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ONTOGuide: A Domain Ontology for the Retrieval and Publication of Online Educational Resources

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Abstract

In today's digital landscape, the exponential growth of information on the web has led to challenges in its organization and management. Often, resources published on the web lack proper structure or appropriate descriptions, thus making it difficult to establish connections with similar resources—a critical issue when searching for

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educational materials. In such searches, the need for clear, reliable, and immediately available information takes precedence. There are strategies to tackle this problem, the use of ontologies stands out as a compelling solution because they offer a well-defined, lucid, and precise structure within specific domains. Consequently, this study focuses on crafting a domain-specific ontology that furnishes the required knowledge for publishing and retrieving educational resources from the web. We follow the methodology outlined in "Ontology Development 101: A Guide to Creating Your First Ontology" to design it. The outcome is a domain ontology applicable from two distinct perspectives: an academic standpoint, catering to those who seek to understand the underlying concepts, properties, and relationships involved in resource publication and retrieval; and an industrial one, serving as a support tool for companies or institutions aiming to navigate the process of publishing and retrieving resources to improve the management of their knowledge bases.

Keywords: educational resources; linked data; ontology; open educational resources; protégé tool; SPARQL.

ONTOGuide: Ontología de dominio para la recuperación y publicación de recursos educativos en línea

Resumen

Hoy en día la información en la web crece de forma exponencial, creando inconvenientes en su organización y gestión debidos generalmente a que los recursos publicados en la web no poseen la estructura adecuada o no están descritos de forma apropiada, lo que impide su relación con otros recursos de su mismo tipo. Esto es crítico cuándo se hacen búsquedas relacionadas con recursos educativos, donde a veces prima la urgencia y sobre todo que contengan información clara y confiable para que el usuario que lanza la búsqueda pueda utilizarlos. El uso de ontologías proporciona una estructura bien definida, clara y precisa sobre un determinado dominio. Por tanto, este estudio se centró en la definición de una ontología de dominio específico que proporcione el conocimiento requerido para publicar y recuperar recursos educativos en la web. Para su construcción se siguieron los pasos propuestos en *Ontology Development 101: A*

Guide to Creating Your First Ontology. La ontología de dominio construida puede ser aplicada en dos perspectivas: una académica, para quienes deseen conocer los conceptos, propiedades y relaciones para la publicación y recuperación de recursos; y una industrial, para quienes desean utilizar la ontología como herramienta de apoyo que los guíe paso a paso para publicar y/o recuperar recursos y así mejorar la gestión de sus bases de conocimiento.

Keywords: herramienta Protégé; *linked data*; ontología; recursos educativos abiertos; recursos educacionales; SPARQL.

ONTOGuide: Ontologia de Domínio para Recuperação e Publicação de Recursos Educacionais Online

Resumo

Hoje em dia, a informação na web cresce exponencialmente, criando problemas na sua organização e gestão, geralmente devido ao facto dos recursos publicados na web não terem a estrutura adequada ou não serem descritos de forma adequada, o que impede a sua relação com outros recursos. do mesmo tipo. Isto é fundamental na procura de recursos educativos, onde por vezes prevalece a urgência e, sobretudo, contêm informação clara e fiável para que o utilizador que inicia a pesquisa os possa utilizar. O uso de ontologias fornece uma estrutura bem definida, clara e precisa sobre um determinado domínio. Portanto, este estudo focou na definição de uma ontologia de domínio específico que forneça o conhecimento necessário para publicar e recuperar recursos educacionais na web. Para sua construção foram seguidos os passos propostos em Desenvolvimento de Ontologia 101: Um Guia para Criar Sua Primeira Ontologia. A ontologia de domínio construída pode ser aplicada em duas perspectivas: uma acadêmica, para quem deseja conhecer os conceitos, propriedades e relações para publicação e recuperação de recursos; e uma industrial, para quem deseja utilizar a ontologia como ferramenta de apoio que os orienta passo a passo para publicar e/ou recuperar recursos e assim melhorar a gestão de suas bases de conhecimento.

Palavras-chave: dados vinculados; ferramenta protégé; ontologia; recursos educacionais abertos; recursos educacionais; SPARQL.

I. INTRODUCTION

The amount of information available online has been steadily increasing for several years. Consequently, it has become evident that users face difficulties locating the specific resources they require during their searches [1]. For instance, educational resources have expanded both in quantity and variety [2], leading to user frustration due to the sheer volume of information available on a given topic. This often leads to obtaining irrelevant results that do not match their initial search intent. Broadly speaking, these challenges can be attributed to the following factors [3]: 1) The limited number of metadata to describe educational resources hinders the accuracy and timeliness of search results, i.e., relevant outcomes. This lack of metadata prevents to establish connections between various sets of similar data. 2) A significant disparity in handling metadata for resource description limits the comprehensiveness of searches aimed at obtaining pertinent results. 3) Most online-published educational resources use descriptions that adhere to specific requirements and interests. Necessary metadata to generate a more accurate and consistent resource description, such as complete source data, educational context, and intended competencies, are often omitted. 4) The absence of a uniform identifier for recognizing web resources. 5) Resources are sometimes published without hyperlinks or a descriptive context that would enable their association with other similar resources.

Considering the challenges above, different strategies have emerged to address them, including: 1) using information retrieval systems that leverage preferences and vocabularies to recommend resources; 2) harnessing linked data, which facilitates resource description and establishing connections between them; 3) employing ontologies for knowledge representation, which favors its unification and description [4]. However, a notable gap persists in understanding how to publish and retrieve information effectively, particularly concerning educational resources [4]. The absence of a complete guide detailing the steps and recommended practices for these activities is notable. The closest existing references are linked data principles and Tim Berners-Lee's 5-star scheme [5].

This research presents a solution to the gap in the educational context by structuring and organizing knowledge within a domain-specific ontology for retrieving and publishing educational resources online. This proposal stems from the significant surge in the use of ontologies in education over the past few years. Ontologies find application across three domains: 1) Communication, where the semantics of a system are established, forming a network of relationships to facilitate comprehension and transformation across diverse contexts while also integrating various user perspectives. 2) Interoperability: Ontologies function as interlingua, fostering exchange between different systems. 3) Systems Engineering: Ontologies offer specification, reliability, and information reusability [3]. These implementations cover the need to effectively retrieve and publish educational resources online across different repositories. To design the proposed ontology, the steps outlined in the methodology of Noy and McGuinness [6] are followed. This approach defines the intended users, educational resources, resource types, and where they are or will be published. Finally, it delineates ten classes generated from the combined strategy of generalization and specialization.

This paper is structured as follows: Section II (Methodology) presents the state-of-the-art analysis and recaps the protocol for constructing the ontology. In Section III (Results), the proposed ontology is detailed, along with its implementation and validation process. Finally, Section IV (Discussion and Conclusions) draws some conclusions and delineates potential paths for future research.

II. METHODOLOGY

This section presents the analysis of related work and outlines the steps followed to construct the ontology.

A. Motivation Scenario

Currently, efforts to develop ontologies that generate recommendations for retrieving and publishing educational resources are being made. The work carried out in this regard has primarily focused on representing essential elements within specific domains. Below, we describe some notable works in this field, which were found

through an exhaustive search in main research databases such as SCOPUS and IEEE:

1) Representation of Datasets. Ontologies are developed to represent and discover datasets that describe resources, e.g., Onto4AIR2 [7] illustrates that this straightforward ontology employs vocabularies like FOAF (Friend of a Friend) for metadata definition[8]; SKOS (Simple Knowledge Organization System) for the representation of controlled vocabularies, taxonomies, and thesauri [8]; schema.org provides a collection of vocabularies used to embed metadata in search engine-friendly web pages [8]; Onto4AIR2 facilitates the construction and management of machine-understandable datasets by allowing the addition of new terms, object properties, rules, or constraints. This approach improves the quality, reliability, and reusability of open repository data. In contrast, [9] focuses on the semantic representation of resources within DAJEE (Dataset of Joint Educational Entities) by applying the linked data principles and interconnecting many resources in the web of data. The DBpedia ontology is instrumental and establishes connections to further enrich the resources in DAJEE by providing categories and links considering the user's input. Daga [10], first presents a mapping for IEEE LOM metadata for linked data, and then an implementation of this study.

2) Resource Recommendation. These ontologies are primarily designed to recommend one or several educational resources relevant to a given search. For instance, an ontology centered on educational standards is developed, thus enabling teachers to simplify their lesson development process. It also serves as a support tool for students by establishing links to pertinent educational resources [11]. Moreover, these ontologies play a pivotal role in delivering personalized recommendations. In [12], the EduCOR educational ontology establishes a foundation for representing online learning resources within customized learning systems. This ontology empowers repositories of educational resources to offer tailored path recommendations aligned with the user's learning objectives, academic inclinations, and psychological considerations. Another notable effort is presented in [13], where the OntoSIDES ontology can track student progress. The outcome of this ontology is a taxonomy comprising 52 classes, encompassing seven main

categories that define various potential student actions, types of pedagogical resources, a selection of medical references, French citations, milestones recorded by students as steps toward obtaining a diploma, and a classification of individuals involved in medical studies.

3) Use of Ontology Properties. The following works use pre-existing and tested ontologies, often combining various ontologies to index and upload sets of documents onto the web and leverage semantic links between resources and their underlying concepts. In [14], a collection of pedagogical resources is indexed, using links to facilitate inferences regarding relevant resources. The authors propose three ontology domains: information retrieval, e-learning, and knowledge engineering. For instance, they systematically organize the e-learning domain to improve information retrieval precision. Then, they harness semantic links between resources using extended inference rules. In [15], the DBpedia ontology's resources and categories are employed to identify related videos through a similarity function. Similarly, [16] uses the PAV (Provenance, Authoring, and Versioning) ontology, which offers provenance properties for resources, including essential metadata for their description. Likewise, [17] presents an approach for in-depth extraction of learning objects (LO) that yield pertinent outcomes from educational search engines. This approach relies on semi-automatic metadata detection and the resource relationships established by the proposed OntoAlgO [17] ontology to generate semantic indexing.

In the reviewed papers, we examine various proposals that use ontologies to improve the retrieval of specific types of educational resources on the web. However, these works often lack comprehensive insights into the essential metadata required for publishing and enhancing the retrieval process of educational resources. Furthermore, they may not delve deeply into generating tailored recommendations based on the proposed solutions.

B. Protocol to Construct the Proposed Ontology

A detailed review of methodological approaches to build ontologies such as Methontology [18], REFSENO (Representation Formalism for Software Engineering

Ontologies) [19], Tove [20], Enterprise Model Approach [20], KBSI IDEF5 [20], and Noy and McGuinness [6] was carried out. The latter was selected for the construction of the ontology proposed in this article due to its versatility and results from previous experiences, Figure 1 summarizes it.

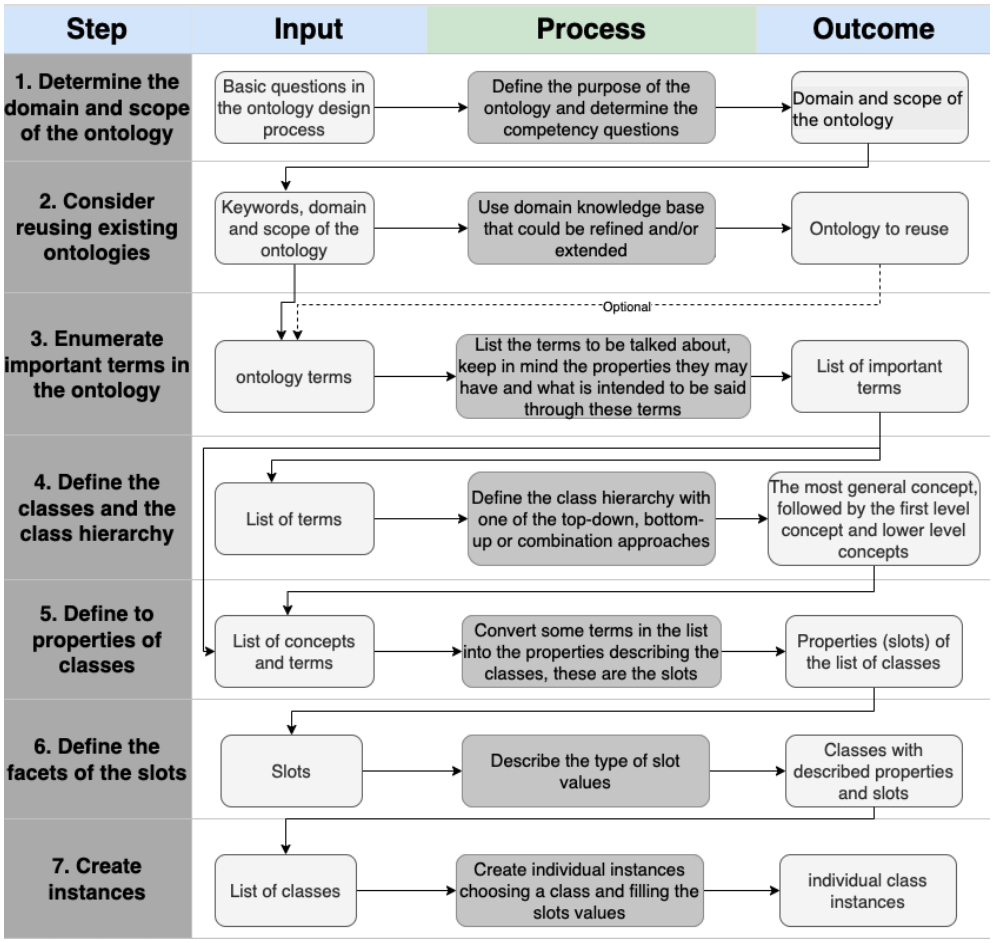

Fig. 1. Steps of the Noy and McGuinness Methodology. Adapted from [6].

The following subsections present the definition of the ontology and its implementation using the RDF markup language, which is the most important due to the simple form of its model for describing resources. This model is essential to store information efficiently, process it automatically, and exchange data between applications in triple form, each made up of a subject, a predicate, and an object. A set of such triples is called an RDF graph [21], which is represented in the Protégé tool.

The Protégé tool allows knowledge to be formally represented in the form of logic-based ontologies and with precisely defined semantics under the World Web (W3C), the standard language for web ontologies. Protégé has experienced a growing demand from users, both in industry and academia [22].

C. Purpose

The overarching goal of the ontology is to provide users with a guide or a set of steps for publishing and retrieving educational resources on the web. Doing so gives individuals interested in these processes an understanding of the required concepts and relationships, irrespective of their chosen approach. This ontology serves the following perspectives:

- ***Academic:*** Those seeking knowledge on a particular subject can employ the ontology to familiarize themselves with relevant terms and relationships.
- ***Productive or industrial:*** Companies or educational institutions aiming to enhance their document management process can use the ontology to facilitate the publication and retrieval of their knowledge bases.

D. Competency Questions

Competency questions are formulated in natural language to ascertain the ontology's scope. These questions, along with their corresponding answers, helped extract the main concepts, their relationships, and properties within the ontology. It's important to note that no existing ontologies are aligned with the defined purpose; therefore, they have not been considered in this design. The proposed ontology aims to address the questions presented in Table 1.

Table 1. Competency Questions

Type	Id	Competency questions
Structure	CQ1	What attributes should be considered when defining an educational resource?
Structure	CQ2	How do educational resources relate to each other on the web?
Individual	CQ6	What specific metadata describes educational resource X?
Individual	CQ7	What is the first recommendation for retrieving and publishing educational resources?

Type	Id	Competency questions
Structure	CQ3	How is metadata written to describe an educational resource?
Structure	CQ4	How does the educational resource relate to the user?
Individual	CQ5	What attributes are associated with the educational resource X?

Type	Id	Competency questions
Individual	CQ8	What recommendations apply to the educational resource X?
Individual	CQ9	Who owns the educational resource X?

E. Definition of Concepts, Properties, and Relationships

The key terms within the ontology resulting from the literature review, metadata of interest for the publication, and retrieval of educational resources are Publication, Owner, User, Publisher, Person, Educational resource, Retrieval, Resource type, Type of Site, Recommendation, and Metadata. Table 2 showcases the classes and their hierarchical arrangement, established through a combined strategy of generalization (top-down) and specialization (bottom-up) to identify the main concepts.

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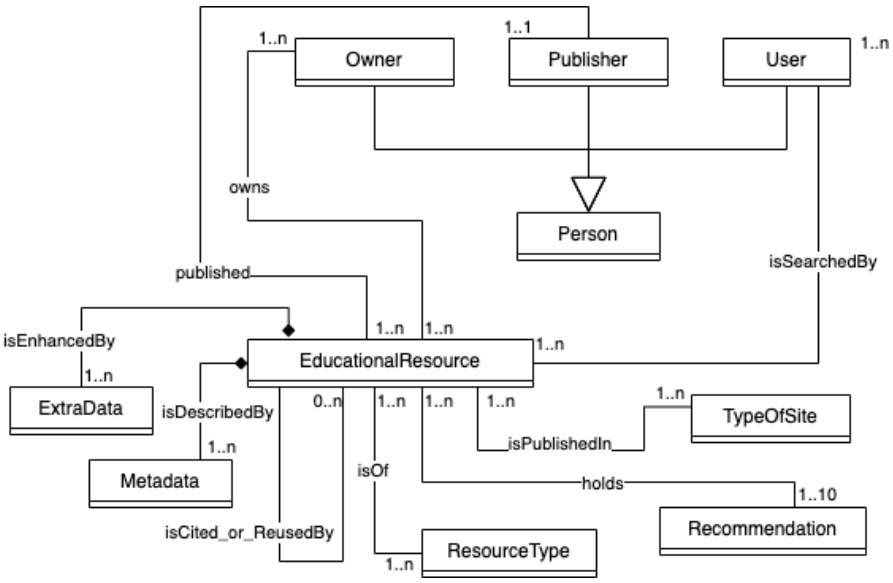


Fig. 2. Definition of class hierarchy.

Table 2. Classes.

Class	Super-concept	Definition	Source
Owner	*Person*	Describes significant attributes that link educational resources to their owners and	Own

Class	Super-concept	Definition	Source
		facilitates the process of publishing or searching for them.	
User	*Person*	Defines significant attributes that connect educational resources with users who wish to retrieve them.	Own
Publisher	*Person*	Specifies crucial attributes that establish connections between educational resources and people interested in publishing them.	Own
Person	*Concept*	Encompasses key attributes of users, publishers, and owners of educational resources.	Based on [7]
EducationalResource	*Concept*	Refers to all forms of digital content intentionally designed for educational purposes and available on a network like the Internet.	Based on [3]
ResourceType	*EducationalResource*	Outlines the various formats that educational resources can take, including textual, audio, visual, audiovisual, and multimedia formats.	Based on [3]
TypeOfSite	*EducationalResource*	Refers to websites or platforms where educational resources are published, such as wikis, video-on-demand pages, web pages, blogs, and others.	Own
Recommendation	*Concept*	Presents a structured sequence of steps necessary for correctly publishing or retrieving educational resources.	Own
Metada	*EducationalResource*	Comprises data aimed at thoroughly and accurately describing the attributes of educational resources.	Based on [3]
ExtraData	*EducationalResource*	Offers additional information that briefly describes essential aspects of the educational resource.	Own

Table 3 describes the relationships that provide complementary information between the concepts.

Table 3. Relationships and Cardinality.

Relationship	Concept	Description
owns	*Owner – EducationalResource*	An owner owns one or many educational resources, while an educational resource is owned by one or many owners.
isSearchedBy	*EducationalResource – User*	An educational resource is searched by one or many users, while a user searches for one or many educational resources.
published	*Publisher – EducationalResource*	A publisher may publish one or many educational resources, while an educational resource is published by one and only one publisher.
isPublishedIn	*EducationalResource – TypeOfSite*	An educational resource can be published on one or many types of sites, while a type of site can host one or many educational resources published within them.

Relationship	Concept	Description
isCited_or_Reused By	*EducationalResource – EducationalResource*	An educational resource might be cited or reused by other educational resources or by none.
holds	*EducationalResource - Recommendation*	An educational resource holds a minimum of one and a maximum of ten recommendations; in turn, a recommendation applies to one or many educational resources simultaneously.
isOf	*EducationalResource - ResourceType*	An educational resource can fall into one or many resource types (isOf), while an educational resource type can be associated with one or many educational resources.
isDescribedBy	*EducationalResource – Metadata*	An educational resource is described by at least one metadata or many metadata entries.
isEnhancedBy	*EducationalResource ExtraData*	An educational resource is enriched by at least one or many pieces of complementary information.

Figure 3 defines the classes' properties along with their corresponding value types, illustrating the overall design of the proposed ontology.

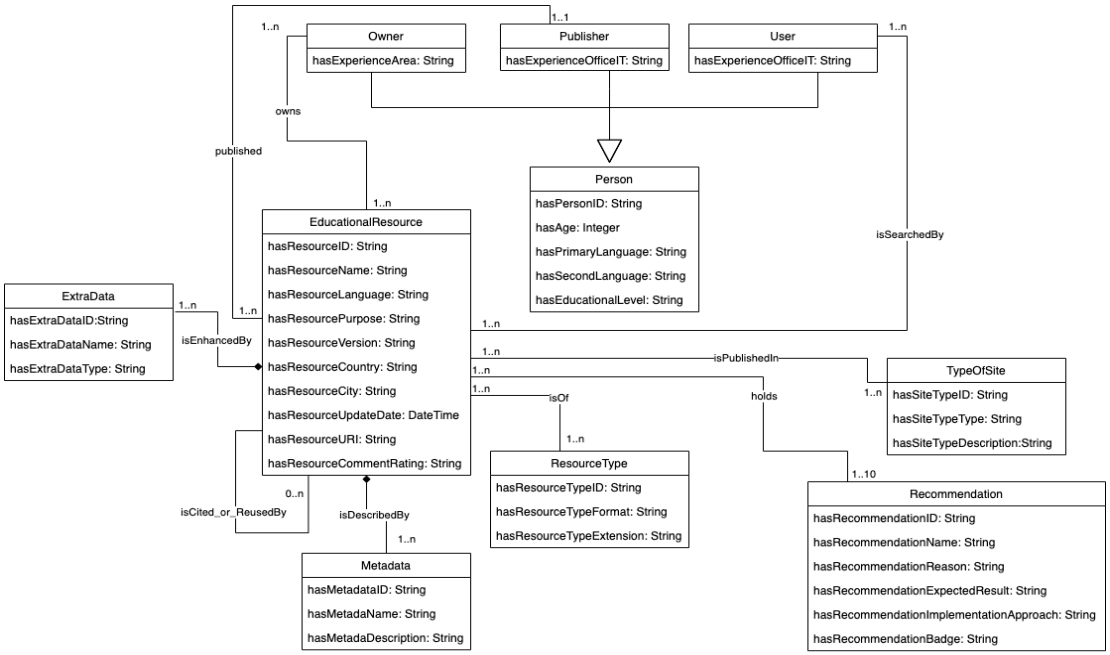


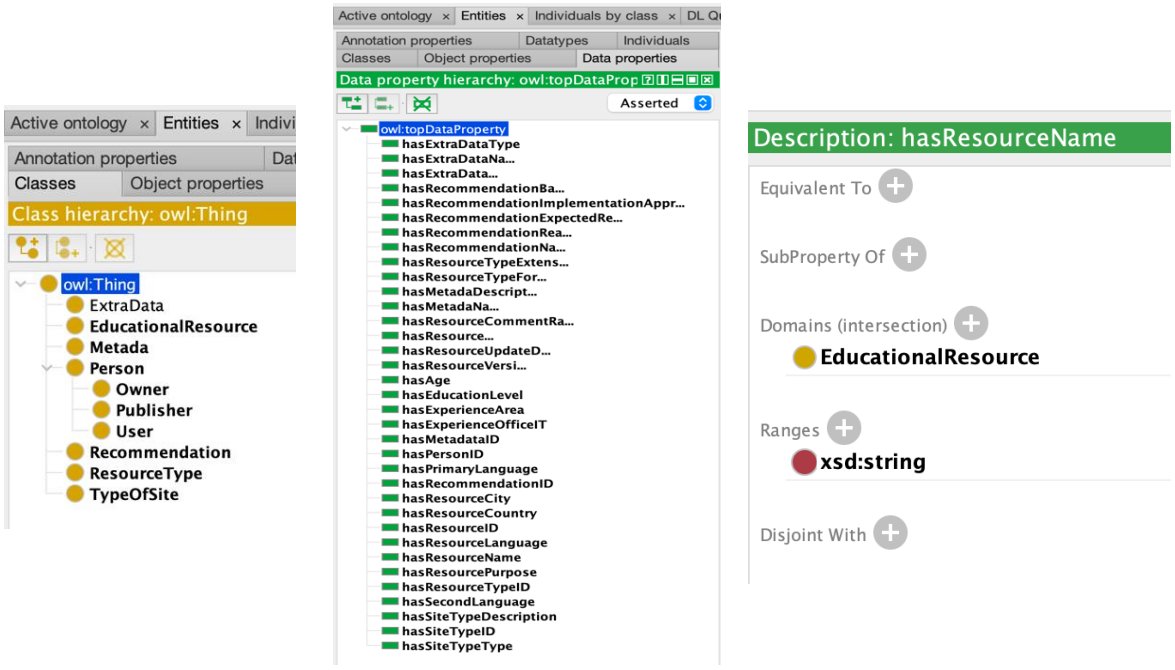
Fig. 3. General design of the ontology.

F. Implementation

Creating the Class Hierarchy. Figure 4 (a) illustrates the classes formulated under a larger entity, denoted by default as OWL:Thing in the Protégé tool. This hierarchy is established by considering the level of each class and its subclasses.

Definition of Data Properties. Figure 4**Fig.** (b) and (c) provide the list of properties, along with an illustrative domain and range example.

Definition of relationships. Figure 5 (a) and (b) depict the ontology relationships list, offering an example of one relationship's description. Each relationship between ontology classes is established while considering the associated cardinality. For instance, the cardinality between an educational resource and a user is many-to-many (the relationship must be completed separately), denoted as isSearchedBy and searchFor in Protégé.



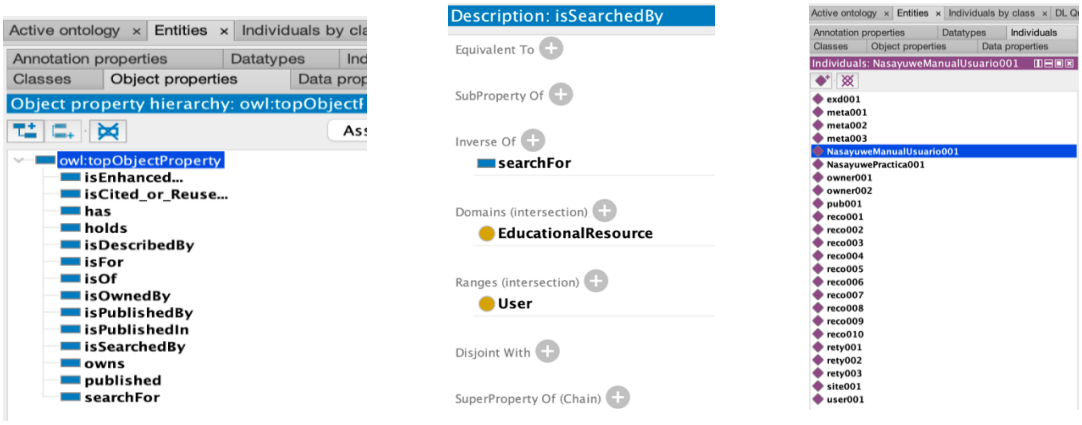
(a) Definition of the class hierarchy in Protégé.

(b) List of properties. Source: Own.

(c) Description of the hasResourceName property.

Fig. 4. Implementation of the ontology classes in Protégé.

Creation of Individuals. Figure 5 (c) showcases the generated individuals alongside their respective properties for a specific context. This step ensures that the ontology effectively addresses the competency questions outlined in Table 2.



(a) List of relationships in Protégé.

(b) Description of the isSearchedBy relationship.

(c) Created individuals

Fig. 5. Implementation of relationships and visualization of individuals of the Ontology in Protégé.

Figure 6 presents the Ontology implementation in Protégé as a graph, providing a visual depiction of the classes, their relationships, and hierarchies.

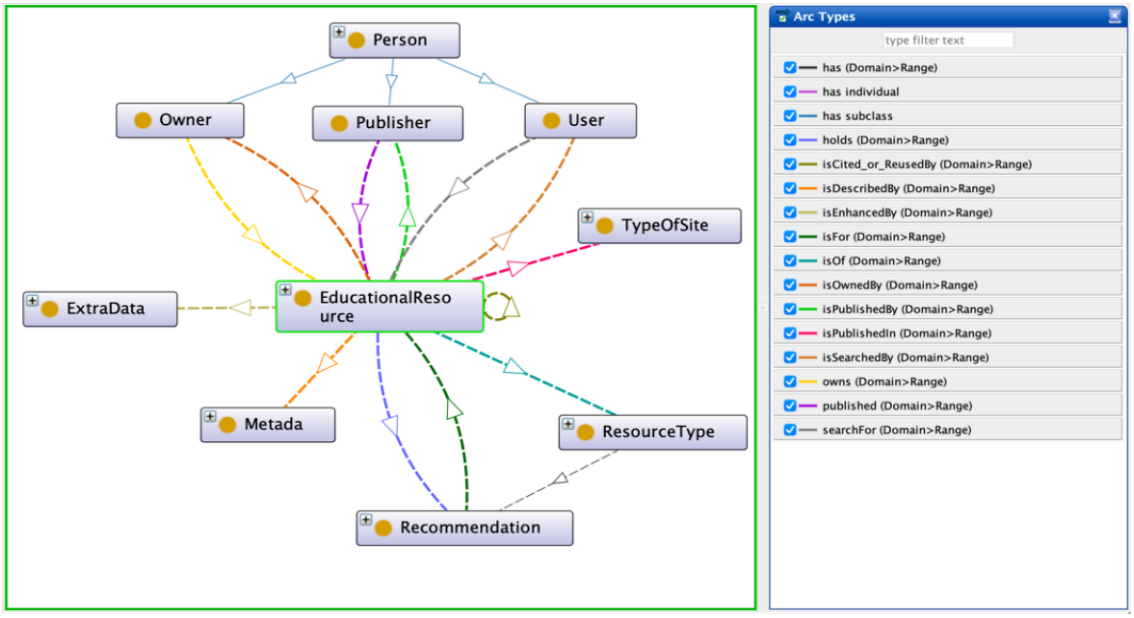


Fig. 6. Ontology knowledge graph.

III. Results

With the OWL ontology generated by the Protégé tool, it is possible to evaluate the ontology to validate if it meets the purpose for which it was built. It evaluates the

performance of the triples [23] in such a way that the validation of the built ontology was made through competency questions executed in SPARQL queries.

The structure of the proposed ontology successfully addresses the formulated competency questions. These are designed to align with the ontology's intended purpose. Table 4 presents the questions in natural language as well as their corresponding SPARQL queries, and the desired answers in natural language.
As a key point, it is highlighted that the responses of the ontology allow for greater expressiveness in the queries that a user can make in an information retrieval system for educational resources, in that sense, the system will be able to recover information with greater relevance and similarity of the metadata of the educational resources to be published to satisfy the needs of users.

Table 4. Competency Questions in SPARQL Query Language.

Id	Competency Questions	Questions in SPARQL	Desired Answers
CQ1	What attributes should be considered when defining an educational resource?	SELECT ?attributes WHERE { ?atributos rdfs:domain onti:EducationalResource . ?atributos rdfs:range ?tipo . FILTER(?tipo in (xsd:string,xsd:dateTime)) . }	An educational resource must have the following attributes: identifier, name, language, purpose, version, country, city, update date, URI, and comments or rating.
CQ2	How do educational resources relate to each other on the web?	SELECT * WHERE { ?relacion rdfs:domain ?clase . ?relacion rdfs:range onti:EducationalResource . FILTER(?clase in (onti:EducationalResource)) . }	Educational resources are related to others through bibliographic citations or links (URIs) within the network or web of data.
CQ3	How is metadata written to describe an educational resource?	SELECT ?atributos WHERE { ?atributos rdfs:domain onti:Metada . ?atributos rdfs:range ?tipo . FILTER(?tipo in (xsd:string,xsd:dateTime)) . }	Metadata is written with an identifier, a name, and a description. For instance, id:metadata001, name: Keywords, and description: publication, nasayuwe.
CQ4	How does the educational resource relate to the user?	SELECT * WHERE { ?relacion1 rdfs:domain ?resource . ?relacion1 rdfs:range ?user . ?relacion2 rdfs:domain ?user . ?relacion2 rdfs:range onti:EducationalResource . FILTER(?user in (onti:User)) . }	An educational resource is retrieved by one or many users, while a user retrieves one or many educational resources.
CQ5	What attributes are associated with the **NasayuweManualUsuario001** educational resource?	SELECT * WHERE { ?atributos rdfs:domain onti:EducationalResource . ?atributos rdfs:range ?tipo . FILTER(?tipo in (xsd:string,xsd:dateTime)) .	The attributes describing the resource are identifier, name, language, purpose, version, country, city, update date, URI, and comments or rating.

Id	Competency Questions	Questions in SPARQL	Desired Answers
		?recurso rdf:type ?type . FILTER(?type in (onti:EducationalResource)) . FILTER(?recurso in (onti:NasayuweManualUsuario001)) }	
CQ6	What specific metadata describes the **NasayuweManualUsuario001** educational resource?	SELECT ?recurso ?metadatos WHERE { ?recurso rdf:type ?type . FILTER(?type in (onti:EducationalResource)) . ?recurso onti:isDescribedBy ?metadatos}	The metadata describing the resource are meta001, meta002, and meta003.
CQ7	What is the first recommendation for retrieving and publishing educational resources?	SELECT ?nombre ?recomendacion ?id WHERE { ?recomendacion rdf:type ?type . FILTER(?type in (onti:Recommendation)) . ?recomendacion onti:hasRecommendationID ?id . FILTER(?id in ("r-paso1")) . ?recomendacion onti:hasRecommendationName ?nombre}	The first recommendation is: Description of the context or purpose of the educational resource.
CQ8	What recommendations apply to the **NasayuweManualUsuario001** educational resource?	SELECT ?recurso ?recomendacion ?nombre ?id WHERE { ?recurso rdf:type ?type . FILTER(?type in (onti:EducationalResource)) . ?recurso onti:holds ?recomendacion . ?recomendacion onti:hasRecommendationID ?id . ?recomendacion onti:hasRecommendationName ?nombre}	An educational resource can hold between 1 and 10 recommendations. In this case, the NasayuweManualUser001 educational resource holds ten recommendations.
CQ9	Who owns the **NasayuweManualUsuario001** educational resource?	SELECT ?recurso ?propietario ?id WHERE { ?recurso rdf:type ?type . FILTER(?type in (onti:EducationalResource)) . ?recurso onti:isOwnedBy ?propietario . ?propietario onti:hasPersonID ?id . FILTER(?recurso in ("NasayuweManualUsuario001"))}	An Owner owns one or many educational resources, while an educational resource is owned by one or several owners. In this case, owner001 owns NasayuweManualUser001.

IV. Discussion and Conclusions

The endeavor to publish educational resources based on established principles is a required and indispensable step that fosters the sharing and ease of access to high-quality resources for users. Therefore, creating an ontology dedicated to publishing and retrieving educational resources on the web not only supports the consolidation of knowledge but also constitutes a valuable contribution to the specific domain. The designed ontology effectively addresses the competency questions through SPARQL, validating its alignment with the defined purpose.

This domain ontology holds applicability from two distinct perspectives: an academic standpoint, catering to those who seek to understand the underlying concepts, properties, and relationships involved in resource publication and retrieval; and an industrial angle, serving as a support tool for companies or institutions aiming to navigate the process of publishing and retrieving resources to improve the management of their knowledge bases.

For future work, the immediate plan involves generating recommendations for publishing and retrieving educational content online. These recommendations stem from the structured organization of specific ontology knowledge. The next step entails implementing a software solution complete with a user interface. This interface will grant access to the designed ontology, which can then be used across diverse environments along with the generated recommendations. Moving forward, the application of machine learning along with the ontology will be explored. The aim is to derive personalized recommendations based on factors such as the environment, subject matter, resource type, and user preferences. The last step's end goal is to introduce these recommendations into productive or industrial environments, thereby enhancing information management practices.

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AUTHORS' CONTRIBUTIONS

Paola-Andrea Otero-Cano: conceptualization, formal analysis, software, investigation, writing-original draft.

Luz-Marina Sierra-Martínez: supervision, investigation, writing-review and editing.

Hugo-Armando Ordoñez-Eraso: supervision, investigation, writing-review and editing.

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