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# An Ontology-Based Approach for Context-Aware e-Learning

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***Abstract* — Context-aware e-learning is an educational model that foresees the selection of learning resources to make the e-learning content more relevant and suitable for the learner in his/her situation. The research reported in this paper was purposed to improve an existing system for personalized e-learning with contextualisation features. This has been done by defining a context model, an ontology-based model to represent a teaching domain that includes contextualization information and a methodology to generate personalized and context-aware learning experiences basing on such structures.**

***Keywords — adaptive e-learning, learning context, knowledge representation, context-aware e-learning, learning design***

## I. INTRODUCTION

*Personalized e-learning* is defined in [1] as a educational model that is tailored to the individual learner's needs and interests. Personalized learning can be used for developing individual learning programs and engage learners into the learning process so that learner's potentials and success can be optimized. Personalized e-learning is not restricted by time, place and learner's other requirements. It is mostly focusing on learner's preferences and current state to provide the learning content correctly. Differently from context-aware e-learning, it does not consider a learner's situation.

*Context Aware e-Learning*, on the other side, provides a learner with highly customized learning content [2]. The customization of content is made by selecting or filtering learning resources in order to make the e-learning content more relevant and suitable for the learner in his/her situation. The filtering process is done considering several parameters related to the environment where the learning takes place.

The purpose of this paper is to report a work performed to define theoretical and technological components needed to extend an already existing system for personalized e-learning with learning contextualization features.

The paper is structured as follows: in the second section a state of the art on learning context modelling is presented while the third section briefly describes the learning platform IWT (Intelligent Web Teacher) [3] that we used as starting point to apply contextualization features.

The fourth section describes the proposed approach from the theoretical point of view by introducing our definition of learning context and methodological components needed to support it and provide contextualisation features in IWT. The fifth section describes the developed prototype while the last one presents some conclusions and planned future works.

## II. RELATED WORK

Several definitions of *context* are available in literature. According to [4], context is defined as "that which surrounds, and gives some meaning to, something else". In [5] instead it is defined as "any information that is used to characterize the situation of an entity". Moreover, according to the ubiquitous computing, "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves." [2].

The IMS Learning Resource Meta-Data Information Model [6] defines a *learning context* as "the typical learning environment where use of learning object is intended to take place". It also proposes a list of feasible contexts for a learning object i.e. school, higher education and training.

Other authors [7] define the learning context as the learner environment and talk about three main environments: the external environment (e.g. classroom, working space, in-person coaches, etc.), the internal environment (e.g. previous beliefs, thoughts, hopes, etc.) and the digital environment. According to [8], instead, a context model for e-learning is composed by seven levels (i.e. technological, pedagogical, methodological, organisational, psychological, related to the subject domain and to the course), each one characterised by several aspects and variants.

In [9] a "static" context model for context-aware e-learning has been defined basing on the analysis of the relevant literature about the topic. The static nature of the context is due to the fact that only parameters that do not change within the entire e-learning course structure have been considered. The defined model is composed by several context parameters divided in sub context parameters. In [2] the same authors have systematized and aggregated such parameters into the following sub-contexts:

- *Profile Context* giving information on learner's personal information, personality type and level of expertise;
- *Preference Context* giving information about learner's approach to learning, intention and learning style;
- *Infrastructure Context* describing learner's situation in terms of network and device used by the learner;
- *Learning Context* giving information about the learning pace, state and comprehension level of the learner.

According to [10] the learning context describes a class of learners within a technological infrastructure with a set of parameters related to the learner category, the educative modality end the educational objective.

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- The *Learner Category* is composed by the average cognitive state (concepts already acquired by the class) and by the social context (learner cultural background).
- The *Educative Modality* is composed by the learning experience period (duration of the learning experience) and by the interaction modality (typologies of learning experience to choose e.g. distance or blended).
- The *Educative Objective* is composed by the educational context (the target kind of instruction e.g. high school, university, PhD, training, etc.), by the motivation for the education (kind of expertise the learner is interested) and by the depth level of the study to achieve.

Basing on the context description, the system proposed in [10] is able to automatically select suitable learning objects by matching context parameters and fields of the IMS metadata [6] connected to learning objects.

Starting from these researches, we provide, in section III, a custom definition of a learning context composed by six levels and several parameters and a context profile stating feasible teaching strategies that may be applied for available contexts. Moreover an abstract domain model able to support the notion of context is defined in the same section as well as an algorithm able to generate a contextualised domain model starting from an abstract one.

## III. THE STARTING POINT

In this section we introduce a learning platform named IWT (Intelligent Web Teacher) that we have adopted as a basis to apply models and methodologies hereafter defined [3]. IWT allows to generate personalized learning experiences and relies on four interacting models as described below.

The ***domain model*** describes the knowledge that is object of teaching through a set of concepts (topics to be taught) and a set of relations between concepts. Such structure can be represented as a concept graph *G* (*C*, *BT*, *IRB*, *SO*) where *C* is the set of nodes representing domain concepts while *BT*, *IRB* and *SO* are sets of arcs corresponding to supported relations whose meaning is explained below:

- *BT* (*a*, *b*) means that the concept *a* belongs to *b* i.e. *b* is understood if and only if every *a* so that *a* belongs to *b* is understood;
- *IRB* (*a*, *b*) means that the concept *a* is required by the concept *b* i.e. a necessary condition to study *b* is to have understood *a* before;
- *SO* (*a*, *b*) means that the suggested order between the two concepts is that *a* precedes *b* i.e. to favour learning, it is desirable to study *a* before *b*.

Figure 1 shows a sample domain model in the didactics of artificial intelligence stating that to understand *logics* means to understand *formal systems*, *propositional logic* and *first order logic* but, before approaching any of these topics it is necessary to have an *outline of set theory* first. In addition, *formal systems* must be taught before *propositional logics* and *first order logic* while it is desirable to teach *propositional logics* before *first order logic*.

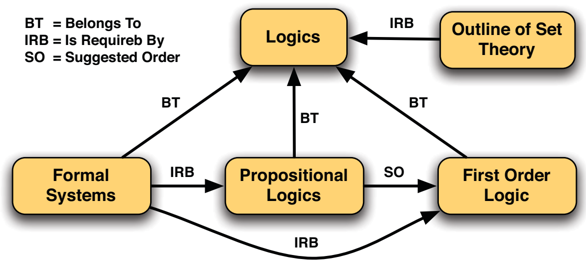


Figure 1. A sample domain model.

A set of *teaching preferences TP* can be also linked to domain concepts to define feasible teaching strategies that should be applied for such concepts. They are represented as an application *TP* (*C* × *Props* × *PropVals*) → [0, 10] where *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties.

Table I presents supported didactical properties and related values. Properties correspond to a selection of fields of the *educational* group of the IEEE LOM Standard [6].

TABLE I. DIDACTICAL PROPERTIES AND FEASIBLE VALUES

| ***Properties*** | ***Feasible Values*** |
|---|---|
| resource type | text reading, video clip, simulation, virtual experiment, etc. |
| interactivity level | low, medium, high |
| age range | 0-5, 6-10, 11-13, 14-18, 19-24, 25+ |
| language | English, Italian, Spanish, German, etc. |
| semantic density | low, medium, high |
| interactivity type | active, expositive, mixed |
| difficulty | easy, medium, difficult |

The ***learner model*** represents a learner and is composed by a cognitive state and a by set of learning preferences. The *cognitive state* represents the knowledge reached by a learner at a given time and associates an evaluation to each available concept of a given domain. *Learning preferences* provide an evaluation of which learning strategies are more feasible for a given learner. Both components are automatically assessed by IWT by analysing results of testing activities and the user behaviour in the learning experience as described in [3]

The ***learning resource model*** is a metadata representing a learning resource and is based on the application of the IEEE LOM standard [6]. It includes the set of concepts that are covered by the learning resource and an additional set of didactical properties representing learning strategies applied by the learning resource.

The ***unit of learning model*** represents a sequence of learning resources needed for a learner in order to understand a set of target concepts in a given domain. In [3] we have described the process to generate a unit of learning starting from a set of a target concepts and from a learner model.

The process, by looking at the domain model, generates a feasible sequence of domain concepts able to teach the target concepts. Then it removes domain concepts already known by the target learner by looking at his/her cognitive state. Eventually it associates to each remaining concept the best matching learning resources taking into account teaching and learning preferences (connected respectively to the concept and to the learner model).

By leveraging on these models, IWT supports a learner centred approach and is able to build the best unit of learning for each learner from a given set of target concepts. Different learners with the same target concepts will have so different units of learning generated by the system.

## IV. THE PROPOSED APPROACH

The domain model of IWT is unable to deal with learning contexts. This means for example that different instances of the domain model are needed to teach a given topic in different university faculties or at different school levels: concepts to be taught may vary as well as teaching strategies.

To overcome this limitation we propose to give teachers the possibility to define learning contexts together with a domain model and to provide algorithms and software tools able to automatically adapt domain models with respect to contexts. In other words:

- the teacher will be able to define available contexts;
- the teacher will be able to include, in domain models, contextualization information that specify how models will change according to contexts;
- the system will be able to build a contextualized and personalized unit of learning given a context, a learner and a set of target concepts.

The next subsection introduces our definition of learning context and defines the *context profile* that states feasible teaching strategies that may be applied for each available context. Subsequent subsections focus on new models and algorithms we have defined to support domain model contextualization in IWT namely:

- the *abstract domain model* able to introduce and support the notion of context;
- the *domain contextualisation algorithm* able to generate a standard domain model starting from an abstract one.

### A. The Learning Context

Starting from the state of the art presented in section II, we have defined our model of learning context by trying to take into account all aspects of the environment surrounding the learner without considering aspects related to the learner itself like profile, previous knowledge, learning preferences, etc. that, as explained in the previous section, are already considered by IWT in the learner model.

We tried to organize these aspects in a five levels, each connected with a extensible lists of possible values:

- *Educational Context* - identifies the environment where the learning takes place, it is composed of two sublevels: country and educational level;
- *Course Subject Context* - identifies the subject domain;
- *Methodological Context* - identifies the e-learning form to apply in the context;
- *Instructional Context* - identifies the teaching strategy to apply in the context;
- *Technological Context* - identifies main technological constraints linked to the context, it is composed of two sublevels: device constraints and network constraints.

The table II summarizes defined level and sublevels as well as feasible values for each one of them.

TABLE II. LEARNING CONTEXT MODEL

| ***Level*** | | ***Feasible Values*** |
|---|---|---|
| Educational Context | | … |
| | *Country* | UK, Italy, Spain, Austria, etc. |
| | *Educational level* | Primary, Secondary, Higher Education, University 1st or 2nd Cycle, Post-Grade, Technical School, Professional Formation, Continuous Formation, Vocational Training, etc. |
| Course Subject Context | | Literature, Mathematics, Physics, Computer Science, etc. |
| Methodological Context | | Self-learning, Asynchronous, Synchronous, Blended/Asynchronous, Blended/Synchronous, Informal learning |
| Instructional Context | | Active learning, Collaborative learning, Direct instruction, Drill and practice, Experiential learning, Game based learning, Inquiry Learning, Problem based learning, etc. |
| Technological Context | | … |
| | *Device Constraints* | Screen size, Computational power, etc. |
| | *Network Constraints* | Bandwidth, availability, etc. |

Basing on that, a learning context can be defined as a feasible configuration of values associated with context levels. Starting from such configuration it is possible for teachers to define a *context profile* stating teaching strategies that may be applied for any available context.

A **context profile** can be so defined as an application $CXP\ (CX \times Props \times PropVals) \rightarrow [0, 10]$ where $CX$ is the set of available contexts, $Props$ is the set of didactical properties and $PropVals$ is the set of feasible values for such properties as defined in table I.

### B. The Abstract Domain Model

The abstract domain model describes the knowledge that is object of teaching at a higher level with respect to the IWT domain model. It supports the notion of context, it also allows to associate a context to each concept and relation and teaching preferences to couples (concept, context) rather then simply to concepts. Such structure can be represented with:

- a *concepts graph G* representing all concepts object of teaching as well as relations between them (supported relations are those already used by IWT);

- a *set of contexts* $CX = \{cx_1, \ldots, cx_n\}$ that is a vocabulary of supported contexts;
- a *concepts labelling relation* $CL \subseteq (C \times CX)$ purposed to label each concept with one or more contexts of *CX*.

The figure 2 shows a graphical representation of a sample abstract domain model obtained as an extension of the one depicted in the previous section. The set *CX* is composed of two contexts: *Computer Science Course at University* and *Mathematics Course at University*. The concepts labelling relation *CL* is graphically represented by circles associated with concepts.

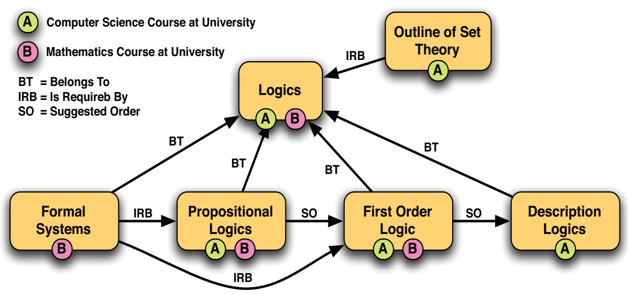


Figure 2. A sample abstract domain model.

Informally speaking this domain model specifies that to understand *logics* means to understand *formal systems*, *propositional logic*, *first order logic* and *description logics* where *formal systems* is only required in university courses about mathematics while the concept of *description logics* is only required in university courses about computer science. Moreover in this latter context (computer science), before approaching any of these topics it is necessary to have an *outline of set theory* first.

Moreover, in any case, *formal systems* must be taught before both *propositional logics* and *first order logic* while it is desirable to teach *propositional logics* before *first order logic* and *first order logic* before *description logics*.

To be coherent, the concept graph *G* must be acyclic and if concept *a* is related to concept *b* with any relation then $CL(a, cx) \rightarrow CL(b, cx)$ for any $cx \in CX$ i.e. if *a* applies to a given context then *b* applies to the same context too. Using a *context profile CXP* as defined in the previous subsection, it is also possible to state feasible teaching strategies that may be applied for any available context in *CX*.

Moreover, a set of *teaching preferences* can be added to the model to define exceptions to the context profile i.e. to specify feasible teaching strategies that may be applied for a given concept in a specific context (so excepting general rules included in the context profile).

Teaching preferences here are defined as an application $TP\ (C \times CX \times Props \times PropVals) \rightarrow [0, 10]$ where *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties as defined in table II.

For example, the following definition for *CXP* and *TP* states that the preferred didactic method to be used in the context of a *computer science course at university* is the *deductive* one. Despite that, to teach *first order logics*, an *inductive* method should be preferred.

- *CXP* (*Computer Science Course at University*, *didactic method*, *deductive*) = 7;
- *CXP* (*Computer Science Course at University*, *didactic method*, *inductive*) = 4;
- *TP* (*First Order Logics*, *Computer Science Course at University*, *didactic method*, *inductive*) = 10.

### C. The Contextualization Algorithm

The contextualisation algorithm is purposed to generate a domain model (as defined in the previous section) composed by a conceptual graph *G'* (*C'*, *BT'*, *IRB'*, *SO'*) and a set of teaching preferences *TP'* starting from an abstract domain model composed by a conceptual graph *G* (*C*, *BT*, *IRB*, *SO*), a set of contexts *CX*, a context profile *CXP*, a labelling relation *CL* and a set of teaching preferences *TP* by selecting a context $cx \in CX$.

The algorithm build *G'* components as well as *TP'* by executing the following steps sequentially:

1. $C' = \{c \in C \mid (c, cx) \in CL\}$ i.e. it is obtained by considering only concepts that apply in the context *cx*;
2. $BT' = \{(a, b) \in BT \mid CL(a, cx) \wedge CL(b, cx)\}$ i.e. it is obtained by considering arcs of type *BT* connecting two concepts that apply in the context *cx*;
3. $IRB' = \{(a, b) \in IRB \mid CL(a, cx) \wedge CL(b, cx)\}$ i.e. it is obtained by considering arcs of type *IRB* connecting two concepts that apply in the context *cx*;
4. $SO' = \{(a, b) \in SO \mid CL(a, cx) \wedge CL(b, cx)\}$ i.e. it is obtained by considering arcs of type SO connecting two concepts that apply in the context *cx*;
5. it initialises any *TP'* (*c*, *p*, *pv*) with *CXP* (*cx*, *p*, *pv*) for any $c \in C$, $p \in Props$ and $pv \in PropVals$ (i.e. the teaching preferences for each concept are initially settled to those defined by the selected context profile);
6. it updates any *TP'* (*c*, *p*, *pv*) with *TP* (*c*, *cx*, *p*, *pv*) for any defined *TP* (i.e. if teaching preferences are explicitly defined for a given concept in the context *cx*, then they override default teaching preferences).

As an example, the figure 3 shows the two domain models that can be obtained through the contextualization algorithm, starting from the conceptual graph in figure 2, by selecting the context *Mathematics Course at University* (up) or *Computer Science Course at University* (down).

Moreover, starting from the sample context profile and teaching preferences defined in the previous subsection, the following preferences will be automatically generated by the contextualization algorithm for the computer science context:

- *TP'* (*c*, *didactic method*, *deductive*) = 7 for any $c \in C$ different from *first order logics*;
- *TP'* (*first order logics*, *didactic method*, *deductive*) = 10;
- *TP'* (*c*, *didactic method*, *inductive*) = 4 for any $c \in C$;

The contextualization algorithm has been integrated in the *unit of learning* generation process of IWT (defined in the previous section) in order to obtain different sequences of learning resources not only basing on the *learner model* of the involved learner (personalization) but also on the context where the learner learns (contextualization).

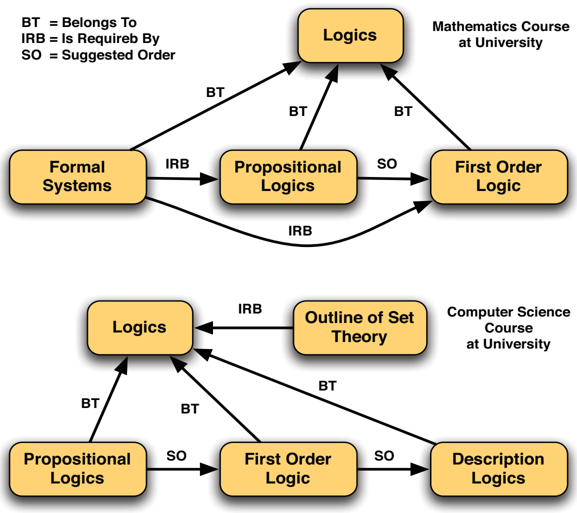


Figure 3. Two samples of contextualized domain models.

## V. The Developed Prototype

The IWT logical architecture is divided in four main layers. The first layer is the *IWT Framework* used by developers to design and implement core services, application services and learning applications. The second layer is composed by *Core Services* providing basic features for the management of users, roles, resources, metadata and ontologies as well as for user profiling and learning personalization.

The third layer is composed by *Application Services* used as building blocks to compose e-learning applications for specific domains. They include blocks for learning content management, learning management, ontology management, communication and collaboration. On the top of the stack, *Learning Applications* covering specific learning scenarios obtained as integration of application services are built.

IWT server side components are completely developed in Microsoft .NET technology and use Microsoft SQL Server for persistency. IWT is an extensible system both at the level of learning resources (with drivers i.e. software components able to edit, manage and deliver a specific kind of resource) and at services level (with plug-ins i.e. software components providing specific back-end services).

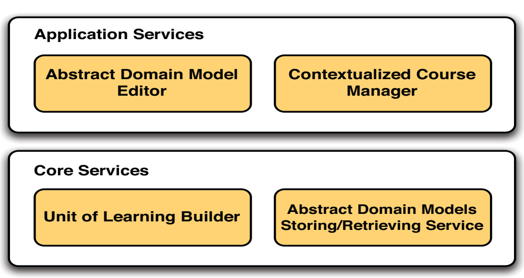


Figure 4. Additional IWT components foreseen.

The integration of context management and knowledge model contextualization features have impacted in the second and third level of the IWT architecture as depicted in figure 4 that also shows provided additional and improved components. In the following we briefly describe developed components and their impact on the architecture.

- *Unit of Learning Builder* is the component that provides personalization features. The new developed version of such component is able to deal with abstract domain models and implements the contextualisation algorithm. It has been developed in C# and deployed as an internal IWT service.
- *Abstract Domain Models Storing/Retrieving Service* are the services responsible for the persistency of defined models. They have been developed in C# and deployed as internal IWT services.
- *Abstract Domain Model Editor* allows to visually build an abstract domain model including concepts, relations between concepts, contexts, context profiles, context labels linked to concepts and teaching preferences linked to context labels. It is a client-side component developed as a Java Applet. It communicates with the abstract domain models storing/retrieving service via a Web services interface.
- *Contextualized Course Manager* is a component able to manage contextualised courses. It allows teachers to select target concepts on an abstract domain model rather than on a standard one and to select a context while assigning the course to a given student. It has been developed as an IWT driver in C# language.

The figure 5 shows the user interface of the abstract domain model editor. Available contexts are listed in the left side of the window. The user can add, remove or rename contexts by exploiting menu items over the list. A colour is associated to each context. Domain concepts are listed under contexts. The user can add, remove or rename concepts by exploiting menu items over the list. Available relations are listed under the list of concepts.

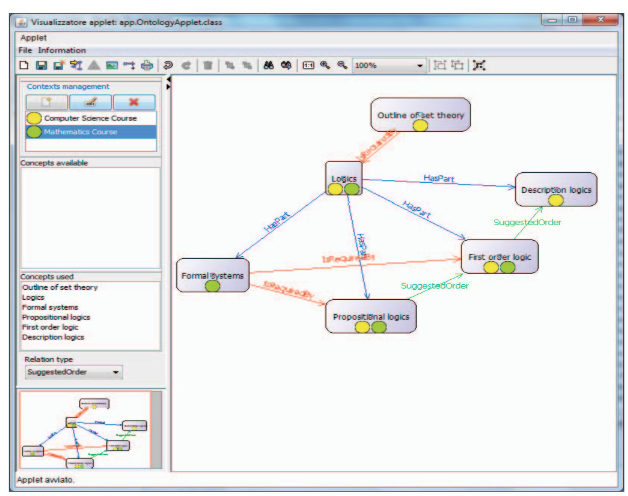


Figure 5. Interface of the abstract domain model editor.

The user can drag a concept from the list and drop it in the workspace. Dropped concepts are represented as rounded boxes with the name of the concept and a sequence of coloured circles, one for each available context. Concepts can be moved and connected with available relations (a relation must be selected and a line must be traced between the two concepts to connect).

By double clicking on a context, the context profile is shown and connected teaching preferences can be settled. By clicking on a coloured circle inside a concept, teaching preferences for the concept (in the corresponding context) can be modified. Such preferences are initially settled according to the context profile but may be changed. Once preferences for a concept in a context are changed the corresponding context label become a diamond to emphasise the modification.

Context labels can be removed from concepts by right clicking on them and selecting the "remove" menu item from the contextual menu. Removing a context label from a concept means that the concept is not active in that context. Once removed a context may be added again by dragging it from the list and dropping it on the interested concept.

By right clicking on a diamond shaped context label it is also possible to select the "remove teaching preferences" button. By doing that teaching preferences connected to the concept (in the corresponding context) are modified and the diamond becomes a circle. A designed model can be saved, printed, redrawn (to improve readability) and zoomed (zoom percentage may be settled). Undo and redo buttons are also provided to remove and redo the last performed action.

## VI. CONLCUSIONS AND FUTURE WORK

This paper describes a research aimed at the definition of theoretical and technological components for context-aware e-learning. Starting from an existing e-learning system able to provide personalized learning (taking into account learner cognitive state and learning preferences), we added a set of features to provide contextualized learning (taking also into account the environment where the learning takes place).

In particular we defined a learning context model, an ontology-based model able to represent a teaching domain that includes contextualization information and an algorithm to generate personalized and context-aware learning courses basing on such structures. In order to experiment defined models and algorithms a prototype was also developed and currently under experimentation.

The experimentation phase will provide comments and suggestions for the improvement of defined theoretical and technological components. In addition to what needed to face experimentation feedbacks, future work will also relate to other improvement as described below.

- The possibility to define an algorithm to automatically obtain a context profile starting from a learning context model will be explored.
- The possibility to define ontologies modelling contexts and relations between contexts will be explored.
- The possibility to define and use templates for teaching preferences will be explored. In such way a template can be assigned to a context, to a concept or to a couple (concept, context) instead of defining extensive set of preferences in each one of these cases.
- The possibility to introduce the inheritance of teaching preferences between concepts connected with relations of a hierarchical type (e.g. the BT one) will be explored.


## VII. AKNOWLEDGEMENTS

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