Ontology of learning objects repository for pedagogical knowledge sharing

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ABSTRACT. Ontology has been receiving considerable attention in the learning objects research community. This paper discusses the key concepts of ontology of learning objects repository and proposes an ontological model for pedagogical knowledge sharing. The ontological model specifies a generic organizational structure for learning objects repository based on pedagogical design categories. An ontology that actualizes such a structure allows the user of the learning objects repository to play an active role in pedagogical development through searching semantically relevant learning objects. An example of ontology for pedagogical knowledge sharing is used to illustrate the concepts of the development and use of ontologies of learning objects repository.

KEYWORDS: *Knowledge sharing, Learning objects repository, Ontology, Pedagogical development, Semantic Web*

Introduction

A learning object is a unit of digital resource that can be shared to support teaching and learning (Wiley, 2000; Wiley, Edwards, 2002). Learning objects are used for knowledge sharing in education (Cohen, Nycz, 2006; Collis, Strijker, 2003; Singh et al., 2007). Along with the increasing use of online and blended teaching/learning systems, such as WebCT as well as e-portfolio systems, learning objects become increasingly valuable and, at the same time, the management of learning objects repository becomes complicated.
There have been metadata standards for learning objects, such as those proposed by Dublin Core (2007), IEEE LTSC (2007), and IMS Guide (IMS, 2006). These standards are used to represent individual learning objects at the collection level, which is similar to library catalogue systems. However, to use learning objects to support teaching and learning at the knowledge sharing level for a specific field, knowledge schema must be applied to the learning objects repository for the domain (Harman, Koohang, 2005; Koohang,

2004). This is because learning objects can be organized in a variety of ways depending upon complex intra-context and inter-context (Wiley, Edwards, 2002). When a virtual learning objects repository is huge and is distributed on the Internet, the use of meta-data and keywords only to search the needed learning objects is inefficient and ineffective since much potential associations with various learning aspects are bypassed (Mustaro, Silveira, 2006). This has lead to approaches to Semantic Web applications that model the relationships between learning objects using formal ontologies (Sicilia, Lytras, 2005).

While meta-data of learning objects describe the artefacts of learning objects that are shared by diverse domains, an ontology represents a knowledge domain that shares the relationships of learning objects within a specific context. There has been moderate literature on ontologies associated with learning objects (Snae, Brueckner, 2007; Zouaq et al., 2007). However, few research reports have provided explicit generic structures of ontologies for knowledge sharing. Our motivation for this article is to propose a generic organizational structure of learning objects for the domain of pedagogy design based on the premise that ontologies can help people better share knowledge (Welty, 2003), and to demonstrate the usefulness of the proposed resource organizational structure for pedagogy design.

In this article we first discuss the key features of ontology of learning objects repository. We then propose a generic structure of ontology for the pedagogy design domain and place the emphasis on ontology development for pedagogical knowledge sharing. Through an example of ontology-based learning objects management system for pedagogical knowledge sharing, we demonstrate the effectiveness of ontology for learning objects repositories.

Ontologies of learning objects repository

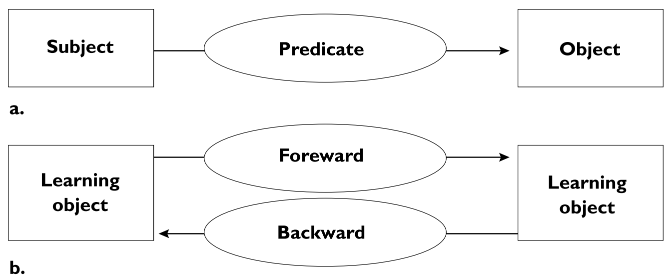
Ontology in the context of learning objects

Ontology is a science that studies explicit formal specifications of the terms in the domain and relations among them (Gruber, 1993). In the general philosophical term, an ontology is a specification of a conceptualization (Gruber, 1995; Guarino, 1995). In the learning objects field, an ontology is typically a network of semantically related learning objects for a specific learning or instructional domain. An ontology allows people to share common understanding of the subject domain of learning objects.

According to RDF-Resource Description Framework (W3C, 2007), a primitive ontology is a triple containing a subject, an object, and a predicate (relationship) (Figure 1a). Its special form, which represents reciprocal relation of learning objects (dual subject and object), is shown in Figure 1b. A large ontology for an entire domain is a composition of a set of primitive ontologies. Given the complexity of learning objects structures in general, a learning object itself can be represented by an ontology.

An ontology for a learning objects repository is a conceptual network of all related learning objects that shows the semantic relationships between the learning objects in the application domain.

Figure 1.
Primitive ontology



Ontology presents the object-oriented vision of learning objects repository

All learning objects are natural objects. Rationally, a learning objects repository can be represented by an object-oriented model. The premise of object-oriented modelling is that objects are grouped into categories or classes for the application domain (Wang, 1999). Classes are organized into hierarchies in which the sub-classes inherit properties from their super-class. For instance, the sub-classes of learning objects inherit meta-data from their super-class (or meta-learning object). A sub-class can inherit from multiple super-classes. Inheritance relationships result in static connections between learning objects. In addition to inheritance relationships, the object-oriented paradigm applies so called message sending from one class to another to make dynamic connections between

the classes. These messages accentuate the dynamic relationships between the classes that represent contingent access paths to objects. All static and dynamic relationships between the classes specify the semantic properties of the entire sets of classes.
The ontology approach is a powerful modelling approach; however, without a domain analysis for particular types of applications, the ontology approach remains a virtual philosophy, rather than a concrete technique for objects reuse (Devedzic, 2004). To build ontologies based on the methodology progression, ontologies of learning objects repository must present the object-oriented vision. The task of a domain analysis for the construction of an ontology is to actualize classes of learning objects and their semantic relationships. It is virtually the central issue in applications of learning objects techniques for particular learning or instructional areas.

Ontologies are user-repository interfaces for the application domains

Ontologies serve as user-repository interfaces that provide views of learning objects in various perspectives to enhance the learning objects repository usability for diverse application domains (Namuth et al., 2005; Smrz, 2004). The ontologies are envisaged as knowledge structures that fit the individual application domains. For instance, a learning objects repository can have two different views: learners' view and instructors' view. An ontology for the learners articulates general interactive learning processes, while an ontology for the instructors describes a scheme of pedagogical development.
Ontologies have been with us for a quite long time. For instance, an ER (Entity-Relationship) chart is a general type of ontology for relational databases. In comparison with ER charts for relational databases, ontologies for learning objects repositories are complicated due to the complex properties of learning objects and the richness of semantics in the learning and instructional context. More importantly, ER charts are basically used only for database designers, but ontologies for learning objects must be used for all creators of learning objects, as well as end-users of learning objects, for the knowledge sharing purpose. Hence, an ontology of learning objects acts as the interface between all users and the learning objects repository.

Ontology vs. meta-data of learning objects

Meta-data standards of learning objects intend to generalize taxonomies and vocabularies for learning objects repositories for all disciplines (Convertini et al., 2006; Dublin Core, 2007; Friesen, 2005; IEEE LTSC, 2007; IMS, 2006; Yordanova, 2007). There is a tacit ontology behind a meta-data standard. Such a tacit ontology is too complicated to present because the semantic relationships between all learning objects are hard to be standardized. Specifically, the taxonomies can never be exhaustive for all disciplines, and vocabularies can be interpreted in a variety of ways depending upon the disciplines. Without the support of ontologies, tagging all types of meta-data and relevant keywords to every learning object could be prohibitively expensive and will eventually make any search engine practically powerless. On the other hand, an ontology of a specific domain for a learning objects repository serves as a map and suggests paths for retrieving candidate learning objects to reach a certain objective of learning or teaching. The use of ontology does not exclude the use of meta-data. As shown later in this paper, when the learning objects repository is huge, standardized meta-data are still useful for searching learning objects through ontologies.

Ontological categories of learning objects for pedagogical development

Applications of ontology to model related components of learning objects repository would contribute to effective reuse of learning objects resources. An organizational structure of learning objects generalized with aspects of pedagogical development can be helpful when the learning objects repository is incorporated into comprehensive pedagogical design. However, in the broader literature, there is a lack of formal ontological description of learning objects repository for pedagogical design. Furthermore, the entire ontology of a learning objects repository is usually large. To provide a large ontology visual and manageable to the user, the entire ontology must be partitioned. This is done through categorizing learning objects and developing the dynamic and inheritance relationships. A formalized generic learning objects category (or meta-learning objects) can help a community in developing aspects of its ontology, especially when the learning objects repository is incorporated into the learning system development.

Next, we discuss generic learning objects categories for pedagogical development through a domain analysis to identify and formalize fundamental types of learning objects and their relationships involved in pedagogical development.

Learning subject

A learning subject is a meta-learning object that defines a discipline. It can have sub-subjects. It is an entry point of the learning objects repository for pedagogical development. A learning subject structure is a type of generalization structure. A typical order of the hierarchy of learning subjects for a learning objects repository is:

- College/School
- Program
- Course
- Topic

A learning subject can have its attributes and descriptions. In the interdisciplinary context, a learning subject can inherit from multiple super-subjects. A topic is a primitive learning subject, and is associated with a learning objective directly.

Learning objective

A learning objective is a learning object that describes a measurable learning outcome. Learning objectives are the key to the use of learning objects (Nash, 2005). Each learning subject retains its learning objectives. Bloom's taxonomy of education objectives (1956) is a framework that has been widely used in all disciplines. The original Bloom's framework includes six levels of learning: knowledge, comprehension, application, analysis, synthesis, and evaluation. Given the recent development in the knowledge management field, the term knowledge is no longer appropriate in this context. If knowledge and comprehension are merged into one level of learning, there are five levels of learning objectives as listed below:

- Understanding - know, define, identify, be aware of, etc.
- Application - apply, formulate, explain, etc.
- Analysis - analyze, organize, resolve, etc.
- Synthesis - design, plan, recommend, etc.

- Evaluation - justify, criticize, evaluate, etc.

Instructional method

An instructional method is a general approach used in teaching. There have been many instructional methods in education, but the following ten types of instructional methods are commonly considered in pedagogical design (Heinich et al., 2002).

- Presentation
- Demonstration
- Discussion
- Drill-and-practice
- Tutorial
- Cooperative learning
- Gaming
- Simulation
- Discovery
- Problem solving

Clearly, the use of information technology in education might bring up new instructional methods beyond this list.

Delivery instrument

A delivery instrument is a teaching and learning tool or technique to implement an instructional method. For instance, a set of PowerPoint slides can be a delivery instrument for presentation. A videoclip can be a delivery instrument for presentation or discussion. Synchronous or asynchronous communication can be a delivery instrument for discussion or cooperative learning. A lab tutorial can be a delivery instrument for problem solving.

Assessment instrument

An assessment instrument is a tool or technique to measure the effectiveness of an instructional method or a delivery instrument through measuring whether students have achieved the learning objectives. For instance, a test that contains quiz questions and/or questions for short answers is an assessment instrument to evaluate whether students understand the topic. An essay assignment or a textbook case analysis report is an assessment instrument for assessing students' analysis competency. A technical assignment is an assessment instrument to evaluating students' problem-solving ability. A list of project requirements can be an assessment instrument to evaluate whether students have reached the evaluation learning objective. A student self-evaluation questionnaire can be an assessment instrument for soliciting students' opinions on an instructional method.

Assessment outcome

An assessment outcome learning object is a documentation of learners' performance. At the elemental level, an assessment outcome learning object can be an individual learner's examination paper. At the collective level, a summary of assessment outcomes can be a learning object to measure the effectiveness of an instructional method, delivery instrument, assessment instrument, or learning objective. In the educational literature the use of assessment outcomes to improve pedagogical design is underreported. This is because traditional educational systems do not store and utilize much assessment outcomes. The pedagogical designers usually use their experiences and tacit knowledge of assessment outcomes to design pedagogies. Along with the proliferation of e-portfolio systems, massive assessment outcome learning objects are stored online. These learning objects provide valuable quantitative and qualitative data for pedagogical development.

Construction of an ontology

An ontology of learning objects repository for pedagogical design is a synthesis of these six categories of learning objects on the contingency of knowledge sharing in the educational community. The first step for the construction of an ontology is to identify the six independent categories of learning objects (learning subject, learning objective, instructional method, delivery instrument, assessment instrument, and assessment outcome). The second step is to synthesize these categories of learning objects by formalizing their semantic relationships.

Although the relationships between the learning objects could be diversified, there are generic semantics that commonly exist among them that could be used for general purposes of pedagogical development. For instance, in terms of inheritance relationships, a top-level *Learning Subject* "has_a" low-level *Learning Subject*. In terms of dynamic relationships, a *Learning Objective* "is_achieved_ through" an *Instructional Method*. The generic semantic relationships among the learning objects are summarized in Table 1.

Table 1.
General semantic relationship between learning objects

Table 1: General Semantic Relationship between Learning Object

		TO					
		Learning Subject	Learning Objective	Instructional Method	Delivery Instrument	Assessment Instrument	Assessment Outcome
FROM	Learning Subject	Is_a Has_a	Achieves				
	Learning Objective		Is_a Has_a	Is_achieved_through	Is_achieved_through	Is_assessed_by	Is_measured_by
	Instructional Mrthodl			Is_a Has_a	Uses	Applies	Is_measured_by
	Delivery Instrument				Is_a Has_a	Is_assessed_by	Is_measured_by
	Assessment Instrument					Is_a Has_a	Generates
	Assessment Outcome						Is_a Has_a

An ontological model would help the user search learning objects by reducing the mental search space. From the viewpoint of information retrieval through hyperlinks, the ontology approach is similar to the widely discussed topic maps (Trippe, 2001). However, our proposed ontological model has explicit descriptions of pedagogical actions. In comparison with general topic maps, the semantic network represented by the ontological model is formalized for problem solving in the pedagogical development domain. From the viewpoint of knowledge sharing (Frank, 2002), our ontological model can be a framework of pedagogical development based on common pedagogical design patterns.

Ontological integration of learning objects: a case study

To learn more about ontology of learning objects, a project was conducted to investigate the effectiveness of ontology for learning objects reuse for pedagogical design. We developed an ontology with a small scale using the proposed framework for ontology development discussed in the previous section. We then developed a software system, called LOSON (Learning Objects Sharing through the ONtology), that can support accessing learning objects in accordance

with the ontological knowledge structure for pedagogical design. As an example, we present the features of LOSON for the Management Information Systems (MIS) learning subject. MIS curricula are highly influenced by the advances of information technology in business. New pedagogical design to meet challenges of information technology is part of an array of educational innovation in MIS. New pedagogical design requires a considerable level of knowledge of the faculty. Pedagogical knowledge sharing among instructors is crucial for the success of MIS education. This prototype is used merely to demonstrate the principles of ontology for pedagogical knowledge sharing discussed above, but not for discussion of the course pedagogical design, which is a topic independent of this study.
The learning objects repository contains a large amount of learning objects, which are virtually stored on the WebCT systems, e-portfolio systems, and the Internet in general. LOSON constructs pointers to the learning objects sources. It is possible for an MIS faculty instructor to obtain a needed learning object by clicking the hyperlink on the visualized ontology network, provided that the learning object is linked to the ontology.
The tool used to build LOSON was Microsoft Excel VBA, since Excel is widely available as a popular end-user computing tool. Two templates of the ontology were stored on separate sheets: inter-relational structure and inheritance structure. The internal database in LOSON-stored learning objects details or hyperlinks to the learning objects. The user was able to search semantically relevant learning objects through the ontological user interface. Figure 2 shows the structure of LOSON.

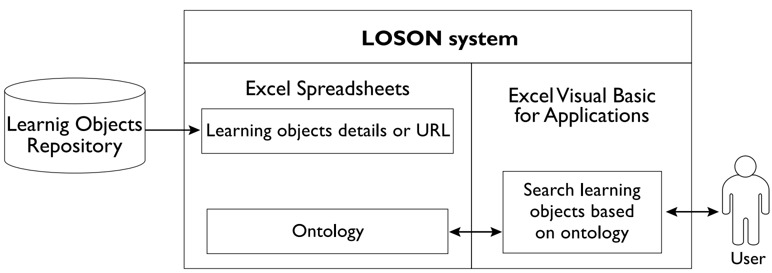
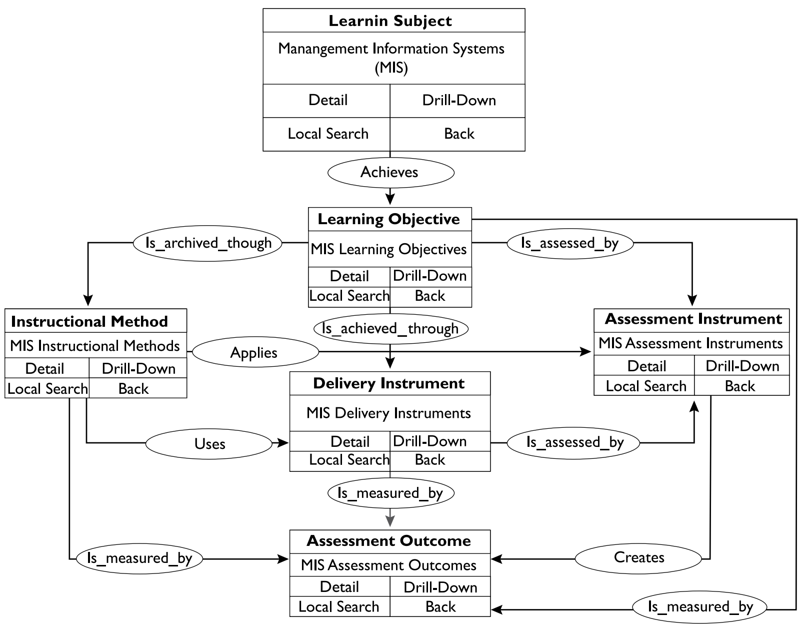


Figure 2.
The structure of LOSON

Figure 3 shows the inter-relational structure of the ontology at the top level. As shown in the ontology network, the learning subject, learning objective, instructional method, delivery instrument, assessment instrument, and assessment outcome learning objects were semantically linked and represent the virtual learning objects repository. Each learning object icon had a number of methods associated with the command buttons. The Detail command button allowed the user to view the details of the learning object through a built-in hyperlink. The Drill-Down command button allowed the user to search learning objects that directly inherit from the current meta-learning object. The Local Search command button allowed the user to search learning objects that were semantically similar to the current learning object using meta-data or keywords. If the user did not specify a search criterion, the system retrieved learning objects one by one in the backward chronicle order. The Back command button allowed the user to view the previous ontology network.

Figure 3.
The general structure of the ontology of learning objects repository



The ontology network provided a variety of ways for the user to navigate the learning objects repository to meet diversified needs of pedagogical knowledge sharing.
Each retrieved learning object was fit into the ontology to display. For example, as shown in Figure 4, the user was able to view

the segment of the ontology related to the meta-learning object *Problem Solving* in the *Instructional Method* category. If a learning object was semantically related to two or more learning objects in the same category, the most current learning object was retrieved first, and others might be retrieved through the Local Search command button.

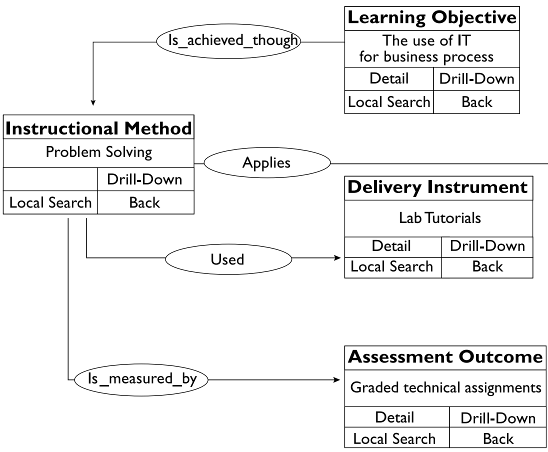
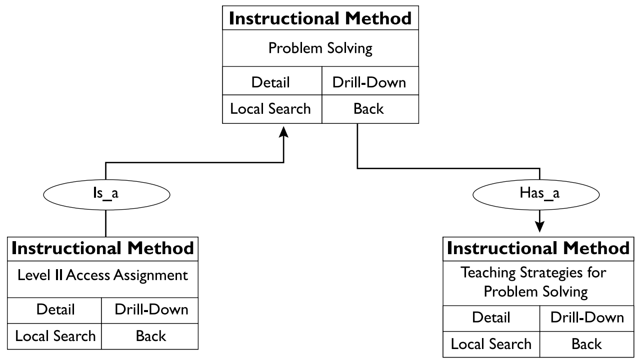


Figure 4.
A learning object and its inter-relationships with other types of learning objects

Using the ontology, the user was able to drill-down a meta-learning object through inheritance relationships. The inheritance structure template of LOSON organized semantic "is_a" and "has_a" inheritance relationships into ontological segments. For example, Figure 5 shows the ontological segment of the inheritance relationships that the learning object *Level II Access Assignment* I "is_a" *Problem Solving*, and the learning object *Problem Solving* "has_a" *Teaching Strategies for Problem Solving*.
It was found that the search of learning objects based on the ontology was much more efficient in comparison with the search based only on meta-data. The following primary lessons have been learned from this prototype.

Figure 5.
A learning object and its inheritance relationships



1. The ontology of the learning objects repository for the pedagogical development domain provides the semantic associations among the learning objects. It is high-level information and codified knowledge of pedagogical development. Hence, it reflects the educational community's memory.

2. The ontology provides a map for the user to navigate the learning objects repository so that he/she is able to search semantically closely bounded learning objects for pedagogical design.

3. To reduce information overload, the ontology can be partitioned into parts so that each part can appear on the screen for the user. The principle of partitioning is that each part of the ontology keeps a semantic unity.

4. There might be multiple entries for the user to reach a particular learning object through a navigation of the entire ontology network. The design of each screen for the segments of the ontology network can be individualized for different types of users. For instance, the layout of display could be adjusted, and short-cuts can be created for sophisticated users to access a specific segment of the ontology. Each user can create his/her own view of the ontology. The ontology of a learning objects repository is plain, and can be shared, or modified, by all authorized users.

5. Finally, knowledge sharing through the ontology is by no means at no cost. To connect a learning object to the ontology, one must define its relationships to other learning objects in accordance with the semantics defined by the ontology. The more relationships are defined, the better the learning object is shared by the domain. This is the nature of knowledge sharing.

Conclusion

The competence of learning objects repository depends not only on the abundance of learning objects, but also the effectiveness of the user-repository interaction. This paper recognizes the problem of lack of ontological models for pedagogical development and proposes a framework of ontology for learning objects repositories. The ontology model is based primarily on pedagogical design structure, and the premise of user-repository interaction. The contribution of this study is in the conceptual construction of the ontology model that can be used for pedagogical development. An ontology does not replace meta-data of individual learning objects; rather it adds explicit relationships between the learning objects that would aid the user to conduct unstructured pedagogical development. As a result, the use of the ontology would allow the user to utilize learning objects in an efficient manner.
This study has primarily focused on the semantic aspects of learning objects repository for pedagogical knowledge sharing, and has shown the way of support for learning objects in the semantic Web era. It raises new questions for all parties involved in learning objects. For educational institutions, there is an organizational need to develop ontologies that contain semantic information about the learning objects repository for various domains. The ontologies should be maintainable to represent the currency of the repository. For software developers, new techniques, and tools for developing and using ontologies for educational knowledge sharing are imperative. Simple learning objects repository systems and naive search engines are no longer adequate. In our view, the ontology proposed here can practically be used for educational development software. For the users of learning objects repositories, new skills

of information literacy are required. They must clearly understand the ontological structure of the organizational learning objects repository, and transform unstructured actions to structured tasks by applying the learning objects repository based on their own a priori knowledge in order to develop their new knowledge.

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Sintesi

Per ontologia in campo informatico, si intende "una scienza che studia le specificazioni formali esplicite dei termini di un dominio e le relazioni tra gli stessi". In questo senso, un'ontologia formale applicata ai repositories di Learning Object si traduce in un network concettuale di tutti i Learning Object appartenenti ad un determinato dominio che mostri le relazioni semantiche sussistenti tra gli stessi. La complessità dei LO ed il loro sempre più diffuso utilizzo per la formazione richiedono strumenti adatti a gestire repositories molto estesi che garantiscano una effettiva condivisione della conoscenza. Gestire, infatti, ampi database e repositories mediante keywords e metadata non è ormai più un sistema adeguato rispetto alle accresciute esigenze della ricerca e allo sviluppo attuale delle tecnologie. Strumenti più precisi per la gestione dei repositories possono derivare dal Web semantico, in cui le relazioni tra i LO sono create in base a ontologie formali. Logicamente, un database di LO può essere rappresentato attraverso un modello object-oriented di tipo insiemistico, con classi e sottoclassi tra le quali sussistono delle forme di comunicazione (messages) ed in cui gli oggetti appartenenti ad una sottoclasse ereditano le proprietà delle classi

superiori. In base a questo modello formale, le relazioni tra le classi saranno sia di tipo statico (le eredità) che dinamico (i messaggi).
Il prerequisito essenziale per costruire una ontologia di questo tipo, quindi, è l'analisi accurata del dominio e delle relazioni tra i suoi elementi. Di fatto, le ontologie agiscono come interfacce tra l'utente ed il repository che può essere interrogato da punti di vista differenti, per esempio, lato discente e lato docente.
Dal punto di vista tecnico e concettuale, gli elementi che intervengono nella costruzione di una ontologia sono sei e devono essere chiaramente definiti in fase preliminare:

1. *Learning subject, un meta-learning object che definisce la disciplina e comprende eventuali sotto-soggetti.*
2. *Learning objective, un LO che descrive un risultato di apprendimento misurabile; ciascun learning subject corrisponde ad una serie di Learning objective.*
3. *Instructional method, un approccio esplicito di insegnamento.*
4. *Delivery instrument, gli strumenti tecnici per la realizzazione del metodo prescelto.*
5. *Assessment instrument, gli strumenti e le tecniche per misurare l'efficacia del metodo e il raggiungimento dei Learning Objective.*
6. *Assessment outcome, la documentazione della performance dello studente. Un esempio sono gli e-portfolio, strumenti poco usati nella formazione tradizionale ma più diffusi in quella telematica; utilissimi per orientare la pedagogia adottata e la progettazione didattica.*

Definiti gli elementi chiave, occorre esplicitarne le relazioni, partendo da alcune funzioni tipiche come "has_a" e "is achieved_by".
Il modello di knowledge sharing così elaborato è stato testato attraverso un prototipo di ontologia e un software creato appositamente (LOSON - Learning Object Sharing through ONtology) e costruito in Excel VBA, in cui sono state fissate le relazioni e le eredità dei LO compresi in un repository dedicato all'educational design.
Il prototipo offre all'utente la possibilità di navigare più liberamente nel repository, in base ad esigenze personalizzate. Partendo da un input iniziale è possibile accedere alla fitta rete di connessioni semantiche che si diramano da quel punto, in modo da ottenere una visione completa e articolata dei materiali disponibili nel database in maniera più efficace rispetto alla ricerca con soli meta-data.
Va comunque sottolineato che una struttura simile richiede impegno nella sua realizzazione e nel suo mantenimento poiché per ogni nuovo elemento inserito nel repository sarà necessario stabilire le sue eredità e le relazioni con gli altri elementi. In effetti, le ontologie non sostituiscono i metadata ma piuttosto esplicitano le relazioni semantiche tra i LO per permettere all'utente di utilizzare tutti i materiali a sua

disposizione nella maniera più corretta.
L'utilità dei LO non dipende, infatti, solamente dalla loro qualità o dal disporre di un database aggiornato e ricco, ma anche dall'efficacia della relazione utente-database, anche nel caso di repositories molto estesi.
La diffusione di ontologie formali per la gestione dei repositories di LO richiederà lo sforzo congiunto delle istituzioni educative, dei tecnici e degli utenti, per la costruzione di nuove ontologie e strumenti adeguati e per un loro corretto utilizzo.