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Ontologies in E-Learning: Review of the Literature

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Abstract

We have witnessed a great interest in ontologies as an emerging technology within the Semantic Web. Its foundation that was laid in the last decade paved the way for the development of ontologies and systems that use ontologies in various domains, including the E-Learning domain. In this article, we survey key contributions related to the development and use of ontologies in the domain of E-Learning systems. We provide a framework for classification of the literature that is useful for the community of practice in categorizing work in this field and for determining possible research lines. We also discuss future trends in this area.

Keywords: *Ontology, E-Learning, Semantic Web, Linked Data*

1. Introduction

Ontologies are formal structures that provide a shared understanding of a certain domain. They represent the semantics of a domain explicitly, enabling intelligent access to information. Since the early nineties, ontologies have been a popular research topic in the artificial intelligence community. These research topics include knowledge engineering, natural language processing, and knowledge representation. In the past decade, with the introduction of the Semantic Web, ontologies have grown in popularity. More recently, the notion of ontology is more prevalent in the E-Learning domain. Semantic Web and ontologies have been used in E-Learning in different ways, such as representing domain knowledge, providing metadata for key concepts and entities in the learning domain, allowing for a richer description and retrieval of learning content, facilitating exchange and sharing of learning content, personalizing and recommending learning content, designing curricula, and assessment of learning [1].

This paper presents a survey of key contributions related to development and usage of ontologies in the E-Learning domain. A strong motivation for embarking on this survey is the increased interest in the development and usage of ontologies since the year 2000. Since 2007, the volume of published papers has grown tremendously. Additionally, the number of computer science publications with "Ontology" in the title or as a keyword increased each year between 2000 and 2012. These searches were carried out against the digital libraries of ACM, IEEE, Science Direct, and Web of Science. This trend of increasing interest in ontologies is apparent in other fields, such as in E-Learning. These trends indicate a growth in interest related to ontologies and the use of ontologies in E-Learning systems, as observed in Figure 1 and Figure 2.

In this article, we comprehensively survey, analyze, and identify current usage and future prospects of ontologies related to E-Learning.

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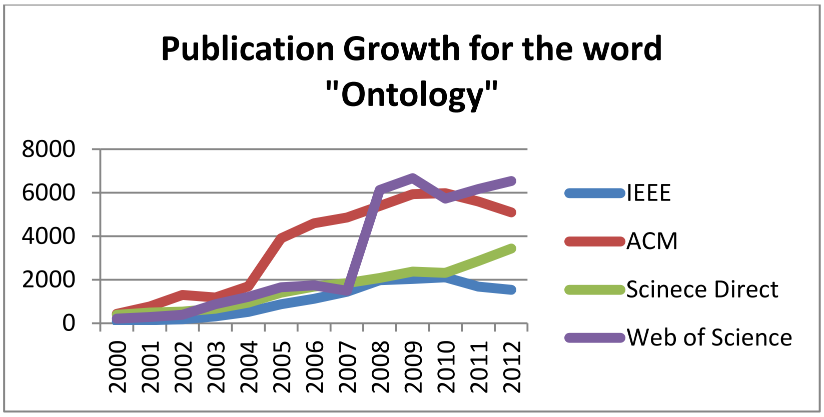

Figure 1. Publication Growth for the Word "Ontology"

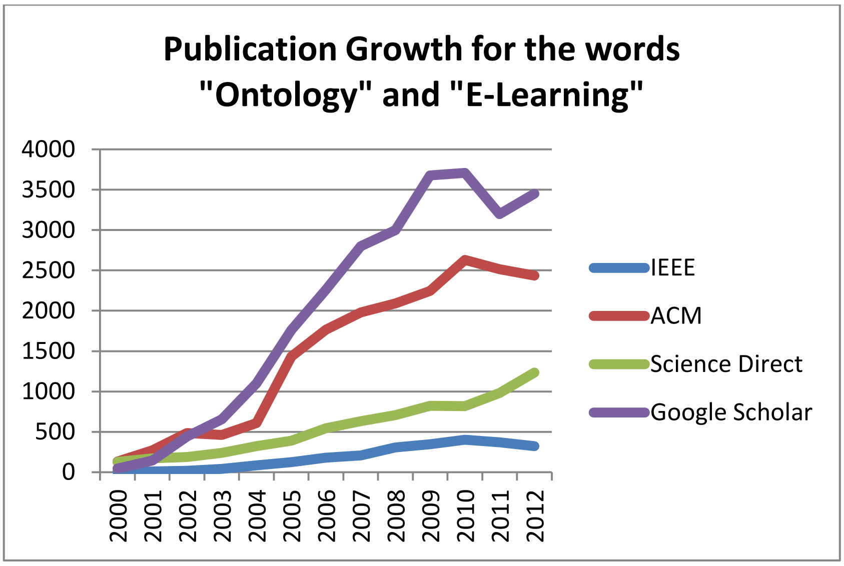

Figure 2. Publication Growth for the Words "Ontology" and "E-Learning"

The organization of this article is as follows: presentation and background on Semantic Web and ontologies in Section 2. Section 3 defines E-Learning and identifies key E-Learning tasks. In Section 4, ontologies and E-Learning intersect as the section describes the usage of ontologies in various E-Learning systems. Section 4 also presents recent trends and developments in the use of ontologies in E-Learning systems. Section 5 provides discussion of the survey analysis and results. It also highlights challenges identified when ontological structures are used within E-Learning systems. Finally, section 6 concludes the article with a summary of the findings, and a glimpse into future trends for the use of ontologies related to E-Learning systems.

2. The Semantic Web and Ontologies

The Semantic Web [2] is defined as "an extension of the current web in which information is given well-defined meaning." It envisions a machine-understandable web with an explicit semantic representation of underlying web pages, web data, and other web resources. In this vision, web-based services will assist humans by understanding more of the content and data on the web, linking them in new meaningful ways. This results in more accurate filtering, categorization, searching, and reasoning about information resources and data. For the Semantic Web vision to flourish and be fully realized, standards for sharing and representation of meanings are required [3]; ontologies serve this purpose.

Ontologies define a common, shareable view of a domain. They give meaning to information structures exchanged by information systems [4]. The formal definition of ontology by Gruber [5] is that an "ontology is a an explicit specification of a conceptualization." Ontologies specify or model the domain using concepts, attributes, and relationships. This explicit formal representation provides meaning for the vocabulary.

2.1. Types of Ontologies

Various classification systems are presented in the literature for ontologies. Mizoughi and colleagues [6] classified ontologies to four types: content, communication, indexing, and meta-ontologies. Content ontologies are further classified as domain, task, and general/common ontologies. Van Heijst and colleagues [7] provide two classifications for ontology types: type and structure of conceptualization, and subject of conceptualization. Guarino [8] classifies ontologies according to their level of dependence on a particular task. They distinguish between top-level, domain, task, and application ontologies. Lassila and McGuinness [9] classify ontologies according to the information need, and richness of the internal structure. They identify the following types of ontologies: controlled vocabularies, glossaries, thesauri, informal is-a hierarchies, formal is-a hierarchies, formal instances, frames, value restrictions, and general constraints. Another ontology classification is based on the subject of the conceptualization [10]. This classification distinguishes between four types of ontologies: domain ontologies, task ontologies, domain-task ontologies, and application ontologies. We use these four types (shown in Figure 3) to guide our review of the literature on the use of ontologies in E-Learning. We describe each type in detail.

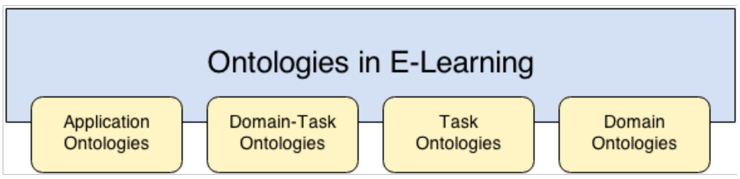

Figure 3. Ontology Classification

Domain ontologies are reusable within a specific domain (medical, biology, tourism, film, sports, history, law, *etc*.,); they represent knowledge and provide vocabulary for concepts and activities within a specific domain. The main characteristic of these ontologies is that they are independent of any specific task or application.

Task ontologies describe vocabulary relevant to a generic task or activity, such as selling, buying, or problem solving. The task can be applied in any domain.

Domain-Task ontologies represent the vocabulary for a task within a specific domain. They are not reusable across domains.

Application ontologies are application-dependent and describe vocabulary relevant to a specific application. They usually extend domain and task ontologies, with greater relevancy to a specific application or problem.

3. E-Learning

Elliot Masie is acknowledged as the first analyst to use the term "E-learning" in 1998. He defined E-Learning as "Learning on Internet time, the convergence of learning and networks. E-Learning is a vision of what corporate training can become. E-Learning is to traditional training as e-Business is to business as usual" [11]. E-Learning is "instruction delivered on a digital device that is intended to support learning" [12]. Although the term appeared within the domain of professional training, it later transferred to primary, secondary, and higher education communities. The term "E-Learning" is synonymous with usage of the internet and web-related technology in the context of education and/or training. A recent definition of E-Learning by the American Society for Training and Development (ASTD) [13] is "the use of electronic technologies to deliver information and facilitate the development of skills and knowledge. "

Dicheva [14] identifies three generations of web-based educational systems. The first generation enabled access to learning materials and online courses, such as Learning Management Systems (LMS) and educational portals. The second generation, which comprised web-based E-Learning systems, used artificial intelligence techniques to support new functions beyond content presentation. For example, these functions might include content adaptation to user preferences, needs, and abilities. These systems are often called educational adaptive hypermedia systems. With advancements in web technology (specifically, the Semantic Web), third generation E-Learning systems appeared. These systems used ontologies and other Semantic Web technologies to enable scalability, reusability, and interoperability of educational content distributed over the Web. With the rapid development of wireless and mobile technology, E-learning is crossing over to mobile devices. The term ubiquitous learning, Mobile-learning or m-Learning [15], is an innovative concept that helps students gain easily accessible information on-demand. This model of learning is classified as fourth generation E-learning.

3.1. Standards in E-Learning

Given advancements in web technology, global agencies, organizations, and publishers began proposing and promoting the use of standards for representing E-Learning content associated with E-Learning systems or educational content. Educational metadata standards have emerged to define a standard specification of a learning resource or component. A Learning Object (LO) is an example of a resource used to facilitate accessibility, interoperability, and reusability of learning materials. Using such standards enables education content publishing with rich, education-specific metadata. This enhances the possibility that the content is recognized by major search engines, making it more accessible to learners. Common standards in the domain of E-Learning include the following: IEEE LOM (Learning Object Metadata) [16], Dublin Core [17], SCORM [18], IMS Question and Test Interoperability (IMS QTI) [19], and IMS Content Packaging [20] [21].

A recent initiative for an E-Learning standard is the Learning Resource Metadata Initiative (LRMI) [22], co-led by the Association of Educational Publishers (AEP) and Creative Commons (CC). LRMI is an international initiative focused on metadata for usability and search-ability of educational resources, rather than cataloguing or classification. "Schema.org" adopts this standard as a repository for metadata used by major search engines such as Google, Yahoo, and Bing.

3.2. E-Learning Content and E-Learning Tasks

E-Learning content refers to the associated learning material and activities. R. Robson authored a detailed review on learning content related to E-Learning, its history, and how it is changing [21]. In E-Learning systems, representation of learning content is accomplished through units of learning called Learning Objects (LOs). Siqueira and colleagues [23] describe three layers for modeling the content of an E-Learning system: (1) representing the semantics embedded in the LOs, (2) representing LOs and learning activities, and (3) coordination of content and activities for achieving the learning objectives. In the third layer, the sequence of learning material (e.g., content and activities) is identified according to characteristics such as knowledge requirements, or the learner profile.

An E-Learning task refers to the processes required for an E-Learning system to provide a specific service for users such as learners, instructors, or curriculum designers. E-Learning tasks include curriculum management and modeling, domain knowledge representation, learner profile personalization, and E-Learning services representation.

4. Ontologies in the Context of E-Learning

Ontologies and other Semantic Web technologies have been discussed in the context of E-Learning since early 2004 [24]. Ontologies are used in various ways in E-Learning systems, depending on the E-Learning task they serve. The following classification is used to review the literature in the area of ontologies with regard E-Learning systems:

- *Curriculum Modeling and management*. Curriculum elements are modeled to facilitate access and retrieval of curriculum information. This enables the curriculum developers to view the overall curriculum and ensure compliance with the vision and mission of the institution. It also provides a structure where learning units can be linked to outcomes and learning objectives. In addition, it also facilitates periodic assessment and review, and it ensures alignment with market needs and standards and accreditation requirements. It also facilitates the building of a new curriculum, and the revision of existing curriculums. In addition, it can be used for program review, assessment, and improvement by :
    - defining major curriculum elements,
    - linking the learning units with objectives and outcomes
    - and linking learning units with other learning units (sequencing, pre-requisite)
- *Describing learning domains* from different perspectives, allowing for a more rich description and retrieval of learning content:
    - Subject domain ontology (history, geography, programming, *etc*.)
    - Learning task ontology (lesson, activity, assessment item, simulation, exercise, LO, feedback)
- *Describing learner data*; this is useful for assessment and personalization. Personalization according to the learner profile may include sequencing the learning material, and tracking the learner performance:
    - Performance data (assessment data)
    - History data (units completed, *etc*.)
- *Describing E-Learning services:*
    - Providing a shared vocabulary for interoperability among various educational systems and the sharing and exchange of data among heterogeneous E-Learning systems

4.1. Curriculum Modeling and Management

A curriculum "maps out how the school facilitates achievement of program learning goals. It is defined by content (theories, concepts, skills, *etc*.), pedagogies (teaching methods, delivery modes), and structures (how the content is organized and sequenced to create a systematic, integrated program of teaching and learning)" [25].

Curricula management refers to the educational institution's "processes and organization for development, design, and implementation of each degree program's structure, organization, content, assessment of outcomes, and pedagogy" [25]. Curriculum management incorporates feedback elicitation from stakeholders; the vision, mission, values, and culture of the institution also influence it. The development is defined as the "development of a formal course of study and the elements of which it is comprised. The contents (*e.g.,* courses, projects, competency examinations) comprising curricula are the means by which programs accomplish educational goals" [26]. The development and review of a curriculum in higher education is a fundamental and dynamic task. Curriculum changes are expected as the profession advances and societal needs change [27].

Given the aforementioned statements on what constitutes a curriculum, and the task of curriculum management, there are a number of entities defined as either objects or tasks. Ontologies can represent these entities in ways that facilitate some defined task within curriculum management. Such tasks include program design, review, and assessment. Using ontologies for curriculum representation also enables decision makers and stakeholders to respond creatively and flexibly to changing cultural and economic climates.

An example of an ontology designed for curriculum management is the CURONTO ontology [28, 29]. CURONTO is designed for the general management of an entire curriculum, in addition to facilitation of program review and assessment. Ontologies can also be used for curriculum resource management, sharing and reuse, providing personalized learning, and improving learning efficiency. It is important that individual course learning outcomes be developed in methods that contribute to overall program learning outcomes. CURONTO supports the curriculum review process, assists in decision-making, identifying gaps, finding repetitions, and aligning standards. In CURONTO, the ontology model is used to map relationships between learning outcomes, learning units, and overall program objectives. It facilitates the review and assessment of the curriculum. The Crampon project [30] sets out to create a knowledge base application to manage and maintain the complex interrelationships between curriculum contents. The data elements and entities in the ontology are cases for inquiry-based learning and their learning outcomes. The knowledge base design uses an ontological construct; however, this work is still in progress. Gescur [31] is a tool that allows educational institutions to manage and evaluate the implementation of the curriculum, and facilitate the curriculum management process. Gescur enables users to analyze how institutions meet standards, assists in planning the academic activities at different granularity levels, and choosing the learning objects for a particular instructional unit. In addition, it provides a platform for enabling the revision of the curriculum from a quality standard perspective in the discipline (*i.e.,* how well quality standards are applied and met). The design of the Gescur system is based on conceptualization of the curriculum management in the secondary school domain, using an ontology that represents all the entities and relations in the domain. As a result, its meaning is formalized and can be understood and exploited by machines. The ontology was used in the development of a web application intended for curriculum management by teachers, departments, and institutions. The conceptual schema was used for generating the data, and supporting the implementation of advanced query facilities.

4.2. Describing Learning Domains

Within the context of E-Learning, two classes define domain ontologies: object-domain ontologies and task-ontologies. Subject-domain ontologies model the subject matter and knowledge elements of a specific domain or part of a domain, such as the history domain. In some instances, it is limited to the content of a specific course or even part of a course. When such ontologies are developed, they are used to annotate learning resources with meaningful conceptual descriptors derived from the domain. In other cases, the subject-domain ontologies provide substance for the learning process. The number of subject-domain ontologies in the literature is enormous; we will limit our description in this section to those incorporated in an E-Learning system. On the other hand, task ontologies are designed to model the structural elements of a learning task. This learning task could be an activity, an assessment item, a simulation, an exercise, a case study, a project, and so on. The main objective of task ontologies is to focus on modeling the learning task, its major components, and the relationship between these components. In addition, task ontologies focus on how these components combine to produce larger components, which are often the structuring of elements within the course. Although differences are present in both types of ontologies, in an E-Learning system, one might find a domain ontology, a task ontology, or both.

An example subject-domain ontology is the "mobile computing ontology" [32] which models conceptual elements in the mobile computing domain, and the relationships between these elements. Another ontology is the "construction education" ontology [33], which provides a model of elements and relations in the field of construction education. Other examples include a Java programming ontology [34], which encompasses all concepts and features of the language construct, and the relationship between objects. A manufacturing ontology [35] is used for knowledge representation of the various concepts and details of the products produced by manufacturers. This ontology serves as an aid to the engineering design process.

Task ontologies can be used to model various e-Learning tasks such as assessment, feedback, pedagogy design, search and retrieval.

4.2.1. Assessment: Assessment is a very important task in the learning process of E-Learning systems. It provides evidence based on the quality of the students intended learning. Using an ontology mapping, the system described in [36] presents a concept map based on assessments from students' learning. The concept map is used as a tool for determining students' knowledge of the topics covered. The student creates a concept map, and this map is converted to an ontology, after which a teacher maps the reference ontology. The reference ontology here is subject-domain ontology. It is compared to the student's answer based on how well they map to each other. An evaluation of the student's learning performance and necessary feedback is provided. The system has a "Teacher Model," which enables the teacher to create the reference ontology. The student is then asked to create the concept map for the content learned within the unit.

Another online assessment system, Ontology E-Learning (OeLe) is presented in [37] and [38]. OeLe is an ontology-based assessment system, which automatically marks the students' free-text answers to questions of a conceptual nature. It does this by mapping the student's answer in the form of a concept map using domain ontology. In addition to marking students' work, the OeLe system also provides feedback and performance evaluations to individual students and teachers. OeLe was piloted during an undergraduate exam in financial accounting. The OeLe E-Assessment platform uses ontologies and other AI techniques to assign scores to students' answers to open questions. OeLe is a web-based system, and the type of assessment items it supports include both closed (multiple choice) and open (text response) answers.

4.2.2.Feedback: Feedback is a learning opportunity and an important component of assessment in any learning environment. It enables students to identify gaps in their learning. In addition, it helps teachers adapt learning designs to the needs of students. Ontologies can play an important role in the design of feedback systems. The work presented in [32] describes an ontology of the "mobile computing" domain, which is used to provide learners with feedback during assessment in the form of recommendations. The ontology models the knowledge learned (domain), and how the knowledge should be learned (task). Feedback is generated automatically for learners. The system provides two types of feedback: student's feedback during learning, and author feedback during course authoring.

Although the OeLe system [37] was originally developed for assessment and marking, it has also been used for generating feedback from the domain ontology used in the annotation and marking processes. Students receive feedback related to their mark, model answer, a description of the concepts for which they did well, and missed marks.

The work presented in [39] describes the Unified Medical Language System (UMLS) as a domain ontology in a tutoring system for medical problem-based learning cases. It uses the domain ontology to assess student answers and generate hints that are relevant to the student activity. The relationships between concepts in the domain ontology are used to assess the correctness of a solution and guide student reasoning toward the correct solution.

The work presented in [40] describes RAMSys, a problem solving system for mathematical exercises based on ontologies. The ontology is used to verify the semantic correctness of mathematical formulas. The ontology infers which properties and relationships can be applied on the objects defined. In addition, the ontology uses the taxonomy of defined symbols in OpenMath to provide feedback for learners.

Another system which uses ontologies for generating feedback is presented in [41]. This system generates feedback to open questions in tests using ontologies and semantic annotations. The feedback is generated by computing the semantic similarity between the annotations of the assessment item and annotations of the student's answer.

4.2.3 Pedagogy design: The system presented in [42] is the Recommendation System of Pedagogical Patterns (RSPP), which uses ontologies to represent pedagogical patterns. A pedagogical pattern is defined as "a detailed description of an educational situation that achieves a specific purpose and that can be repeated given similar circumstances" [42]. The pedagogical patterns ontology (OntoPP) provides a shared representation of pedagogical patterns. In addition, OntoPP provides a standard vocabulary that permits the re-use and sharing of concepts related to a particular knowledge area. This ontological system provides pattern recommendations for educators.

With the goal of helping teachers in planning collaborative learning (CL) scenarios, the work described in [43] presents an intelligent authoring tool called CHOCOLATO. This tool leverages ontologies to represent knowledge related to different pedagogies and collaboration practices. CHOCOLATO provides intelligent guidance that helps teachers create theory-based CL. CHOCOLATO uses information from students and the learning environment to recommend theory-based settings focused on improving the quality of the learning process. The core of CHOCOLATO is the Collaborative Learning Ontology, a pedagogical framework that explicitly and formally represents the core characteristics of learning theories using ontologies. The ontology is built by extracting the core concepts from learning theories and identifying the semantic relations between them. These characteristics are linked with information that can be obtained from students and the learning environment. The system design facilitates efficient pattern searching to find the best CL scenarios, given a set of values in the learning environment.

4.2.4 Search and Retrieval: The CUBER project (Curriculum Builder in the Federated Virtual University of the Europe of Regions) described in [44] presents an ontology-based framework which supports learners in searching higher education courses. This ontology describes the metadata and the semantics of the learning resources. Using the learner profile, it finds the best match from course descriptions. The design of the ontology is based on the LOM standard for E-Learning.

The work presented in [45] is an ontological approach for the enhancement of LOM metadata elements, with semantics to facilitate retrieval of learning objects. It uses an ontology-based query expansion algorithm, utilizing constructs in the ontology such as relations and sub-classes.

The E-Learning framework described in [35] uses an ontology model for representing, storing and retrieving domain knowledge in an E-Learning system. The ontology represents manufacturing (product-process) concepts, learning concepts, and use context. It provides a standardized model for describing new product formation. It is based on the existing configuration rules and structures to facilitate search and retrieval of learning content.

The Information Workbench [46] is a platform for collecting, storing, editing, reporting, and analyzing learning resources. The ontology is used for the presentation and structuring of courses available. In addition, it provides automated matching and retrieval of course modules by defining semantic relations between course topics and terms.

4.3. Describing Learner Data

Learner data is data related to an individual learner, such as a learner profile (personal data), completed content (progress made), and performance data. There are a number of standards for representing learner data, such as PAPI (Public and Private Information) [11], IMS LIP (Learner Information Package) [12], eduPerson [13], Dolog LP [14, 15], FOAF (Friend of a Friend) [16], and so on. Although they share related characteristics (*e.g.,* they provide descriptions of people), they vary on main purpose and the way in which a given system may use their embedded information. Some E-Learning systems use metadata from more than one standard to produce a learner profile. The presentation and contrast related to the primary standards characteristics in [17] denote the importance and the completeness of IEEE PAPI and IMS LIP. The IMS LIP standard is a similar design to classic CV, and the PAPI standard considers student's progress and performance [47].

4.3.1. Representation of a Learner Model: The adaptive e- learning system called Adaptive-Courseware Tutor (AC-ware Tutor) is a probabilistic student model based on a Bayesian network and ontologies [48]. It provides information about the state of a given student’s knowledge. This enables adaptation of the learning content according to the student’s learning needs and requirements. The ontology represents the expert’s knowledge in this system. In addition, it includes knowledge tests for evaluating a student’s knowledge before and after a knowledge test.

The work presented in [47] is a student model based on student's academic progress and personal characteristics. Basic student characteristics include demographic information, knowledge of the domain (level), background and interests, learning styles and interaction preferences, and learning goals. The E-Learning system adopts the basic principles of the student model described in [49] to the needs and characteristics of an adult learner in a distance learning educational framework.

Paneva [50] presents an ontology-based student model for E-Learning systems. The ontology described comprises two main parts: general student information and information about the student's behavior in the learning domain.

4.3.2. Personalization: Personalization is tailoring learner content based on their different needs and preferences. These preferences may include learning style, progress in the learning process, individual background knowledge, and technical needs and requirements (*e.g.,* the device they use while accessing the E-Learning system).

Personalization can be achieved through different methods based on the needs of the user [51]. Content personalization can be obtained through user choice selection, or using the student profile. The user is presented with relevant content suitable for their needs. Another form of personalization is called link or navigation personalization. This method presents links relevant to the learner based on their navigation history. Presentation personalization is presenting content to the learner in the look and feel related to learner choice and preference.

The work in [52] describes a context-aware platform which provides personalized services to the learners. It uses an ontology-based context model with accompanying rule-based context-aware algorithms. These algorithms capture the behavior of the learner and provide relevant material.

The ONTODAPS systems [53] is an ontology-driven disability-aware personalized E-Learning System. ONTODAPS personalizes learning resources and services for students with or without disabilities. In addition, it provides appropriate levels of learner control by allowing them to personalize learning resources.

The work presented in [54] describes a learning environment which personalizes E-Learning related to pedagogy and a personalized educational process. The framework is based on web services, the description of the semantic information of learning units, and the relationship between units.

PASER (Planner for the Automatic Synthesis of Educational Resources) [55] is a retrieval engine for automatic and personalized curricula construction, based on appropriate learning object combinations. The personalization is designed to meet the learner's profile and preferences. The system consists of "(a) a metadata repository for storing learning object descriptions, learner profiles and domain ontology, (b) a deductive object-oriented knowledge base system for querying and reasoning about RDF/XML metadata, called R-DEVICE and (c) a planning system called HAPEDU that automatically constructs course plans" [55].

The work presented in [56] describes a model for building personalized E-Learning experiences. This model accounts for different cognitive states and learning preferences of learners. In addition, it supports experts in modeling educational domains using ontologies. Using these models, personalization is achieved through "(i) modeling of educational domains by means of E-Learning ontologies; (ii) modeling of learner cognitive state and preferences (Student Model); (iii) annotation of Learning Objects with metadata and semantics connections between learning objects and ontologies elements (learning object model) and (iv) modeling of E-Learning experiences (E-Learning experience model)" [56].

A framework for personalized E-Learning is presented in [57] which interprets metadata-annotated learning resources. This framework is designed to understand learning resource annotations with respect to standard ontologies for learning materials. It also considers specific domain ontologies which describe the particular subject being taught, enabling. In addition, it enables personalized delivery of learning resources. Ontologies used for the adaptive hypermedia system include a domain ontology (document space description, document relationships, and concepts covered by the document space domain), a user ontology (describing learner characteristics), and an observation ontology (modeling different user interactions with the hypertext).

Another approach to personalized learning and student modeling is described in [49] and [58]. This work focuses on the student's cognitive state and cognitive process. It provides a diagnosis related to the student's knowledge state, and achievement quality of the learning objectives. The Student Model (SM) is part of the ITS architecture, with ontologies used as the knowledge representation model. This design incorporates a number of ontologies including student profile otology (personal information), a student state ontology (progress), and a learning objectives ontology.

A Semantic Web-based modeling approach for document annotation and user competency profile development is presented in [59]. This ontology is the binder between learning material and learners. The user navigation inside the ontology is monitored, and the next concept of interest is recommended through a collaborative filtering method. Subsequent content-based document recommendations are provided to the user by concept selection and competency profile. The AEHS system [60] uses an ontology model based on thinking styles and domain ontology. Individual learners receive different educational content and activities according to their particular learning style and characteristics.

4.4. Describing E-Learning Services

Within an E-Learning system, ontologies are often used for describing E-learning services and components for collaboration between heterogeneous E-Learning systems. Using ontologies to describe services and resources results in learning resources that are searchable, accessible, and sharable.

As described in section 3.1, standard specifications for describing learning resources and services such as IEEE LOM (IEEE, 2002), Dublin Core (DCMI, 1990), IMS consortium (IMS, 2001), and SCORM (ADL, 2004), have been developed and used in E-Learning systems. These specifications facilitate accessibility, reusability, and interoperability across heterogeneous learning resource systems.

A Learning Object Repository (LOR) is a collection of available learning objects, which enable educators to share, manage, and utilize educational resources. Sharing and reusing such resources is enhanced when LORs are integrated with Learning Management Systems (LMSs). The work presented in [33] describes a model for representing a learning object repository using ontologies. A prototype LOR for describing Learning Objects in the construction domain is presented. This ontology annotates the learning object, resulting in a discoverable and reusable learning object.

There is increased demand in learning resource collaboration between heterogeneous E-Learning systems. Ontology mapping is another area of importance related to E-Learning systems with respect to the diversity in learning resource metadata. Ontology mapping facilitates the interoperability and sharing of learning resources. The work described in [61] presents an ontology mapping technique for conflict detection and resolution between local ontologies. In addition, this technology maps learning objects to a single Common Ontology (CO). The authors recommend a common ontology (CO) which incorporates all known metadata standards for learning, such as the IEEE LOM, Dublin Core (DC), *etc*.

5. Results and Discussion

As presented in our review of the literature, ontologies are used in E-Learning systems for various purposes and different applications. Ontological structures are used to model domain knowledge, enable resource sharing and reuse, and facilitate various E-Learning tasks. According to the classification model (described in section 2 of this article), we observe the majority of ontologies surveyed were classified as task ontologies, as seen in Figure 4

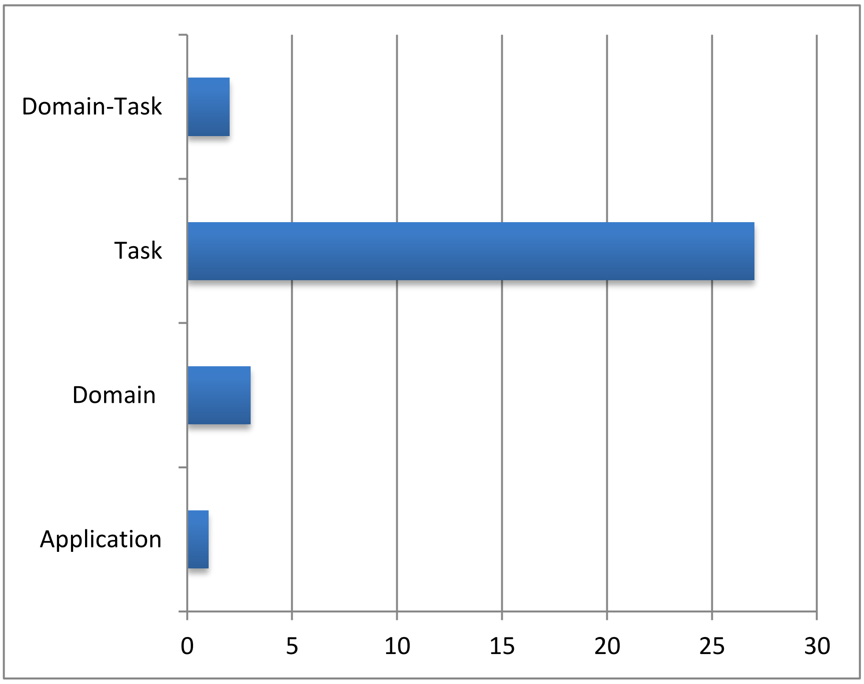

Figure 4. Classification of Ontologies Surveyed

The popularity of this type of E-Learning domain ontology can be attributed to vocabulary descriptions relevant to generic tasks and activities in the domain. In addition, this type of ontology is applicable to any subject domain. Another prevalent class related to ontology usage in E-Learning systems is domain ontologies. Their popularity stems from core knowledge representation and vocabulary for concepts within the specific domain.

With regard to the classification of E-Learning tasks described in section 4, Figure 5 demonstrates that the majority of ontologies surveyed were classified for learning personalization. According to our survey of the literature, personalization of learning is popular due to the specific tailoring of pedagogy, curriculum, and learning environments with respect to learner needs and requirements.

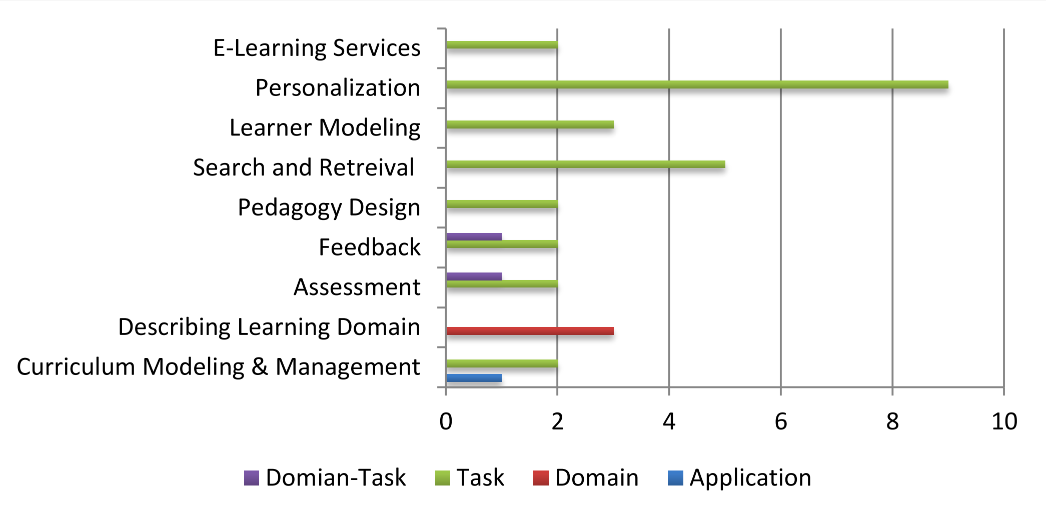

Figure 5. Ontology Classification According to E-Learning Task

The task of search and retrieval related to learning resources is second in popularity with E-Learning ontologies. Locating relevant information is a core task in any E-Learning environment. Ontologies are commonly used to facilitate focused search and retrieval based on semantic metadata description of learning resources.

Another important finding from this study is that some ontologies used for assessment and feedback are classified as task and domain-task ontologies. Domain ontologies are primarily used to describe the learning domain subject matter.

In general, ontologies used for curriculum management in E-Learning systems are designed to support various curriculum-relevant tasks, such as mapping of external criteria to the curriculum. This mapping ensures the program meets performance quality criteria. It also enables the management of process change in curriculum elements, taking into consideration the effect of the change on other curriculum elements. Moreover, the use of ontologies in curriculum design facilitates browsing the curriculum according to different user needs (students, faculty, and management). E-Learning tasks have also benefitted from ontologies in facilitating pedagogy design, learning resource searching, assessment, and feedback. Ontologies also facilitate learner modeling for services such as personalization and recommendations. In addition, ontologies have been used to facilitate sharing and reuse of learning resources between heterogeneous E-Learning systems.

Analysis of the literature indicates a number of work surveyed do not present detailed class and property descriptions for ontologies used. Moreover, some ontologies are not accessible online for the purpose of detailed surveys.

6. Conclusion and Emerging Trends

In the context of E-Learning, ontologies and the Semantic Web have risen in popularity over the past decade. These topics remain relevant with respect to recent trends in linked data, service-oriented education, and the educational Semantic Web. Linked data and the Semantic Web are providing solutions for problems related to E-Learning. The Linked data approach offers opportunities to overcome the challenges associated with sharing, reuse, and discoverability of learning resources. Using technologies such as Linked data and Semantic Web will facilitate distributed data retrieval from heterogeneous E-Learning systems, metadata mediation, and sharing and reuse of learning resources. There is a growing trend toward learning resource exposure described with IEEE LOM or ADL SCORM as linked data [62].

In addition, the *Linked Universities* project is an alliance of European universities engaged in exposing their public data as linked data. "Linked data is a set of principles to put raw data on the Web, making them Web addressable and linkable, so that they can be easily accessed, discovered, connected and reused. The idea is that data from different institutions and organizations can contribute to a common data space on the Web: the Web of Data." [63].

To enable linked educational data, the deployment of an E-Learning system and implementation of developed ontologies requires a platform for collection, storage, delivery, and analysis of educational materials and the descriptions of educational processes. It should provide open access to learning materials. The basic requirements for such a platform should provide:

- Location of learning resources on the Web.
- Learning resource creation and editing capabilities.
- Linking learning resources with external sources, such as digital libraries, multimedia resources, and social networks.
- The ability to combine and analyze learning resources.

In conclusion, we observe the vital role ontologies have in the development of E-Learning systems. The future of E-learning content rests in designing accessible learning content, driven by new tools and technologies.

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