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Improving Learning Object Reuse Through OOD: A Theory of Learning Objects

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Abstract The concept of a learning object (LO) has spread quickly without a very specific universal definition, and though born originally from the idea of object oriented design, with a goal of providing high levels of reusability for digital learning resources, it is being developed generally without reference to the ideals of the object oriented design paradigm. This has resulted in challenges to reusability and interoperability. We therefore present a theory of learning objects (including OOGLOM - Object Oriented Generic Learning Object Model). We develop UML models to illustrate OOGLOM as well as illustrate how it provides interoperability.

Keywords E-Learning, Learning Object, Reusability, Learning Component

1 Introduction

Digital learning material was originally introduced as large monolithic pieces of data, mainly with the intent of facilitating access across internetworks[1] including the Internet. More recently developers saw reuse as an important goal and the concept of a learning object (LO) was then introduced as a major research and development area. While many definitions abound the IEEE LOM draft standard [LTS02] defines a learning object as *"any entity, digital or non-digital, that may be used for learning, education or training "*. LOs were intended to bring with their use, the ability to represent learning material in discrete, small, independent pieces which could be used and reused in various situations with other pieces of learning material. This idea was well used in the software engineering world in the context of modular design and programming and more importantly object oriented design and programming. Unfortunately the

[1] An Internetwork is an interconnection of networks, the internet is one such example

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most popular definition for learning objects given by the IEEE LTSC [LTS02] is a very broad one which did very little to specify what digital material should be considered learning objects and which ones were not. In fact the definition is noted by several authors as being so broad that it excludes no entity in the Universe [Wil02],[DH03],[SH04].

This has had a negative impact on the interoperability and general reusability of learning objects in that it has led generally to the development of several different definitions and models of learning objects. These various models find different ways of dealing with the various challenges for the environment and instructional approach of institutions for which the models were designed. Such models designed for specific environments, have been coined Implementation Specific/Organization Specific (IS/OS) models [AM09]. According to [Wil02] the main goal of learning objects is the provision of discrete chunks of searchable and reusable pieces of digital learning material. Throughout the literature it is well documented that meeting this goal is difficult [AB05, Tom05, Lib05]. We have also noted that not much attention has been paid to the issue of object orientation in the search for a definition and clarity of the concept of learning objects. However it is our opinion that object orientation is important factor, as it is the main basis upon which one can reasonably anticipate achieving reusability and interoperability from *objectifying* e-learning content. The entities often regarded as learning objects by the vast majority of models are simply e-learning content in the form of documents, videos images or combinations of these. They generally take no advantage of the reusability features generally available when using object technology.

In section 2 we highlight some of the challenges to the goal of learning object reuse that have arisen as a result of the lack of a precise well defined theory of learning objects. We highlight how these challenges are handled in a variety of popular learning object models in section 3 and indicate the weaknesses and strengths of these models. We then present a theory of learning objects (including our Object Oriented Generic Learning Object Model (OOGLOM))in section 4, which overcomes these challenges (discussed in section 2) and increases the reusability of learning objects by providing common base classes from which we believe any learning object model may be developed. The existence of this common base model based on object orientation presents a powerful platform for learning object reuse.

2 Challenges to the Goal of Learning Object Reusability

The use of a very broad definition of learning objects has resulted in the absence of a well defined theory of learning objects, which has in turn resulted in a variety of interpretations of what learning objects actually are, their characteristics, components and size among other issues. To highlight the need for a theory of learning objects, we have selected and discussed in this section a few challenges to reuse that have arisen. We use an example throughout the section to highlight these challenges.

2.1 Example

In this example we consider learning objects based on the definition mentioned in the introduction. A teacher wishes to create a lesson (a learning object) from learning objects currently available in a repository. As illustrated in Figure 1, the teacher will create the learning object and add to the repository. The teacher may retrieve existing learning objects from the repository and utilize them in the creation of the new learning object. This new learning object is then made available via the internet to learners.

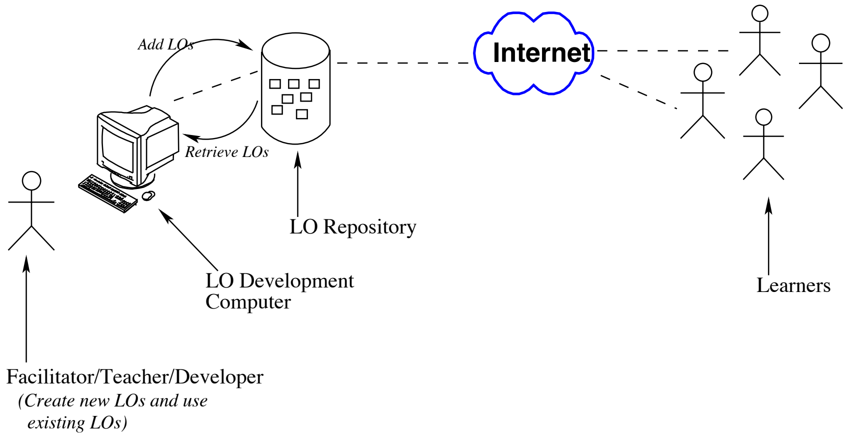


Figure 1 – Creating a Lesson using Learning Objects Approach

Let us assume the lesson to be created is on making *Chicken Pasta Ahola* - a special (fictitious) italian entree. Let us also assume that the repository contains a wide variety of learning objects on various subjects, but that our teacher has found and selected six learning objects to be used for creating the new learning object. The main characteristics of the six learning objects are specified in table 1.

Learning Objects	**Content Summary**	**Type**	**Size**
LO1	Image of Pasta	JPEG	500K
LO2	Kitchen Preparation	DOC	20K
LO3	Cooking Spaghetti	RTF	15K
LO4	Making Sauces	PPT	30K
LO5	Draining Pasta	MPEG	4MB
LO6	Italian Cooking	PDF	10K

Table 1 – Six LOs selected by the Teacher

2.2 Finding an appropriate level of granularity

Our teacher is interested in LO2 because it deals with kitchen preparation. LO2 is a PDF file which covers a variety of issues in kitchen preparation - such as selecting pots, ingredients, organizing, and cleaning. Our teacher is specifically interested in selecting pots for cooking spaghetti and tomato sauce. This presents a challenge for the teacher who has a difficult time reusing such a large learning object, not all of which is needed. If the LO is actually made up of smaller independent LOs these would be easier to reuse. She could instead retrieve that small learning object that covers her specific interest. This is the generally accepted rule in software engineering and also learning object development and use. This would require the developers of the existing LOs to have defined the LOs in terms o small self contained LOs. How would they know how small the small LOs should be?

The granularity of learning objects has been defined as the size of learning objects [WGR00]. Because the idea behind learning objects is making learning material much smaller than they had been traditionally, the question arises as to how small is small enough? Typically it is understood that as the grain size of learning objects decrease (i.e. increased granularity) reusability increases (that is the learning object can be more easily used in a variety of contexts) while reuse value decreases. The decrease in reuse value is mainly due to the fact that in general the smaller the objects get, the less contextual or meaningful they often become. Developers therefore face the challenge of developing learning objects that meet an appropriate level of both reuse value and reusability. According to [SM02], this occurs at the intersection of these two concepts. This however does not give a very specific answer to the problem. In fact the solution to this problem is complicated by the fact there are different approaches to measuring learning object granularity. This gives rise to our second challenge to learning object reuse discussed below. In general organizations often allow the grain size(s) to be determined by the needs of the given organization[TY05], thus often limiting the opportunities for flexible reuse beyond that organization [Dod02].

2.3 Determining a measure of learning object granularity

As discussed in the previous section, the issue of LO granularity speaks to the size of the LO. There remains however the question of how to define the size of a LO. In [WGR00] it is argued that there are two main approaches to measuring granularity. One school of thought called a media-centric approach is that LO size is determined by the size of the media. Using this approach, the largest of our six LOs would be LO5. A second approach is to use the nature of the content to determine the size of the LO. In [Wil02] a taxonomy of LOs is proposed based on the notion that granularity ought to be based on LO content complexity. Using this second approach, LO5 would no longer be the largest, infact it would be one of the smallest LOs of the six. Without a consistent measure of LO granularity, what is considered a *small* and (therefore reusable) LO in one model and thus system may be considered quite *large* in another. This has significant implications for reuse and interoperability of LOs[Dod02].

2.4 Many incompatible models

Owing to the fact that various institutions develop their own means of defining appropriate granularity as well as their own means of characterising what is a LO and what is not, there are several models of LOs in terms of taxonomies and component architectures. These models are not necessarily compatible with each other thus limiting the level of reuse of LOs from one institution to another. In our very simple example there are various file types representing LOs. One of the most evident forms of incompatibility is illustrated here. How can we compose new LOs from existing ones when we have various standards for the format or media type of a LO? We need standards to define their interfaces for interoperability with each other and with the systems that they will be utilized in.

2.5 Reusability of extracted LOs

In our example let us assume that the teacher wishes to extract some sections from LO6, the PDF file on Italian Cooking. If the sections, tables and figures are labelled she will need to find a way to replace these labels with labels that are appropriate for the new usage context. She will also need ensure that references embedded in the text such as *"in the previous section"* or *"see the example in section 6"* are removed or appropriately updated. Furthermore the given sections may bundle assessment together with instruction and our teacher may only be interested in the instruction. Depending on the way in which these are presented in the document it may be quite hard to extract instruction on cooking macaroni and cheese from the assessment associated with it or even from the assessment related to cooking “chicken alfredo”.

One of the main goals in learning object reuse is the idea that one would be able to decompose a large learning object and reuse its constituent smaller parts. The challenge is that:

1. A constituent smaller part may be reusable in terms of its actual content but there may be difficulty in ease of reuse because of inherent interdependencies between it and its original context. This is difficult to solve because learning material characteristically will include references to other parts within it.

2. A constituent learning object may be very difficult to reuse because it covers multiple concepts or learning activities that a user may not necessarily wish to reuse together. South and Monson in [SM02] suggest and we agree that a learning object should cover no more than one concept. Other literature such as [L'A01] suggest similar approach and define a single learning object in the NETg model to include a single learning objective, an activity and an assessment. How easily can the three components in the latter be used independently?

The lack of a single approach to handling decomposition affects reusability. Our Theory of learning objects presented in section 4 resolves these challenges by enforcing some simple criteria in how we define learning objects, their granularity and composition/decomposition.

3 Reusability in Popular Learning Object Models

In this section we examine the content models of popular learning object systems. Each of these models represent an alternate way of handling the challenges posed in section 2. We examine them in order to see how the challenges may be handled and the strengths and weaknesses of various approaches.

3.1 The Learnativity Content Model

Wagner in [Wag02] cites the following taxonomy upon which the Learnativity Content Model is built. The Learnativity Content Model presents five aggregation levels. These are:

- *Content assets:* Content assets include raw data such as photographs, audio and video files and applets.

- *Information objects:* Information objects represent the most granular form of content. There are various types of information objects including Concepts, Facts, Procedures etc.

- *Learning objects:* Learning Objects are formed by assembling a collection of relevant information objects to teach a common job task on a single enabling learning objective.

- *Learning components:* Learning objects can be bundled into larger entities known as learning components such as Lessons and Courses.
- *Learning environment:* When Learning Components are wrapped with additional functionality such as communication tools, peer-to-peer computing and other practice-specific support those entities are called Learning environments.

The learnativity model is arguably flexible in that it forms the basis for organisation specific plans that extend the architecture for content. It also according to Wagner helps to visualize the relationship beteen granularity and reusability. Verbert and Duval in [VD04] question the rationale behind the restriction to three levels of aggregation of learning objects (note that the first two levels are not learning objects in that they are unable to independently facilitate any learning). We also suggest that in addition to the question of relevance of a fixed number of granularity levels, that it is also important to question the implicit restriction to combining only objects of the same granularity. It is in worth considering a scenario where we may combine learning objects of differing granularities. This would mean for example allowing for a combination of a learning object in the Learnativity model with a Learning Component of that model. This could be quite useful for example in a system which allows dynamic adaptation and where a student's under performance in one lesson may result in the need to do a course (a learning component) combined with some remedial lesson (a learning object).

3.2 The CISCO RLO/RIO Model

In [BLW99], CISCO defines a Reusable Learning Object(RLO) as a collection of 7 ± 2 RIOs (Reusable Information Objects). To make a complete learning experience or lesson from a collection of RIOs an overview, summary and assessment are added to the packet. This model is illustrated in figure 2. In the Cisco model the RIO is a piece of information that is built around a single learning objective. Each RIO is composed of three components, content items, practice items, and assessment items. This model presents a very useful means by which a well defined process of learning and assessment can take place. The model places a 7 ± 2 limit on the number of RIOs in an RLO and the number of content items in RIOs. This is based on the instructional approach used by CISCO. For high levels of reusability and interoperability it would be useful to have more flexibility. This can be achieved by making components such as the content items in the RIOs into independent finer grained learning objects. Such fine grained learning object can be reused by other learning objects in separate contexts. While finer grained learning objects can suffer from low reuse value due to loss of context, we believe that the appropriate balance of granularity and context can be achieved when the learning object size is no smaller than necessary to cover a single specific learning objective. In other words it would be useful to have a learning object such as a content or practice item so long as it covers a single specific learning objective as is the case in the CISCO Model.

3.3 Aggregation model of the IEEE LOM

The IEEE LTSC has developed a learning object metadata (LOM) standard known as the IEEE LOM [LTS02]. In order to do this they present a definition of a learning object and make certain assertions about what a learning object is and its architecture. One such assertion is given in their description of the metadata field aggregation level.

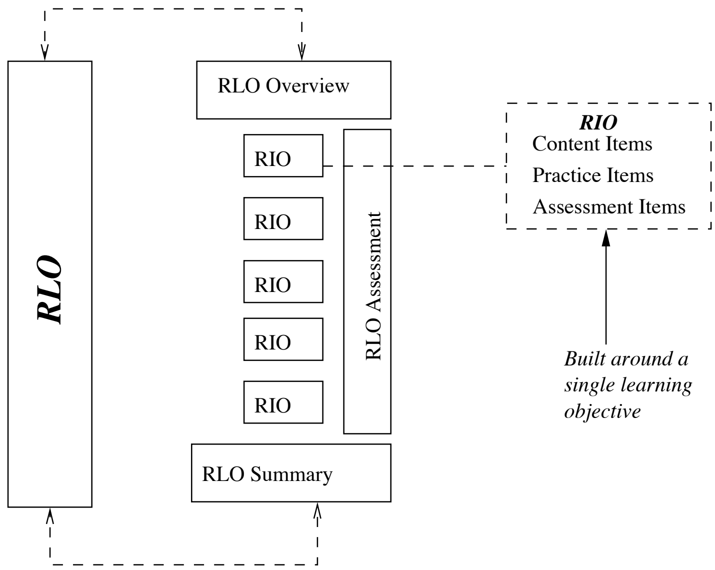


Figure 2 – Cisco RLO/RIO Model

They suggest that there are four learning object aggregation levels. The granularity levels are named as levels one(1) to four(4). Level 1 represents the smallest level of granularity, level 2 represents a collection of level 1 objects, level 3 is made up of level 2 objects and level 4 the largest level of aggregation is made up of level 3 objects or can recursively contain other level 4 objects. In [BMO08], the model is noted as having general and vague aggregation levels because for instance they do not specify or describe explicitly the meaning of the various aggregation levels (although an example is provided). Also we suggest as we did with the Learnativity model that greater flexibility and reuse oppurtunity can be achieved if aggregation is acommodated across granularity levels.

3.4 NETg Content Model

Netg (now aquired by SkillSoft) was one of the first to use the learning object concept for its courses [Wil02]. It has a hierarchy of four levels - course, unit, lesson and topic. A course contains independent units, a unit contains independent lessons and a lesson contains independent topics. A topic represents an independent learning object that contains a single objective and has a corresponding activity and assessment [L'A01, Wil02]. This model is very well structured and has in fact proven to be highly reusable within the context of the Netg environment or another similar environment [Fuh03]. On the other hand the level of flexibility is limited if we were to consider other learning environments. Firstly the model features *tight coupling* of components within the topic in that they are not distinct and independent of each other or the topic within which they exist. These components for example assessment and activity could easily be reusable in other contexts if the model's design were to facilitate this. As with the CISCO model discussed earlier, each of these could easily represent a reusable learning object because each surrounds a learning objective. The Netg model would be greatly improved by providing for this level of reuse.

3.5 Shareable Content Object Reference Model (SCORM)

The SCORM content aggregation model contains assets, shareable content objects (SCOs) and content aggregations. An asset is an electronic representation of media, text, images, audio, web pages or other data that can be represented in a web client. A SCO represents a collection of one or more assets and should be independent of its learning context. A SCO can then be reused in various learning contexts. A Content Aggregation is a map (a content structure) that can be used to aggregate learning resources in a well integrated unit of education (for example course, chapter, and module) [ADL04]. This model provides better levels of flexibility by not imposing the organizational specifics on the model. In the case of SCORM the flexibility is such that it allows the user to determine the deepest level of disaggregation. SCORM allows this level of flexibility to allow for protection of content that may have copyright restrictions and reuse may be restricted.

We believe that the need for such protection should not hamper the reusability of learning objects and that this protection would be best provided in an object oriented implementation through private data accessible only through the methods of the learning object itself. In this way learning objects are always developed such that its constituent components are always reusable through object methods by other objects or users with the permission to do so. SCORM is powerful in that it facilitates the provision of a very general model upon which more specific learning object design may be built. In this way the model lends itself to technical interoperability. On the other hand it does not specifically tell us what a learning object is in the model. The issue of learning object size and granularity remain quite vague in that a SCO may in one implementation cover one learning objective or concept while in another case it may cover ten and in yet another it may be a collection of images not specifically covering any learning objective. SCORM is more of a general content aggregation model and not specifically a learning object model. To improve upon it as a learning object model it would be useful to include some base definition for what is a learning object and what is not and how that fits into the content aggregation model. Di Nitto in [NMM+06] discusses how this may be done by suggesting the introduction of an atomic learning object and a complex learning object. Our theory includes similar entities.

3.6 Abstract Learning Object Model (ALOCoM)

Verbert and Duval in [VD04], present a learning object model which allows for generalization of some of the popular learning object models including Learnativity, SCORM and Netg. In this general model, a distinction is made between three types of entities: *content fragments*, *content objects* and *learning objects*. *Content fragments* are learning content elements in their most basic form, such as text, audio and video and they represent individual resources uncombined with any other. *Content objects* are sets of content fragments. They aggregate content fragments and add navigation. Content fragments are instances and content objects are abstract types. At the next level, *learning objects* aggregate instantiated content objects and add a learning objective. They define a topology between their components and can communicate with the outside world. Aggregations of learning objects can be made. The model does not specify the number of aggregation levels. The model is useful in that it is not overly specific therefore lending itself to better levels of reuse than some of the other models we have discussed. Notice that the model does not distinguish learning object types whether in terms of size or pedagogical significance. This is useful for the purposes of allowing application to a variety of learning environments but of course this means that the metadata model must be sophisticated enough to speak to the pedagogical description of the learning object to facilitate knowledge of its context and use. An ontology supporting this model has been developed and coined the ALOCOM Ontology [VJD+06].

Having examined these models we are able to highlight our motivation for developing our theory of learning objects.

- We need a clear and precise definition for a learning object as well as its properties and structure. The existence of multiple interpretations of the definition in the IEEE LOM (which is the starting point for many researchers) has resulted so many different streams of research that development and progress in the field is slow. Furthermore learning objects from various developers are far from interoperable with each other. Although SCORM exists as a de facto technical standard, SCORM is so flexible and broad itself in terms of instructional design that what constitutes a learning object (conceptually and in terms of learning object models) in SCORM will vary from one user to the next which is also a challenge in many cases. SCORM could be far more beneficial if all users had some similar ideas about what a learning object is and is not. In SCORM it is possible that an image and a lesson could be comparable learning objects, despite the obvious fact that their complexities and usefulness in instructional situations are vastly different.

- An approach to granularity that allows us to identify an atomic learning object based on both content and activity is necessary. This will allow us to have two reusable learning objects on the same content but different activities. This is in contrast to the coupling seen in the CISCO and NETg models. This makes the entities called topics in the NETg model for instance decomposable into independent learning objects which assess, provide content and provide learning objective on a particular content. This is useful because each of these can be reused with other learning objects. It would then be possible to create two topics with the same objective but different content and assessment.

- The various models are important to resolve the needs of the various institutions. However we need some sort of a common ground in order to facilitate integration and interoperability. Without this we will continue to see limitations in reuse of learning objects as users very often are interested in using learning objects from various sources. A generic learning object model is therefore necessary. One that includes an atomic learning object and defines composite learning objects based on these atomic learning objects. The model should not define rules for composition in specific terms. For example it should not limit the number of atomic learning objects that can be combined to form a composite. This should be a function of the specific environment and threfore allow institutions to create IS/OS models based on the generic model.

- Finally we must shift the concept of a learning object from simply e-learning content and begin to apply its roots in object oriented technology. Object technology has inherent features which if properly utilized will positively affect reusability. the models we examined are limited by the fact that they all view learning objects basically as small pieces of e-learning content which may have various forms and which cannot ‘do ’anything. According to Mohan and Daniel in [MD06], object-oriented technology can seamlessly support the design of learning objects, and it can be used to take learning objects out of their current static form and imbue them with behaviors that allow them to be more meaningful in an instructional context.

4 A Theory Of Learning Objects

In this section we present a theory of learning objects based on object-orientation. This theory of learning objects is important, firstly because there is not a specific working definition of a learning object that developers and researchers have agreed on, resulting in limitations to reuse and interoperability. We therefore need some relatively stable fundamental principles and definitions in the area in order to promote consistent development in the field.

A second reason why a theory of learning objects is important is that not much attention has been paid to the issue of object orientation in the search for a definition and clarity of the concept of learning objects. Object orientation is an important factor in our estimation, as it is the main basis upon which one can reasonably anticipate achieving reusability and interoperability from objectifying e-learning content. The entities often regarded as learning objects by the vast majority of models are not able to make use of the features of object orientation intended to produce reusability and interoprability such as inheritance, polymorphism and instantiation, because they are not objects in the sense of object orientation.

Many models and definitions seek to achieve high reusability by simply defining e-learning content as being fine-grained. While fine granularity has proven an important issue in achieving high reusability, the notion of fine granularity must be supported by clear definitions of grain size and mechanisms to support composition, decomposition and self description among others, if reuse is to be achieved. Object orientation allows us to place these features and mechanisms into the learning object itself.

Thirdly a theory of learning objects is necessary to bring together two concepts whose significance should be evident (though it generally is not) in learning object definitions and models. These are pedagogy and object orientation.

Finally such a theory is important because it provides a basis on which the concept of learning objects can be properly fitted into the e-learning context.

A theory of learning objects must be clear and specific on what digital entities are learning objects and which ones are not, while being broad enough to facilitate different types of instructional approaches and thus learning object models. This section begins by discussing some concepts which need clarification in the context of our work. We then outline the assertions of the theory of learning objects, highlighting issues such as the definition of a learning object and its properties.

4.1 Definitions of Concepts

Our theory is dependent on certain definitions which we will present in this section. The concepts which we discuss in this section are terms that we intend to take a specific meaning in the context of our work. In order to prevent confusion we clarify them prior to their use. The concepts are as follows:

- Learning Experience

- Learning Objective
- Learning Object Independence
- E-Learning
- Learning Components
- Pedadgogical Activities
- IS/OS Models

4.1.1 Learning Experience

The term learning experience is often used to very generally describe a sequence of events that a learner participates in to achieve one or more *learning objectives*.

4.1.2 Learning Objective

A learning objective is a statement that captures specifically what knowledge, skills and/or attitudes learners should be able to exhibit following a *learning experience*. Learning objectives are measureable, and are concisely expressed. More details on measuring and writing of learning objectives can be found in [Ser03].

4.1.3 Learning Object Independence

Every learning object is created with a purpose. This purpose is defined by learning objectives. The learning object must have all the content or data and operations required for it to be used to meet the given purpose or learning objective. We use the term independence to refer to the learning object's ability to stand on its own in terms of the content required to meet this objective. We are not referring here to the object's ability to stand on its own technically but rather pedagogically.

It means therefore that the learning object content must be such that there are no references to other learning objects or content outside of itself, which may or may not be available in a reuse scenario. It also means that any figure, formula, table etc. being referred to, must be within the learning object, or the ability to find it or create it must be within the learning object. The point is that the learning object must be capable of delivering on the learning objective independent of the reuse context.

This independence does not mean that prerequisite learning and activities are the responsibility of the learning object itself. Instead the independence relates to the accomplishment of only the relevant objective. The statement of a learning objective occurs within the context of an assumption of prerequisite knowledge, skills and/or attitudes and as such it would not be necessary to cover such prerequisites in the learning object or to refer to an object containing it.

Independence also does not mean that the technical matters such as required platform for execution are contained within the object itself. It may need specifc software or computing facility to work, and this is not related to the content for the objective to be met. Such matters relate to the technical framework which must be available for the learning object's use to be technically feasible in the first place.

4.1.4 E-Learning

E-Learning is the use of information and computer technologies (ICTs) to create learning experiences [Hor06]. According to [Hor06], E-learning comes in many forms.

- Standalone Courses
- Virtual-Classroom Courses
- Learning Games and Simulations
- Embedded e-learning
- Blended learning
- Mobile Learning
- Knowledge Management

These are only a few of the many forms of e-learning that have been observed and discussed in the literature.

4.1.5 Pedagogical Activities

Pedagogical Activities are the types of educational activities that occur in traditional learning and therefore also occur in e-learning. We propose that there are four main types of pedagogical activities. These are *Curricular Activities* (statements of pedagogical intentions and often the methods used to achieve them), *Instructional Activities* (e.g. teaching, facilitating, dictating, illustrating, demonstrating etc.) and *Assessment Activities* (multiple choice test, oral examination, essay assignment, interviewing and observing etc.) and *Research Activities*. Depending on the instructional design theories being applied these could occur using various tools and in different orders.

In the context of this research we will focus only on the first three as we are specifically interested in the content created and used for learning experiences in a formal education setting. We base our ideas on the fact that in general, these three sets of learning activities are generally used, though in various orders or using various tools. These three activities together have been called the Curriculum-Instruction-Assessment triad in [Pel04]. Each of these pedagogic activities have artifacts (which we call learning components, discussed next), associated with them, and these can be detailed in terms of their parts, possible types and also possible forms.

4.1.6 Learning Components

A Learning Component is e-learning material created by a learning object to meet one or more specific objectives. Such material is a file and in a format such as pdf, html, mvi, mpeg, jpeg etc. A learning component is different from a learning object in that the learning component is an actual piece of e-learning material designed to result in or to be used in some pedagogic activity as a part of a learning experience. They are created through the operations of learning objects. Learning objects on the other hand are more abstract and are a collection of data and operations that are generated in some learning object development system based on content and pedagogical stipulations from facilitators or teachers. Such objects can then be used and reused to create new learning components of different forms, and in different usage contexts.

Learning Components run in (or are used in or plugged into) specific e-learning systems. We call them learning components because they are a part of a larger e-learning system. Learning Components are used directly in learning experiences by the learner using an e-learning system.

4.1.7 IS/OS Models

It has been pointed out in literature such as [CS01, Lib05] that it is very difficult to create a useful learning object model (and thus) learning objects that suit the needs of all types of intitutions and organizations. Rather it is often most suitable to create LOs that are apart of an overall institutional strategy. Many of these models have enough in common that a general learning object model was proposed by [VD04]. We also propose a generic model and we see the need to distiguish those models that are specific to institutional or organizational approaches, such as NETg(SkillSoft) and CISCO RLO. We call these models (Institution Specific or Organization Specific) IS/OS models.

5 A Theory of Learning Objects

In this section we outline the main points and features of our theory of learning objects.

5.1 Basic Learning Object Definition

A learning object is an instance of a learning object class (defined later). It consists of data such as learning content and metadata, as well as operations that are used to manipulate and retrieve the data and to create learning components. There are two basic types of learning objects. Atomic Learning Objects (ALOs) and Composite Learning Objects(CLOs).

5.1.1 Atomic Learning Objects (ALOs)

An atomic learning object is an instance of the atomic learning object class, which is a subclass of the learning object class. ALOs consist of data such as learning object content, metadata and a reference to a single learning objective and operations that may be used to manipulate or use the data in the ALO for the creation of a learning component. The learning component created by an atomic learning object is used for a single pedagogic activity satisfying the referenced learning objective only.

5.1.2 Composite Learning Objects (CLOs)

A composite learning object is an instance of the composite learning object class, which is a subclass of the learning object class. CLOs consist of data such as a list of learning objects (composite or atomic), metadata and operations that may be used to manipulate or use the data in the CLO for the creation of relatively complex learning components by recursively parsing through a hierarchy of learning objects accessible through the list of learning objects within it. The learning component created by a CLO may consist of a combination of artifacts covering multiple learning objectives based on the characteristics of the learning objects contained within the CLO's list of learning objects.

5.2 Learning Object Properties

In this section we examine the properties of learning objects according to our theory.

5.2.1 Independence

A learning object is *independent* of any other learning object. It is independently capable of doing the tasks necessary to create the expected learning component. The design of a learning object must however focus solely on that which is necessary to meet its objective. The assumption is that the learner using such an object has already met the necessary prerequisites.

5.2.2 Granularity

The smallest learning object has a size of 1, (ALO) and will create a learning component for a single pedagogic activity (e.g.instruction, assessment) satisfying a single learning objective. Therefore only a single specific learning objective may be referenced, by an atomic learning object. Larger learning objects (CLOs) can be created by combining these atomic learning objects to create composite learning objects. Composite learning objects may also be created by combining composite learning objects with other composite learning objects and/or atomic learning objects. The size of a composite learning object is the total number of atomic learning objects within the composite. The means of determing the size or granularity of a composite learning object is demonstrated later. The size of a learning object is important because it tells us about the level of disaggregation that can take place.

5.2.3 Reusability

Reusability defines the ability of the learning object to be used in a variety of contexts with little or no modifications made to it. Our theory encourages and increases learning object reusability by:

- Requiring loose coupling. This is enforced by ensuring that any learning object that can be used to facilitate a pedagogic activity surrounding a single learning objective be defined as a single independent atomic learning object, and that activities such as assessment and instruction be covered in independent learning objects. The atomic learning object is independent of its context and can be easily reused in other contexts with similar pedagogic requirements. We therefore define different categories or types of learning objects based on pedagogic activities and therefore the learning components they create. We also keep contextual information within the learning object to a minimum within the learning object. this keeps the learning objects from being tightly coupled to any usage context.
- Requiring strong cohesion. This is enforced by requiring that only one pedagogic activity surrounding one single learning objective be covered in an atomic learning object. This is closely related to the previous point and is enforced through the use of categories of learning objects. These categories are determined by pedagogic activities in a given model, although we propose that these will very frequently be as discussed earlier (curriculum, instruction, and assessment or variations of these).
- Introducing principles of object orientation. This results in the ability to utilize features of object orientation such as inheritance, encapsulation, information

hiding and polymorphism which generally increase reusability. These features among others and how they improve reusability of learning objects are the subject of the work in [AM10a].

- Providing an optimal unit of learning object size or granularity. We define granularity based on padagogic activity and learning objective. This allows developers to create learning objects that are fine grained and thus highly reusable that are still meaningful to faciliators or teachers and learners. We suggest that this is the area of optimal granularity [SM02] because it reflects the intersection between technical utility (fine-grained) and instructional utility (1 pedagogic activity surrounding 1 learning objective).
- Providing a common model upon which many IS/OS models may be built. This is particularly important because it is made possible simply by subclassing the ALO and CLO classes to reflect the charcateristics of specific IS/OS models. These models must meet certain criteria that we call reuse criteria (discussed later in this chapter). This often requires some "tweaking of the models".

Reusability of our learning objects is also facilitated through the use of a context model which can be used for defining various reuse contexts. This context model is discussed in [AM10b].

5.2.4 Assemblability

A given learning object can be incorporated into new assemblies other than the one it was originally created for (In fact a learning object may not necessarily be created for a specific assembly). This is the case whether the learning object is composite or atomic. The learning object interface allows for the seamless assembly of learning objects and for them to work together to create learning components of different sizes and formats.

5.2.5 Contextualizability

A learning object of any size must function in a manner consistent with its current usage context. It must generate its references, labels, headings, sub-headings, templates, formats, positioning within the context of its new assembly and or IS/OS model when being reused. This contextualization does not affect the content of the learning object or the pedagogical impact or significance, rather it simply contextualizes the behaviors of the learning object.

5.2.6 Interoperability

Learning objects share a common interface. This results in all learning objects looking essentially the same to each other and to applications or users. This common interface is achieved through the use of inheritance, interfaces and polymorphism, all features of object oriented programmimg. This allows the learning objects to be interoperable with each other. Thus a given learning object can easily and seamlessly be replaced by another in an existing assembly. As indicated earlier, IS/OS models can be created based on the OOGLOM, the use of inheritance and adherance to the reuse criteria discussed later. Learning objects from such models will all be interoperable with each other because they all share the common learning object interface defined in OOGLOM.

5.2.7 Flexibility

This is the ease of changing the learning object to meet revised design requirements. An example is where the course design changes and a given component of current course is simply replaced as discussed above. At the most granular level it involves the editing of data elements in atomic learning objects to result in changes to the learning coponents which can be generated. At higher levels of granularity this can be the removal or replacement of learning objects of any size with another learning object of any size dependent on learning object specification. Flexibility can also be seen in the ease of changing the sequence or ordering of the learning objects in an assembly.

5.3 Learning Object Structure

In this section we discuss the structure of a learning object. As we have emphasized the learning object in our theory is an object based on object orientation. As such its structure can be illustrated with UML class diagrams.

Figure 3 is a UML diagram which illustrates the structure of the learning object classes in our theory. We have named this Object Oriented Generic Learning Object Model (OOGLOM). The diagram illustrates the main operations of a learning object class. It can also be seen from the diagram that the learning object content is in atomic learning objects and that composite learning objects consists of a list of learning objects, which may of course be atomic ones or other composite ones. In essence a composite learning object may be represented as a tree of learning objects where the leaves are atomic learning objects which contain the actual content. Furthermore by invoking the main operation (RunLO) of a CLO it will cause the recursive invocation of all RunLO operations on all LOs included.

In the case of an ALO the RunLO method will result in the creation of a learning component based on the data and operations contained in that learning object. The learning component would perform only one pedagogic activity surrounding a single learning objective. In otherwords it could be a single examination question or assignment based on a single specific learning outcome. If RunLO were to be invoked on a CLO the learning component generated would be based on the content of all the constituent ALOs and would therefore be a large component consisting of the pedagogic activities of the various atomic learning objects included. The organization and sequencing of the various pedagogic activities in the learning component is based on the sequncing and organization of the composite learning objects.

5.3.1 Learning Object Composition and Decomposition

A learning object of size 1, is known as an atomic learning object. A learning object of size greater than 1 must be a combination of other learning objects and is called a composite learning object. A composite learning object therefore carries in its data section a data structure (an ordered list of children) which stores all the instances of learning objects (both composite and atomic) which are components of this composite learning object. The composite learning object may therefore be represented as a tree. The nodes of the tree are learning objects, those with children are composite learning objects and the leaves of the tree are atomic learning objects. The traversal of the content of a composite learning object is therefore a recursive parsing through to the leaves of the tree where the actual content would be located.

Formally we can state, given that:

L_R is the set of all learning objects in a repository R

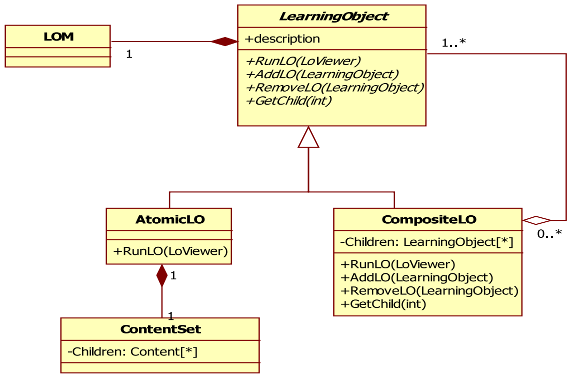


Figure 3 – UML diagram of OOGLOM

L_A is the set of all atomic learning objects in R
L_C is the set of all composite learning objects in R
$L_R = L_A \cup L_C$
$L_A \cap L_C = \emptyset$
A Composite learning object l, is defined as follows:
$l = (L, l_0)$, *where*

1. $L =< l_1, l_2, l_3 \ldots l_n >$ is a finite sequence of learning objects where $l_i \in L_R$
2. l_0 is the root of the tree representing l, and the elements of L are the branches (or children) of l_0 and they are all at the same level.
3. The size of l is given by $Size(l) = \sum_{i=1}^{n} Size(l_i)$; if $l \in L_A$, $Size(l) = 1$
4. The execution of l is given by $l.RunLO()$

6 Reusability Criteria of the Theory

Our theory of learning objects is grounded in the satisfaction of eight key reuse criteria, necessary for providing high reusability as well as pedagogic and technical meaningfulness. In this section we discuss these eight criteria. In Table 2 we demonstrate how well these criteria are met by the models discussed in section 3.

6.1 Criterion 1: Definition of a learning object

The definition for a learning object is critical to research and development of reusable learning objects. Without a clear stable definition, learning objects cannot be easily reusable because the question of what is a learning object will continue to elude developers. We deem the definition of a learning object to be incomplete, vague or otherwise problematic unless it:

1. States that the entity must be a digital entity,
2. Clearly distinguishes a learning object from all other entities that may be referenced in a learning experience,

3. States that at least one learning objective or outcome must be covered by the entity,
4. States that the entity must facilitate at least one identifiable pedagogical activity e.g. instruct, assess.
5. States that the entity must be able to *independently* realize its activity or activities.

Our actual definition is clearly more specialized (especially by making the learning objects, object in object orientation), however these represent minimal criteria against which we can measure or examine other definitions.

6.2 Criterion 2: Definition and Measure of LO granularity

The size of a learning object is defined by the number of learning objectives and activities covered by that learning object. More precisely, the size of a learning object is given by the number of atomic learning objects within that learning object. In other words a learning object which has one single pedagogical function covering a single learning outcome has a size of 1 and is considered an atomic learning object. If the components of such a learning object were extracted they would be smaller than learning objects, perhaps *information and/or media objects* [Wag02]. This criterion is important because it informs aggregation and disaggregation of learning objects. Most models examined do not meet this criteria. In some cases granularity is measured by learning objective. A single learning object is determined to have a single objective, but may be responsible for multiple pedagogical activities. This is seen in the Netg and CISCO models for example which we therefore indicate in table 2 as meeting the criteria to a limited extent.

In other models such as IEEE no measure of granularity based on learning objectives or pedagogic activity can be determined. While many models do allow you to determine a granularity based on objectives such as ALOCoM or NETg, they do not speak to types of learning objects in terms of pedagogic activities. This means that reusable (and meaningful) portions of learning content may be tightly coupled into the learning object.

6.3 Criterion 3: Facilitate Different Types or Categories of LOs

The model must allow different kinds or categories of learning objects based on various pedagogical activities such as *assessment* and *instruction*. This is important to facilitate singularity of purpose for atomic learning objects, which is a fundamental component of our theory. In some models such as NETg different pedagogic activities are accomodated only as features within a learning object. This can hamper reusability of the learning object especially outside of the Netg type environment.

6.4 Criterion 4: Allow Aggregation of Different Types and Sizes of LOs

Another important criterion for reuse would be allowing any of the various types and sizes of learning objects within a model to be combined with each other. In the NETg model [L'A01], there is a requirement for lessons to be made up of topics and units to be made up of lessons and so on. There is no room in this model for a learning object made up of two topics and a lesson (which is made up of topics). Depending on the instructional approach being used this may be a useful allowance. This flexibility can be achieved using SCORM, [ADL04] or GLOM [VD04], which do not prescribe either a specific number of aggregation levels or rules for aggregating different sized learning objects.

6.5 Criterion 5: Allow Flexibility in the Number of LOs that can be Aggregated

The learning object model should allow flexibility in the number of learning objects that can be combined to create larger learning objects. This would greatly improve the reusability by making the model more adaptable to a variety of environments. The CISCO model for example limits the number of reusable information objects that may be found in a reusable learning object. While this may be useful for the instructional model used in CISCO training it may not be appropriate for another learning environment.

6.6 Criterion 6: Loose Coupling between LOs

This criterion is a requirement that there are minimal relationships between the smaller learning objects in larger learning objects. This improves the reusability of the component learning objects by ensuring that they each have a clear specific purpose, and can be used independently in other learning object scenarios. This is easily achieved by enforcing criterion 1 (point 5) and criterion 2.

6.7 Criterion 7: Strong Cohesion within LOs

As we discussed before the smallest learning object should be one whose size is 1, which means it has one pedagogic activity covering one objective. Within this learning object all data and operations should be as closely related as possible. This improves reuse by making the entity itself generally useful in its current state in other situations. Furthermore this increases reusability by making it easier to extend or enhance learning objects. Strong cohesion and loose coupling work hand in hand to increase reusability by maximizing the degree of interaction within a learning object and minimizing the degree of interaction between learning objects.

6.8 Criterion 8: Facilitate Various Instructional Approaches

An important criterion for a learning object model to support reuse is that it should not limit the user to a specific instructional or pedagogical approach. Several of the models surveyed showed such limitations. Examples are CISCO's RLO model [BLW99] and NETg [L'A01, Fuh03]. The SCORM content aggregation model provides a high level of flexibility for this purpose but once objects have been defined and used it can be quite confusing to determine how to facilitate reuse and resequencing in other contexts [NMM$^+$06].

6.9 Meeting the Criteria

In summary these criteria are necessary because they ensure a high level of reusability for learning objects. Criterion 1 ensures that it is clear what entities are learning objects, removing the ambiguity that exists in the IEEE LOM definition. Criterion

Criteria	*Learnativity*	*Netg*	*CISCO*	*IEEE*	*SCORM*	*ALOCoM*
1	Y	Y	Y	N	N	Y
2	L	L	N	N	N	L
3	N	N	N	N	N	N
4	N	N	N	N	Y	Y
5	Y	Y	N	Y	Y	Y
6	Y	N	Y	UA	N	Y
7	Y	L	Y	UA	N	Y
8	Y	L	N	UA	Y	Y

Y	Yes
N	No
L	Limited
UA	Unable to Assess

Table 2 – Reuse Criteria and Popular Models

2 provides a definition of granularity, which is absolutely necessary for extracting well defined entities from a decomposition process. Criteria 3, 4 and 5 all improve the level of flexibility for learning object use across multiple instructional designs and pedagogical approaches. Criterion 6 and 7 ensure that LOs extracted from a decomposition process are well defined, independent and highly reusable by minimizing interdependencies and coupling.

Table 2, shows the eight (8) reuse criteria we have discussed and how well they are met by the six (6) of the most poular learning object models which were discussed in 3. We can see from the table that most of the models we discussed do not meet many of the reuse criteria we have examined. These criteria are significant in that they give assurance of reusability - for example criteria 6 and 7 ensure that each learning object, even at the smallest level is independently useful and as another example, criteria 4 and 5 ensure flexibility for different instructional approaches. Our criteria also explicitly defines granularity in terms of an atomic learning object by requiring the smallest learning object to cover only one learning objective.

With the exception of criterion 3, each criteria is met by at least one model indicating that these criteria have been considered by various developers. By pulling all such imporant criteria together into one theory and base model (OOGLOM) we have the oppurtunity to enhance all models by building them on top of OOGLOM. Doing this will result in them each meeting all the reuse criteria, while maintaining their own specific features and becoming interoperable with each other due to the common denominator of the OOGLOM and specifcally the ALO. The reader will note that we have not been able to assess the IEEE aggregation model under some criteria. This is due to the fact that enough information is not provided about the intended use of the learning objects in this model. This challenge has been cited in [BMO08].

7 Using OOGLOM as the Basis for IS/OS Models

In this section we aim to show how the popular models in Table 2 can be implemented using OOGLOM in such a way that they retain their original characteristics as implementation or organisation specific models, refered to as IS/OS models [AM09], but due to the object oriented approach, their learning objects can easily be integrated into other learning objects based on different models. We therefore illustrate that the learning objects from any of these models are seamlessly interchangeable and thus OOGLOM presents a means of unification among models. In addition OOGLOM increases reusability by using object orientation and by enforcing the eight reusability criteria discussed above.

The UML model of OOGLOM shown in Figure 3, illustrates some of the most important features of the learning object class. A few points are worth highlighting. Firstly the OOGLOM is designed to facilitate the design and/or implementation of IS/OS models. Whilst many models discussed in the previous section have several drawbacks identified in section 3 they are generally satifactory for their own repositories and specific applications. The benefit of OOGLOM is to make the learning objects from these models more easily useful in a broader sense by making them reusable in other repositories and other organizations.

OOGLOM is ideal in that it resolves the challenges and limitations to LO reuse by meeting the criteria discussed in the previous section, while still allowing the implementation of IS/OS models by providing an atomic learning object class whose specific characteristics can be determined through inheritance and polymorphism. The OOGLOM also provides a composite learning object class which will allow easy aggregation of learning objects (both atomic and composite) in accordance with the rules of the IS/OS model being implemented. In Figure 4 we illustrate OOGLOM as a base layer upon which any IS/OS models may be developed. It is important to note that we see OOGLOM as a base upon which the various learning object classes can be specified through inheritance by extending the learning object classes in OOGLOM (which are actually abstract). Furthermore an organisation's repository would be populated by creating instances of these classes.

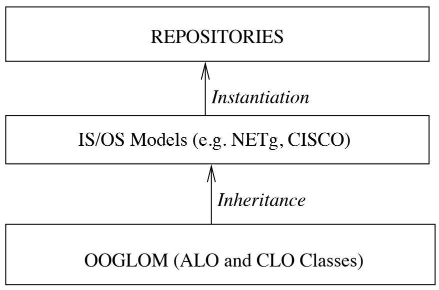
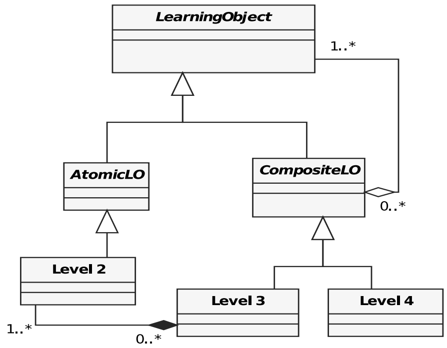


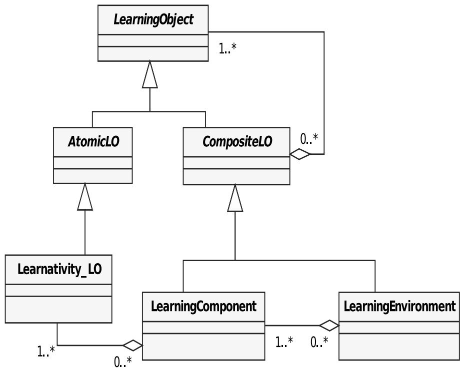
Figure 4 – OOGLOM as a base layer for IS/OS models

7.1 UML Models of Popular IS/OS Models

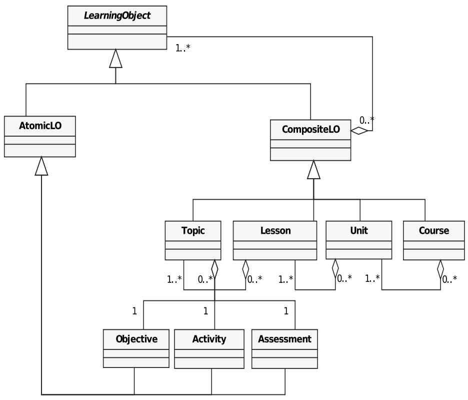
To illustrate the usefulness of our OOGLOM as a means of providing interoperability of learning object models we have provided a UML model of some of the models studied illustrating how they can be implemented as IS/OS models using OOGLOM's ALOs and CLOs through inheritance. Repositorie(s) for a given organization may be populated through instantiation of the new classes created through inheritance. In some cases the reader will notice that the OOGLOM actually improves on the reusability original model by providing looser coupling as in CISCO and NETg where the components of the learning object are themselves broken into separate independent



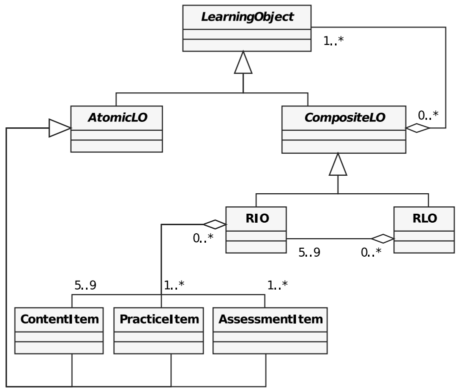
(a) IEEE Aggregation Model



(b) Learnativity LO Model



(c) Netg LO Model



(d) CISCO RIO/RLO

Figure 5 – UML models of IS/OS models using OOGLOM

atomic learning objects. This is necessary to meet the criteria discussed in section 6.

7.2 Conclusion and Future Work

In this paper we have reviewed several popular learning object models highlighting areas of strength as well as areas where reusability of the learning object could be improved. We have also introduced a theory of learning objects which if utilized increases flexibility, reusability and interoperability of learning objects belonging to various models. We have been able to show using UML modelling that these popular models may be built upon OOGLOM, our object oriented generic LO model. The learning objects from these models can then be easily seen as subsets of the set of learning objects from OOGLOM. Future work involves:

- The implementation of Learning Object Development and Deployment System which will facilitate testing of our theory. This includes the design of and implementation of a repository.

- Development of an IEEE LOM Profile suitable for our application.
- The investigation of the application of component based software design principles to learning object development and assembly.

References

[AB05] N. Armitage and C. Bowerman. The lom approach - a call for concern? *Computer Assisted Language Learning*, 18:109–118, 2005.

[ADL04] ADL. *Shareable Content Object Reference Model(SCORM) Content Aggregation Model*. Advanced Distributed Learning, 4th edition, August 2004.

[AM09] Claudine Allen and Ezra Mugisa. Object oriented generic learning object model (ooglom). In *The Eighth IASTED Conference on Web Based Education*, 2009.

[AM10a] Claudine Allen and Ezra Mugisa. Achieving learning object interoperability and reusability through object orientation. In *Proceedings of The Second International Conference of Education Technology and Computer*, 2010.

[AM10b] Claudine Allen and Ezra Mugisa. A space-based learning object context model: Balancing reusability and meaningfulness. In *Proceedings of E-LEARN World Conference on E-Learning in Corporate, Government Healthcare, and Higher Education (E-LEARN) 2010*. AACE, 2010.

[BLW99] C. Barrit, D. Lewis, and Wayne Wieseler. Cisco systems reusable information object strategy - definition, creation overview and guidelines. Technical report, CISCO Systems, 1999.

[BMO08] Panos Balatsoukas, Anne Morris, and Ann O'Brien. Learning objects update: Review and critical approach to content aggregation. *Educational Technology and Society*, 11(2):119–130, 2008.

[CS01] Betty Collis and Allard Strijker. New pedagogies and re-usable learning objects: Toward a new economy in education. *Journal of Educational Technology Systems*, 30(2):137–157, 2001.

[DH03] Eric Duval and W. Hodgins. A lom research agenda. In *The Twelfth Intenational World Wide Web Conference*, Budapest, Hungary, 2003.

[Dod02] Mahesh H. Dodani. The dark side of object learning: Learning objects. *Journal of Object Technology*, 1(5):37–42, 2002.

[Fuh03] Colleen Fuhs. Elevating commitment to learning to new heights. *United States Distance Learning Association Journal*, 2003.

[Hor06] William Horton. *E-Learning by Design*. Pfeiffer, 2006.

[L'A01] J. J. L'Allier. Netg's precision skilling: The linking of occupational skill descriptors to training interventions. 2001.

[Lib05] O. Liber. Learning objects: Conditions for viability. *Journal of Computer Assisted Learning*, 21:366–373, 2005.

[LTS02] LTSC. Ieee standard for learning object metadata. Technical report, IEEE, 2002.

[MD06] Permanand Mohan and Ben Daniel. Towards object oriented design patterns for learning objects. In *Proceedings of the Sixth International Conference on Advanced Learning Technologies (ICALT'06)*, 2006.

[NMM+06] Elisabetta Di Nitto, Luca Mainetti, Mattia Monga, Licia Sbattella, and Robert Tdesco. Supporting interoperability and reusability of learning objects: The virtual campus approach. *Educational Technology and Society*, 9(2):33–50, 2006.

[Pel04] James W. Pellegrino. Complex learning environments: Connecting learning theory, instructional design and technology. In Norbert M. Seel and Sanne Dijkstra, editors, *Curriculum Plans and Processes in Instructional Design: International Perspectives*. 2004.

[Ser03] Teaching Support Services. Learning objectives: A basic guide, 2003.

[SH04] M. Sosteric and S. Hesemeier. A first step toward a theory of learning objects. In *Online Education using Learning Objects*, pages 32–42. RoutledgeFalmer, 2004.

[SM02] Joseph South and David Monson. A university-wide system for creating, capturing and delivering learning objects. In *The Instructional use of Learning Objects*. Agency for Instructional Technology, 2002.

[Tom05] C. Tompsett. Reconfigurability: Creating new courses from existing learning object will always be difficult. *Journal of Computer Assisted Learning*, 21(6), 2005.

[TY05] Kelvin Thompson and Francisca Yonekura. Practical guidelines for learning object granularity from one higher education setting. *Interdisciplinary Journal of Knowledge and Learning Objects*, 2005.

[VD04] K. Verbert and E. Duval. Towards a global component architecture for learning objects: A comparative analysis of learning objects content models. In *Proceedings of ED Media 2004, World Conference on Educational Multimedia, Hypermedia and Telecommunications.*, 2004.

[VJD+06] K. Verbert, J. Jovanovich, E. Duval, D. Gasevic, and M. Meire. Ontology-based learning content repurposing: The alocom framework. *International Journal on E-Learning*, 5(1):67–74, 2006.

[Wag02] E. D. Wagner. Steps to creating a content strategy for your organisation. *The e-Learing Developer's Journal*, 2002.

[WGR00] David Wiley, A. Gibbons, and M. Recker. A reformulation of the issue of learning object granularity and its implications for design of learning objects. 2000.

[Wil02] David Wiley. Connecting learning objects to instructional theory: A definition a metaphor and a taxonomy. In *The Instructional Use of Learning Objects*. Agency for Instructional Technology, 2002.

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