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Semantic interoperability model for learning object repositories

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Abstract: Interoperability among repositories requires syntactic and semantic compatibility, achieved through the adoption of metadata standards. However, different learning object repositories currently use diverse metadata standards to describe their resources, so multiple metadata standards describe the same term, and vice versa. This paper proposes an ontology-based interoperability model, featuring a shared vocabulary (SV) and a set of matching rules. The SV establishes a common terminology for learning objects, while the matching rules enable translation between the SV and any metadata standard. As a result, both deposit and search for learning objects can be conducted using any metadata standard, thanks to the rules that ensure seamless translations where needed. To evaluate the proposed model, a prototype has been developed, which implements the SV and matching rules. This experience has shown that using ontologies and matching rules to provide an interoperability model for learning objects repositories is a valid, flexible and user-friendly solution.

Keywords: semantic interoperability; learning object repositories; metadata standards; open.

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1 Introduction

The open access movement has emerged as a solution to the crisis in the traditional model for scientific communication. It is based on statements presented in various conferences, including Budapest (Chan et al., 2002), Bethesda (Suber, 2003), Berlin (Mittelstraß, 2003) and El Salvador (Congresso Mundial de Informação em Saúde e Bibliotecas e do Sétimo Congresso Regional de Informação em Ciências da Saúde, 2005), which advocate for researchers to publish and share their work without economic, technical or legal barriers. To support this movement, universities and educational institutions have implemented Institutional Repositories (IRs) where researchers can publish their work. IRs provide a set of services to the community, allowing institutions to manage and disseminate digital resources, while ensuring long-term preservation, distribution and access (Lynch, 2003).

A Learning Object Repository (LOR) is an Institutional Repository (IR) that specifically includes educational resources called Learning Objects (LO). LOs are characterised by their accessibility, reusability and interoperability (Polsani, 2003), and can be defined as a digital object that is designed for learning, teaching and training purposes (IEEE Standard Computer Dictionary, 1990). This means that LORs provide a platform for institutions to manage and disseminate LOs, while ensuring their long-term preservation and access.

Currently, there are numerous metadata standards available, and each repository chooses the one that best meets its specific needs and objectives for defining LO. The Dublin Core standard (DC) (Dublin Core Metadata Initiative Metadata Terms, 2012) is the most widely used as it offers a general description of any digital object. For a more specific description of LO, the Learning Object Metadata standard (LOM) (IEEE Learning Technology Standards Committee, 2002) is commonly utilised, although its extensive metadata content means that only a few repositories have implemented it. Additionally, some repositories have implemented Metadata Object Description Schema Standard (MODS) (Metadata Object Description Schema, 2018), Machine-Readable Cataloging standard (MARC) (Network Development and MARC Standards Office, 1999), and DataCite (DataCite Metadata Working Group, 2016) to a lesser extent. One of the intent of open access initiatives is to achieve interoperability between repositories, enabling the development of a repository network that increases visibility and reusability, not only for humans but also for machines (Confederation of Open Access Repositories, 2012).

As numerous standards have emerged, the challenge of achieving interoperability has become evident. Various proposals have been put forth to tackle this issue over time. Among the earliest initiatives was the GEM project (Gateway to Educational Materials) (Sutton, 1998), which brought together a comprehensive range of metadata, employed controlled vocabularies, provided a well-defined syntax, implemented harvesting tools and established GEM interfaces.

Furthermore, the DCMI educational community[1] (DC-EC) has been developing a proposal to describe LO, which incorporates certain educational metadata into the DC standard. This metadata includes information such as the intended audience, mediator, educational level and instructional method, among others.

This article focuses on the challenge of achieving semantic interoperability between repositories at the metadata level and presents an ontology-based interoperability model. Its primary contributions include the ability to maintain the adopted metadata standard for each repository while also allowing for flexibility when a new repository is added, as well as the use of matching rules to facilitate the necessary translations. This solution is implemented as a top layer, meaning that repositories are not required to change the metadata standard they are using. The approach utilises local ontologies, a Shared Vocabulary (SV) and matching rules to establish interoperability between repositories.

Local ontologies provide a conceptualisation of the standard metadata implemented by repositories, while the shared vocabulary constitutes a global ontology that encompasses both common terms and more specific terms that provide detailed descriptions of LO. This interoperability model improves deposit and optimises the search in LOR.

This article is organised as follows. Section 2 introduces the related works, which helps to provide context for the proposed interoperability model. Section 3 is the main section of the article, where the proposed interoperability model and shared vocabulary ontology are presented and described. Section 4 presents examples to illustrate the proposed model and how it can be used in practice. Finally, Section 5 presents the conclusions.

2 Related work

Interoperability among LORs is beginning to be threatened by the emergence of multiple metadata standards. Immediately, Dublin Core (DC) and Learning Object Metadata (LOM) became the most popular ones. As a result, some works have proposed a set of metadata that combines elements from both standards.

Duval et al. (2002) referred to the considerations that should be taken into account when using metadata standards. Their proposal aims to establish a common understanding between two communities, DCMI and IEEE LOM, taking into account modularity, extensibility, refinement and multilingualism. Balatsoukas et al. (2011) conducted a study to analyse which metadata are most important or useful for students, who are among the main users of LO and LOR. The result was a list of metadata: *title, abstract, keywords, interactivity, type of educational resource, difficulty* and *audience.* Other metadata identified, such as *date, language* and *cost,* were considered to have less relevance. Similar results were obtained by Plodzien et al. (2006), Liddy et al. (2003) and Small et al. (1998). Maarof and Yahya (2008) proposed the recovery of LO from LOR using metadata such as *title, keywords, description* and *location*. These metadata are used in the LORIuMET (Learning Object Repositories Interoperability using Metadata) repositories as the central LOR. However, these solutions are not flexible and involve adopting the proposed vocabulary.

The OAI-PMH protocol is one of the earliest and most widely adopted protocols for achieving interoperability among digital repositories. However, it is true that the protocol requires the use of the Dublin Core (DC) metadata standard, which may limit its ability to capture the full complexity of metadata used by some repositories.

To address this limitation, various guidelines and extensions to the OAI-PMH protocol have emerged over time, such as Driver, Open Aire and Sistema Nacional de Repositorios Digitales (SNRD) in Argentina. These guidelines provide additional criteria and recommendations for metadata filling and repository interoperability beyond the basic OAI-PMH protocol.

For instance, Driver has different versions, and it focuses on syntactical interoperability using the OAI-PMH protocol, and on semantic interoperability through the use of controlled vocabularies. Open Aire builds on the Driver guidelines and adds specific criteria, such as the requirement for repositories to be fully open access and the inclusion of project identification. On the other hand, SNRD in Argentina follows the Driver 2.0 guidelines and adds others more specific to developing a national digital repositories network.

Overall, these guidelines are important for ensuring that digital repositories can effectively communicate and exchange data with each other, even if they use different metadata standards or formats. They help to establish a common framework for metadata filling and exchange, which in turn promotes interoperability and makes it easier for researchers to discover and access relevant resources across multiple repositories.

In the context of semantic interoperability, ontological solutions have been widely proposed. Three approaches can be mentioned in this regard (Stuckenschmidt and Van Hameler, 2005):

- The global ontology approach proposes defining a shared vocabulary among systems through a global ontology.
- The multiple local ontologies approach involves each system having its own ontology describing its own vocabulary.
- The hybrid ontology approach involves each system having its own ontology, and there is an upper-level ontology that serves as a shared vocabulary. This upper-level ontology is composed of common terms belonging to local ontologies.

Wang and Ye (2009) noted the ease of managing data heterogeneity in statistical information in China using the hybrid ontology approach. In Zheng and Terpenny (2013) implemented local ontologies in various obsolescence management systems and use a shared vocabulary with common terms in the obsolescence domain. Although these proposals are not related to LOR, they serve as good interoperability solutions.

Gómez-Dueñas (2009) proposed an interoperability model between libraries and LOR in Colombia. They suggest using a controlled vocabulary for semantic interoperability. Vian et al. (2011) reused DC and LOM ontologies and identify common terms to define a shared vocabulary. They then establish matching rules between them. The main components of this approach are repositories, multi-agent systems (composed of an index agent and search agent), matching rules, domain ontologies and a search service with an interface.

Koutsomitropoulos et al. (2010) proposed an ontology based on DC with additional metadata from LOM, such as *version, state, interactivity type, resource type, intended end-user role, context* and *difficulty*, among others. Casali (2013) proposed a system assistant for uploading and managing LOs that use a LOM ontology. The advantage of this approach is its flexibility and adaptability in case of changes.

Koutsomitropoulos and Solomou (2018) proposed an ontology that facilitates the description and recovery of LOs. The ontology, based on LOM, allows for semantic interoperability between repositories. The use of Simple Knowledge Organisation System (SKOS) promotes the transformation of organisational thesaurus and, thus, LO discovery in heterogeneous LOR.

Koutsomitropoulos (2019), the author suggests aligning metadata from different repositories, considering the most representative metadata to be the title, description, and keywords. These metadata are matched into an ontological schema, the LOs are classified into SKOS standards and saved into an ontological repository, which helps teachers and professors reuse previously classified LOs.

In Koutsomitropoulos et al. (2020) suggested performing a federated query in different repositories, and then aligning the retrieved metadata to a combined ontology of the DC and LOM standards. Finally, there are metadata that are automatically populated using keywords by linking them to thematic thesaurus for specific domains. In this case, the embedded metadata must be reviewed by a curator or instructor who decides on the incorporation of the open LO into the common repository.

Castillo et al. (2019) proposed an ontology to conceptualise the main characteristics of the POHUA repository (Repositorio de la Universidad de las Américas Puebla, Mexico). López et al. (2019) suggested evaluating institutions according to dimensions such as technical, syntactic, semantic, organisational, cultural and educational to define an interoperability model for repositories and Learning Management Systems (LMS).

The work of Limani et al. (2019), although oriented towards digital libraries, proposes the use of links. They model these links based on an emerging standard, and then represent and publish them through a semantic web stack.

Similarly, Patrício et al. (2018) proposed the development of a super-ontology to mitigate the limitations identified between existing bibliographic ontologies and linked open data techniques. According to the authors, there is a lack of a common conceptual framework for the diversity of standards, which are generally used together, as well as limitations in semantic web languages for bibliographic data interoperability requirements. In conclusion, their proposal improves the existing contributions with an interoperability model, where the main features are the mapping rules, allowing the repository to maintain its vocabulary.

3 Interoperability model for LOR

Figure 1 depicts the interoperability model proposed in this article. The model, based on a hybrid ontology approach, offers a solution to the problem of metadata heterogeneity in repositories. It consists of five layers that provide flexibility and enable repositories to maintain their local metadata. The top layer is the common interface, which implements search and deposit services using the Shared Vocabulary (SV). The Mediator layer performs the mapping between SV and local ontologies, which takes place in the rule-based programming layer. The next layer is local ontologies, and finally, the bottom layer is the data source that includes the LOR, which implements different metadata standards. As shown in Figure 1, there are bidirectional arrows indicating that the search can be performed top-down, from the SV interface to a single LOR, or bottom-up, from each LOR to SV. According to the proposal of specialised sites such as the Confederation of Open Access Repositories (COAR),[2] the end users of this model can be divided into two groups: those who want to deposit LO in a repository (teachers, students, researchers), and those who want to search for LO in some repositories that are part of the model.

The top layer is the search and deposit services layer, which is implemented in harvester repositories that collect metadata from several repositories using the SV. In this case, it is possible to search for resources in one place, facilitating the retrieval of resources hosted in LOR that use different metadata standards. The harvested repositories must have enabled the OAI-PMH protocol. Figure 2 shows the schema proposed for performing searches. The data provided for searching for a LO includes the values of metadata belonging to the SV (step 1 *Search* LO, in the line of 'User'). Then, in the Mediator layer, matching is performed (mapping rules in the line of 'Harvester Repository' in Figure 2). As a result, metadata belonging to the specific metadata standard implemented in the LOR is obtained. For instance, the mapping can translate from SV to OntoDC, OntoLOM, OntoMODS and OntoDataCite. The results of SPARQL queries are dumped into JSON files and sent to the harvesting repository to display the search results.

Figure 1 Interoperability model for LOR

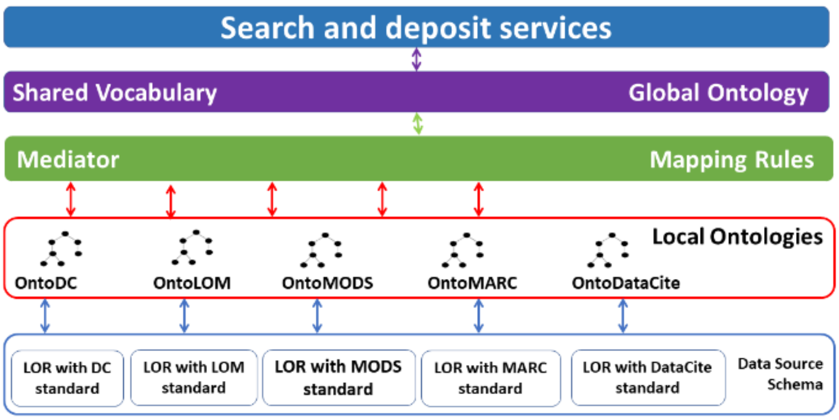


Figure 2 Schema for performing top-down search

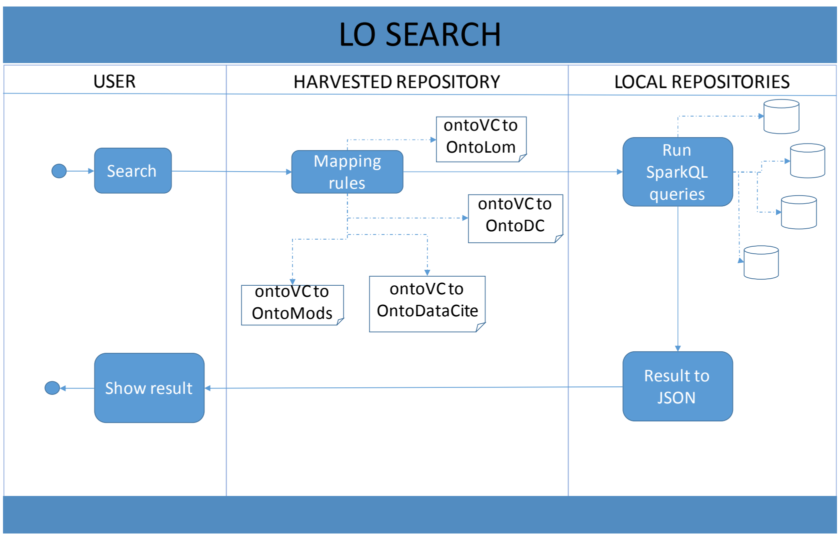
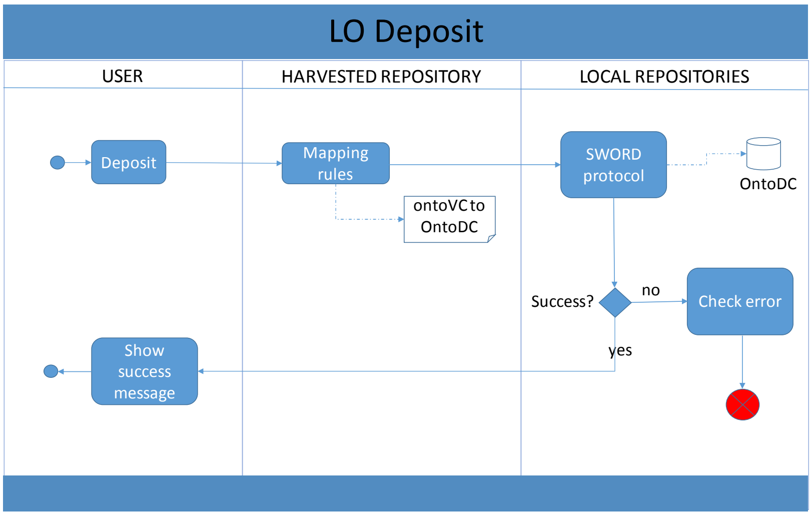


Figure 3 Schema to perform deposit from local repositories



From another perspective, Figure 3 depicts the schema for performing a deposit. In this example, *OntoDC* and its sources are considered as instances. The user inputs the SV metadata, and mapping rules are applied to translate from *OntoVC* to *OntoDC*. Finally, the SWORD protocol either accepts or rejects the deposit.

The proposed model's functionality is demonstrated using standard metadata ontologies such as *OntoDC*, *OntoLom*, *OntoMods* and *OntoDataCite*, although others could be used. If a repository with a different standard is to be added, it will only require adding mapping rules between *OntoVC* and the new standard ontology. This single action is the advantage of using a hybrid approach model, as mentioned earlier.

3.1 Methodology

The methodology used in the development of the proposed model is based on ontology development, known as the hybrid approach, which involves three stages (Wang and Ye, 2009). The first stage is the definition of the Shared Vocabulary, which is further divided into three stages: data source analysis, analysis and definition of common terms and global ontology definition. The second stage is the local ontology definition, which is divided into two stages: data source analysis and local ontology definition. The third stage involves mapping between local ontologies and global ontologies or shared vocabulary.

Stages one and three were executed to generate the proposed model, while stage two consisted of selecting one of the available metadata ontologies instead of developing a new one. To accomplish the first stage, OntoVC was developed, which represents the SV. The Methontology (Fernández-López et al., 1997) methodology was followed.

To perform stage three, the context-based mapping strategy was used (Euzenat and Shvaiko, 2013), which involves selecting ontologies to be considered for the mapping and then selecting the terms according to the context in which they will be used. Semantic Web Rule Language (SWRL) was used to describe the mapping (De Farías et al., 2015).

In the first phase of development, automatic mapping was considered using different tools, such as the AgreementMaker tool,[3] SILK and LIMES. Some results were obtained, but there were gaps in matching at the semantic level, and some matches were not detected at all. Owing to the fact that OntoVC is based on OntoDC, there is a high degree of correspondence between both.

Two techniques were used to carry out tests: the Based similarity matcher and the Parametric string matcher. The first technique evaluates string similarities between each concept belonging to each ontology. The second technique also compares string similarities but sets parameters to identify the degree to which the matching can be performed. For instance, the Label parameter sets the threshold at which the string matches can be accepted, and the Comment parameter sets the threshold at which a comment associated with the concepts must be matched.

The matching results between OntoVC and OntoDC provided by AgreementMaker for the Based similarity matcher technique show many matches with a degree of similarity close to 100%. The results with the Parametric string matcher technique with parameters set to Label = 65% and Comments = 65% show higher coincidences with values between 80% and 90%. This result is due to the fact that OntoVC is based on OntoDC.

Regarding the matching between OntoVC and OntoLOM, the results using a Based similarity matcher have been poor, with only 3 classes and 5 properties, but it improved when the Parametric string matcher technique was used, with 12 classes and 34 properties. This result is due to the fact that metadata belonging to the educational category was considered when OntoVC was defined.

As for the matching between OntoVC and OntoMODS, the Based similarity matcher technique could only find matches between classes, but not between properties.

The AgreementMaker tool has shown a good level of accuracy and reliability in its results from a syntactic point of view. However, there are some mistakes from a semantic point of view when the tool finds two identical strings as a match, even though the semantics of these concepts are different. For instance, it may find a coincidence between 'physicalDescription' and 'description', but the semantics of these concepts are dissimilar.

Owing to the weakness of the tool in semantic matching, a manual matching using a context-based mapping strategy has been decided upon. Recent advances in machine learning, such as knowledge graph embedding, have led to the application of these techniques in ontology matching problems. Doan et al. (2004) developed GLUE, a system that employs learning techniques to create semantic mappings between ontologies semi-automatically. Ichise (2008) proposed the use of several concept similarity measures for machine learning, using real-world data. Similarly, Nezhadi et al. (2011) presented a method for combining similarity measures from different categories, without having ontology instances or any user information about the alignment of two given ontologies.

More recently, Laadhar et al. (2020) proposed POMap++ as a novel local matching learning approach that combines ontology partitioning with ontology matching learning. On the other hand, Iyer et al. (2020) proposed VeeAlign, a supervised deep learning-based ontology alignment system that computes a contextualised representation of concepts based not only on their label, but also on the surrounding multifaceted neighboring concepts. Bento et al. (2020) presented a methodology to align ontologies automatically using machine learning techniques. Specifically, the authors use convolutional neural networks to perform string matching between class labels using character embeddings. Finally, Hertling et al. (2020) presented MELT-ML, a machine learning extension to the Matching and EvaLuation Toolkit (MELT), which facilitates the application of supervised learning for ontology and instance matching.

Although these proposals show promising results, they have not yet been able to achieve impressive results in ontology matching and have typically performed worse than rule-based approaches. Some of the main reasons for this are poor context modelling, overfitting of standard DL models and the sparsity of data sets caused by class imbalance of positive alignment versus negative pairs. Other issues that need to be resolved include the integration of the largest size not yet feasible with good matching accuracy and the complete automation of the ontology matching process.

3.2 Shared vocabulary: definition, integration and derivation rules and mapping rules

To define the SV, the OntoVC ontology was developed. However, this ontology was not created from scratch; rather, it was based on the DCOntoRep ontology (López et al., 2019). DCOntoRep is an ontology that conceptualises the LO description schema. It is based on the DC metadata schema and the Sistema Nacional de Repositorios Digitales (SNRD) recommendation. This ontology covers more general metadata used to define any digital resource but lacks a more accurate description for the LO. So, the new ontology, OntoVC, addresses this issue by including new concepts proposed in LOM, MODS and DataCite metadata schemas.

In the development of OntoVC, the following metadata schemas were considered as data sources, according to the stages proposed in the hybrid methodology: LOM, MODS and DataCite. Logical rules, such as integration and derivation rules, refine the OntoVC ontology by making explicit restrictions among concepts, attributes and relationships. These rules are written using the SWRL language as part of the ontology definition.

From the analysis of the aforementioned standards, three categories of metadata emerged to describe the LO accurately. The first category is *Content*, which provides general information about the object, such as *author*, *title*, *subject*, *keywords*, among others. The second category is Intellectual *Property*, which describes the conditions under which the LO is shared in an Open Access. And the third category is *Instantiation*, which provides specific information about the published instance, such as the *date of publication*, *embargoed period* (if any), *type*, and *format* of the LO, among other characteristics.

Figure 4 shows the definition of these metadata categories in OntoVC. Each category is defined in the ontology as a class.

Figure 4 Main metadata categories

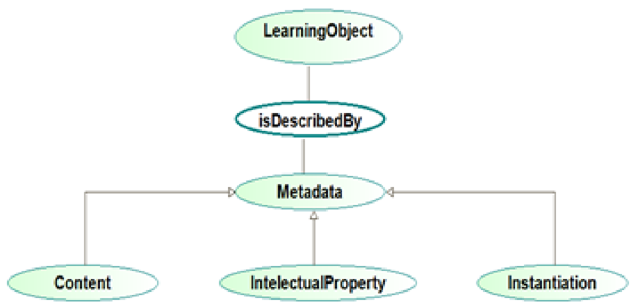
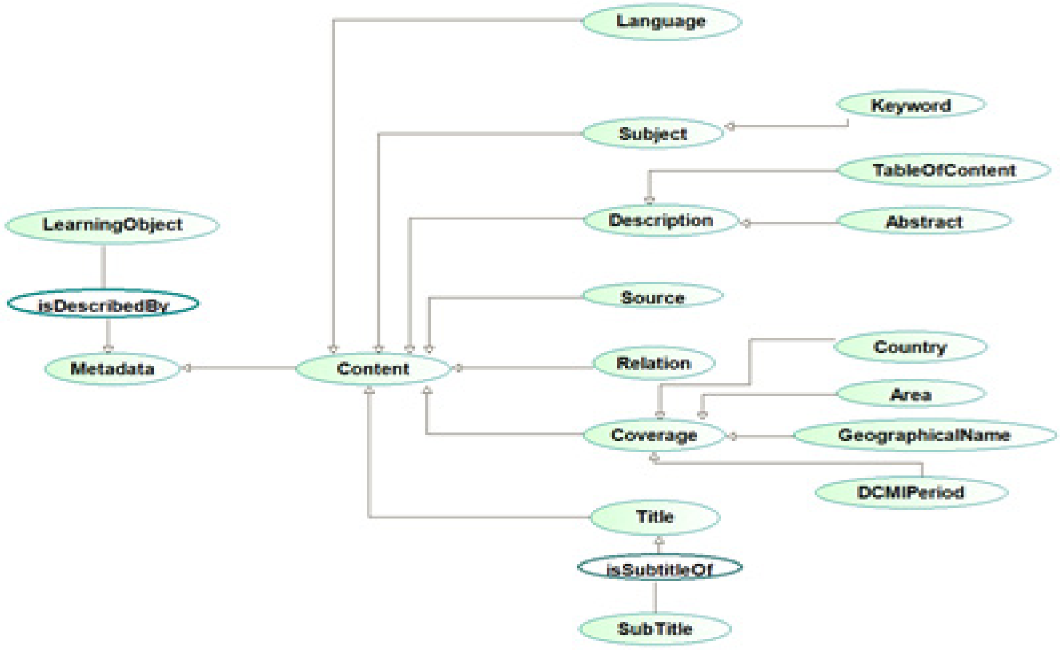


Figure 5 provides a more detailed view of the Content category, which comprises seven subclasses: *Language*, *Description*, *Subject*, *Source*, *Relation*, *Coverage* and *Title*. An analysis has been conducted on each class defined in OntoVC, which has identified equivalent metadata proposed for different standards. Tables 1 and 2 present a section of this analysis

Figure 5 Terms belonging to content category



As an example, the *Title* class represents a distinguishing name of a LO, which can also include a subtitle. In Figure 5, the *Title* and *SubTitle* concepts are connected through the *isSubtitleOf* relationship. Table 1 displays the analysis of this class, as per the interpretation of various metadata standards.

Table 2 summarises some of the equivalences expressed in the SWRL language for the Content category. The first column displays the concepts belonging to OntoVC. For each concept, the second column presents the rules, which map from OntoVC to OntoDC, OntoLOM, OntoMODS and OntoDCite.

Table 1 Title class analysis

	Title
Standard	*Equivalent metadata*
DC	*dc:Title.* It is a content metadata.
LOM	*lom:General/Title.* It is a General metadata.
MODS	*Mods:TitleInformation* and Mods:*AlternativeTitle* for substructure
DataCite	Datacite:*Title* and datacite:*TitleType* *TitleType* has a controlled list of values: *alternativeTitle*, *subtitle*, *translatedTitle* among others

Table 2 Mapping rules – category content

OntoVC	*Rules*
Keyword	OntoVC: Keyword(?x)→OntoDC: Subject(?x)
	OntoVC: Keyword(?x)→OntoLOM: Subject(?x)
	OntoVC: Keyword(?x)→OntoDCite: Subject(?x)
	OntoVC: Keyword(?x)→OntoMODS: Subject(?x)
Language	OntoVC:Language(?x)→OntoDC:LinguisticSystem(?x) ∧ OntoDC:Language(?x)
	OntoVC: Language(?x)→OntoLOM: Language(?x)
	OntoVC: Language (?x)→OntoDCite: Language (?x)
	OntoVC: Language (?x)→OntoMODS: Authority(?x, ‘ISO639-3’) ^ OntoMODS: Language(?x)
Abstract	OntoVC: Abstract(?x)→ OntoDC: Description (?x)
	OntoVC: Abstract(?x)→OntoLOM: Description (?x)
	OntoVC: Abstract(?x)→OntoDCite: Description (?x)
	OntoVC: Abstract(?x)→OntoMODS: Abstract (?x)

Table 2 Mapping rules – category content (continued)

OntoVC	*Rules*
Source	OntoVC: Source(?x) → OntoDC: Source (?x) En LOM no hay una correspondencia En DataCite no hay una correspondencia En MODS no hay una correspondencia
Relation	OntoVC: Relation(?x) → OntoDC: Relation (?x) OntoVC: Relation(?x) → OntoLOM: Relation (?x) OntoVC: Relation (?x) → OntoDCite: RelatedIdentifier (?x) OntoVC: Relation (?x) → OntoMODS: RelatedItem (?x)
Country	OntoVC: Country (?x) → OntoDC: Coverage (?x) OntoVC: Country (?x)→OntoLOM: Coverage (?x) OntoVC: Country (?x)→OntoDCite: GeoLocationPlace (?x) En MODS no hay una correspondencia
Title	OntoVC: Title(?x) → OntoDC: Title (?x) OntoVC: Title (?x) → OntoLOM: Title (?x) OntoVC: Title (?x) →OntoDCite: Title (?x) OntoVC: Title (?x) → OntoMODS:Title (?x)
SubTitle	OntoVC: subTitle(?x) → OntoDC: Title (?x) OntoVC: subTitle (?x) → OntoLOM: Title (?x) OntoVC: Title (?x) → OntoDCite: titleType (?x, 'Subtitle') OntoDCite: ^ Title (?x) OntoVC: Title (?x) → OntoMODS: subTitle (?x)

The *Description* class has two subclasses: *TableOfContent* and *Abstract*, which identify different parts of the LO's description. The *Subject* class has a *Keyword* sub-class, which includes the most important words related to the LO.

The second metadata category is the *Intellectual Property*. Figure 6 shows the *Intellectual Property* class and its sub-classes: *Agent*, *Publisher* and *Right*, which represent the different agents involved, the publisher and the work's rights respectively. The *Agent* concept also has sub-classes: *Creator* and *Contributor*. The former represents the author (or authors) of the LO, while the latter depicts someone involved in the authorship of the work, such as a grant, advisor of a scholarship. Table 3 shows the analysis of the *Creator* class, as part the standard interpretation of various metadata.

Figure 6 IntellectualProperty category

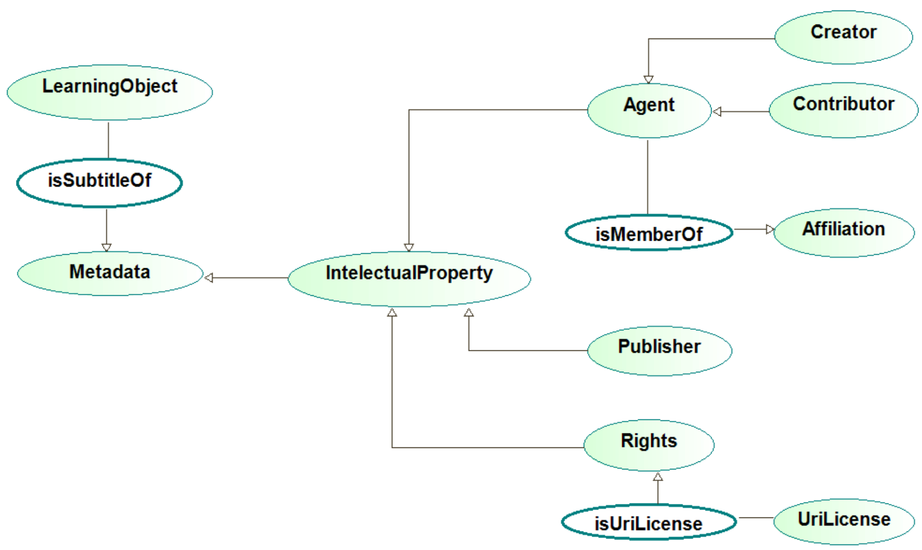


Table 3 Creator class analysis

Creator	
Standard	*Description*
DC	*Dc:creator, it has Last name- Name* format. It is used a single instance for each author.
LOM	*Lom:LifeCycle \Contribute\Entity and Lom:LifeCycle\Contribute\Role*. Where Role must have as its value the author, in order to be equivalent to the concept Creator.
MODS	*mods:name*. It has the elements: *namePart*, *displayForm, affiliation*, *role* and *description*.
DataCite	Datacite:*Creator*. It is divided in values: (i) creatorName: familyName, givenName, (ii) nameIdentifier: nameIdentifierScheme, schemeUri, (iii) affiliation

It also includes the *Affiliation* concept, which represents the author's institution. The *isMemberOf* relationship connects the Agent with *Affiliation* concepts. This representation is in accordance with SNRD guidelines.

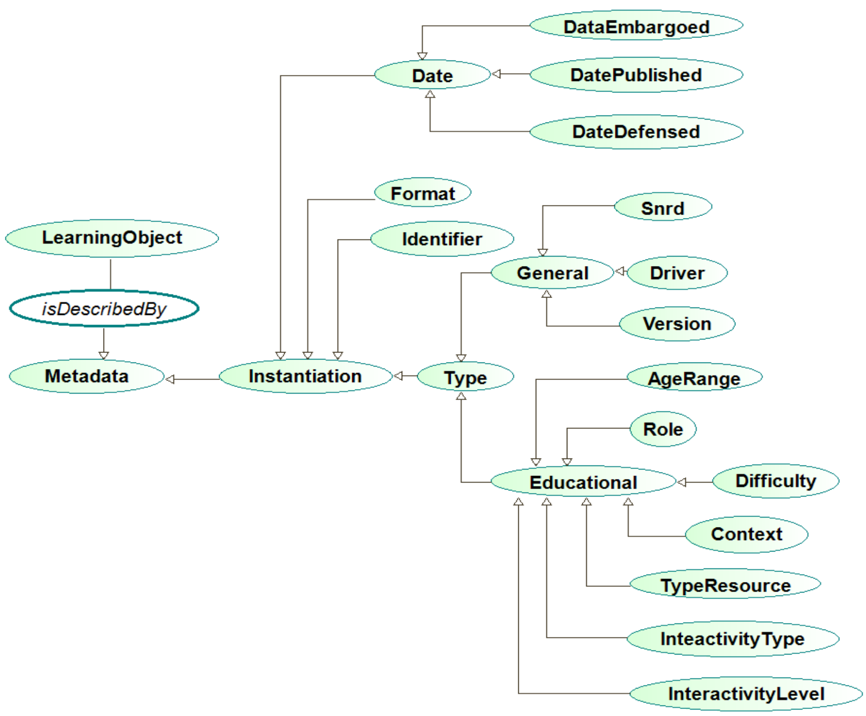
In the case of copyright metadata, DC, LOM and Datacite use the *Right* tag with different optional values depending on the access type, such as *restrictedAccess*, *embargoedAccess* and *openAccess*. In the OntoVC ontology, these values have been identified as *Right* instances. Additionally, since Creative Commons is the most popular copyright licence, the *URILicense* concept has been added to OntoVC and the *isUriLicense* relationship links the *Right* and *URILicense* concepts.

The next category comprises the LO instances. The *Instantiation* concept is added as a subclass of Metadata. Figure 7 shows the concepts belonging to this category. According to the metadata standards analysis, the *Date*, *Format*, *Identifier and Type* concepts have been added as subclasses of *Instantiation*.

As regarding the *Type* concept, different metadata standards and the SNRD recommend using controlled vocabularies. Therefore, two subclasses of *Type* are defined: *General* and *Educational*. *General* has *Driver*, *Snrd* and *Version* as its subclasses to represent the types of digital objects when the LO is considered as a general digital object. On the other hand, the *Educational* class is added to record the pedagogical information about the LO. In this case, *TypeResource*, as an *Educational* subclass, refers to LO types such as narrative text, essay, assessment, among others. Additionally, other subclasses of *Educational* were defined, considering metadata belonging to the LOM educational category, such as *InteractivityLevel*, *InteractivityType*, *Difficulty*, *Role*, *IntendedEndUserRole*, *AgeRange* and *Context*. These concepts help to give the LO a more specific definition.

For instance, the *IntendedEndUserRole* tag belonging to LOM identifies the main LO addressee. Its values defined in LOM are teacher, author, learner and manager. Similarly, in MODS, the *TargetAudience* tag has the same meaning as the *IntendedEndUserRole* in LOM. Therefore, OntoVC has the *IntendedEndUserRole* concept, as defined in LOM. A similar analysis has been performed on the rest of the metadata to add new concepts to the OntoVC ontology.

Figure 7 Instantiation category



3.3 Definition of integration and derivation rules

The value that the concept type adopts varies according to the Drive or SNRD guidelines. Rules 1 to 3 define equivalences between Drive and SNRD values. For example, the *Artículo* value from SNRD is equivalent to the *Article* value from Drive (see rule 1). The *Libro* value from SNRD is equivalent to the *Book* value from Drive (rule 2). Additionally, the *Modelo Industrial* value from SNRD is equivalent to the *Patent* value from Drive (rule 3)

LearningObject(?lo) ^ Snrd (?d, 'Articulo') ^ hasSnrdType(?lo,?d) → hasdDriverType (?lo, 'Article') (1)

LearningObject(?lo) ^ Snrd (?d, 'Libro') ^ hasSnrdType(?lo,?d) → hasDriverType (?lo, 'Book') (2)

LearningObject(?lo) ^ Snrd (?d, 'Modelo Industrial') ^ hasSnrdType(?lo,?d) → hasDriverType (?lo, 'Patent') (3)

Rules 4 and 5 demonstrate the dependencies between *Type* and the concepts in the *Educational* category. For instance, if a LO is associated with the *Article* value of the *DriverType*, it must also be associated with the *Expositive* value of the *InteractivityType* concept (rule 4) and the *Narrative Text* value of the *TypeResource* concept (rule 5)

LearningObject(?lo) ^ Driver (?d, 'Article') ^ hasDriverType(?lo,?d) ^InteractivityType(?t, 'expositive')→ hasInteractivityType(?lo,?t) (4)

LearningObject(?lo) ^ Driver (?d, 'Article') ^ hasDriverType (?lo,?d) ^TypeResource(?t, 'Narrative Text')→ hasTypeResource(?lo, ?t) (5)

Rule 6 depicts the restriction when the LO is a published version. In this case, it must have an associated publication date.

LearningObject(?lo) ^ Version(?v, 'Published') ^ hasVersion(?lo,?v)^ DatePublished(?dp) → hasDatePublished(?lo,?dp) (6)

Rule 7 shows the restriction when the LO has embargoed access (the *Right* concept has embargoedAccess as a value). In this case, it must have an associated end date that means the end of the embargo.

LearningObject(?lo)^Driver (?d, 'Article')^hasDriverType (?lo,?d) Rights(?r, 'EmbargoedAccess')^ DateEmbargoed(?de) → hasDateEmbargoed(?lo, ?de) (7)

Similarly, rules have been incorporated to define restrictions when the LO is a *type of thesis*, such as a doctoral thesis (Driver: Doctoral Thesis and SNRD: *Tesis Doctoral*), master's thesis (Driver: *MasterThesis* and SNRD: *Tesis de Maestría*), or bachelor's thesis (Driver: *BachelorThesis* and SNRD: *Tesis de Grado*). Rule 8 states that every thesis must have a collaborator with the role of director. Rule 9 states that every thesis must have an defend date.

LearningObject(?lo) ^ Driver (?d, 'Doctoral Thesis') ^ hasDriverType(?lo,?d) ^ Snrd (?s, 'Tesis Doctoral') ^ hasSnrdType (?lo,?s) ^ Contributor (?c, 'Director')→ hasContributor(?lo,?c) (8)

LearningObject(?lo) ^ Driver (?d, 'Doctoral Thesis') ^ hasDriverType(?lo,?d) ^ Snrd (?s, 'Tesis Doctoral') ^ hasSnrdType (?lo,?s) ^ DateDefense (?de) → hasDateDefense(?lo,?de) (9)

Following with metadata from the *Educational* category, there are some relationships between the values that the metadata can adopt. For instance, rules 10, 11 and 12 show the dependencies of *resource type* with *interaction type* and *interaction level* values. Rule 10 states that if the *resource type* has the value simulation, then the *interaction type* must have an active value, and the *interaction level* must have a very high value. Rule 11 states that if the *resource type* has the value slide, then the *interaction type* must have an expositive value, and the *interaction level* must have a medium value. Finally, rule 12 states that if the *resource type* has an Exercise value, then the *interaction type* must have an active value and the *interaction level* must have a medium value.

LearnigObject(?lo) ^ InteractivityType(?i, 'Active') ^ hasInteractivityType(?lo,?i) ^ TypeResource(?r, 'Simulation') ^ hasTypeResource(?lo,?r) ∧ InteractivityLevel(l, 'Very High') → hasInteractivityLevel(?lo, ?l) (10)

LearnigObject(?lo) ^ InteractivityType(?i, 'Expositive') ^ hasInteractivityType(?lo,?i) ^ TypeResource(?r, 'Slide') ^ hasTypeResource(?lo,?r) ∧ InteractivityLevel(l, 'Medium') → hasInteractivityLevel(?lo, ?l) (11)

LearnigObject(?lo) ^ InteractivityType(?i, 'Active') ^ hasInteractivityType(?lo,?i) ^ TypeResource(?r, 'Exercise') ^ hasTypeResource(?lo,?r) ∧ InteractivityLevel(l, 'Medium') → hasInteractivityLevel(?lo, ?l) (12)

3.4 Definition of mapping rules

As part of this process, mapping rules have been developed to establish equivalent concepts between OntoVC and various metadata ontologies. For the purposes of this discussion, we will focus on OntoDC (which represents the DC metadata standard) and OntoLOM (which represents the LOM metadata standard), but it is worth noting that similar rules could be developed for other ontologies as well.

These mapping rules establish relationships between concepts, such as equating the OntoVC Title concept with the OntoDC Title concept. Rule 10 establishes this equivalence through a bidirectional relationship between OntoVC and OntoDC.

OntoVC:Title (x) ⇔ OntoDC:Title(x) (10)

The rules described in Table 4 show the necessary rules in a general way to map between the OntoVC concepts and the metadata standards ontologies taken as reference, namely OntoDC (DC standard), OntoLOM (LOM standard), OntoDCite (Data Cite standard) and OntoMODS (MODS standard). The following section presents these rules for the cases studied.

Table 4 Mapping rules from OntoVC to OntoDC and OntoLOM

OntoVC	*Rules*
Keyword	OntoVC: Keyword(?x)→OntoDC: Subject(?x)
	OntoVC: Keyword(?x)→OntoLOM: Subject(?x)
	OntoVC: Keyword(?x)→OntoDCite: Subject(?x)
	OntoVC: Keyword(?x)→OntoMODS: Subject(?x)
Language	OntoVC:Language(?x)→OntoDC:LinguisticSystem (?x) ∧ OntoDC:Language(?x)
	OntoVC: Language(?x)→OntoLOM: Language(?x)
	OntoVC: Language (?x)→OntoDCite: Language (?x)
	OntoVC: Language (?x)→OntoMODS: Authority(?x, 'ISO639-3') ^ OntoMODS: Language(?x)
Creator	OntoVC: Creator(?x)→OntoDC: Creator(?x)
	OntoVC:Creator(?x)→OntoLOM:RolesVocabulary(?x)
	OntoVC: Creator (?x) → OntoDCite: CreatorName (?x)
	OntoVC: Creator (?x) → OntoMODS: Name(?x) ^ OntoMODS: Role(?x, creator)
SNRD	OntoVC: SNRD(?x) →OntoDC:VocabularyEncondinyScheme(?x, 'DCMIType) ^ OntoDC:type(?x)
	OntoVC:SNRD(?x)→OntoLOM:LearningResourceVocabularyItem (?x)
	OntoVC: Snrd (?x)→OntoDCite: ResourceTypeGeneral (?x)
	OntoVC: Snrd (?x)→OntoMODS: TypeOfResource (?x)
Context	OntoVC: Context(?x) →OntoDC: Audience(?x)
	OntoVC:Context(?x)→OntoLOM:ContextVocabularyItem (?x)
	En DataCite no hay una correspondencia
	En MODS no hay una correspondencia

4 Case study

This section presents examples of depositing and searching for LO. To demonstrate how the model works, a software prototype called SV Repositories has been developed, which uses OntoVC to describe and search for LOs, as shown in Figure 8. The image shows two options: to search for an LO (01/search in Figure 8(b)) and to deposit an LO (02/deposit in Figure 8(b)).

Figure 8 Prototype for search and deposit of LO (a) presentation (b) option menu

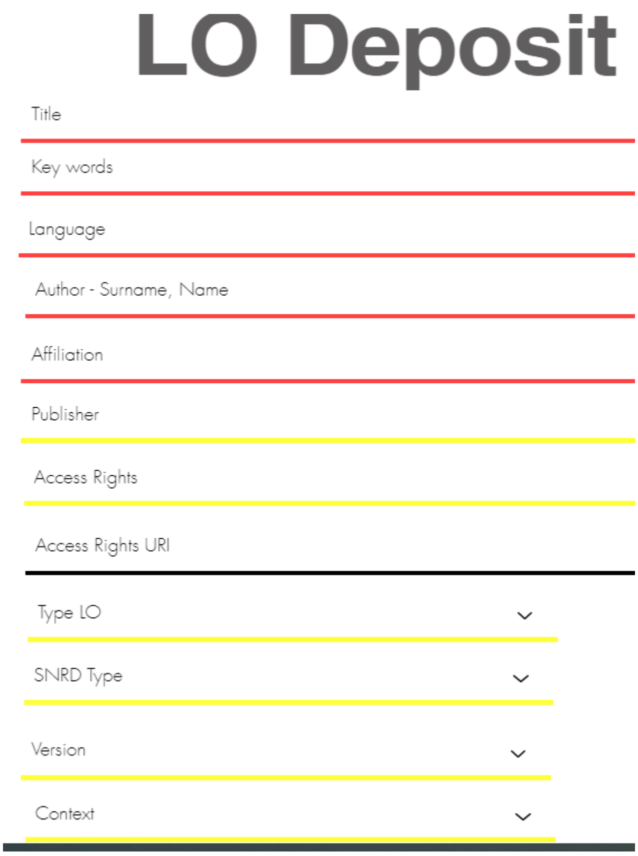
(a) (b)

First, the LO is described using OntoVC (Sub-section 4.1), followed by an example of a search (Sub-section 4.2).

4.1 Depositing LO

When selecting option 02/deposit, a new window will open (see Figure 9), where the user can provide the description of the LO. Figure 9 displays the metadata that needs to be filled, including input values such as *title*, *keywords*, *language*, *author's first and last name*, *affiliation*, *publisher*, *access rights*, *access rights URI*, *type of LO*, *SNRD type*, *version* and *context*.

Figure 9 LO description using OntoVC

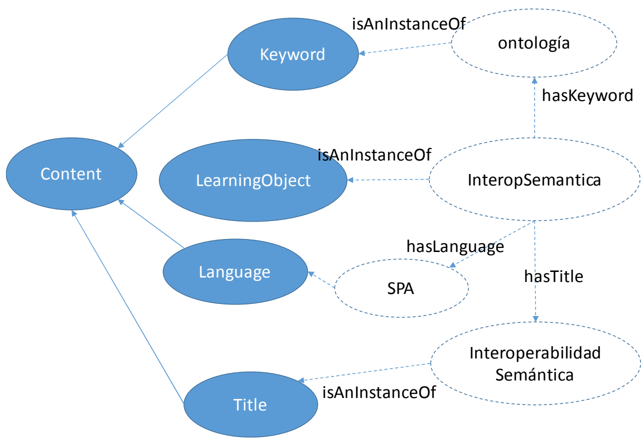


As an example, suppose the LO is an *article* written in *Spanish* with a *Creative Commons* licence associated.

Its *title* is 'Interoperabilidad Semántica', the *keyword* is 'ontología' and the *author* is 'Gutiérrez, María de los Milagros', *affiliated* with the 'Facultad Regional Santa Fe', which is also the *publisher*. Regarding educational features, the *context* is 'Educación Superior', the *difficulty level* is 'Media' and the *intended end user role* is 'estudiante'.

Instances in the OntoVC ontology are created based on these values. To aid in understanding, only the content category instances *for title*, *keyword* and *language* are shown in Figure 10.

Figure 10 Instantiation of LO in OntoVC



After the data is entered, the derivation rules are executed to obtain derived values from the previous ones, such as the *driver* (see equation 11), *interactivity type* (see equation 12), *interactivity level* (see equation 13) and *age range* (see equation 14).

LearningObject(?lo) ^ Snrd (?s, 'Articulo') ^ hasSnrdType(?lo,?s) ^ Driver (d?, 'Article') → hasdDriverType (?lo,?d) (11)

LearningObject(?lo) ^ Driver (?d, 'Article') ^hasDriverType(?lo,?d) ^ Snrd (?s, 'Artículo') ^hasSnrdType (?lo,?s)∧ InteractivityType(?t, 'Expositive') → hasInteractivityType(?lo, ?t) (12)

LearnigObject(?lo) ^ InteractivityType(?i, 'Expositive') ^ hasInteractivityType(?lo,?i) ^ TypeResource(?r, 'NarrativeText') ^ hasTypeResource(?lo,?r) ∧ InteractivityLevel(l, 'Very Low') → hasInteractivityLevel(?lo, ?l) (13)

LearnigObject(?lo) ^ Context(?c, 'Higher Education') ^ hasContext(?lo,?c) ^ AgeRange(?a, '18 up') → hasAgeRange(?lo,?a) (14)

Next, the mapping rules are executed to obtain the equivalent descriptions in other metadata standard ontologies. For simplicity, this example only considers OntoDC. Table 5 summarises the mapping rules executed for each concept, providing the equivalent values in OntoDC that are required to deposit the LO.

Finally, the LO can be deposited in a repository that uses the DC metadata standard. In this case, the SWORD protocol can be used, which ensures syntax interoperability among repositories.

Table 5 Mapping rules executed for the example

Concept	*Mapping rule*
Title	OntoVC: LearningObject(?lo) ^ OntoVC: Title(?t, 'Interoperabilidad Semántica') ^ OntoVC: hasTitle(?lo,?t) → OntoDC: Title (?t, 'Interoperabilidad Semántica')
Language	OntoVC: LearningObject(?lo) ^ OntoVC: Language(?l, 'SPA') ^ OntoVC: hasLanguage(?lo,?l) → OntoDC: LinguisticSystem(?l, 'ISO639-3') ^ OntoDC: Language (?l, 'SPA')
Keyword	OntoVC: LearningObject(?lo) ^ OntoVC:Keyword(?k, 'ontología') ^ hasKeyword (?lo,?k) → OntoDC: Subject(?k, 'ontología')
Creator	OntoVC: LearningObject(?lo) ^ OntoVC: Creator(?c, 'María de los Milagros Gutiérrez') ^ hasCreator(?lo,?c) → OntoDC: Creator(?c, 'María de los Milagros Gutiérrez')
Affiliation	OntoVC: Creator(?c, 'María de los Milagros Gutiérrez') ^ OntoVC: Affiliation (?a, 'Universidad Tecnológica Nacional. Facultad Regional Santa Fe. Cidisi, Argenitna') ^ isMemberOf(?c, ?a)→ OntoDC: Description (?a, 'Universidad Tecnológica Nacional. Facultad Regional Santa Fe. Cidisi, Argenitna')
Publisher	OntoVC: LearningObject(?lo) ^ OntoVC:Publisher(?p, 'Universidad Tecnológica Nacional') ^ hasPublisher (?lo,?p) → OntoDC: Publisher(?k, 'Universidad Tecnológica Nacional')
Rights	OntoVC: LearningObject(?lo) ^ OntoVC:Rights(?r, 'openAccess') ^ hasRights(?lo,?r) → OntoDC: Rights(?r, 'openAccess')
UriLicense	OntoVC: Rights(?r, 'openAccess') ^ UriLicense(?u, 'http://creativecommons.org') ^ isUriLicense (?r,?u) → OntoDC: RightsStatement (?u, 'http://creativecommons.org')
Snrd	OntoVC: LearningObject(?lo) ^ OntoVC: Snrd (?s, 'Artículo') ^ OntoVC: hasSnrd (?lo,?s) → OntoDC: Type (?s, 'DCMIType') ^ Type (?s, 'Text')
Context	OntoVC: LearningObject(?lo) ^ OntoVC: Context (?c, 'HigherEducation') ^ hasContext (?lo,?c) → OntoDC: EducationLevel (?c 'HigherEducation')
Role	OntoVC: LearningObject(?lo) ^ OntoVC: Role (?r, 'Learner') → OntoDC: Audience (?r, 'Learner')

4.2 Searching for LO

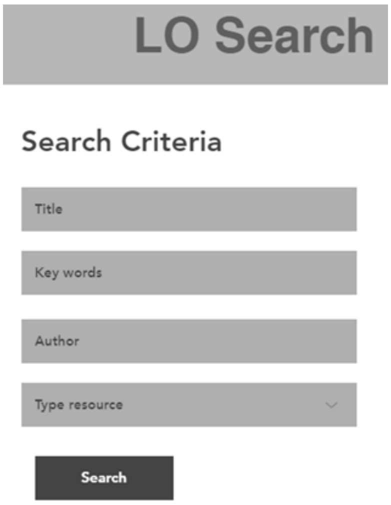
When the option 01/LO Search is selected, a new window will open (see Figure 11), where the user can enter the values required for searching. For example, in Figure 11, a search for

LO with the *keyword* ‘ecuaciones diferenciales’ is performed. To find LOs that match this condition, the matching rules that identify equivalent concepts in OntoDC, OntoLOM and other ontologies are applied. In this case, equation (15) shows the matching rule for OntoDC, while equation (16) shows the matching rule for OntoLOM.

OntoVC: LeaninObject (?lo) ^ OntoVC: Keyword(?k, ‘ecuaciones diferenciales’) ^ hasKeyword (?lo,?k) → OntoDC: Subject(?k, ‘ecuaciones diferenciales’) (15)

OntoVC: LeaninObject (?lo) ^ OntoVC: Keyword(?k, ‘ecuaciones diferenciales’) ^ hasKeyword (?lo,?k) → OntoLOM: Subject(?k, ‘ecuaciones diferenciales’) (16)

Figure 11 Search criteria



Using these values, the search is performed in different repositories. SPARQL query 17 shows the search in a repository implementing OntoDC, while SPARQL query 18 shows the search in a repository implementing OntoLOM.

```
SELECT ?title ?creator ?type ?language
WHERE {(?subject OntoDC:defines ?title. {(?creator
OntoDC:creator ?title. ?type OntoDC: DCMIType ?title.        (17)
?language OntoDC: LinguisticSystem ?title.
FILTER regex(str(?subject, 'ecuaciones diferenciales')}
```

```
SELECT ?title ?author
?learningResourceVocabularyItem ?language
WHERE {(?subject
OntoLOM:GeneralPropertiesCategory ?title. ?author
OntoLOM:Entity ?title. ?                                     (18)
learningResourceVocabularyItem
OntoLOM:VocabularyItem ?title. ?language
OntoLOM:Language ?title.
FILTER regex(str(?subject, 'ecuaciones diferenciales')}
```

Figure 12 shows results obtained from different repositories.

Figure 12 Search results

5 Conclusions

This article presents an interoperability model for LOR based on an ontological solution with a hybrid approach. Several tasks were performed, including the definition and implementation of a common vocabulary represented in the OntoVC ontology, the search and selection of the metadata standard ontologies most used by repositories, and the definition and implementation of mapping rules between OntoVC and each of the selected ontologies. Different ontology matching techniques were evaluated to provide the necessary mapping rules for the model. Initially, the AgreementMarker tool was used to perform mappings among ontologies, but the results were unsatisfactory for both the base similarity matcher and the parametric string matcher. Therefore, a manual mapping using a context-based strategy, which considers the semantic associated with each of the terms, was performed. To demonstrate the validity of the proposed model, a prototype was developed that shows how to deposit and search for a LO using this proposal. The execution of OntoVC instantiation, derivation and mapping rules was demonstrated for the deposit action, while the execution of mapping rules and SWRL queries to search local ontologies was demonstrated for the search action. The proposal achieved the objectives and semantic interoperability among repositories, as demonstrated by the presented examples.

The proposal has the advantage of being flexible. If there is a need to add a new data source with a different metadata standard, it would require only the inclusion of mapping rules in both directions, from OntoVC to the new metadata standard and vice-versa.

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