Description of an Instructional Ontology and its Application in Web Services for Education*

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Abstract

In the last years, important steps have been undertaken to bring the e-learning web to its full potential. In this paper, I describe an ontology that can serve as a further step in this direction. The ontology captures the instructional function of a learning resource, in other words, its "essence" from a teaching/learning perspective, an aspect not yet covered by learning object metadata standards. It offers the well-known advantages of ontologies: it can provide humans with a shared vocabulary and can serve as the basis for the semantic interoperability for machines. The article motivates the need for such an ontology and describes several educational Web services that can benefit from it. To exemplify the generality of the ontology, the article describes how the ontology can be mapped onto several knowledge representations currently used in e-learning systems.

1 Introduction

1.1 Motivation

Imagine Eva, a teacher, preparing a lesson. Yesterday, in class, she introduced the concept of *gravity*. The learning progress analyzer of her pupils noticed that some kids were not able to apply the new knowledge. Therefore, Eva orders her authoring tool to search the web for examples and interactive exercises that specifically train the application of gravity. On the web-page of Anton, a fellow teacher, the tool finds the necessary resources, and, in addition, an abstract description of an instructional strategy which is based on a real-world-problem teaching approach, especially appropriate for learning physical concepts. The tool shows its findings to Eva and offers to feed them into a course generator. Eva accepts, and the course generator assembles a curriculum that follows the instructional strategy and is adapted to the knowledge of her class. The next day, her pupils work with the new learning materials. Depending on their personal interests, a browsing service adds links to learning resources that provide real-world application of gravity. For Clara, it adds a link to a NASA site that describes the relation between gravity and space ships; Bert is offered a page describing airplanes. After the lesson a data mining service analyzes the paths of the pupils and makes suggestions to Eva what content to include permanently in the course.

In the last years, important steps have been undertaken to achieve such a scenario. The development of sophisticated web-based e-learning systems with a wide range of learner support on the one hand and integrating architectures on the other hand could sum up to a critical mass that brings the Web to its full e-learning potential. In this paper, I describe an ontology that can act as a binding glue between different systems and services and serve as a basis for interoperability with respect to instructional matters.

In the remainder of the introduction, I will briefly summarize the need and scope of the here proposed instructional ontology and describe the shortcomings of today's e-learning standards. The subsequent section portrays a number of potential educational Web services that can profit from such an ontology. Section 3, the main part of the paper, describes the ontology in detail. It is followed by a proof of concept illustrating how the ontology can be mapped onto three frequently used knowledge representations. The paper concludes with a description of related work.

1.2 Benefits of Using an Ontology

An ontology expresses a common understanding of a domain that serves as a basis of communication between people or systems. The need for ontologies has been widely recognized (for a recent discussion see [World Wide Web Consortium, 2004]) therefore I will only summarize some expected benefits. In education, widespread appliance of such a shared instructional vocabulary offers advantages for teachers and learners. A more accurate search for learning resources, made possible by the explicit instructional function, leads to better reuse and less duplication, hence faster authoring of curriculums. By seeking instructionally appropriate learning material, learners can bridge knowledge gaps more efficiently.

The pedagogically relevant information of the ontology also brings forth better Web services. It can increase the accurateness of a service because at design time, a Web service developer can foresee different functionality depending on the type of the resource. For most educational services,

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the information whether a resource contains a definition or an example will be of use. Similarly, service composition is enhanced. For instance, a requester service can require different actions from a provider depending on the instructional type of a resource. Furthermore, interoperability is eased. Then, in theory, each system can provide its own specialized service and make use of the services offered by others.

1.3 Scope of the Ontology

The ontology described in this paper provides a vocabulary that captures the "instructional semantics" of a virtual or text-book learning resource. In general, each learning object serves a particular pedagogical role. These roles are reflected in the classes of the ontology.

The ontology of instructional objects covers instructional theories only partially, namely those parts that describe the learning materials independently of a specific learning context. Hence, it does not encompass learning goals. Learning goals are one primary cause why in a specific context an instructional object is selected, but as instructional objects can serve to attain various goals and one goal of the ontology is re-use, I excluded learning goals and other context-specific information.

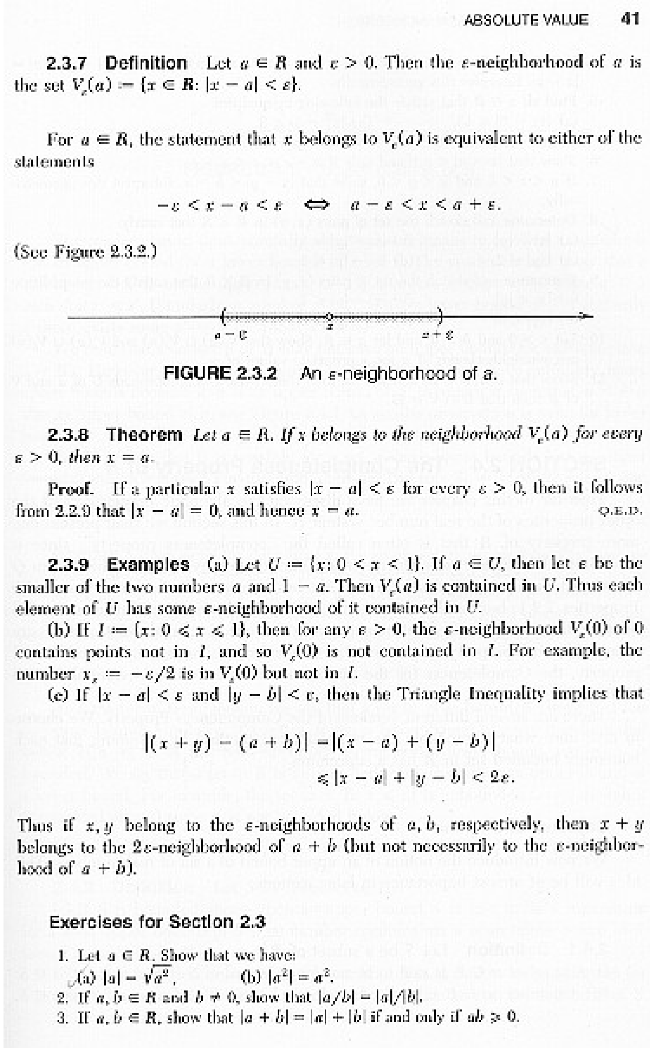
A concrete example illustrates best the entities described by the ontology. Figure 1 presents several learning resources (taken from [Bartle and Sherbert, 1982]), clearly divided into several distinct paragraphs. Each paragraph serves a particular *instructional role*. The first two introduce two concepts (a *definition* and a *theorem*), the third provides *examples of applications* of the concept, and the last one offers to the learner *activities to apply* the concept. These reseource can be assembled by an author or a Web service to compose a page in a course (as it was done here).

The ontology provides a standardized vocabulary of the instructional function of a resource. Additionally, the ontology can be used to partially describe the instructional strategy that underlies the composition of a curriculum. A (simplified) strategy for the example in Figure 1 is the following: To introduce a new concept x, present learning resources in the order *concept* x*, examples for* x*, exercises for* x.

Seminal work regarding ontologies and instructional design was done by Mizoguchi. [Mizoguchi and Bourdeau, 2000] lay out how ontologies can help to overcome problems in the domain of artificial intelligence in education. The work presented in this article was designed to be a step towards this goal.

1.4 Shortcomings of Today's E-Learning Standards

Today's standards prove the (commercial) importance of reuse and interoperability of learning material. For this article, particularly relevant standards are IEEE Learning Object Metadata (LOM, [IEEE Learning Technology Standards Committee, 2002]), and IMS Learning Design (LD, [IMS Global Learning Consortium, 2003]). LOM's educational category allows a description of resources from an instructional perspective. Possible types of learning resources are, among others, *Diagram, Figure, Table, Exercise, Narrative Text, Exam*. In LOM, these values are provided as a list, without taking into account the inherent structure which a representation as an ontology as envisaged in this article would provide. More critical, the LOM types mix instructional and technical information. The first three values of the above example describe the format of a resource, whereas the last three cover the instructional type. They represent different dimensions, hence should be separated. Furthermore, several instructional objects are not covered by LOM (e.g., *definition, example*). IMS LD describes ordered activities in learning and the roles of the involved parties. It does not represent single learning resources and their instructional functions.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2.3.7 Definition Let $a \in R$ and $\varepsilon > 0$. Then the ε-neighborhood of a is the set $V_\varepsilon(a) := \{x \in R: |x - a| < \varepsilon\}$.

For $a \in R$, the statement that x belongs to $V_\varepsilon(a)$ is equivalent to either of the statements

$$-\varepsilon < x - a < \varepsilon \iff a - \varepsilon < x < a + \varepsilon.$$

(See Figure 2.3.2.)

$a - \varepsilon$ $\quad$ a $\quad$ $a + \varepsilon$

FIGURE 2.3.2 An ε-neighborhood of a.

2.3.8 Theorem *Let $a \in R$. If x belongs to the neighborhood $V_\varepsilon(a)$ for every $\varepsilon > 0$, then $x = a$.*

Proof. If a particular x satisfies $|x - a| < \varepsilon$ for every $\varepsilon > 0$, then it follows from 2.2.9 that $|x - a| = 0$, and hence $x = a$. Q.E.D.

2.3.9 Examples (a) Let $U := \{x: 0 < x < 1\}$. If $a \in U$, then let ε be the smaller of the two numbers a and $1 - a$. Then $V_\varepsilon(a)$ is contained in U. Thus each element of U has some ε-neighborhood of it contained in U.

(b) If $I := \{x: 0 \leqslant x \leqslant 1\}$, then for any $\varepsilon > 0$, the ε-neighborhood $V_\varepsilon(0)$ of 0 contains points not in I, and so $V_\varepsilon(0)$ is not contained in I. For example, the number $x_\varepsilon := -\varepsilon/2$ is in $V_\varepsilon(0)$ but not in I.

(c) If $|x - a| < \varepsilon$ and $|y - b| < \varepsilon$, then the Triangle Inequality implies that

$$\begin{aligned}|(x + y) - (a + b)| &= |(x - a) + (y - b)| \\ &\leqslant |x - a| + |y - b| < 2\varepsilon.\end{aligned}$$

Thus if x, y belong to the ε-neighborhoods of a, b, respectively, then $x + y$ belongs to the 2ε-neighborhood of $a + b$ (but not necessarily to the ε-neighborhood of $a + b$).

Exercises for Section 2.3

1. Let $a \in R$. Show that we have:
 (a) $|a| = \sqrt{a^2}$, (b) $|a^2| = a^2$.
2. If $a, b \in R$ and $b \neq 0$, show that $|a/b| = |a|/|b|$.
3. If $a, b \in R$, show that $|a + b| = |a| + |b|$ if and only if $ab \geqslant 0$.

Figure 1: A page from a mathematics textbook that contains several types of instructional objects.

To summarize, today's standards do not cover the instructional function of a learning resource, and, in addition, were not designed for the Semantic Web. However, the full e-learning potential of the Web will only be reached if Semantic Web techniques are supported. The following section describes several educational Web services and their usage of an ontology of instructional objects.

2 Web Services Using an Instructional Ontology

This section provides several examples of Web services and their possible benefit from an ontology of instructional objects.

Course Generator. A course generator (e.g., [Ullrich, 2003]) assembles learning resources to a curriculum that takes into account the knowledge state of the leaner, his preferences, learning goals, and capabilities. If (third-party) resources are annotated by their instructional function, a course generator can include them in a curriculum. Work in this direction was done in Open Corpus Hypermedia. For instance, [Henze and Nejdl, 2001] propose an approach based on a domain ontology. The additional use of an instructional ontology can lead to a more accurate selection of the resource to be included.

Learner Modeling. A learner model stores personal preferences and information about the learner's mastery of domain concepts. The information is regularly updated according to the learner's interactions with the content. A user model server such as Personis ([Kay *et al.*, 2002]) can use the information about the instructional function of a learning resource for more precise updating. For instance, reading an example should trigger a different updating of the mastery of a concept than solving an exercise.

Browsing services. Services that support the user in browsing through content benefit if the instructional function of a learning resource is made explicit. They can better select and classify the presented objects. Systems that adaptively add links to content ([Brusilovsky *et al.*, 1998]), can decide what link to add and how to classify them more appropriately. Similarly, tools that generate concept maps can better adapt the maps to the intended purpose, both with respect to the selection and the graphical appearance of the elements. A dictionary that provides a view on the dependencies of the domain elements can sort the element with respect to their instructional type.

Authoring support. An ontology of instructional objects assists authors by allowing for better search facilities and by describing an conceptual model of the content structure. It offers teachers with a set of concepts at the adequate abstractness level to talk about instructional strategies. They describe their teaching strategy at a level abstract from the concrete learning resources. Hence, instructional scenarios can be exchanged and re-used. An ontology of instructional objects can additionally support the author by providing an operational model in the sense of [Aroyo and Mizoguchi, 2003] that provides hints to the author, e.g., what instructional objects are missing in his course.

Additional service that can profit from the ontology are, for instance, data mining, interactive exercises, and intelligent assistants.

3 Description of the Ontology of Instructional Items

The goal of this work is to provide an ontology that describes a learning resource from an instructional perspective. The ontology does not describe the content taught by the learning material, e.g., concepts in physic and their structure. Instead, each class of the ontology stands for a particular instructional role a learning resource, for instance a paragraph in a text-book, can play. For some objects, determining the role is straightforward. In most text-books, exercises are distinctly marked. For other objects, it may be less obvious.

In order to provide an ontology that can be applied in a large variety of contexts, it was necessary to analyze a significant amount of sources. Here, sources ranged from text classification ([Mann and Thompson, 1988]), over instructional design theories (e.g., [Reigeluth, 1999]) to instructional oriented knowledge representations which were implemented in e-learning systems (e.g., [van Marcke, 1998; Specht *et al.*, 2001; Pawlowski, 2002; Lucke *et al.*, 2003; Cisco Systems, Inc, 2003]).

In addition to theoretical applicability, an ontology should be easily understandable for authors. Therefore, one design goal was to come up with a limited set of classes which still encompasses all necessary instructional objects. Two teachers and two instructional experts reviewed the ontology, and, besides minor suggestions which were integrated, rated it very positively.

In the following, I will describe the classes and properties of the ontology of instructional objects. Figure 2 shows the class hierarchy. The ontology was implemented using Protégé ([Gennari *et al.*, 2003]).

Instructional Object. "Instructional object" is the root class of the ontology. Several properties are defined at this level: a unique identifier; "learning context", which describes the educational context of the typical target audience; and "field", which describes the field of the target audience. The field of an instructional object can differ from the domain the resource describes. For instance, a mathematical concept can be illustrated by an example from economics or from medicine. An additional slot includes Dublin Core Metadata, e.g., information about creator of the resource. The property "analogous" indicates that an instructional object shares some aspects with another instructional object.

Concept. The class "concept" subsumes instructional objects that describe the central pieces of knowledge, the main pieces of information being taught in a course. Pure concepts are seldom found in learning materials. Most of the time, they come in the form of one of their specializations "fact", "definition", "law", and "process". Albeit concepts are not necessarily instruction-specific because they cover types of knowledge in general, they are included in the ontology because they are necessary for instruction. Learning objects often have the instructional function of presenting a concept.

Concepts rarely stand alone, more often than not they depend on another concept. This is represented by the *depends-on* property which has its range the class "concept".

Fact. An instructional object that is a "fact" provides information based on real occurrences; it describes an event or something that holds without being a general rule. An example is "Euclid lived from about 365 to 300 BC". In mathematics, the line of distinction between facts and examples is fuzzy as most facts can be considered as examples, for instance "$\sqrt{2}$ is irrational.".

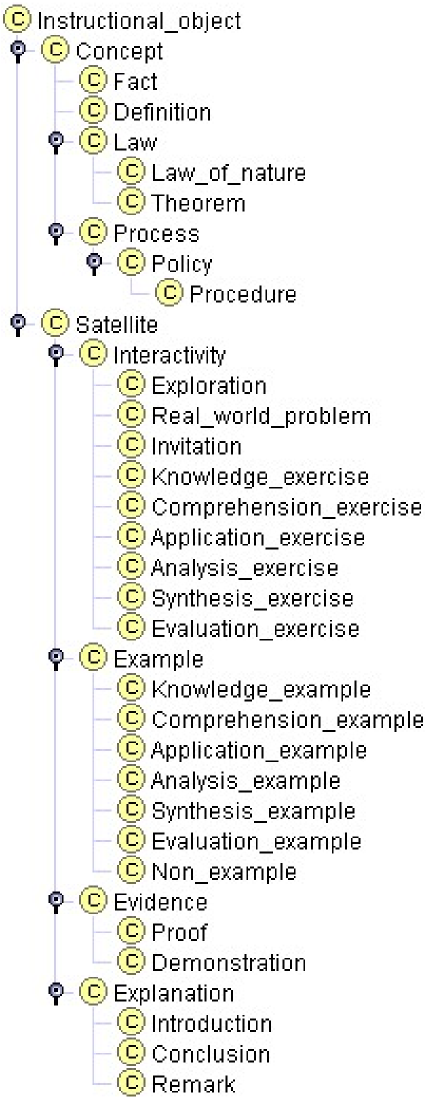

Figure 2: Class hierarchy of instructional objects.

Definition. A "definition" is an instructional object that states the meaning of a word, phrase, or symbol. Often, it describes a set of conditions or circumstances that an entity must fulfill in order to count as an instance of a class. Examples for definitions are "A group is a mathematical structure consisting of…" and "The middle ages describes the period of time that….".

Law. An instructional object that is a "law" describes a general principle between phenomena or expressions that has been proven to hold, or is based on consistent experience.

Law of Nature. A "law of nature" is a scientific generalization based on observation. Typical examples are Kepler's first law of planetary motion: "The orbit of a planet about a star is an ellipse with the star at one focus.", or Einstein's equivalence of mass and energy: "$E = mc^2$". Similar laws of nature exist in biology, chemistry, etc.

Theorem. A "theorem" is an instructional object which describes an idea that has been demonstrated as true. In mathematics, it describes a statement which can be proven true on the basis of explicit assumptions. Examples are "The intersection of submonoids is a submonoid", or Gödel's incompleteness theorem.

Process. "Process" and its subclasses describe a sequence of events. The deeper in the class hierarchy, the more formal and specialized they become. A process provides information on a flow of events that describes how something works and can involve several actors. Typical examples are "the process of digestion", and "how is someone hired in a company".

Policy. A "policy" describes a fixed or predetermined policy or mode of action. One principal actor can employ it as an informal direction for tasks or a guideline. Curve sketching in mathematics, for instance, provides a general guideline of how to determine the essential parts of a function. Similar guidelines exist for analyzing a work of literature.

Procedure. A "procedure" consists of a specified sequence of steps or formal instructions to achieve an end. It can be as formal as an algorithm. Typical examples are Euclid's algorithm, or instructions to operate a machine.

Satellite. "Satellite" elements (the name was adopted from [Mann and Thompson, 1988]) subsume instructional objects which are not the main building blocks of the domain to be learned, but elements that provide additional information about the concepts. In principle, concepts provide all the information necessary to describe a domain. However, from an instructional point of view, the satellite objects contain crucial information. They motivate the learner, and offer engaging and challenging learning opportunities. Every satellite object offers information about one or several concepts. The identifiers of these concepts are enumerated in a "for" property.

Interactivity. An instructional objects that is an "interactivity" offers some kind of interactive aspect. It corresponds to the "active" type of interactivity in LOM's educational category. An interactivity is more general than an exercise as it does not necessarily have a defined goal that the learner has to achieve. It is designed to develop or train a skill or ability related to a concept. The difficulty of an interactivity is represented in the property of the same name.

The subclasses of "interactivity" do not capture technical aspects. In general, the way how an interactivity is realized, for instance as a multiple choice question or an erroneous example, is independent of its instructional function. A well-designed multiple choice question can target knowledge as well as application of a concept.

Exploration. "Exploration" is an instructional object in which the user can freely explore aspects of a concept without a specified goal, or with a goal but no predefined solution path. Cognitive tools ([Lajoie and Derry, 1993],) or simulations are typical examples of an exploration object.

Real World Problem. "Real world problems" are frequently used in instructional design, especially in constructivist theories, e.g., [Jonassen, 1999]. They describe a situation from the learner's daily private or professional life that involves open questions or problems. Solving the problems requires knowledge about a set of concepts. Authentic real world problem are an excellent way of motivating the learner as they can directly experience the relevance of a concept.

Invitation. An "invitation" is a request to the learner to perform a specific activity. For instance, it can consist of a call for discussion with other students. Meta-cognitive hints often have the form of an invitation, e.g., "Reflect on what you have learned".

Knowledge, Comprehension, Application, Analysis, Synthesis, Evaluation Exercise. Instructional objects from these classes correspond to typical exercises found in learning materials. The classes were adopted from [Bloom, 1956] and differ in the educational objective they aim the student to achieve, e.g., whether a learner can recall or apply a concept. Recently, new classifications have emerged, for instance PISA's *literacies* [Schleicher, 1999]. It may be necessary to include them in the future, but currently Bloom's taxonomy is dominantly used.

Example. An "example" serves to illustrate a concept. Similar to interactivities, it has a "difficulty" slot.

Knowledge, Comprehension, Application, Analysis, Synthesis, Evaluation Example. These subclasses of "example" are similar to those of exercises. They illustrate concepts with different educational objectives.

Non-Example. A "non-example" is an instructional object that is not an example of a concept but is often mistakingly thought of as one. It includes "counter-examples".

Evidence. An "evidence" provides supporting claims, for instance observations or proofs, made for a law or one of its subclasses. Therefore, the "for"-property of an evidence has a range the class "law".

Proof. A "proof" is a more strict evidence. It can consist of a test or a formal derivation of a concept.

Demonstration. A "demonstration" consists of a situation in which is shown that a specific law holds. Experiments in physics or chemistry are typical examples of demonstrations. Note that the demonstration of a procedure, e.g., by showing how a curve is sketched is not a demonstration in the here-described sense, but is an application example.

Explanation. An "explanation" provides additional information about a concept. It elaborates on some aspect, points out important properties.

Introduction. An "introduction" contains information that leads the way to the concepts.

Conclusion. A "conclusion" sums up the main points of a concept.

Remark. A "remark" provides additional, not obligatory information about an aspect of a concept. It can contain interesting side information, or details on how the concepts is related to other concepts.

4 Mapping Knowledge Representations onto the Ontology

An ontology fulfills its purpose if it is used by a large number of parties. As the ontology of instructional objects described in this article is a new development, only its potential usefulness can be shown. Section 2 outlined educational Web services and their benefit from the ontology. This section describes three knowledge representations, two of them used in e-learning systems, and shows that the ontology can be used to describe the representation.

4.1 DocBook

DocBook [Walsh and Muellner, 1999] serves a standard for writing structured documents using SGML or XML. DocBook elements describe the complete structure of a document down to basic entities, e.g., the parameters of functions. The elements in-between are the most interesting in the scope of this article. DocBook offers several elements that describe content at paragraph level (called "block" elements).

DocBook	**Instructional Object**
Example	Example
Procedure	Procedure
CmdSynopsis/FuncSynopsis	Definition
Highlights	Summary
Para,Figure	depends on content

Table 1: Mapping of a selection of DocBook elements and instructional objects

Table 1 contains a mapping between DocBook elements and instructional objects. "CmdSynopsis" and "FuncSynopsis" describe the parameters and options of a command; "Highlights" summarizes main points. As one can see, although DocBook was not designed for educational purposes, several elements such as "example" and "procedure" can be directly described by the ontology of instructional objects. However, such a table functions as a very rough guideline only. To infer the exact instructional purpose of a block element by its tag alone is not possible in general. Especially with regard to abstract elements such as "para" (paragraph) or "figure", the content has to be taken into account in order to determine the correct instructional function.

Although DocBook is not directly related to e-learning purposes, it is of interest here because its way of structuring content in rather unspecified paragraphs is similar to systems such as [Henze and Nejdl, 2001; Weber and Brusilovsky, 2001; Bra *et al.*, 2002].

4.2 WINDS

WINDS ([Specht *et al.*, 2001]), a Web-based Intelligent Design and Tutoring System, uses the adaptive learning environment ALE to provide several adaptive hypermedia features, e.g., adaptive link annotation. Its knowledge representation is based on Cisco's learning objects and provides the following types: Introduction, Issue, Fact, Definition, Example, Non-example, Simulation, Process, Procedure, Guidelines, Criteria, Analogy, Instruction, Summary, Tests.

Most of the types can be directly matched onto the ontology, unsurprisingly, as Cisco's learning objects served as one source for the here described ontology, too. However, in the ontology, "analogous" is introduced as a property between two instructional objects, and not as a stand-alone element. The reason is that every object can serve as an analogy for another object, regardless of its type.

4.3 <ML>^{3}

The "Multidimensional Learning Objects and Modular Lectures Markup Language", <ML>^{3} ([Lucke *et al.*, 2003]), is used by 12 German universities that encoded 150 content modules. It is of particular interest in the scope of this article because its design was explicitly influenced by pedagogical considerations. <ML>^{3} represents learning materials in "content blocks". These blocks are of the type "definition", "example", "remark", "quotation", "algorithm", "theorem", "proof", "description", "task", or "tip". Because of its pedagogical background, most <ML>^{3} elements directly correspond to an instructional object. Some element, such as "quotation" and "description" can not be mapped directly. Again, it is necessary to asses the instructional purpose of the element. For instance, does the quotation serve as a bibliographical reference? Then it is no instructional object in the true sense. Or does the quotation introduce a concept, e.g., by citing a famous scientist? Then it would be classified as an "introduction".

5 Related Work

Seminal work regarding ontologies and e-learning was done by Mizoguchi. [Mizoguchi and Bourdeau, 2000] lay out how ontologies can help to overcome problems in artificial intelligence in education. [Aroyo and Mizoguchi, 2003] describe how an assistant layer uses an ontology to support the complete authoring, for instance by providing hints on the course structure. The work in this paper has a different focus but fits well in their approach.

[Dolog *et al.*, 2004] propose a architecture for personalized e-Learning based on Web services. In the architecture, a personal learning assistant integrates personalization services such as a recommendation and a link generation service and thereby provides a personalized access to learning resources. They also describe an ontology for learning resources. However, their ontology does not represent the instructional function of a resource. Both ontologies complement each other.

Using APeLS ([Conlan *et al.*, 2003]), an author can describe his courses on a level which abstracts from the concrete learning resources and focuses on learning goals. He writes a *narrative* which references to a group of candidate resources that each fulfill the learning goal. The concrete element chosen depends on the learner's individual context. In the current version of APeLS, learning goals are concepts of the domain being teached. Using the ontology of instructional objects allows for the integration of commonly shared instructional goals, thereby enabling for better re-use and adaptability.

An approach of integrating e-learning systems which is not based on web-services is described by [Brusilovsky, 2004]. In this architecture, called KnowledgeTree, a *portal* takes care of the management and offers an integrating access to the learning resources. The learning resources are not stored in a central repository but offered by *activity* and *value-adding servers*. An activity server presents the learning resources to the learner and handles her interactions with the resources. A value-adding server adds functionality to the resources, similar to the Web services described in Section 2. Hence, in the same way the Web services benefit from an ontology of instructional objects, KnowledgeTree servers can use this additional information to provide better learner support.

6 Conclusion

This article describes an ontology of instructional objects which captures the educational "essence" of a learning resource. This ontology is supposed to serve as a shared and common understanding that can be communicated between people and applications. A number of Web services were described to illustrate how they benefit from the ontology. Additionally, the connections between two document structuring standards and the ontology exemplified the applicability of the ontology.

An ontology is never completely stable and always the result of integrating different viewpoints. To stimulate discussion and to enhance the scope of the ontology, the author has set up a forum at his homepage (`http://www.activemath.org/~cullrich/oio.html`). It is the hope of the author that the ontology is one step forward to bring the Web to its full e-learning potential.

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We use ontology and semantic web services [15] as the primary means to meet these requirements. Ontology is the theory of conceptualisation.Â These database web services are deployed in Java EE enabled application server and provide full flexibility of data retrieval, so that any analysis methods can be performed on them. Since most of the procedure in this case has been simplified by Java EE platform, the remaining tasks are mainly about defining the meta-models of the database structure, the description of the web service competence, and the semantics for advertising the generated web services. These all can be modeled by using ontology.Â By using the OWL model, database schema, semantic description of web services are automatically generated.