teachers

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Abstract: The planning of lessons and courses is a very complicated work. Unfortunately many teachers tend to prepare their lessons without profiting from the experiences of their colleagues. In this paper we show how the collaboration of teachers could be supported by a community software that supports the collaboration focusing on the knowledge elements that form the topic of the lesson that is to prepare. Starting from the didactical model of Heimann, Otto and Schulz, we have designed an ontology that comprises most of the information that is necessary to design a lesson in computer science.

1 INTRODUCTION

Every teaching person has to realize that the conceptual design of courses and lessons is a very complicated and difficult task. There is a large variety of influencing factors that have to be considered and many decisions have to be made. It is nearly impossible to keep all these circumstances in mind while designing a course of lessons. Thus teachers tend to make many of these decisions more from the heart than based on rational deliberations.

On the other hand it would be very helpful for a teacher if she/he could share the experiences that other colleagues have made with similar topics. To this purpose the teachers would have to describe all the circumstances of these experiences very closely, which might be quite annoying. In order to enhance the exchange of experiences between teachers, the information from other colleagues would have to be presented "just in time", exactly at the point of a specific lesson planning process where it is needed and only in the case that most of the circumstances are similar. This requires a theoretical framework that offers suitable structures and categories on the one hand as well as properly defined terms, concepts and notions on the other, allowing to describe a specific teaching situation as precisely as possible.

After many years of deliberations about semantic systems that might support the collaboration of teachers (Hubwieser and Schlichter, 1998), based on the experiences we have made during the design and implementation of a new mandatory subject of informatics in Bavarian secondary schools (Hubwieser, 2006) and stimulated by the rapid evolution of the semantic web, we have developed an ontology that is based on the *Berlin Model*, which was one of the first rational decision-making models that was suitable for everyday teaching (Uljens, 1997). Additionally we integrated three different (so far quite separate) theories, as described already by Staller (2006): (1) Prerequisite analysis of Instructional design following Smith and Ragan (2005), (2) two taxonomies of learning objectives (Anderson and Krathwohl, 2001, Fuller et al., 2007), and (3) the ACM Computing ontology (Cassel et al., 2007).

The final goal of our research process is to develop a software system (called *PrepSpace*) that supports teachers in the collaborative design of courses and lessons. Besides that, there are many other application areas of our ontology as well, e.g. the retrieval of teaching materials, the design and automatic evaluation of student assessments, the comparison of courses of lessons.

Meanwhile our ontology has become quite stable and PrepSpace has reached the first prototype state, thus we decided to publish the state of our work right now in order to put it up for discussion.

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2 THEORETICAL BACKGROUND

2.1 The Berlin Model

The Berlin Model was developed by Heimann, Otto and Schulz, see Uljens (1997). We have chosen this model as the theoretical framework for the teacher education courses in informatics at the Technische Universität München (Brinda and Hubwieser, 2009).

Following the Berlin model the design of educational lessons has to start with the consideration of the preconditions in two different areas: firstly the *socio-cultural* preconditions, which comprise e.g. the legal requirements for school education, didactic approaches as well as IT infrastructures in schools. Secondly, the *anthropogenic* preconditions describe the attributes of the students like age, gender, prerequisite knowledge or social status.

In a second step the teacher has to make his/her decisions about the four main aspects of a lesson: *intentions, content, methods and media*.

Finally the consequences of the course or the lesson have to be considered, regarding the (anthropogenic) learning progress of the students as well as more global (socio-cultural) consequences like the improvement of the educational level of a region or of the whole country.

Our system is designed to support this strategy of planning by a maximum of information that is offered to the teacher exactly at the right time he/she needs it during the design process.

2.2 Learning Objectives

We will refer to the definition of (Smith and Ragan, 2005, p. 96): “A learning objective is a statement that tells what learners should be able to do when they have completed a segment of instruction.”

Concerning the granularity of the objectives, (Anderson and Krathwohl, 2001, p. 15f) suggest three categories:

- *Global* Objectives: “Complex, multifaceted learning outcomes that require substantial time and instruction to accomplish;”
- *Educational* Objectives: derived from global objectives by breaking “them down into a more focused, delimited form;”
- *Instructional* Objectives, with the purpose “to focus teaching and testing on narrow, day-to-day slices of learning in fairly specific content areas.”

2.3 Taxonomies

Our starting point was the the taxonomy of Anderson and Krathwohl (2001), shortly called AK from now on. Following AK, we regard learning objectives as a combination of a certain type of *knowledge* and an observable *behavior* specification (called cognitive process) concerning this type of knowledge, together forming the two dimensions of the AK-Taxonomy:

(1) The *knowledge dimension* is partitioned into *A. factual, B. conceptual, C. procedural, and D. metacognitive knowledge,*

(2) the *cognitive process dimension* contains the following levels of behavior: *1. remember, 2. understand, 3. apply, 4. analyze, 5. evaluate, and 6. create*.

A certain cell of the AK-taxonomy is specified by a combination of a letter (for the knowledge dimension) and a digit (for the cognitive process dimension), e.g.: *A1, B3, D6* (see figure 1).

Recently a working group of the ACM *Special Interest Group on Computer Science Education* (SIGCSE) elaborated a specific taxonomy for computer science (Fuller et al., 2007), which splits the cognitive process dimension of the AK-taxonomy into the two subdimensions *producing* and *interpreting*. The *producing* subdimension represents the more active part of the learning process and contains the steps *none, apply, and create*. The remaining activities of the cognitive process dimension are arranged on the *interpreting* subdimension: *remember, understand, analyze, evaluate*. This results (in combination with the knowledge dimension) in a three-dimensional taxonomy, which we will shortly call *SIGCSE-taxonomy*.

2.4 Learning Objective Analysis

In order to illustrate our theoretical considerations through this paper, we present an exemplary learning process P1, specified by a “final examination” task T1. Once the students have finished P1, they should be able to solve the following task T1:

Write a method of a suitable Java class that calculates and prints (on screen) the values of a square function $f(x) = ax^2 + bx + c$ for a given set of equidistant arguments $\{x_1, ..., x_n\}$. The following parameters should be set by the user of the program:

- *a, b, c: double (parameters of the function f),*
- *x_min, x_max: double (borders of the x values),*
- *n: int (number of arguments x_i to calculate $f(x_i)$).*

The students have to learn certain *knowledge elements* in order to solve this task. Some of them are shown in the graph of the learning objectives in figure 1, represented by the denominators of the learning objectives, e.g. “conditional repetition”). Additionally the corresponding cell of the AK-taxonomy is indicated at the lower end of the nodes.

2.5 Prerequisite Relations

The prerequisite analysis of learning steps is a very important part of the instructional design process, as described by Smith and Ragan (2005). Although the prerequisite concept is not suitable to enhance constructivistic learning, obviously many situations in educational work and research require such an analysis.

We transfer the concept of prerequisite analysis to sets of learning objectives in order to find prerequisite relations. We regard a *prerequisite relation* P as a set of pairs of learning objectives: P = {(O1, O2)| O1 is prerequisite of O2}. Instead of (O1, O2) ∈ P, we shortly write P: O1 → O2.

As pointed out in (Hubwieser, 2008), we suggest two different types (PH, PS) of prerequisite relations that might connect learning objectives in pairs O1, O2:

The hard prerequisite relation (PH) is forced by a substantial or logical dependency, e.g.: concept2 contained in objective O2 is logically based on concept1 contained in objective O1. This means that it is not possible to understand concept2 without having understood concept1.

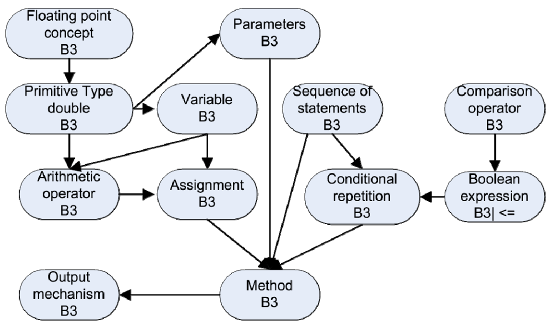

Figure 1: Prerequisite structure of task T1.

The soft prerequisite relation (PS) is suggested by didactical deliberations: It is not necessary, but advisable to reach objective O1 in order to ease or to improve the learning process towards O2, e.g. to apply teaching or working methods that support didactical principles.

Whereas PH often can be derived from logical relations, PS needs empirical research. Using learning objectives as nodes and prerequisite relations as edges, we can draw prerequisite graphs representing PH or PS or a combination of both. In this paper we will restrict our deliberations to PH. Applied to our example of the task T1, this leads to the prerequisite graph that is shown in figure 1.

2.6 Subject Domain Knowledge

The most important aspect of the design of courses is the description of the knowledge that the students should gain during the lessons. We decided to represent it in the form of *knowledge elements* (shortly KE), similar to the proposal of Pedroni and Meyer (2010). The granularity of these KEs should be approximately about the learning content of one single lesson.

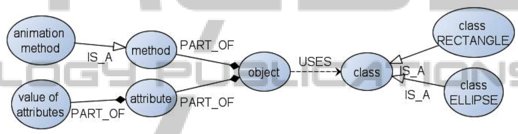

Figure 2: Knowledge elements in grade 6.

The knowledge elements are connected by associations that are induced by the logical structure of the subject domain. The *ACM Computing Ontology* (Cassel et al., 2007) proposed the following associations: *is_a* (generalization), *part_of* (aggregation) and *uses* (unspecified relationship). Figure 2 shows (partly) the result of a curriculum analysis of grade 6 of the subject of informatics in Bavaria, using these associations.

3 THE ONTOLOGY

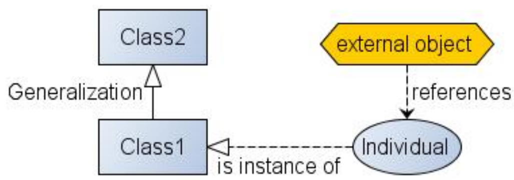

Figure 3: Notation of the following figures.

The following figures 4 and 5, that show parts of the ontology, are drawn manually (using the graphic editor *yEd*) in order to produce more readable figures compared with Protege plugins like *Jambalaya*.

Additionally we have simplified the graph in some parts by restricting ourselves to some exemplary individuals and properties.

The core part of the ontology of *PrepSpace* is dedicated to the concepts that are the most important for the design of courses and lessons (see figure 4):

- *learning objectives*, connected by prerequisite relations,
- subject domain *knowledge elements*, connected by the associations *is_a*, *part_of*, *uses* (especially *implements*).

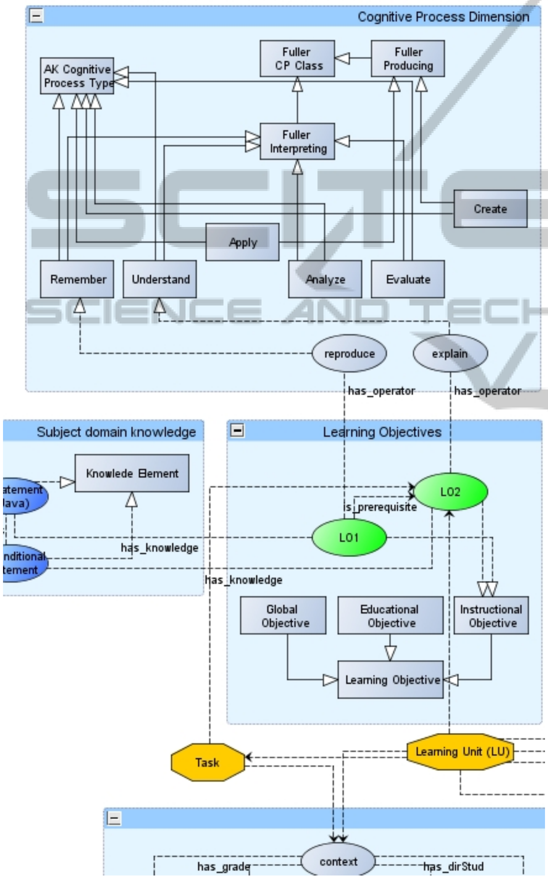

Figure 4: The central area of the ontology.

The *lesson* to be planned is represented by an external object (outside of the ontology), called *learning unit* (LU). A second type of external objects is used to represent the *tasks* that are designed to test the intended learning objectives.

We represent our ontology using the Web Ontology Language OWL 2.0. In order to operate on the prerequisite graphs automatically, we have to perform logical reasoning on it, e.g. chaining a sequence of transitive relations or applying predicate calculus. Thus we want our ontology to be decidable, therefore we use OWL DL (Description Logics).

The external elements for tasks and learning units are connected by the association *has_context* with the application *context* of the course which represents the most important preconditions following the Berlin Model, e.g. grade, school type, subject, state or direction of study.

The cognitive process dimension of the AK-taxonomy is implemented by a subclass hierarchy following AK p. 67f (see figure 5). The extended SIGCSE taxonomy is integrated in our system a similar way. The implementation of the knowledge dimension offers the docking slot for the subject domain ontology, e.g. the *ACM Computing Ontology* (Cassel et al., 2007). Similarly to the cognitive process dimension, we constructed a hierarchy of subclasses with the root class *Knowledge* that follows the major types and subtypes of the AK-taxonomy (p. 46), see figure 5.

The remaining decision fields *methods* and *media* following the Berlin Model are covered by the classes and individuals of the two areas *Methodology* and *Media* in the ontology, which are connected to the learning units by suitable properties (e.g. *has_media*). These areas offer specific didactical knowledge, e.g. proposals for teaching strategies like team work or partner work or schemata for time planning.

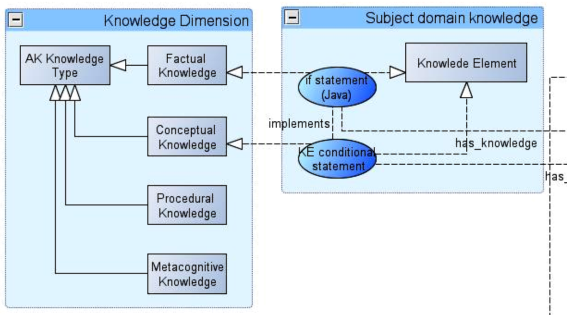

Figure 5: The knowledge dimension of the ontology.

Let us assume that a certain teacher aims to enable her/his students to solve the task T1 that is described above (see 2.4). She/he might specify the following learning objective for the lesson: “apply the *method* concept in an object oriented programming language”. We regard this as an instructional objective, belonging to the cell B3 following AK. In the case that our ontology contains the information shown in figure 1, the reasoner (we use *HermiT,* see Motik, Shearer, Horrocks (2009)) will produce a tree of prerequisite objectives that might look as (partly) shown in figure 6.

To describe these general dependencies between knowledge elements we define an object property *has_dependency* with *is_a*, *has_part* (inverse of *part_of*), *uses* and *implements* as its subproperties.

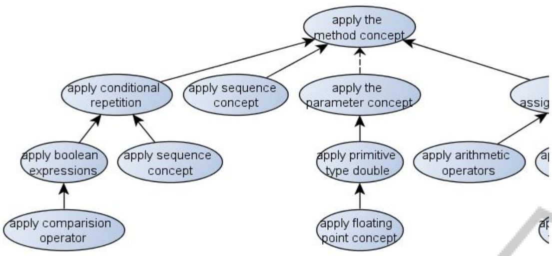

Figure 6: Part of the prerequisite tree.

As we are interested in dependencies between learning objectives, we can define the PH *has_direct_prerequisite* as follows:

```
SubObjectPropertyOf(
  ObjectPropertyChain(
    :has_knowledge :has_direct_dependecy
    :has_objective)
    :has_direct_prerequisite)
```

Often one is interested in the overall dependencies of a learning object (e.g. what has a student learned if he has reached this learning object?). This is a more general case than direct dependencies:

```
SubObjectPropertyOf(
  :has_direct_prerequisite
  :has_prerequisite
)
```

Further, general dependencies without restrictions to the next dependent learning objective are transitive:

```
TransitiveObjectProperty(
:has_prerequisite ).
```

4 USE CASE

Let us assume that a teacher wants to prepare her/his lesson following the *Berlin Model*. Thus, the preparation will start with the consideration of the precondition areas. We will support some of them by offering a specific part of the ontology for the context of a lesson: grade, school type, teaching subject, state/country and direction of study.

Now the decisions concerning the four areas *intentions*, *content*, *methods* and *media* have to be made. All these decisions are connected to the (external) LU-object by references to the corresponding objects of the ontology, e.g. to learning objectives.

Regarding the *content* decision, the teachers will start to use our system by picking certain knowledge elements (KE) that represent the central topics of the lesson. *PrepSpace* will be able to present a certain part of the graph of the subject domain knowledge that surrounds the picked KE, showing all the other KEs that are linked to the concerned one by one of the properties *is_a*, *part_of* or *uses*. By this way the teacher is able to inspect the knowledge area that is relevant to the intended learning process.

The next step might be to specify the *intention* of the lesson by fixing the learning objects the students should achieve by adding a cognitive process operator to the KE, e.g. *explain*. *PrepSpace* will present a prerequisite graph of learning objectives, enabling the teacher to assess quite precisely, which objectives the students have to achieve before the intended learning step might take place.

After exploring the knowledge and objectives of the intended lesson, the teacher starts to think about the teaching *methods*, strategies and *media* she/he wants to apply in the lesson. As much didactical knowledge about these areas is represented in *PrepSpace*, the teacher can get many hints and proposals directly from the system. This is the point where the user will profit mainly from the collaboration with other teachers that is mediated by *PrepSpace*. The teacher might look in the (web based) system after the methods or media that other teachers have used (and assessed) in lessons to the same KE or similar learning objectives.

5 RELATED WORK

In their prophetic paper Mizoguchi and Bourdeau (2000) proposed a framework for ontology-based intelligent systems and elaborated a roadmap to this goal. This proposal triggered a lively discussion about educational ontologies and intelligent systems that were built upon these, which was particularly productive at the workshops of the SW-EL (*Applications of Semantic Web technologies for E-Learning*) series.

The heavy-weight OMNIBUS ontology (Mizoguchi, Hayashi, Bourdeau, 2007) is built to support all the concepts necessary for understanding learning, instruction and instructional design. For our purpose it is too general on the one hand, but misses the close description of the subject domain knowledge structure and of the learning objectives on the other hand. Dicheva, Sosnovsky, Gavrilova, Brusilovsky (2005) produced an ontological overview of the Ontologies for Education field and offer an ontology-driven web portal in order to compare and combine different proposals for educational ontologies.

Pedroni and Meyer (2010) have developed the concept of *trucs* (testable, reusable units of cognition) to describe knowledge elements and their dependencies.

Kasai and Yamaguchi (2005) presented a Semantic Web System for helping teachers plan lessons that is based on some specific ontologies, particularly on a goal ontology.

Recently an ACM SIGCSE working group (Cassel et al., 2007) continued the ongoing work on the ACM Ontology of Computing and proposed a new ontology that served as a starting point of our considerations concerning the subject domain area of learning processes.

6 FUTURE WORK

Currently we are preparing a close empirical survey on how teachers prepare their lessons. After developing a questionnaire based on expert interviews, we will perform a survey using this questionnaire, searching for different types of preparation strategies. Finally we will adopt our tool to the results of this study, before we will roll it out for public usage.

Further we prepare to use the ontology as well to manage research results that concern learning paths, learning difficulties or the comparison of different teaching approaches for the same knowledge element.

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