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A Workflow for Learning Objects Lifecycle and Reuse: Towards Evaluating Cost Effective Reuse

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ABSTRACT

Over the last decade Learning Objects (LOs) have gained a lot of attention as a common format for developing and sharing digital educational content in the field of technology-enhanced learning. The main advantage of LOs is considered to be their potential for component-based reuse in different learning settings supporting different learning activities. However, despite the importance of the concept of reuse and its potential benefits in digital educational content production and deployment, there are only sporadic efforts to study issues related to LOs reuse that would allow interested parties (such as people, organizations and initiatives) to assess the conditions for and eventually implement systematic LOs reuse within the context of learning activities design and development. This is a drawback in adopting the LOs paradigm towards reducing costs and effort. In this paper, we study existing efforts for the definition of the different steps involved during the LOs lifecycle, we identify the aspects of LOs reuse within the context of learning activities design and development, we propose a thorough workflow for LOs lifecycle that can support LOs reuse and enable us to define a set of metrics for cost effective LOs reuse, and discuss the cost effectiveness conditions in various use cases.

Keywords

Learning object, learning objects lifecycle, reuse workflow, cost metrics, cost effectiveness.

Introduction

Over the last decade Learning Objects (LOs) have gained a lot of attention as a common format for developing and sharing digital educational content in the field of technology-enhanced learning. Within the rich literature related to LOs, the issue of reuse appears to be an important one (Wiley, 2002; Polsani, 2003; McGreal, 2004; Caswell et al., 2008). This is mainly due to the fact that design and deployment process of high quality educational resources is very expensive, and therefore, any effort to reduce development costs is highly desirable (Zimmermann et al., 2006). However, despite the importance of the concept of reuse and its potential benefits in educational content production and deployment, there are only sporadic efforts to study issues related to LOs reuse that would allow interested parties (such as people, organizations and initiatives) to assess the conditions and eventually implement systematic LOs reuse within the context of learning activities design and development. This is a drawback towards the large scale adoption of the LOs paradigm aiming at reducing costs and effort.

In this paper, we study existing efforts for the definition of the different steps involved during the LOs lifecycle that can support LOs reuse and we identify their limitations. Based on the discussion of existing proposals, we propose a thorough workflow for LOs lifecycle that can support LOs reuse within the context of learning activities design and development. Finally, we use the proposed LOs lifecycle workflow to define a set of metrics so as to measure the cost effectiveness of LOs reuse and we extract recommendations that can facilitate interested parties to take more informed decisions about the potential benefits of LOs reuse.

Learning Objects Lifecycle and Reuse

What is Learning Objects Reuse?

The main arguments in favor of LOs reuse are twofold. On one hand, LO reuse is highlighted due to the anticipation of cost reductions in the design and development of educational resources while maintaining quality. This is based on the assumption that the more times a LO is reused in different learning settings the more cost effective that LO becomes. On the other hand, LO reuse can be an indicator for a high quality education resource. This is under the assumption that the more a LO is reused the more likely it is to be of high quality as more teachers and/or learners will have the opportunity to interact with it and provide feedback on its use and quality. However, despite the importance of the concept of LOs reuse, the technology-enhanced learning (TeL) community has not agreed to a

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commonly accepted definition of the term 'reuse' resulting to multiple interpretations. The concept of LOs reuse, just as the concept of LOs, is presented in LOs literature in different ways as shown in Table 1.

Table 1. LOs Reuse Definitions

Authors	Definitions
Wiley (2002, p. 12)	*"LOs can be used over and over again in similar contexts or in domains other than those for which they were designed".*
Polsani (2003, p. 4)	*"A LO is predisposed to be reused in multiple instructional contexts".*
Palmer & Richardson (2004, p. 5)	*"Reuse is the extent to which a LO can operate effectively for a variety of users in a variety of learning contexts over time in order to achieve the same or a different objective from that envisaged by its supplier".*
Rensing et al. (2005, p. 4), Zimmermann et al. (2007, p. 49)	*"Reuse of LOs is any kind of use of existing LOs which are already used in a certain context for teaching or learning by trainers or learners in a new context to serve the same or a new purpose".*
Colossus (2005, p. 1)	*"To reuse the LO with a different group of learners for which the LO was originally created".*
Van Assche & Vouorikari (2006, p. 451)	*"Reuse is effective to the extent that a learning resource or any part of it can be fit into another learning resource or in another context for learning".*

Hence, based on the above definitions, we can conclude that the ability to reuse LOs includes the ability to reuse them in a different learning context and/or for a different targeted group and/or for the attainment of a different learning objective and/or for a different subject matter. Thus, one can note that the dimensions that affect the potential for LOs reuse are similar with the characteristics that define a learning activity (Beetham, 2007; Conole and Fill, 2005). According to Beetham (2007) a *learning activity* is a specific interaction of learner(s) with other(s) and with an environment (optionally involving resources, tools and services) that is carried out in response to a task orientated towards specific learning outcomes. Furthermore, according to Conole & Fill (2005) there are three (3) dimensions that constitute a learning activity:

- **The context** within which the activity occurs, this includes the subject matter (i.e., physics, geography, math, arts, etc.), the level of difficulty, the intended learning outcomes (i.e., recall, understand, etc.) and the environment within which the activity takes place (i.e., computer-based, lab-based, etc.).
- **The pedagogical approach** adopted (i.e., problem based learning, inquiry based learning, etc.)
- **The tasks** undertaken to achieve the intended learning outcomes. Tasks can be described by the type of task (i.e., reading, writing, viewing, etc.), the techniques used (i.e., presenting, discussing, arguing, etc.), associated tools and resources (i.e., computer, software, mobile devices, etc.), the interaction (i.e., class based, group based, etc.) and roles (teacher, learner, group leader, etc.) of those involved and the assessments (i.e., formative, summative) associated with the learning activity (Falconer et al, 2006).

Based on the above discussion and assuming that the pedagogical approach adopted can be considered as part of the context within which the activity occurs (Conole, 2007; Bailey et al., 2006; Weitl et al., 2004), in this paper we adopt the following definition for the concept of LO reuse: "Learning object reuse can be defined as the extent to which a Learning Object can be used in different digital or non digital learning activities, where a learning activity is defined as the interaction of learner(s) with other(s) and with a learning environment, which emerges as a result of performing a task within a particular learning context in order to achieve one or more learning objectives" (Sampson & Papanikou, 2009, p. 34)

Learning Objects Lifecycle

In order to study the process of LOs reuse, we need study the LOs lifecycle. In the literature there are some works that attempt to define the steps involved in the LOs lifecycle (Rensing et al., 2005; Collis & Strijker, 2004; Van Assche & Vuorikari, 2006). Most works study the LOs lifecycle in relation to the design and development of Learning Object Repositories (LOR). McGreal (2004) has defined LORs as systems that "enable users to locate, evaluate and manage learning objects through the use of "metadata", namely descriptors or tags that systematically describe many aspects of a given learning object, from its technical to its pedagogical characteristics" (p. 3). First, Collis & Strijker (2004) argue that a LO can pass through six (6) different steps (following one another) during its lifecycle:

- **Obtaining**: the first step of the lifecycle is obtaining or creating a LO.
- **Labeling**: the LO created in the previous step is described with educational metadata.
- **Offering**: the LO is offered in a LOR so that other people can find it and retrieve it.
- **Selecting**: a user searches and selects from a LOR the LO that will suit the new needs.
- **Using**: after a LO is selected, it can be used either as it is in a new environment or modified in order to match the needs of the new environment within which the LO will be used.
- **Retaining**: after the use of the LO there are three possible choices, namely, the future use of the LO, its revision or its retraction from the LOR.

There are two main weaknesses in this proposal. First, in order for individual users to make use of existing LOs, they must be able to efficiently search for LOs and then evaluate the LOs returned as a result of that search, as to whether or not they are appropriate to be reused for meeting their specific expectations (Campbell, 2003). For that reason, in our work we propose that the step of "Selecting" should be explicitly identified as separate steps, namely, searching for appropriate LOs and selection of the most appropriate ones. Second, this proposal does not take into consideration the possibility of disaggregating a LO into its constituent parts and the selection of those suitable parts for the new learning activity (Colossus, 2005; Weitl et al., 2004). Therefore, if a LO is not reused in a learning activity as it is, then, two (2) more steps may be required, that is the modification and/or the aggregation with other LOs.

Another attempt to define the steps implemented in the LOs lifecycle was made by Rensing et al (2005) where the step of "Using" in (Collis & Strijker, 2004) is further analyzed. Considering both re-use (defined by Rensing et al (2005) as, any kind of use of existing LO, which are already used in a certain learning or teaching context) and re-purposing (defined by Rensing et al., 2005) as, the modification of the LO in a way that suits a new learning or teaching context, which differs from the learning or teaching context that the LO was created for) this proposal identifies the extra steps of:

- **Modularization** of the LO, that is splitting the LO into several smaller LOs and selecting the appropriate ones.
- **Adaptation** of the LO, namely the modification of the LO with regard to at least one of its aspects (defined by Rensing et al (2005) as language, layout or terminology) to make it fit to a new learning or teaching context.
- **Aggregation** of the LO with other LOs to create a new one.

However, this proposal does not take into consideration issues that have important influence in time and cost of development, such as the selection of the appropriate LOs, the description of the LOs derived from the reuse process with metadata and the integration of the LO into the new learning or teaching context (Van Assche & Vuorikari, 2006).

The most complete effort for the explicit definition of the steps involved in the LOs lifecycle was made by Van Assche & Vuorikari (2006). The authors describe the LOs reuse in relation to a LO quality management policy and compared to the other two proposals, they add the following steps in the process of LOs lifecycle:

- **Approve**, where a LO before published in a LOR is reviewed (i.e., peer review) in order to ensure its high quality
- **Evaluate** that includes the criteria based on which the selection of suitable LOs for reuse is made
- **Integrate** that includes the technical (i.e., integration in a LMS) and/or pedagogical integration (expressed as the reshuffling the sequence of LOs in their proposal) of the LO into a new learning or teaching context.

Also, Van Assche & Vuorikari (2006) present the step of "Repurpose & Reuse" where the transformation of the LO takes place so that it can be reused in a new learning or teaching context. They argue that in this step the following actions may occur:

- **Disaggregation** of the LO into its constituent parts.
- **Aggregation** of the LO with other LOs.
- **Modification** of the LO content and/or of the sequence of the constituent parts of the LO.

Yet, in literature we can find more modification types that can be applied to a LO. These are divided into three (3) main dimensions (Zimmermann et al., 2006; Colossus, 2005; Duval & Hodgins, 2003):

- **Modifications to the LO layout/appearance**, when different LOs are combined to create a new LO, then modifications to LO appearance are needed or when different accessibility needs are addressed (i.e., people with

disabilities) then modifications to the display of the content is needed (i.e., white font and black background, so as to be accessible from low vision people)

- **Modifications to the LO content**, when different languages or terminology are addressed or when the sequence of the constituent parts of the LO is modified.
- **Modifications to the LO technical format** when different content delivery media and/or technology is addressed (i.e., mobile devices)

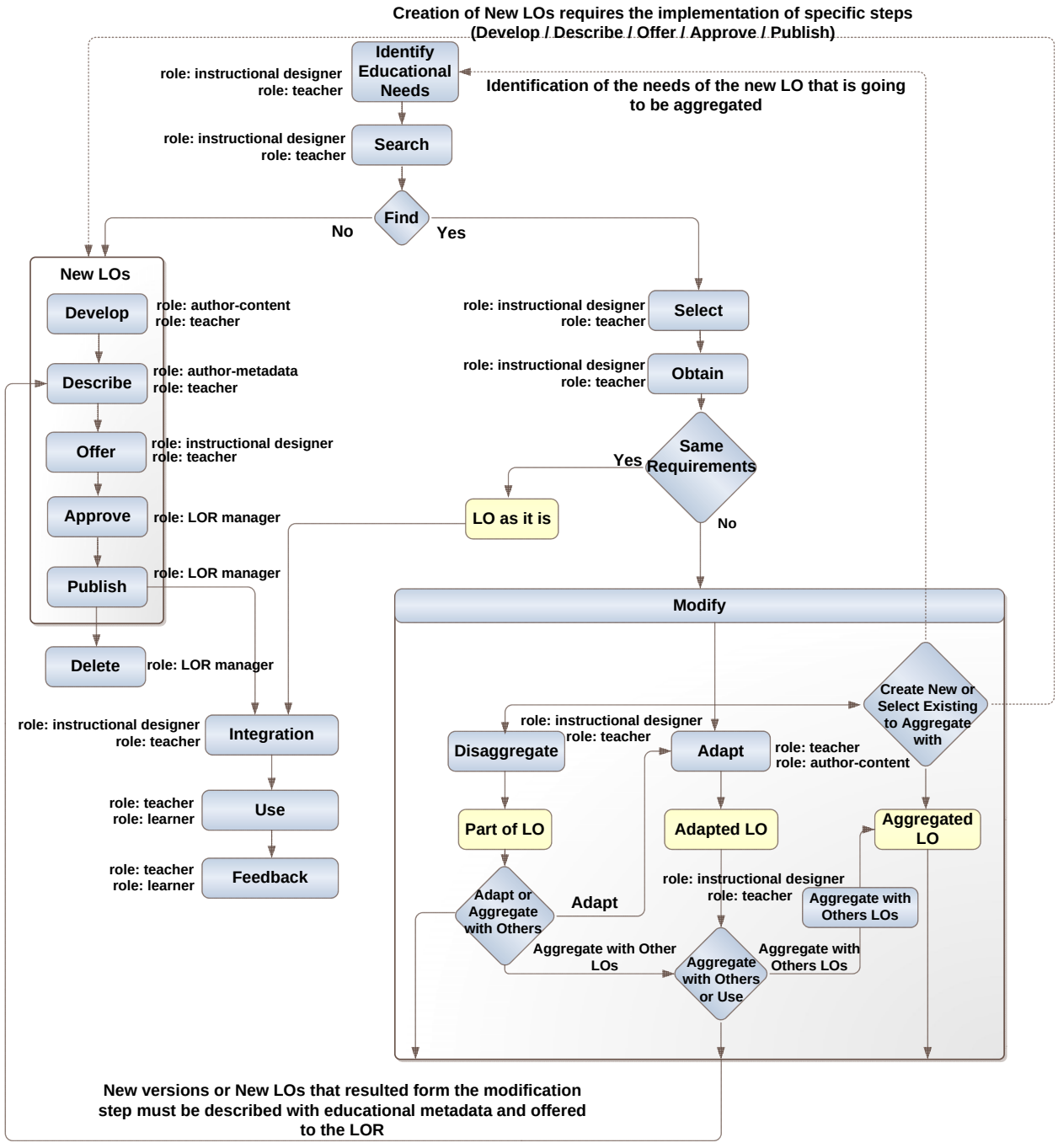

Figure 1. Learning Objects Lifecycle Workflow

Furthermore, none of the above approaches include in the LOs lifecycle the identification of needs that will lead to the selection of an appropriate LO or, if an appropriate LO does not exist, to the development of a new one. Identification of needs and intended learning outcomes are the first factors that influence the LO development

process (Palmer & Richardson, 2004). Finally, another important step not mentioned in the above approaches that encourages the LOs reuse in different learning or teaching contexts, is the step of LOs feedback. Feedback is defined as the process in which teachers and/or learners provide their advices/comments and/or ratings to a specific LO related to its use and quality (Weitl et al., 2004; Currier et al., 2004). Feedback is needed to support LO selection and maintain quality control. The feedback step could be integrated into the step of a LO's metadata characterization. However, it may include components such as rating that cannot be integrated in any of the IEEE LOM (IEEE LTSC, 2002) elements, so it is suggested to comprise an individual step.

Proposed Workflow for Learning Objects Lifecycle

Based on the discussion of existing proposals presented in the previous section, we propose a thorough workflow (including roles and their related functions) for LOs lifecycle in which LOs reuse is examined from the perspective of learning activities design and development. The proposed workflow assumes that the learning activities of an educational scenario have been already designed; we then begin with the phase of population learning activities with LOs. The participating roles in the workflow are the following:

- **Teachers**: Their role is twofold. On the one hand, they can develop new LOs to supports their learning activities, possibly describe them with educational metadata and offer them to a LOR for future use by other users. On the other hand, they can re-use existing LOs (by applying modifications or not) to support learning activities towards the attainment of specific learning objectives.
- **Authors**: One can identify two (2) categories of authors, namely, the authors of educational content (role: author-content) and the authors of educational metadata (role: author-metadata). The authors of educational content (role: author-content) are responsible for the development of educational content in the form of LOs, ensuring that the produced LOs correspond to the learning objectives that were defined by the instructional designer. Authors may consist of sub-entities such as: (a) subject experts, who are responsible for developing learning content on a specific subject (i.e., astronomy, mathematics, biology), (b) graphic designers, who are responsible for developing the graphical elements of a LO, as well as, its look and feel and (c) technical developers, who make use of specific software tools in order to implement the desirable level of interaction among the LO and its user. The authors of educational metadata (role: author-metadata) are responsible for characterizing LOs with educational metadata.
- **Instructional Designers**: They define learning objectives and they design appropriate learning activities that will lead to the accomplishment of these objectives. They are responsible for designing and/or selecting appropriate LOs that will support the learning activities they wish to implement. Moreover, they facilitate authors to create and/or adapt LOs by providing advices regarding the instructional design of the LO, they can support the authors of metadata to describe LOs with educational metadata and they offer them to the LOR.
- **LOR Managers:** They are responsible for the LOR's policy, such as rights, terms of use and quality mechanisms. They approve and publish LOs to the LOR offered by the teachers and/or instructional designers. Finally, they are responsible for the possible retraction of LOs from the LOR.
- **Learners**: They are the final users of the LOs and the main participants in the learning activities. They also provide their feedback related to the use and quality of the LOs.

The functions that the proposed workflow includes are described below:

- **Identify Educational Needs:** The first function of the proposed workflow is the identification of educational needs. During this function the "role:instructional designers" or the "role:teachers" define the requirements that a LO must fulfill in order to be successfully used to support the learning activity they wish to implement. Therefore, the result of this function must be the explicit definition of the dimensions of the learning activity (as they have been defined in previous section) in which the LO will be used.
- **Search:** Before a LO is developed from scratch the "role:instructional designers" or the "role:teachers" searches the LOR (this can be one LOR or a federation of LORs) to examine if there is one or more existing LOs that fully or partly fulfill the requirements of the new learning activity (as defined in the previous function) and, therefore, they can be reused to a certain extent. Searching in a LOR includes searching based on criteria (fill in text fields or select a value from a vocabulary) that correspond to certain metadata elements and the return of one or more results which fulfill the search criteria. The result of this function is not a LO, but one or more metadata records that correspond to the search criteria. If the search results do not return a LO that fulfill these requirements, then the "role:instructional designers" can inform the "role:authors-content" to proceed to the

function of “Develop” a new LO. Alternatively, the “role:teachers” can proceed to the function of “Develop” a new LO. Otherwise, the “role:instructional designers” or the “role:teachers” proceed to the function of “Select”.

- **Develop**: At this function the “role:authors-content” or the “role:teachers” develop a new LO to support the learning activity with the requirements defined by the roles that participate to the function “Identify Educational Needs”.
- **Describe**: At this function the LO developed in the previous function is described with educational metadata following either IEEE LOM or an application profile created to serve specific needs. The “role:authors-metadata” characterize with educational metadata the LO developed by the “role:authors-content” or the “role:teachers” characterize with educational metadata the LO that they have developed during the previous function.
- **Offer**: The LO that has been already described with metadata in the previous function is offered to the LOR by the “role:instructional designers” or the “role:teachers”, so that other users can use it.
- **Approve**: Before a LO is published to the LOR and made available to its users, it may be reviewed (according to the LOR policy) by the “role:LOR managers”(i.e., peer review) in order to ensure its quality.
- **Publish**: Since a LO has been described with educational metadata and considered to be suitable for use, it can be made available (with or without usage restrictions or cost) by the “role:LOR managers” to other users of the LOR.
- **Select**: The “role:instructional designers” or the “role:teachers” in this function should evaluate the LOs returned as a result of the function “Search” in order to select the one that satisfies to a certain extent the requirements of their learning activity. The fundamental criterion that should affect the decision of LO selection must be the requirements defined in the function “Identify Educational Needs”. If a LO fulfills those requirements, then it can be reused as it is. Otherwise the LO must be modified in order to meet the specific requirements of the learning activity in hand. Other criteria that influence the decision of LO selection are comments made by other roles (role:learners and/or role:teachers), evaluations (i.e., peer review) of the LO or number of users downloaded the LO. A LO selection may be also based on copyright restrictions or cost.
- **Obtain**: Since the appropriate LO has been selected, the “role:instructional designers” or the “role:teachers” can obtain it. This sometimes requires usage permission by the owner of the LO or payment. Provided that LO fulfills the requirements of the new learning activity at the function of “Select”, then the “role:instructional designers” or the “role:teachers” can reuse the LO directly after integrating it into their learning activity. Otherwise they must go the function of “Modify”.
- **Modify**: Often, direct reuse of a LO is not feasible because it does not match the requirements of the learning activity that it will be used, as a result the following sub-functions may occur:
    - *Disaggregate*: In this sub-function, the “role:instructional designers” or the “role:teachers” decompose the LO into its constituent parts and those parts that match the requirements of the new learning activity are identified. The disaggregated LO constitutes a new LO. However, this LO may not be suitable as it is to cover completely the requirements of the new learning activity. Therefore the “role:instructional designers” should inform the “role:authors-content” to proceed to the function of “Adapt” an existing LO. Alternatively, the “role:teachers” can proceed to the function of “Adapt” an existing LO.
    - *Adapt*: In this sub- function, the “role:authors-content” or the “role:teachers” modify the LO, so as to fit to the requirements of the new learning activity. Adaptations may occur in the three (3) different dimensions that were defined in the previous section, namely, adaptations to the LO layout/appearance, adaptations to the LO content and adaptations to the LO technical format.
    - *Aggregate with other LOs*: In this sub-function, the “role:instructional designers” or the “role:teachers” aggregate the LO with other(s) LO(s) and thus a new LO is created. The LOs used for aggregation may result from the selection through the LOR or may be new LOs developed from scratch. When existing LOs are used, then their disaggregation or adaptation may be required.
- **Integrate**: At this function the “role:instructional designers” or the “role:teachers” integrate the LO into the environment that supports the learning activity in hand.
- **Use**: At this function the LO is used in a specific learning activity by the “role:learners” and/or the “role:teachers” towards the attainment of specific learning objectives.
- **Feedback**: In order for the LOs to be retrieved and used effectively in different learning activities more information are required about how they were used in practice, beyond the information derived by their educational metadata records provided by the “role:authors-metadata” or the “role:teacher”. A number of techniques are used in order for “role:learners” and/or “role:teachers” to provide feedback in the LOs of a LOR. The most commonly used techniques are comments (referring to the context of use of the LO and its usefulness)

and ratings (the use of star ratings and/or hit counters that illustrate the number of downloads of a certain LO give a good indication of users' impression about the LO) (Gehringer et al., 2007; Kay & Knaack, 2007)

- **Delete**: The "role:LOR managers", who are responsible for publishing a LO may decide that the LO must be retracted and, therefore, removed from the LOR, under certain circumstances.

Metrics for Cost Effectiveness of LOs Reuse

In this section, we use the proposed workflow of LOs lifecycle, so as to define metrics for cost effective LOs reuse, which can facilitate interested parties (people, organizations and initiatives) to assess the cost for systematic LOs reuse. Despite the importance of the concept of LOs reuse and its potential benefits, it seems that there are not proposed metrics for measuring the cost of LOs reuse, so as to enable us to perform a cost-benefit analysis. For this purpose, we propose to identify and adapt relevant cost metrics as in the field of software engineering.

Related Work

In the field of software engineering, reuse is considered as a very important factor for productivity and quality of software systems. As a result, a number of methods have been developed to measure the cost effectiveness of software code reuse (Frakes & Terry, 1996). Component-based Software Development (CBSD) is commonly accepted as a cost effective approach, as it emphasizes on the creation of software systems using reusable components (Washizaki et al., 2003). However, although software components reuse promises reduction in the development cost and time, as well as benefits in productivity and quality, its application in practice does not necessary ensure that these benefits can be achieved. Therefore, appropriate metrics and models have been proposed as tools to measure and assess the impact of reuse (Hafefh et al., 2002).

Within this context, Poulin et al. (1993) described a set of cost metrics for software components re-use used by the IBM company (http://www.ibm.com) that are the most commonly used mainly because they are simple to understand and easy to calculate during the software development process (Mascena et al., 2005). Theis main cost metrics are:

- **Relative Cost of Reuse (RCR)**, which is defined as the cost for reusing a software component divided by the cost normally incurred to develop it for one-time use,
- **Relative Cost of Writing Reusable Software (RCWR),** which is defined as the cost for developing a reusable software component divided by the cost of developing it for one-time use.

These metrics can be used as input in a return on investment model (ROI), upon which managers may rely their business decisions.

In the TeL literature, there are some works that have applied metrics from the software engineering field for the purpose of measuring the potential reusability of learning objects. Cuadrado & Sicilia (2005) explores the possibility of using existing object oriented design metrics proposed by Chidamber & Kemerer (1994) and adapting them to the LO domain, so as to measure the complexity of individual LOs internal structure and consequently assess their potential reusability. Cervera et al (2009) have also adapted these metrics in their study to measure potential reusability and quality of individual LOs by means of correlation between these metrics and their metadata. Finally, Mat Noor et al (2009) applied the metrics proposed by Cuadrado & Sicilia (2005), so as to measure the potential reusability of individual LOs selected from existing LORs (such as MERLOT and SMETE). However, these works assess only the potential reusability of individual LOs and they do not propose metrics for measuring whether the process of LOs reuse is cost effective in practice. In order to achieve that, we should be able to perform a cost-benefit analysis within a well-defined workflow of the LOs lifecycle (this has been defined in previous section), where cost variables can be assigned for each function of the workflow and metrics for cost effective LOs reuse can be defined.

Proposed Metrics

In this section, we assign cost variables that correspond to all different functions of the proposed workflow of LOs lifecycle, so as a cost-benefit analysis to be feasible. Table 2 presents these variables.

Table 2. Identified Costs of the Proposed LOs lifecycle Workflow

LOs Lifecycle Workflow Functions	Cost Variable
Identification of Educational Needs	C_{needs}
Search	C_{search}
Selection	C_{select}
Obtain	C_{obtain}
Disaggregation	$C_{disaggregate}$
Adaptation	C_{adapt}
Aggregation with Other	$C_{aggregate}$
Integration	$C_{integrate}$
Feedback	$C_{feedback}$
Description	$C_{metadata}$
Offer	C_{offer}
Approval	$C_{approve}$
Publish	$C_{publish}$
Development	$C_{develop}$

Next, we present a set of metrics that can facilitate measuring the cost effectiveness of LOs reuse.

Cost to Create a Single Non-Reusable LO (C2CNRLO)
This metric is defined as the cost needed to develop a non-reusable LO from scratch. According to the proposed LOs lifecycle workflow, the functions that are needed to develop a single non-reusable LO are: a) identify educational needs, b) develop, c) integrate and d) feedback. As a result, C2CNRLO metric can be calculated using the following formula:

$$C2CNRLO = C_{needs} + C_{develop} + C_{integrate} + C_{feedback}$$

Additional Cost for Reusable LO (ADC4RLO)
This metric is defined as the additional cost needed to create a reusable LO. According to the proposed LOs lifecycle workflow, the additional functions that are needed to develop a reusable LO are: a) describe, b) offer, c) approve and d) publish. As a result, ADC4RLO metric can be calculated using the following formula:

$$ADC4RLO = C_{metadata} + C_{offer} + C_{apporve} + C_{publish}$$

We should mention here that ADC4RLO takes its maximum value if the particular LO is reused only once. Provided that the particular LO is frequently re-used, then ADC4RLO could be reduced to practically zero

Cost to Create a Single Reusable LO (C2CRLO)
This metric is defined as the cost needed to create a reusable LO from scratch. According to the proposed LOs lifecycle workflow, the cost needed to create a reusable LO (C2CRLO), includes the cost needed to create a non-reusable LO (C2CNRLO), as well as the additional cost needed to create a reusable LO (ADC4RLO). As a result, C2CRLO metric can be calculated using the following formula:

$$C2CRLO = C2CNRLO + ADC4RLO$$

Cost to Create a Sequence of LOs within a new Learning Activity (C2CLO)
This metric is defined as the cost needed to create from scratch non-reusable LOs (C2CNRLO) and/or reusable LOs (C2CRLO) for the needs of a new learning activity. This metric can be calculated as follows:

$$C2CLO = \sum_{i=1}^{K1} C2CNRLO_i + \sum_{i-1}^{K2} C2CRLO_i$$

Where:

- (K_1) is the number of non-reusable LOs developed for the purpose of the new learning activity
- (K_2) is the number of reusable LOs developed for the purpose of the new learning activity

Cost to Reuse a Single LO within a new Learning Activity (C2RLO)
This metric is defined as the cost needed to reuse a LO (with or without modifications). According to the proposed LOs lifecycle workflow, we should examine two (2) cases:

- *Cost to reuse a LO without modifications in the new learning activity ($C2RLO_{AsIs}$)*: when a LO is reused without modifications in a new learning activity, then the functions that are implemented based on the proposed LOs lifecycle workflow are the following: a) identify educational needs, b) search, c) select, d) obtain, e) integrate and f) feedback. As a result, $C2RLO_{AsIs}$ metric can be calculated using the following formula:

  $$C2RLO_{AsIs} = C_{needs} + C_{search} + C_{select} + C_{obtain} + C_{integrate} + C_{feedback} = (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain}$$

- *Cost to reuse a LO after modifications in the new learning activity ($C2RLO_{modify}$):* when a LO is reused after modifications in a new learning activity, then the functions that are implemented based on the proposed LOs lifecycle workflow are the following: a) identify educational needs, b) search, c) select, d) obtain e) disaggregate f) adapt, g) aggregate with others, h) describe, i) offer, j) approve, k) publish, l) integrate and m) feedback,. In this case except the additional functions (in relation to the case of reusing a LO without modifications) that may emerge due to LO modification (namely, disaggregate, adapt, aggregate with other LOs), the functions of description, offer, approval and publish to the LOR have been added, since it is most likely that a modified LO needs to have its educational metadata updated and it must be offered to the LOR as a new LO in order to be available to other users. Consequently, within the context of calculating the Cost to Reuse a LO after modifications, we should examine three complementary (3) cases:
  - Cost to reuse after disaggregation ($C2RLO_{disaggregate}$): this metric can be calculated using the following formula:

    $$C2RLO_{disaggregate} = C_{needs} + C_{search} + C_{select} + C_{obtain} + C_{disaggregate} + C_{metadata} + C_{offer} + C_{apporve} + C_{publish} + C_{integrate} + C_{feedback} = (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain} + C_{disaggregate}$$

  - Cost to reuse after adaptation ($C2RLO_{adapt}$): this metric can be calculated using the following formula:

    $$C2RLO_{adapt} = C_{needs} + C_{search} + C_{select} + C_{obtain} + C_{adapt} + C_{metadata} + C_{offer} + C_{apporve} + C_{publish} + C_{integrate} + C_{feedback} = (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain} + C_{adapt}$$

  - Cost to reuse after aggregation with other LOs ($C2RLO_{aggregate}$): this metric can be calculated using the following formula:

    $$C2RLO_{aggregate} = C_{needs} + C_{search} + C_{select} + C_{obtain} + C_{aggregate} + C_{metadata} + C_{offer} + C_{apporve} + C_{publish} + C_{integrate} + C_{feedback} = (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain} + C_{aggregate}$$

As a result, the cost to reuse a a single LO within a new learning activity could be equal to the following minimum and maximum values:

$$C2RLO = \begin{cases} (min)\ (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain} = C2RLO_{AsIs} \\ (max)\ (C2CRLO - C_{develop}) + C_{search} + C_{select} + C_{obtain} + (C_{aggregate} + C_{disaggregate} + C_{adapt}) = C2RLO_{modify} \end{cases}$$

The total cost of reusing LOs in a new learning activity can be calculated as follows:

$$C2RLO = \sum_{i=1}^{M1} C2RLO_{AsIs\ LOi} + \sum_{i=1}^{M2} C2RLO_{modify\ LOi}$$

Where:

- (M_1) is the number of LOs reused without modifications for the purpose of the new learning activity
- (M2) is the number of LOs reused after modifications for the purpose of the new learning activity

Cost Benefit due to Reuse LO (CB2RLO)
This metric is defined as the total cost benefit that derives from the total cost of creating a sequence of non-reusable LOs and/or reusable LOs minus the cost of reusing LOs (with or without modifications) for the same learning activity. As a result, CB2RLO metric can be calculated using the following formula:

$$CB2RLO = C2CLO - C2RLO$$

Discussion

Based on the proposed metrics for measuring the cost effectiveness of LOs reuse, we can discuss the conditions of different cases, in which LOs reuse can be considered as cost effective. For this purpose, we examine the Cost Benefit due to Reuse (CB2RLO) metric, which should have a positive value, so as to consider that the LOs reuse is cost effective. This means that the following formula should be valid:

$$CB2RLO = C2CLO - C2RLO > 0 \Rightarrow C2CLO > C2RLO \Rightarrow$$

$$\sum_{i=1}^{K1} C2CNRLO_i + \sum_{i-1}^{K2} C2CRLO_i > \sum_{i=1}^{M1} C2RLO_{AsIs\,LOi} + \sum_{i=1}^{M2} C2RLO_{modify\,LOi} \quad (1)$$

Assuming that: $K_1+K_2 = M_1+M_2$

From the above formula, we can consider the following four (4) cases:

1. *The learning activity can be designed with non-reusable LOs that are developed from scratch or by reusing LOs without any modification:* for this case, formula (1) is transformed as follows:

   $\sum_{i=1}^{K} C2CNRLO_i > \sum_{i=1}^{K} C2RLO_{AsIs\,LOi}$. By analyzing this formula, we get the following result:

   $$\sum_{i=1}^{K} C_{develop} > \sum_{i=1}^{K} (C_{search} + C_{select} + C_{obtain}) .$$

2. *The learning activity can be designed with non-reusable LOs that are developed from scratch or by reusing LOs which have been all modified:* for this case, formula (1) is transformed as follows:

   $\sum_{i=1}^{K} C2CNRLO_i > \sum_{i=1}^{K} C2RLO_{modify\,LOi}$. By analyzing this formula, we get the following result:

   $$\sum_{i=1}^{K} C_{develop} > \sum_{i=1}^{K} (C_{search} + C_{select} + C_{obtain} + C_{disagregate} + C_{aggregate} + C_{adapt} + ADC4RLO) .$$

3. *The learning activity can be designed with reusable LOs that are developed from scratch or by reusing LOs without any modification:* for this case, formula (1) is transformed as follows:

   $\sum_{i=1}^{K} C2CRLO_i > \sum_{i=1}^{K} C2RLO_{AsIs\,LOi}$. By analyzing this formula, we get the following result:

   $$\sum_{i=1}^{K} (C_{develop} + ADC4RLO) > \sum_{i=1}^{K} (C_{search} + C_{select} + C_{obtain}) .$$

4. *The learning activity can be designed with reusable LOs that are developed from scratch or by reusing LOs which have been all modified:* for this case, formula (1) is transformed as follows:

   $\sum_{i=1}^{K} C2CRLO_i > \sum_{i=1}^{K} C2RLO_{modify\,LOi}$. By analyzing this formula, we get the following result:

   $$\sum_{i=1}^{K} C_{develop} > \sum_{i=1}^{K} (C_{search} + C_{select} + C_{obtain} + C_{disagregate} + C_{aggregate} + C_{adapt}) .$$

If we group the costs, $C_{search} + C_{select} + C_{obtain}$ and consider them as a total cost for searching and obtaining LOs from a typical LOR and if we also group the costs $C_{disaggregate} + C_{aggregate} + C_{adapt}$ and consider them as a total cost for modifying an existing LO then from the formulas described above, we can conclude the following:

- **Case 1:** The process of reusing a sequence of LOs (without any modifications) for a new learning activity is cost effective only if the sum of the costs to search and obtain them from a LOR is lower than the sum of the costs to develop them (as non-reusable LOs) from the scratch.
- **Case 2:** The process of reusing a sequence of LOs (with modifications) for a new learning activity is cost effective only if the sum of the costs of: a) searching and obtaining them from a LOR, b) modifying them and c) offering them back to the LOR is lower than the sum of the costs to develop them (as non-reusable LOs) from the scratch

- **Case 3:** The process of reusing a sequence of LOs (without any modifications) for a new learning activity is cost effective only if the sum of the costs to search and obtain them from a LOR is lower than the sum of the costs to develop them from the scratch as reusable LOs and offer them to the LOR.
- **Case 4:** The process of reusing a sequence of LOs (with modifications) for a new learning activity is cost effective only if the sum of the costs of: a) searching and obtaining them from a LOR and b) modifying them is lower than the sum of the costs to develop them from the scratch as reusable LOs and offer them to the LOR.

For cases 2 and 3, we should mention that Additional Cost for Reusable LO (ADC4RLO) could be reduced to practically zero provided that the particular LO is frequently reused.

An essential cost of the LOs reuse process is the cost of searching and obtaining LOs from LORs. For this purpose, it is important that the LOs process of reuse is supported by effective LORs that can significantly facilitate their end users to narrow their search results and select more easily LOs for reuse within a given learning activity. This will substantially lower the costs for searching and obtaining LOs from the LORs and will make the LOs reusability process more cost effective. Moreover, when modifications to the LOs are needed these increase significantly the cost compared to the cost needed to create the LO from scratch and reduce the potential cost benefits of reuse. Therefore, further analysis would be needed to study under which circumstances LO modifications are costs effective over LO development from scratch. This observation supports the need for LORs to stimulate the versioning and its sharing among LOR users. Finally, possible automatic modifications (i.e., automatic LO modification for different disability categories) can significantly lower the cost of LOs reuse.

Conclusions

The main advantage of Learning Objects in Technology-enhanced Learning has been claimed to be their potential for component-based reuse in different learning settings. Nevertheless, there are only sporadic efforts to study issues related to LOs reuse that would allow interested parties (people, organizations and initiatives) to assess and implement systematic LOs reuse. In this paper, we have studied the concept of LOs reuse within the context of learning activities design and development, we studied and discussed the limitations of existing proposals for LOs reuse and we proposed a thorough workflow for LOs lifecycle that can capture LOs reuse processes. Based on this workflow, we proposed a set of metrics for measuring the cost of LOs reuse as a process rather than measuring only the potential reusability of individual LOs. This is an important issue for large scale deployment of the LO paradigm, since it contributes towards assessing the conditions for LOs reuse being cost effective. The proposed metrics bare the potential for cost benefit analysis of the LOs reuse process from interested parties within the framework of Open Resources Initiatives.

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