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

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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 interoperbility. 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.

## 1 INTRODUCTION

Digital learning material was originally introduced as large monolithic pieces of data, mainly with the intent of facilitating access across internetworks 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. Learning objects 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 most popular definition for learning objects given by the IEEE LTSC [16] 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 [3],[11], [1]. This has had a negative impact on the reusability and interoperability 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 individuals or institutions for which the models will be implemented. We have coined such models designed for specific environments, as (Implementation Specific/Organization Specific) IS/OS models [5]. According to [3] 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

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documented that meeting this goal is difficult [6, 19, 15]. 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 and interoperability of learning objects by providing common base classes from which we believe any learning object model may be developed.

## 2 CHALLENGES TO THE GOAL OF LEARNING OBJECT REUSE

As discussed previously, the absence of a well defined theory of learning objects has 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 this theory of learning objects, we have selected and discussed in this section a few challenges to reuse that have arisen as a result of the absence of a well defined and well understood theory of learning objects.

### Finding an appropriate level of granularity

The granularity of learning objects has been defined as the size of learning objects [23]. 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 [4], 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[18], thus often limiting the opportunities for flexible reuse beyond that organization [10].

## Determining a measure of learning object granularity

As discussed in the previous section, the issue of learning object granularity speaks to the size of the learning object. There remains however the question of how to define the size of a learning object. In [23] it is argued that there are two main approaches to measuring granularity. One school of thought called a media-centric approach is that learning object size is determined by the size of the media. A second approach is to use the nature of the content determine the size of the learning object. In [3] a taxonomy of learning objects is proposed based on the notion that granularity ought to be based on LO content complexity. Without a consistent measure of learning object granularity what is considered a *small* learning object in one model and thus system may be considered quite *large* in another. This has significant implications for reuse and interoperability of learning objects[10].

## 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 learning object and what is not, there are several models of learning objects in terms of taxonomies and component architectures. These models are not necessarily compatible with each other thus limiting the level of reuse of learning objects from one institution to another.

## Reusability of extracted LOs

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 learning objects. The challenge is that:

1. A constituent smaller learning object may be highly 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 [4] suggest that a learning object should cover no more than one concept. Other literature such as [14] and [3] define a single learning object in the NETg model to include a learning objective, an activity and an assessment. In this area again the lack of a single approach to handling decomposition affects reuability.

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.

## 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 strenghths and weaknesses of various approaches.

### The Learnativity Content Model

Wagner in [22] 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 [20] 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).

## The CISCO RLO/RIO Model

In [8], CISCO defines a Reusable Learning Object(RLO) as a collection of $7 \pm 2$ 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 1. 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. model places a $7 \pm 2$ 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.

## Aggregation model of the IEEE LOM

The IEEE LTSC has developed a learning object metadata (LOM) standard known as the IEEE LOM [16]. 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. They suggest that there are four learning object aggregation levels.*These aggregation levels also speak to the issue of the content models, which we are examining here.* 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 the largest level of aggregation is made up of level 3 objects or can recursively contain other level 4 objects. In [7], the model is noted as having general and vague aggregation levels because for instance they do not specify or describe explicitly the various aggregation levels. Also we suggest

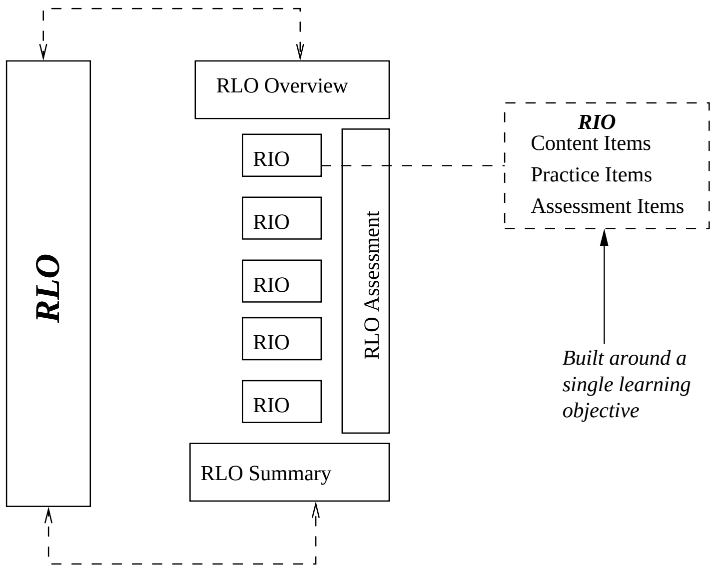



Figure 1: Cisco RLO/RIO Model

as we did with the Learnativity model that greater flexibility and reuse oppurtunity can be achieved if aggregation is acommodated across granularity levels.

## NETg Content Model

Netg (now aquired by SkillSoft) was one of the first to use the learning object concept for its courses [3]. 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[14] and [3]. This model is very well structured and has infact proven to be highly reusable within the context of the Netg environment or other similar environment. 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.

## 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)[2]. 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 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 [17] 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.

## General Learning Object Content Model

Verbert and Duval in [20], 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 [21].

## Taxonomy for Flexible Learning Object Development (TFLOD)

The objective of this model was to present a means by which a higher level of reuse could be facilitated through taking items that would normally be components of an indivisible learning object in other models and making them into separate learning objects. At level 1 where the smallest learning object resides for example we have curriculum items (statement of a single learning objective and the activities and content surrounding this), instructional items (content surrounding a single learning objective), assessment item (assessment surrounding a single learning objective). Collections of these items with other items of the same category give rise to the next larger grained learning object within the category as indicated in table 1. The taxonomy however is intended to allow the develoment of composite learning objects from combinations of learning objects of different categories and of different granularities, which would give rise to types of learning objects that cannot be noted in the table. This way it becomes possible to allow combinations of curriculum items with instructional Units of Instruction or assessment items and therefore some support may be given to various instructional approaches. While this

| ***Granularity Levels*** | ***Curriculum LOs*** | ***Instructional LOs*** | ***Assessment LOs*** |
|---|---|---|---|
| *Level 4* | Course Curriculum | Course Instruction | Course Assessment |
| *Level 3* | Module Curriculum | Module Instruction | Module Assessment |
| *Level 2* | Curriculum Unit | Unit Instruction | Unit Assessment |
| *Level 1* | Curriculum Item | Instructional Item | Assessment Item |

Table 1: Taxonomy for Flexible LO Development (TFLOD)

taxonomy presents some increased flexibility it still very much based on the nature of the environment it was designed for (Caribbean High Schools and undergraduate programs in Caribbean Colleges and Universities) [13].

# 4 A THEORY OF LEARNING OBJECTS

In this section we present a theory of learning objects based on a set of critical defining criteria, which we will discuss in section 4. A theory of learning objects is important 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 need some relatively stable fundamental principles and definitions in the area in order to promote consistent development in the field. An important feature of such a theory is that it be clear enough and specific enough 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. In section 5 we examine how a model called Object Oriented Generic Learning Object Model, *OOGLOM* (a part of this theory) can be used in a practical sense and show using UML, the fact that it offers a means of unification and thus becomes a basis for reusability and interoperability across models.

## The Theory

Our theory of learning objects is summarised in the following points:

- **Learning Object Definition:** A learning object is defined as a digital entity which is designed specifically to **independently** execute or carry out atleast one pedagogic activity (e.g. explain, guide, show, instruct or assess) surrounding one or more learning objective or outcomes. These activities represent different types or categories of learning objects in a model.

- **Learning Object Properties:**

  – *Independence:* A learning object is not *dependent* on any other learning object (or any other content) to realize its activity or activities.

  – *Structure:* In the very general sense a learning object will carry both data and methods in keeping with the concept of object oriented design. The data consists of several items including a metadata object, the content for the learning object, and information on the nature of the learning object such as pedagogical information among other items. The methods include constructor(s) to instantiate the learning object as well as other methods which use the data to carry out the learning activity of the learning object.

  – *Granularity:* The smallest learning object has a size of 1,(atomic learning object) and carries out one single pedagogic activity (e.g. instruction, assessment) surrounding a single learning objective. Larger learning objects 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 of a composite learning object is demonstrated later.

  - *Reusability:* Reusability defines the ability of the learning object to be used again in a different context with little or no modifications made to it. In section 4, we discuss criteria for achieving learning object reusability.

- **Learning Object Classification:**
  - All learning objects are members of a learning object class. *Learning object reuse is therefore enhanced through the use of features of object oriented design such as* ***inheritance, polymorphism, encapsulation*** *and* ***instantiation****.*
  - There are two subclasses of the learning object class. These are the Atomic Learning Object(ALO) class and the Composite Learning Object(CLO) class. Relationship among these three classes is given by the UML diagram in Figure 2 and gives us the model we call OOGLOM.
  - The learning objects of all IS/OS models that meet the reuse criteria stipulated in section 4 are all members of subclasses of either the ALO Class or the CLO Class.

- **Learning Object Organization:** Figure 2 is a UML diagram which illustrates the organization of the learning object classes in our theory. We have, as indicated earlier named this Object Oriented Generic Learning Object Model (OOGLOM). The Diagram illustrates a few of the 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 may be made up of 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 Composite LO it will cause the recursive invocation of all RunLO operations on all LOs included.

- **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

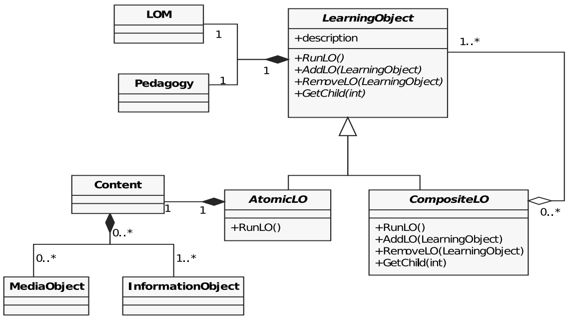



Figure 2: UML diagram of OOGLOM

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 $R$

$L_A$ 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 $l.RunLO()$

The significance of this theory surrounds increasing reusability by:

1. Providing a definition of learning objects that is specific enough to allow us to be able to identify a certain subset of all learning material and classify them in particular as learning objects, as opposed to the very broad definitions given by IEEE LOM [16] as well as the scaled down version given by Wiley [3].

2. Requiring loose coupling. This is enforced by ensuring that any entity that can be used to facilitate learning of one clearly defined concept be designed as a single independent atomic learning object, and that activities such as assessment and instruction be covered in independent learning objects.

3. Requiring strong cohesion. This is enforced by requiring that only one activity surrounding one single learning outcome be covered in an atomic learning object.

4. Introducing principles of object orientation resulting in the ability to utilize features such as inheritance, encapsulation, information hiding and polymorphism which generally increase reusability.

5. Providing a unit of learning object size or granularity, based on pedagogic activity and learning objectives/outcomes. This allows developers to create learning objects that are fine grained (highly reusable) objects that are still meaningful as learning objects.

6. Providing a common model upon which many implementation and organization specific (IS/OS) models may be built.

## Reuse Criteria of the Theory

Our theory of learning objects is grounded in the satisfaction of eight key reuse criteria, necessary for overcoming the challenges discussed in section 2. In this section we discuss these eight criteria which are important for reusability in learning objects. These criteria are satisfied by our theory and thus our model. In table 2 we demonstrate how well these criteria are met by the models discussed in section 3. In the section 5 we will show how these models can each be implemented using our OOGLOM, and therefore improved as they will satisfy the discussed reuse criteria. More importantly the fact that they can each be implemented using OOGLOM implies interoperability across these models, once OOGLOM is used as their base.

### 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 carry out at least one identifiable pedagogical activity e.g. instruct, assess, guide, review etc.,

5. States that entity must be able to *independently* realize its activity or activities.

### Criterion 2: Definition and Measure of LO granularity

The size of a learning object is defined by the number of learning outcomes and/or activities covered by that learning object. This means that a learning object that covers one learning outcome through two activities such as instruction and assessment has a size of 2. On the other hand 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*. 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 others such as IEEE no measure of granularity can be determined.

### 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 outside of the Netg type environment.

### 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 [14], 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. [2] or GLOM [20], which do not prescribe either a specific number of aggregation levels or rules for aggregating different sized learning objects.

### 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.

### 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 and criterion 2.

### 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 activity covering one objective. Within this learning object all material and activity 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.

### 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 [8] and NETg [14] and [12]. 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 [9].

In Table 2, show the eight reuse criteria we have discussed and how well they are met by the seven models we looked at. We can see from the table that Most of the model we discussed do not meet many of the reuse criteria we have examined. These criteria are significant and in that they give assurance of reusability - for example criteria 6 and 7 ensure that each learning object, even at the smallest level

| *Criteria* | *Learnativity* | *Netg* | *CISCO* | *IEEE* | *SCORM* | *GLOM* | *TFLOD* |
|---|---|---|---|---|---|---|---|
| 1 | Y | Y | Y | N | N | Y | Y |
| 2 | L | L | N | N | N | L | Y |
| 3 | N | N | N | N | N | N | Y |
| 4 | N | N | N | N | Y | Y | Y |
| 5 | Y | Y | N | Y | Y | Y | Y |
| 6 | Y | N | Y | UA | N | Y | Y |
| 7 | Y | L | Y | UA | N | Y | Y |
| 8 | Y | L | N | UA | Y | Y | L |

| | |
|---|---|
| Y | Yes |
| N | No |
| L | Limited |
| UA | Unable to Assess |

Table 2: Reuse Criteria and Popular Models

is independently useful and as another example, criteria 4 and 5 ensure flexibility for different instructional approaches. 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 the reuse criteria, while maintaining their own specific features and becoming interoperable with each other due to the common denominator of the OOGLOM atomic LO. 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 [7]

## 5 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 [5], 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 2, 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 3 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.

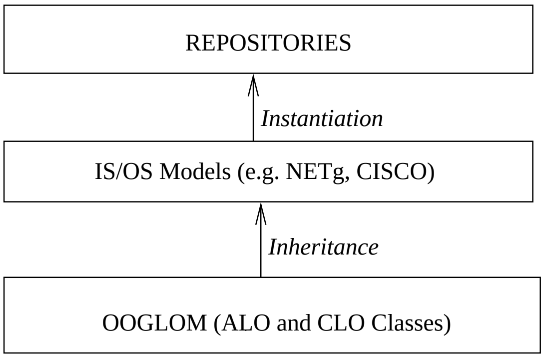



Figure 3: OOGLOM as a base layer for IS/OS models

## Using OOGLOM: Proposed System Design - LODDS

In this section we want to show practically how OOGLOM can be used to develop higher level (IS/OS) learning object models and their related LOs. We do this by walking step by step through the developent of learning objects using the intended system (which we have coined LODDS (Learning Object Development and Deployment System) and finally by illustrating UML designs of the popular models using OOGLOM. The use of OOGLOM is relatively simple and involves several steps for the institution or developer wishing to develop learning objects for a repository:

- STEP 1 - Specify IS/OS Model

1. Specify Organisation or Institution Name
2. If the model is already defined in the system select it otherwise it will need to be created as specified below:
   (a) Specify Categories or Types (these types correspond with pedagogical activities) of Atomic Learning Objects and Composite Learning Objects in your model. *Example CISCO will have assessment items and practice items which would be subclasses of the ALO class.*
   (b) Provide a definition for each of these Categories or Types of Atomic Learning Objects and Composite Learning Objects.
   (c) Provide any rules or criteria for the aggregation of Learning Objects in the model. Example CISCO's model would require that between 5 and 9 RIOs can be combined to give a RLO. This would be specified using a simple, easy to use graphical user interface. *By default the system will allow any number of ALOs and any number of CLOs to be combined, with no restrictions on order etc.*

- STEP 2 - Create Learning Objects through authoring from scratch at the ALO level and authoring through aggregation at the CLO level. The development environment would of course use terms other than ALO based on the model information provided at STEP 1. *Learning object content is always in ALOs and never directly in a CLO. The content of a CLO is actually a sequence of LOs.*

- STEP 3 - Examine automatically generated LOM object and make additions or changes where necessary.

- STEP 4 - Save LO to repository.

This simplified algorithm is used to illustrate mainly how a developer would interact with the system. The facility which allows the specification of an IS/OS model but which transparently utilizes OOGLOM to do so is one of the most powerful aspects of our solution, because we increase reuse by enforcing certain criteria through object orientation without taking away the specificity of the IS/OS model. This also ensures that at the most fundamental level (the ALO level), learning objects developed using this approach will be highly interoperable with each other independent of their original IS/OS model. The system is to be designed as a simple web based client-server system named *Learning Object Development and Deployment System* (LODDS). The system may be deployed across the Internet or an organization intranet. The server side is to be supported by a database to store learning objects developed for the implementing organisation. Set up of the server is done via web Interface. On the client-side the interface is also web based and can be accessed using a web browser. As illutrated in figure 4, there are four(4) user roles anticipated for the system.

- **Administrator** - The Administrator is responsible for initial setup and continuous maintenance of the system. This includes setting up and maintaining users and permissions, IS/OS models and vocabularies to be used by the system. The Administrator is responsible for the certification process of all LOs in the repository.

- **LO Author** - The LO Author is responsible for creating Atomic Learning Objects in particular, and possibly assembling CLOs. It is imagined that these LOs will be created in collaboration with the educators, curriculum developers and/or facilitators involved. These LOs are created using an interface called the *Creation Palette* and saved in the organization's repository.

- **Facilitator** - The Facilitator is responsible for facilitating learning experiences and will, based on a variety of considerations assemble CLOs to form intended learning experiences. These could be classes, courses or lessons dependent both on the model being used and the organizational approach. The CLOs are created using an *Assembly Palette*

- **Student** - Students utilize a graphical interface called an *LO Viewer* for viewing LOs.

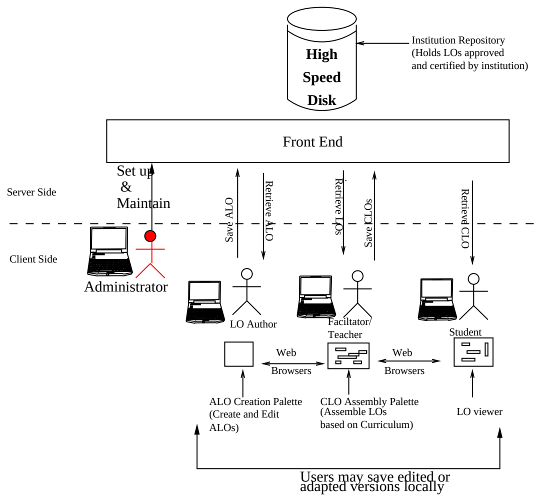
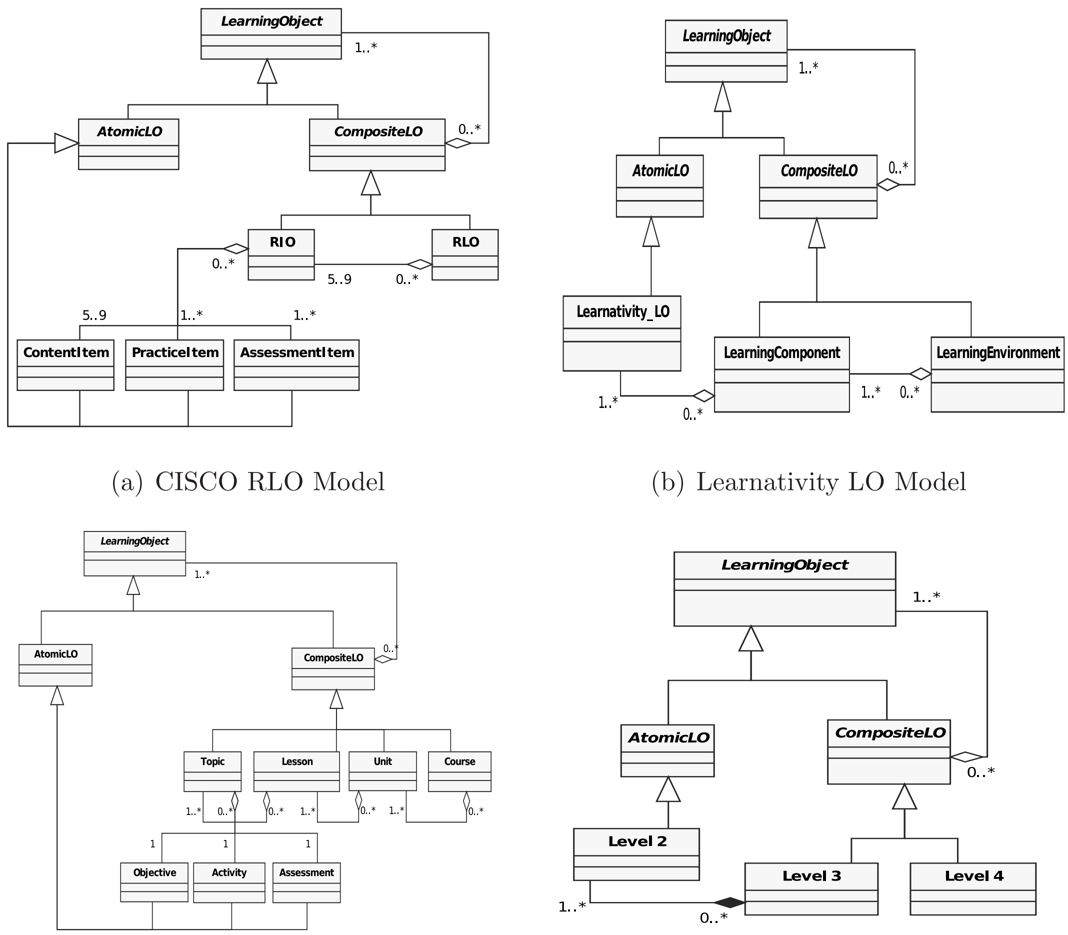



Figure 4: Learning Object Development and Deployment System (LODDS)

## 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 atomic learning objects. This is necessary to meet the criteria discussed in section 4.




(a) CISCO RLO Model

(b) Learnativity LO Model

(c) Netg LO Model

(d) IEEE Aggregation Model

Figure 5: Four IS/OS Models using OOGLOM

## 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 objectcould 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 our LODDS 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.

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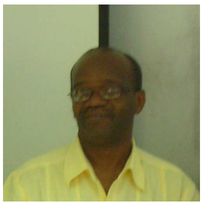

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