Making Learning Design Standards Work with an Ontology of Educational Theories

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Abstract. In this paper, we present an ontology of educational theories their relation to learning design. This ontology takes into account learning design (LD) specifications such as OUNL-EML and IMS-LD at the conceptual level (1), semantic web standards such as OWL at the formal level (2), as well as JAVA standards at the implementation level (3).

This ontology is intended to provide a knowledge base for any IMS-LD compliant authoring systems/LKMS, in order to provide services to authors of LD scenarios. The ontological engineering (OE) has been done using the Hozo ontology editor at levels 1 and 2 respectively.

Introduction

The research presented in this paper follows the initial idea developed in [1] [2] [3], regarding the elicitation through ontological engineering (OE) of instructional design, instruction, learning and knowledge in an authoring system.

The foundations of ontological engineering issues in authoring systems were established in [4] [5], in which we presented (a) a case analysis and (b) the rationale behind it. In (a), specifically, an author assisted by an authoring system or a *Learning and Knowledge Management System* (LKMS) needs to select a relevant learning design (LD) strategy in order to produce a learning scenario. In this case, the author benefits from having access to the theories on which such strategies rely. In (b), we have introduced the rationale for concrete situations in the authoring process that exploit a theory-aware authoring system. In the present article, we propose an ontology of educational theories which describes these theories and their links to the LD, in order to make authoring systems theory-aware. We also discuss the question of having this ontology compliant to e-learning standards in order to provide shareable and reusable services.

Our former research was based on [6] for the representation of the educational theories, and on MISA [7] for that of the learning design process. Recently, in order to enhance and complete these representations, our work has been further inspired by the following: the Open University of the Netherlands' Educational Modeling Language (OUNL-EML) [8] and the IMS Learning Design [9] (IMS-LD) specifications.

In section 1, we give an overview of related work and e-learning technologies standardization efforts. In section 2, we discuss the needs/requirements of authors/learning designers, and the services that an appropriate system could provide in this respect. In section 3, we propose an educational ontology which integrates LD specifications, following which we propose an OWL formalization of this ontology. We conclude in section 4 by summarizing our contribution and by listing our objectives in terms of further work.

1. Overview of Related Work and E-learning Technologies Standardization Efforts

In e-learning, ontologies are increasingly used to organize LD knowledge in authoring systems and LKMS [10] [11] [12] [13] [14]. In most cases, ontologies facilitate the referencing and the retrieval of semantically marked-up learning objects [10] [15]. The most valuable characteristics of ontologies in this respect are shareability, explicitness, and formalism.

Concurrently, recognized standard-initiating organizations have set forth the importance of sharing a common view of the educational field. In 2002, the European Committee for Standardization (CEN/ISSS) conducted a survey of educational modeling languages (EMLs) [16], in which the six existing EMLs were compared. Two distinct groups seemingly emerged. The first, consisting of CDF, LMML, Targeteam, and TML, restricts itself to the modeling of learning content and structure. These languages seem to ignore the existence of pedagogical models. The second consists of PALO and OUNL-EML, and this group lives up to the survey's working definition of EML: "*An EML is a semantic rich information model and binding, describing the content and process within "units of learning" from a pedagogical perspective*" [16]. The survey has shown that the expressive power of OUNL-EML exceeds that of PALO. The OUNL-EML [8] [17], now called EML, aims at providing a pedagogical meta-model. It consists of four extendable models which describe: (a) how learners learn (based on a consensus among learning theories); (b) how units of studies which are applicable in real practice are modeled, given the learning model and the instruction model; (c) the type of content and the organization of that content; and (d) the theories, principles and models of instruction as they are described in the literature or as they are conceived in the mind of practitioners. EML and its subsequent integration to IMS-LD has been to date the most important initiative towards integrating instructional design preoccupations in the international e-learning standardization effort [7].

IMS-LD [9] takes the EML information model as its base. For binding purposes, it is made compatible with the IMS specifications: CP, QTI, CD, SS [9]. The LD is positioned as the containment framework for all these specifications allowing instructional design (called "Learning Design" in IMS and henceforth in this paper) to be included into content packages. According to [9] "*A Learning Design is a description of a method enabling learners to attain certain learning objectives by performing certain learning activities in a certain order in the context of a certain learning environment. A learning design is based on the pedagogical principles of the designer and on specific domain and context variables*". In this definition, the place of educational theories in the LD specification is not clear. As a result, however, it underlines the importance of educational theories in the LD specification, since most of existing LD tools fail to explicitly integrate educational theories.

Indeed, the current learning technologies standards and specifications mainly focus on describing knowledge about learning design and content (e.g. LOM, Dublin Core, SCORM, CANCORE), thus offering only limited support to describe knowledge of the educational theories. Consequently, authors/learning designers cannot rely on assistance stemming from theories in their learning design process. Why are LD standards so limited? It may be because of the lack of representation of this theoretical knowledge as well as the lack of a compliance mechanism between these standards and this theoretical knowledge. Such a problem has been one of the concerns of the Learning Object Repository Network (LORNET) research network in Canada. LORNET is developing an authoring environment in the form of a LKMS compliant with IMS-LD standards; we believe that such an LKMS could benefit from providing authors with access to LD theories in order to enhance the quality of their design, and to improve their expertise. "*A taxonomy of pedagogies is a common request as this would enable people to search for learning designs according to the embedded pedagogy*" [17]. In order to thus make LD standards work with a representation of LD theories, a technical solution is needed.

2. Why linking LD Standards to a Representation of Educational Theories?

Assuming that the main user is an author/learning designer, this section introduces: the needs of an author for such a knowledge representation, the resulting services he/she can expect from an appropriate system, and how theses services can be supported through the binding of LD standards to theories. Our goal is consequently to provide services whose specific purpose would be linked to consultation of theories, eventually linking such theories to learning designs based on those theories.

Some needs of the author using an authoring system, as suggested in [5] [18], are the following: (a) Query about which theories apply best to a specific LD, or about design principles related to theories; (b) Extract, (re)view and browse among theories in order to select LD strategies, or among templates of LD scenarios; (c) Review examples of good LD scenarios or principles in order to design a LD scenario; (d) Reuse or modify a template of LD scenario; (e) Validate (check consistency) among design principles.

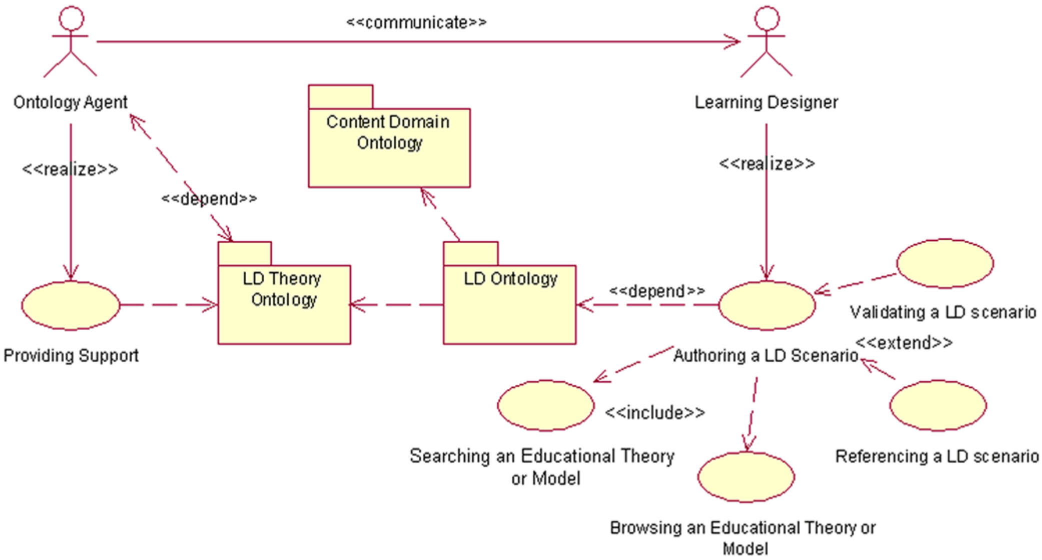

Figure 1. Main Use Cases and Provided Services

Table 1. Example of a Service: Searching a Theory

Use Case Goal	**Perform a search to find a suitable theory**	
Success End Condition	The suitable theory is found and provided by an agent.	
Failed End Condition	No input from the author or no matching theory.	
Primary Actor	**User:** Author / Learning Designer	
DESCRIPTION	**Step**	**Branching Action**
The author searches for appropriate theories for sequencing instruction that would map an LD activity structure in a particular LD scenario.	**1**	**Author:** wants to select a given type of instructional activity
	2	**Ontology Agent:** consults the ontology
	3	**Ontology Agent:** performs queries as to which theories could map the learning design activity
	4	**Ontology Agent:** outputs a list of suitable theories from the ontology
	5	**Author** selects a theory item in the list

Such a system should therefore assist an author in designing scenarios while improving expertise gained in LD. More specifically, this system should provide the following services [12]: (a) Assist the author in the selection of an appropriate LD method with regards to a scenario and encourage the application of a wide range of available LD methods when requested; (b) Inform this author about a particular LD method when queried; (c) Check and highlight errors in the authoring/design of a scenario when validation is needed/required. (d) Provide relevant examples. These services can be provided through a repository of LD scenarios [17] linked to a learning design ontology, as illustrated in Fig. 1. The LD ontology itself consequently depends on the LD theory ontology and the content domain ontology (cf. section 3 for details). Fig. 1 also shows that searching, browsing, referencing and validation services are common requests. Some of these could be directly provided by a software agent to the author (searching, browsing), while other services (referencing, validation), could be provided through an authoring system or LKMS. Table 1 shows a detailed use case of a search that might be conducted by an author indicating the type of support potentially given by the agent.

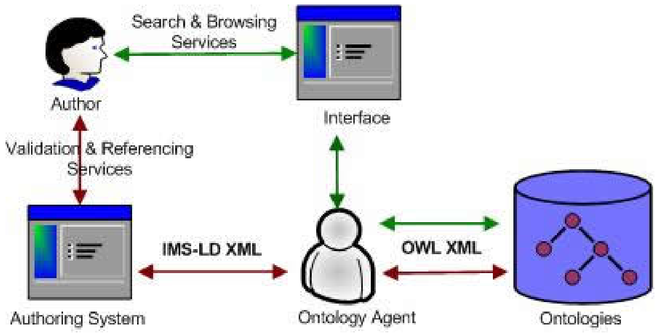

Figure 2. Interactions between Agent and Author during Authoring Process

Fig. 2 shows the interactions and flow of information between the agent and the author while providing those services. The possibility of using LD standards for other services [19] [20], is also explored. For instance, in the case of a validation service, an agent aware of the LD standards would be able to highlight errors or check the consistency of a scenario during the authoring process. This means that with a representation of the LD, an agent would be able to follow and assist the author in the process of authoring a LD scenario. This active assistance is possible only if the ontologies involved are well formalized given that the agent will need to query and reason about the elements within the ontology, which also explains why OWL is used (cf. section 4 for details). Clearly, an author would benefit from these services if the LD was linked to a representation of theories. We assume that the authoring system or LKMS used for indirect services is compliant with LD standards. On the basis of these hypotheses, we now propose how LD standards and LD theories could be connected.

3. Integration of LD Standards through Representation and Binding with Theories

This section describes the solution that has been developed in order to realize this integration: 1) an EML representation in the ontology, 2) a binding mechanism between LD and theories. As a preliminary to this discussion, we first elaborate on our OE methodology:

3.1. Methodology

Our methodology follows the three main steps of OE (before implementation): 1) analysis , 2) conceptualization, 3) formalization, followed by an evaluation [21] and documentation of the ontology.

- *Analysis of the domain.* This step was done by creating a glossary of terms, and includes the following tasks: (a) Identifying each the type of each term (Class, Properties, Individuals); (b) Adding an informal description for each term; (c) Adding synonyms and acronyms if available;
- *Conceptualization.* The conceptual modeling includes the following tasks: (a) Creating models of classes; (b) Creating *ad hoc* property models.
- *Formalization.* This step was conducted using Hozo [5]. For each class: (a) Add the subclasses in order to create taxonomies of classes; (b) Add predefined properties; (c) Add *ad hoc* properties; (d) Add comments (or annotations) if necessary; (e) Add axioms if

necessary. This is an iterative process, which stops once the ontology is stabilized. Finally; (f) Add individuals.

- *Evaluation*. This step [21] is performed during the conceptualization and formalization steps: (a) Verification: check (assisted by the editor) if the ontology is syntactically correct. (b)Validation: make sure (with domain experts) that the ontology correctly models the real world (domain) for which it was created.
- *Documentation*. At this stage, we document the ontology using OWL terminology: (a) *Creating a dictionary of classes*. For each class, indicate the: identifier, equivalent class, super and sub-classes, individuals, class property; (b) *Creating a dictionary of properties*. For each property, indicate the: name, type, domain, range, characteristics, restrictions; (c) *Creating a dictionary of class axioms*: indicate boolean combinations; (d) *Creating a dictionary of individuals*. For each individual, indicate the: individual name, type name, ObjectPropertyValue, DataPropertyValue.

3.2. An Ontological Conceptualization Compliant with EML & IMSL-LD

We argued previously that LD standards have a very limited connection to theories. Because IMS-LD [9] relies upon EML, we examined the EML meta-model [8] and how LD relates to theories in this meta-model. Fig. 3 shows that the "Unit of Study" is at its heart and relates to theories, to content domain and to learning models. In our view, ontologies could try to match this structure and we thus propose a structure consisting of three ontologies (Fig. 4), in which the "Learning Design Ontology" corresponds to the "Unit of study" and includes the "Learning Model", while relating to the two other ontologies, the "Learning Design Theories", and the "Content Domain" Ontology.

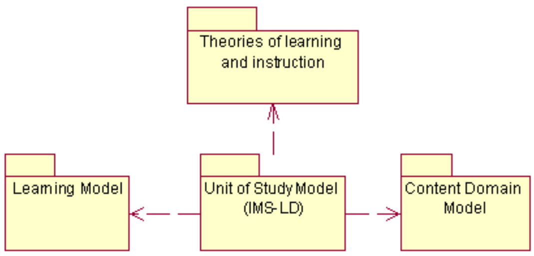

Figure 3. The EML meta-model

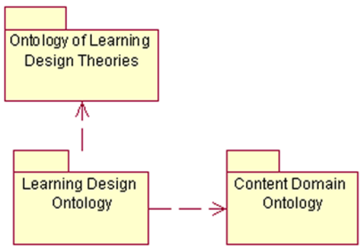

Figure 4. The resulting ontologies

This conceptualization builds upon the ontology of theories presented in [4], and takes into account the classes proposed by EML [8] and extracted from [22]. Classes for theories in EML are paradigm-based: "behaviourism", "rationalism", and "pragmatism-sociohistoricism".

Table 2. Classes and Properties of the Ontology of Educational Theories

Classes	• **Theory:** theory of knowledge, learning theory, theory of instruction, ID theory; • **Paradigm:** Behaviourism, Rationalism, Pragmatism-Sociohistoricism (EML); • **Learning Theory:** Piaget, Bruner, Vytgosky, other; • **Theory of Instruction:** Inquiry teaching, Socratic, Algo-Heuristic, other; • **Instructional Design Theory:** Component Display, Elaboration, other;
Properties	• A theory of knowledge **has** a paradigm as one of its parts; • A theory of learning, instruction, and instructional design **has** a paradigm as an attribute; • A theory of learning, instruction, and instructional design **has** the following parts: o theorist, concepts, principles, paradigm, content domain, reference, date; • Theories of learning, instruction, and instructional design **rely on** a theory of knowledge; • Models issued from a theory are **extracted from** a theory; • Models emerging from practice (eclectic) are **extracted from** practice; • Learning Designs are **inspired by** models.

It appears that these classes correspond, in our ontology, both to the theory of knowledge on which each theory of learning relies, and to the main paradigms identified, although the names sometimes differ [23] [24] [25]. Although these classes should allow for classifying all theories of learning, instruction and instructional design, EML adds another class, called “eclectic”, for learning design models that have emerged from practice as opposed to being based on theory. This “other” class has therefore been added to our ontology. Table 2 shows the classes and properties which consequently were obtained as a result of the conceptualization. As a result Fig. 5 shows an UML representation of the theories which binds with the IMS-LD. The main entities of the ontology (theory, paradigm, model, domain and LD) are in grey.

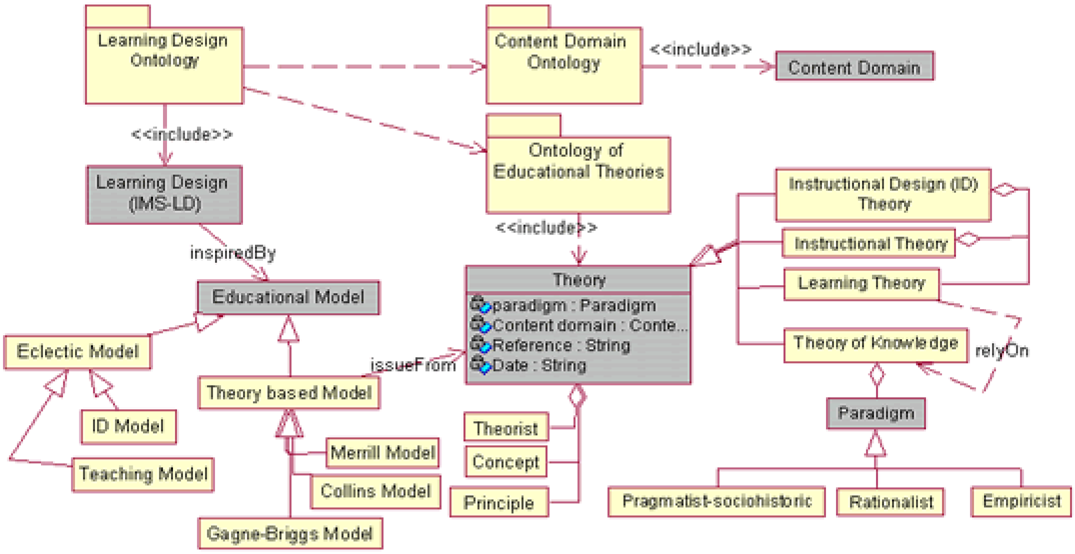

Figure 5. A UML representation of the ontology of theories

What theories are mapped to the LD, and how? Table 2 illustrates examples of how we conceive the binding mechanism between LD and educational theories.

Table 3. An Excerpt of the Binding Mechanism

IMS-LD Element	Binding by Properties	Matching Classes (C) /Instances (I) of Theory
Method	**Type of Paradigm**: * Instructivist (Behaviourist) * Constructivist (Rationalist) * Socioconstructivist (Sociohistoric)	(C): * Gagné Th., Merrill Th., ... * Piaget’s Th., Collins’ Th., Bruner Th., …. * Vygotsky’s Th., Wenger’s Th., ...
Learning Objective	**Type of Learning:**	(C): Mager’s Th., Bloom’s Th., Gagné’s Th., … (I): Reigeluth’s learning objectives [6]
Support / Learning Activity	**Control of Learning:** * Teacher-centered * Learner-centered * Team-based	(C) * Gardner’s Th., Gagné’s Th., Merrill’s Th., … * Piaget Th, Collins Th., Bruner Th., … * Vygotsky’s Th., Wenger Th., ...
Activity Structure	**Sequencing of Instruction**	(C) Gagné-Briggs’ events, Collin’s techniques...

4. Formalizing and Implementing the Ontology for Agent Use

The software agent receives a LD scenario description and retrieves a selection of matching theories available on a web-based knowledge base using a set of emerging standards (RFD-S, OWL) and tools (Hozo, Jena2). To achieve this goal, a formalization (level 2 in [26]) followed by an implementation (level 3 in [26]) of the ontology was necessary.

The formalization was done in OWL (*Web Ontology Language*) using the Hozo ontology editor. OWL is designed for use by applications that need to process information in addition to displaying information to humans. In comparison to XML, RDF, and RDF Schema (RDF-S), it facilitates better machine interpretability of Web content since it provides additional vocabulary along with a formal semantics. OWL has three increasingly-expressive sublanguages: OWL Lite, OWL DL, and OWL Full [27]. Our formalization was conducted using OWL DL. The Hozo editor allows for the creation of classes and properties, in addition to a graphic representation of the ontology, the hierarchy of classes and the properties. It also generates the OWL code as shown in Fig. 6 (right window).

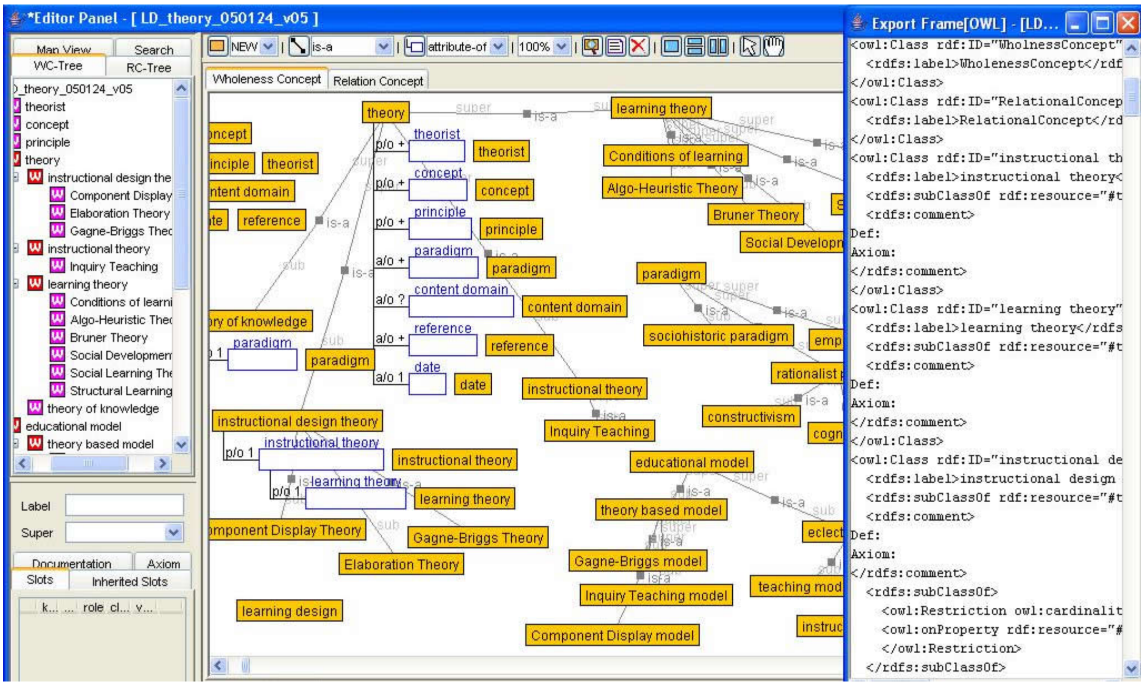

Figure 6. Formalization of the Ontology of Educational Theories in Hozo

A subsequent ontology implementation using Jena2 is in progress. Jena2, developed by Hewlett-Packard, is a Java framework for programming Semantic Web applications. It includes useful features, including an ontology API, a reasoning system, a query language (RDQL). The *ontology API* offers support for the implementation of the above-formalized ontologies (RDFS, OWL) into JAVA classes. The *reasoning system*, an inference engine, together with rule sets for RDFS / OWL, works with the ontology API in order to infer additional facts from a particular ontology source. *RDQL* offers support for querying a networked knowledge base consisting of the above elements, and allows the agent to query the ontology of theories about elements of LD scenario specified by the author.

5. Conclusion

In merging LD standards with an ontology of theories to serve the needs of authors working within an authoring system or a LKMS, we found that IMS-LD cannot link the learning design with instructional design theories. We developed a solution that integrates LD in a structure of ontologies, and allows for communication between LD and theories. We described the ontology of theories with its classes and properties. A first version has been formalized in OWL using the Hozo ontology editor. This work needs to be further developed to provide the services expected by its users. The ontology also needs to be merged with the ontology of the three instructional models (Gagne-Briggs, Merrill and Collins) that has been previously developed [4]. Furthermore, a deeper integration of LD standards is envisaged within an ontology of LD. The agent will be implemented according to JAVA standards. At this point, our work will be interfaced with the LKMS developed by LORNET. Both an evaluation of the ontology and of the services provided by the agent are foreseen. The evaluation of the ontology itself then follows criteria and guidelines by [21]. The services provided by the agent to a learning designer in the process of authoring using an IMS-LD compliant tool will be evaluated in the following way: a mockup will represent the interactions between the agent and the human author, in the context of a real task. Three LD experts will judge the services' relevance, usefulness and meaningfulness.

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