

Semantic Description of the IMS Learning Design Specification

Manuel Lama, Eduardo Sánchez, Ricardo R. Amorim, and Xosé A. Vila
Departament of Electronics and Computer Science, Faculty of Physics.
Campus Univesitario Sur s/n, University of Santiago de Compostela.
15782 Santiago de Compostela, A Coruña, Spain.
lama@dec.usc.es, eduardos@usc.es, rramorin@usc.es, vila@dec.usc.es

Abstract. In this paper we present a learning design ontology that is based on the IMS Learning Design (IMS LD) specification. The IMS LD is a metadata standard that describes the elements of the design of any teaching-learning process on the basis of a well-founded conceptual model. However, this specification has been modelled and represented using the XML-Schema language, which is not expressive enough to describe the semantics of all the elements of such conceptual model. To solve these limitations, we have developed an ontology using Protégé at the knowledge level, and then translated into OWL, to represent it in the standard language of the Semantics Web, and first order logic, to formalize the axioms defined in the ontology.

Keywords. IMS Learning Design; Ontologies; Semantic Description; Formal Axioms.

1. Introduction

In the last years, the growing of the Internet have opened the door to new ways of learning and education methodologies. Furthermore, the appearance of different tools and applications has increased the need for interoperable as well as reusable learning contents, teaching resources and educational tools [1]. Driven by this new environment, several metadata specifications describing learning resources, such as IEEE LOM [2] or Dublin Core [3], and learning design processes [4] have appeared. In this context, the term *learning design* is used to describe the method that enables learners to achieve learning objectives after a set of activities are carried out using the resources of an environment. From the proposed specifications, the IMS Learning Design (IMS LD) [5] has emerged as the *de facto* standard that facilitates the representation of any learning design that can be based on a wide range of pedagogical techniques.

The metadata specifications are useful solutions to describe educational resources in order to favour the interoperability and reuse between learning software platforms. However, the majority of the metadata standards are just focused on determining the vocabulary to represent the different aspects of the learning process, while the meaning of the metadata elements is usually described in *natural language*. Although this description is easy to understand for the learning participants, it is not appropriate for software programs designed to process the metadata. To solve this issue, ontologies [6] could be used to describe *formally*

and *explicitly* the structure and meaning of the metadata elements; that is, an ontology would semantically describe the metadata concepts. Furthermore, both metadata and ontologies emphasize that its description must be shared (or standardized) for a given community.

In the educational domain, authors have developed ontologies to: (1) describe the learning contents of technical documents [7]; (2) to model the elements required for the design, analysis, and evaluation of the interaction between learners in computer supported cooperative learning [8]; (3) to specify the knowledge needed to define new collaborative learning scenarios [9]; or (4) to formalize the semantics of learning objects that are based on metadata standards (like LOM) [10]. The focus of that research is either on the development of a taxonomy of concepts on the basis of an established theory or specification [7,8,9], or on the formal definition of the metadata using an ontology language [10]. However, none of them deal with the formal description of the meaning of the concepts, and they do not address the ontological modelling of any specification for learning design.

In this paper, we present a *learning design ontology* based on the IMS LD Level A specification. In this ontology, the IMS LD elements are modelled in a *concept taxonomy* in which the relations between the concepts are explicitly represented. Furthermore, a set of *axioms* constraining the semantics of the concepts has been formulated from the restrictions (available in natural language) identified in the analysis of the IMS LD specification.

The paper is structured as follows: in section 2, the need for a learning design ontology is justified; in section 3, the concept taxonomy and the ontology axioms are described; then, in section 4, an example that illustrates how the ontology could be used; finally, the contributions of the paper are summarized.

2. The Need for a Learning Design Ontology

The IMS Learning Design specification is a metadata standard that describes all the elements of the design of a teaching-learning process [5]. This specification is based on: (1) a well-founded *conceptual model* that defines the vocabulary and the functional relations between the concepts of the LD; (2) an *information model* that describes in an informal (natural language) way the semantics of every concept and relation introduced in the conceptual model; and (3) a *behavioural model* that specifies the constraints imposed to the software system when a given LD is executed in runtime. In other words, the behavioural model defines the semantics of the IMS LD specification during the execution phase.

To facilitate the interoperability between software systems, the IMS LD specification has been formally modelled through the XML-Schema language [11,12]. However, the knowledge model of this language is not expressive enough to describe the semantics (or meaning) associated to the elements of the IMS LD. Thus, the main limitations of the XML-Schema language are [13]:

- Hierarchical (is-a) relations between two or more concepts cannot be *explicitly* defined. Therefore, there are no inheritance mechanisms facilitating the representation of concept taxonomies. For example, in the IMS LD specification, the `Learner` and `Staff` elements do not inherit the attributes and relations of the `Role` element: they are just included as XML sub-elements of the `Role` element.

- General and formal constraints (or *axioms*) between concepts, attributes, and relations cannot be specified. These axioms describe more precisely the semantics of the concepts, because they constrain how the instances of the concepts could be created. For instance, the axiom “*if an Act is executed in the context of a Play, and both have a given value for the time limit attribute, the value of this attribute for the Play should be greater or equal than the value for the Act*” could not be represented in the XML-Schema language.

To solve these limitations of the XML-Schema language, a software system processing any given LD should automatically manage the semantics of the specification, guaranteeing that both restrictions and concept hierarchy are verified. Therefore, the modelling of the IMS LD specification needs to be enriched in order to describe *explicitly and formally* the semantics of its elements. To achieve this goal, we have developed an ontology [6], as it facilitates the semantic description of the conceptual model as well as the definition of formal axioms related to both information and behavioural models. This ontology is based on a knowledge model that includes complex taxonomic relations (like both hierarchical and ad-hoc relations, disjoint and exhaustive partitions, etc.) as well as formal axioms.

3. The Learning Design Ontology

To develop the Learning Design ontology we have created a *concept taxonomy*, which describes the elements of the IMS LD conceptual model and the IMS LD information model, and a *set of axioms*, which formally constraint the semantics of the concept taxonomy on the basis of the explanations formulated in natural language in both information and behavioural models.

3.1. Description of the Concept Taxonomy

The upper node of the LD ontology is the `Unit of Learning` concept (Figure 1) that defines a general module of an educational process, like a course or a lesson. Following the IMS LD specification, a unit of learning is modelled as a content package [5] that integrates the description of both the LD and the set of resources related to it. The `Resource` concept allows to represent various entities, like physical resources (Web pages, files, etc.), and concepts whose attribute description is domain-dependent (learning objectives, prerequisites, etc.). To model the different kinds of resources, we have extended the IMS LD specification with a new hierarchy of concepts (grey boxes in Figure 1). In this way, when a LD concept refers to any of the resource properties, it establishes a relation with the `Item` concept, which in turn, has a set of subclasses that replicate the hierarchical structure of the resources (following a one-to-one correspondence). These two hierarchies have been introduced to decouple the references to the resources (`Item` hierarchy) from their modelling (`Resource` hierarchy). Thus, if two applications use the same LD to model a course, but define the resources in a different way (for example, if the learning objectives are specified either as textual description or through their corresponding attributes), the LD does not need to be changed because the links to the resources are indirectly established through the `Item` hierarchy.

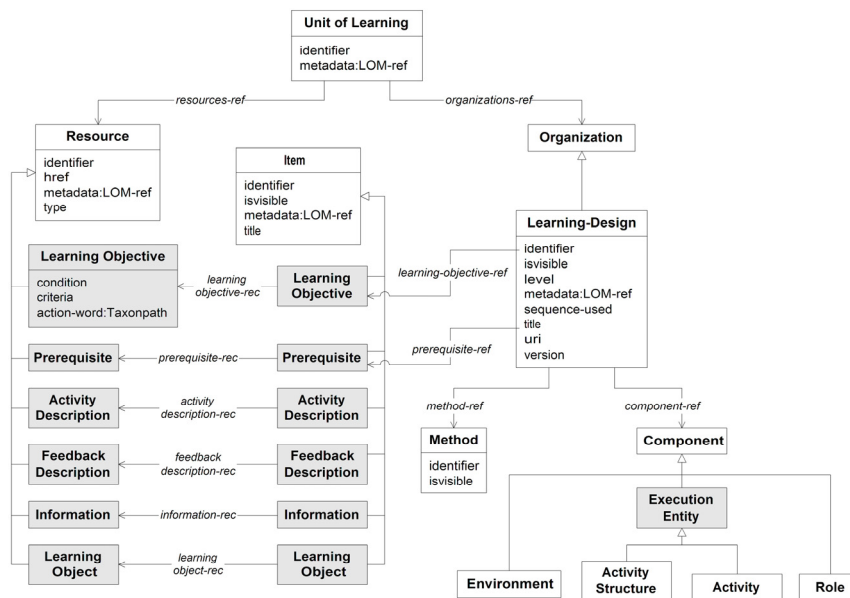


Figure 1. Upper concepts of the Learning Design ontology.

Learning Design Description

The Learning Design concept is related to the Learning Objective and Prerequisite concepts, which define the intended outcomes when the unit of learning is carried out, and the previous knowledge needed to participate in it, respectively. Both concepts are subclasses of the Item concept, and therefore they will be mapped onto the Learning objective and Prerequisite concepts of the Resource hierarchy.

The Learning Design concept has a number of Components used to describe the learning process: the Execution Entities to be carried out, which can be Activities or Activity Structures (groups of activities that will be executed in sequence); the Roles that participate in the execution of those activities as instances of the Learner and Staff concepts; and the Environments that describe the educational resources to be used in the activities. These concepts constitute an exhaustive and disjoint partition, because an instance of a Component must necessarily be an instance of one of its subclasses.

The Learning Design concept is also related to the Method concept, which describes the dynamics of the learning process (Figure 2): a method is composed of a number of instances of the Play concept that could be interpreted as the *runscript* for the execution of the unit of learning. All the play instances have to be executed in parallel, and each one consists of Act instances, which could be understood as a *stage* of a course or module. The Act instances must be executed in sequence (according to the values of the execution order attribute), and they are composed by a number of Role Part instances

constitute a disjoint and exhaustive partition, because an instance of the `Activity` concept should be either a learning or a support activity.

Every concept involved in the dynamics of the learning process (`Method`, `Play`, `Act`, and `Activity`) establishes a relation with one of the subclasses of the `Complete Unit` concept, which indicates when an execution is finished. In the IMS LD Level A, this condition can be specified through the `time limit` attribute, which define the temporal duration of the execution, or referred to an instance of the entity of which is composed by. For example, an act would be completed when the instance of the `Role Part` pointed out by the relation `when-role-part-completed` has finished. Furthermore, in both Level B and C of IMS LD, the modelling of these subclasses will be extended to enable the specification of more complex completion conditions.

3.2. Description of the Learning Design Ontology Axioms

The three models of the IMS LD specification contain a natural language description of the semantics of all the taxonomy concepts, including the *constraints* that should verify their instances when they are created and managed by a software system. To incorporate these restrictions to the LD ontology we have applied the following procedure: first, the description of the constraints is identified in the text of IMS LD; then, if necessary, this description is reformulated considering the elements of the LD concept taxonomy (concepts, relations, and attributes); and, finally, the restrictions are represented in a declarative, formal, and language-independent way as *axioms* in first order logic. In Table 1, three axioms obtained following this procedure are presented.

Depending on the stage where the axioms are applied, we distinguish between two different kinds of axioms:

- *Design axioms*, which determine how the instances of the taxonomy concepts will be created when a given learning design has been specified. For example, the first axiom of the Table 1 will not allow to create a play with a value for the time limit attribute less than the time limit of any of its acts. Following the procedure previously described, we have extracted and formally defined 28 axioms, most of them from the IMS LD concept and information models.
- *Runtime axioms*, which are associated with the management and monitoring of the execution of the learning design created during the design phase. For example, one of the axioms of this category must guarantee that the plays of the method are executed in parallel. However, to specify many of these axioms it is necessary to *extend* the LD ontology for including a runtime model (not defined in the IMS LD specification) that would represent the different states of execution of the learning design. Currently, these axioms have been extracted from the behavioural model.

From a modelling point of view, the formal definition of the semantic constraints of the LD concepts is the main advantage of the learning design ontology when compared with the IMS LD XML-Schema specification. On one hand, the semantics of the concepts is *completely* included in the ontology (not only the taxonomic structure), and, on the other hand, the programmers will not need to interpret the descriptions of the IMS LD models in order to translate its meaning into software systems designed towards to manage learning design elements.

Table 1. Formal definition of some ontology axioms identified in the analysis of the IMS models. For the IMS LD Level A, 28 axioms have been identified.

Design Axiom 1	IMS LD Specification <i>(natural language)</i>	<i>Page 38 (item 0.2.2):</i> “The time limit specifies that it is completed when a certain amount of time has passed, relative to the start of the run of the current unit of learning. The time is always counted relative to the time when the run of the unit-of-learning has been started. Authors have to take care that the time limits set on role-parts, acts and plays are logical.”
	Explanation	The value of the attribute <code>time limit</code> of a <code>Method</code> must be greater than the value of the <code>time limit</code> of any <code>Play</code> . That is, the <code>Play(s)</code> cannot finish after the <code>Method</code> .
	Formal Description	$\forall m, p, cm, cp \mid m \in \text{Method} \wedge p \in \text{Play} \wedge cm \in \text{Complete-Method} \wedge cp \in \text{Complete-Play} \wedge \text{play-ref}(p, m) \wedge \text{complete-unit-of-learning-ref}(cm, m) \wedge \text{complete-play-ref}(cp, p) \rightarrow \text{time-limit}(cm) \geq \text{time-limit}(cp)$
Design Axiom 2	IMS LD Specification <i>(natural language)</i>	<i>Page 90:</i> “The same role can be associated with different activities or environments in different role-parts, and the same activity or environment can be associated with different roles in different role-parts. However, the same role may only be referenced once in the same act.”
	Explanation	For the same <code>Act</code> , the <code>Roles</code> involved in the execution of the <code>Act</code> are disjoint.
	Formal Description	$\forall a, r, rp \mid a \in \text{Act} \wedge r \in \text{Role} \wedge rp \in \text{Role-Part} \wedge \text{role-part-ref}(rp, a) \wedge \text{role-ref}(r, rp) \rightarrow \neg \exists rp1 \mid rp1 \in \text{Role-Part} \wedge rp1 \neq rp \wedge \text{role-part-ref}(rp1, a) \wedge \text{role-ref}(r, rp1)$
Runtime Axiom 1	IMS LD Specification <i>(natural language)</i>	<i>Page 25 (item 0.2.1):</i> “The <code>create-new</code> attribute indicates whether multiple occurrences of this role may be created during runtime. When the attribute has the value “not-allowed” then there is always one and only one role instance.”
	Explanation	If the value of the attribute <code>create-new</code> is “not-allowed”, it can have an only instance of the <code>Role</code> at which it is applied.
	Formal Description	$\forall r \mid r \in \text{Role} \wedge \text{create-new}(r) = \text{“not-allowed”} \rightarrow \neg \exists r1 \mid r1 \in r$

4. Sample Scenario

The scenario presents a learning design that models a unit of learning in the environmental education. This learning design has been obtained from the Educator’s Reference Desk site (<http://www.eduref.org>), a well-known site of resources for the educational community that is commonly used as a reference for the verification of the pedagogical expressiveness of the EML UONL [14]. The unit of learning, entitled *environmental determinism*, is applied to two groups of students during the same period of time: one group for the in-classroom modality and the other group for the e-learning modality. The proposed activities in the learning design are: (1) a presentation of introductory topics related to the study domain; (2) a number of sessions of practice using the local region like an environmental laboratory; (3) development of activities like collaboration in classroom, data collection in field, preparations of reports, etc.; and (4) evaluation of the learning process through examination tests.

As Figure 3 shows, the method of the unit of learning consists of two different plays: Env-Det-Pres-Play and Env-Det-Dist-Play, one for presential learning, and the other for distant learning. The acts of both plays have the *same activities*, and the difference between them is the schedule considered for these activities: the e-learning group will execute the activities asynchronously. Thus, the method completes its execution after one month and 20 days, the Env-Det-Dist-Play play will finish after one month and 10 days, and

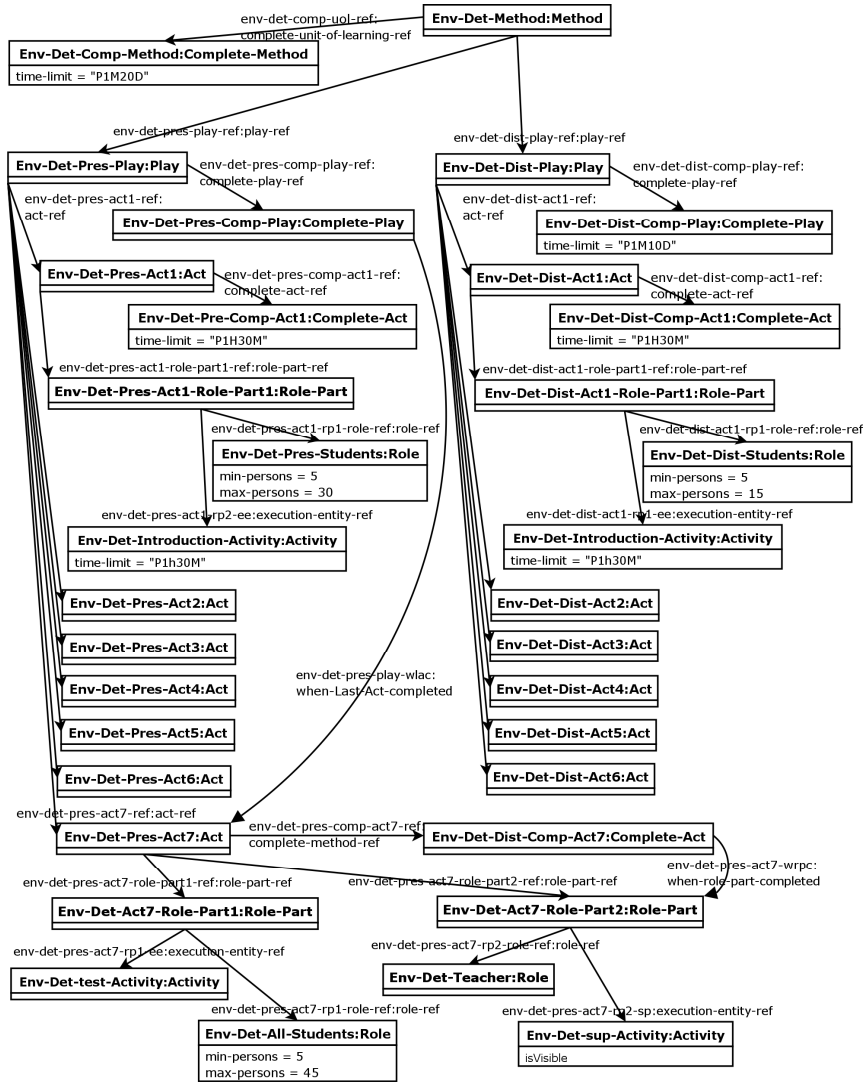


Figure 3. LD ontology instances for the learning design of the unit of learning of the sample scenario.

the `Env-Det-Pres-Play` play is completed when the seventh act finishes the execution (when-last-act-completed = `Env-Det-Pres-Act7`), that is, when the role part `Env-Det-Act7-Role-Part2` has been completed. To guarantee the consistence between the time limit values for the method and the two plays, the first axiom of the Table 1 is verified. However, this axiom cannot be applied to the `Env-Det-Pres-Play` play, because it does not define a value for the time limit attribute.

According to Figure 3, for the role `Env-Det-Pres-Sudents`, the values for the attributes `min-persons` and `max-persons` are 5 and 30, indicating the minimum number of students that justify economically the course and the maximum capacity of the classroom respectively. In order to guarantee the consistence of the values of these attributes, the following axiom is verified:

$$\forall r \mid r \in \text{Role} \rightarrow \text{max-persons}(r) \geq \text{min-persons}(r)$$

In the two plays of the method, the first act will be completed in one hour and 30 minutes, and the activity `Env-Det-Introduction-Activity` will be finished in the same period of time. In this case, the specification of the act and its roles is consistent, because the value of the time limit of the act equals the time limit of the activity related with the role part that is executed in the context of the act. The general axiom related to this condition could be expressed as:

$$\forall a, ca, actv, cactv, as, rp \mid (a \in \text{Act} \wedge ca \in \text{Complete-Act} \wedge \text{complete-act-ref}(ca, a)) \wedge (rp \in \text{Role-Part} \wedge \text{role-part-ref}(a, rp)) \wedge (actv \in \text{Activity} \wedge cactv \in \text{Complete-Activity} \wedge \text{complete-activity-ref}(cactv, actv)) \rightarrow \text{time-limit}(ca) \geq \text{time-limit}(cactv)$$

In the seventh act all the `students` must carry out an activity consisting on an examination test (`Env-Det-test-Activity`), while the `teacher` has to explain how the test should be answered by the students (`Env-Det-sup-Activity`). Therefore, as established by the second axiom of Table 1, the roles that participate in the role parts of a same act have to be different. In this case, the roles (`students` and `teacher`) are involved in different role parts (or in other words, in different activities).

5. Conclusions and Future Work

The IMS LD specification is expressive enough from the point of view of the learning process designers. Nevertheless, the informal specification of the IMS information and behavioural models increases the complexity of the IMS LD to be understood by programmers, as they are not usually educational specialists. With the development of the learning design ontology the semantics of the concepts is precisely defined, and, in consequence, there should be no misinterpretations or errors when the instances of the concepts are created or manipulated in runtime. Furthermore, the expressiveness of the IMS LD specification is preserved.

The learning design ontology has been developed at the knowledge level using the Protégé tool. Then, the ontology was directly translated into the OWL [15] language (it can be downloaded from http://www.eume.net/ontology/imslld_a.owl), which is the W3C recommendation for the Semantic Web. The ontology is also available in first order logic to enable the reasoning with the formal axioms defined in the ontology construction. Currently,

the ontology is used to exchange knowledge between the software agents developed in the context of the EUME project [16], whose aim is to enable teachers and students the ubiquitous access to hardware devices and services available in the classroom.

As future work we have planned to translate the ontology axioms into SWRL [17], which is the language currently proposed to express restrictions in OWL. On the other hand, we are working on the extension of the ontology to include the concepts and axioms of the levels B and C of the IMS LD specification.

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