

A Survey of Semantic Technology and Ontology for e-Learning

Abstract

Semantic technology and ontology (STO) are being investigated in various areas. In the e-learning context, many studies have used STO to address problems such as the interoperability of learning objects (LOs), modeling and enriching learning resources, and personalizing educational content recommendations. This study systematically reviewed research on STO in e-learning systems from 2008 to 2018. The review was guided by three research questions: RQ1: “What are the major uses of ontology in e-learning systems?” RQ2: “What is the state of the art in educational ontology?” and RQ3: “What are the various applications of STO-based learning systems?” Based on 134 papers, we analyzed six types of ontology use and five aspects of educational ontology, as well as e-learning systems that use semantic approaches. The observations obtained from this survey can benefit researchers in this area and help guide future research.

Keywords: Semantic Web, semantic technology, ontology, e-learning

1. Introduction

Semantic technology and ontology (STO) have been applied to a wide range of domains such as biomedicine [1, 2], agriculture¹, and education [3, 4]. *Semantic technology* refers to the Semantic Web and its related technologies, including RDF, RDFS, and OWL. An ontology is a set of axioms stated in an ontology language [5]. Ontologies defined in W3C standards such as OWL largely

¹ AGROVOC: <http://aims.fao.org/vest-registry/vocabularies/agrovoc-multilingual-agricultural-thesaurus>.

facilitate data resource sharing and reuse, and are key components of the Semantic Web. In the last 10 years, STO has attained substantial achievements in many fields [137-138]. For example, based on the linked data principle, the Linked Data Cloud² contained 1,224 datasets with 16,113 links as of June 2018. Google uses the Knowledge Graph³, which collects information from various sources to enhance its search results. In the educational area, STO application in e-learning was investigated as early as 2000 [7] and has become more significant in recent years.

Although technologies such as machine learning and intelligent computing have been applied to education to solve various problems in e-learning environments (e.g., the interoperability of learning objects (LOs), modeling and enriching learning resources, and personalizing educational content recommendations [4] [6]), among them, STO has accounted for a large portion of approaches from 2000 to 2012 [7]. The characteristics of STO, including resource sharing and reuse, knowledge modeling, and inference [8], make it ideal for solving e-learning problems. For example, STO can be used to model and manage course resources and design personal recommendations. Thus, the objective of this survey was to provide a systematic overview of the latest applications of STO in e-learning environments. The findings of this study can be used to guide future research in this area.

To perform a comprehensive and systematic review of recent research, we formulated the following three research questions based on the following objectives:

RQ1 What are the major uses of ontology in e-learning systems?

RQ2 What is the state of the art in educational ontology?

RQ3 What are the various applications of STO-based learning systems?

² The Linked Open Data Cloud: <https://lod-cloud.net/>.

³ The Knowledge Graph: https://en.wikipedia.org/wiki/Knowledge_Graph.

Based on these research questions, a set of keywords were identified: (“ontology” OR “semantic technology”) AND (“learning” OR “education”). These keywords were used to search for papers from 2008 to 2018 in five databases: ACM Digital Library, IEEE Xplore Digital Library, Springer, ScienceDirect, and Web of Science. The reason for using “learning” instead of “e-learning” was to avoid missing relevant studies. As shown in Table 1, 3,039 papers were initially retrieved (including duplicates). Then, we defined the following five exclusion criteria: (1) papers not in English, (2) papers not accessible online, (3) papers less than six pages, (4) studies not in the field of e-learning or learning technology, and (5) studies not related to STO. We applied the above criteria by reading abstracts and looking further into the retrieved papers to filter out irrelevant studies, such as learning analytics not involving STO. Finally, we selected 134 papers (without duplicates). Among them, 11 papers were surveys related to e-learning and STO.

Table 1 Number of papers retrieved from databases, 2008–2018

Database	Number of papers retrieved	Number of papers selected
ACM	350	27
IEEE	871	27
Springer	695	16
ScienceDirect	318	42
Web of Science	805	22
Total	3,039	134

The remainder of this paper is organized as follows: Section 2 reviews survey papers related to STO-based e-learning. Section 3 classifies and summarizes the uses of ontologies in e-learning environments. Section 4 analyzes five aspects of educational ontologies. Section 5 reviews the major applications of ontology to education, and section 6 concludes the paper.

2. Related Work

The application of STO to e-learning was studied as early as 2000 [7]. The application of knowledge-based methods such as rule-based reasoning and intelligent computing methods such as multiagent systems in e-learning environments was discussed in [9]. Those authors suggested using integrated knowledge based/intelligent computing methods to solve e-learning problems, including learning path generation and LO recommendation. Tarus, Niu, and Mustafa [10] reviewed ontology-based recommendation systems for e-learning from 2005 to 2014. That study noted that ontology improved the quality of recommendations, and that the use of hybrid recommendation methods can enhance recommendation performance. Klačnja-Milićević, Ivanović, and Nanopoulos [11] also surveyed recommendation techniques for e-learning but did not limit them to ontology-based approaches. That study advocated extensions of tag-based recommender systems for personalization in e-learning environments. In [7], 190 papers published between 2000 and 2012 on adaptive e-learning systems (AESs) were analyzed. That study showed that the dominant technique used in AESs was machine learning, accounting for 52% of the papers, whereas 18% used STO-based approaches. Yalcinalp and Gulbahar [12] reviewed the use of ontologies to support personalization in Web-based environments. They suggested that the development of educational ontologies requires collaboration between educational and technological experts. However, that review did not discuss detailed techniques, approaches, and applications related to personalized Web-based learning systems. Kurilovas and Juskeviciene [13] studied ontology development tools and concluded that Protégé was the best tool for creating ontologies in e-learning environments. Pereira et al. [14] reviewed linked open data (LOD) technology in educational environments. They

summarized the three main applications of LOD as follows: educational data as linked data, interoperability of different sources based on linked data, and consumption of linked data. They also highlighted a number of challenges, such as reusing existing educational resources, high consumption costs, and managing constantly changing repertories.

In this survey, we focused on STO-based e-learning systems in the last 10 years. Different from the abovementioned surveys, we looked into the various uses of ontology in e-learning systems. By reviewing various aspects, such as the level of semantic richness in educational ontologies, we have also elucidated the state of the art in current educational ontologies. In addition, we have sorted out different STO-based applications. Our findings can be beneficial for many researchers, including ontology developers and e-learning researchers.

3. Ontology Use in e-Learning Environments

In e-learning environments, ontologies are used to model knowledge related to *course resources, LOs, curricula, learner models, teaching methods, and education-related activities*. Figure 1 shows the current research trends in ontology use as indicated by the 123 selected papers (excluding 11 survey papers from 134 total papers). As seen in the figure, in 42% of the papers, ontologies were used to model course resources. In about 17% of the papers, LOs, as well as learners and contexts, were modeled as ontologies. In addition, 16% of the papers addressed education-related activities using ontologies, while 9% modeled teaching and learning methods based on ontologies. Only 7% of the studies modeled curricula and syllabi. We review the six types of ontology used for e-learning in the subsections below.

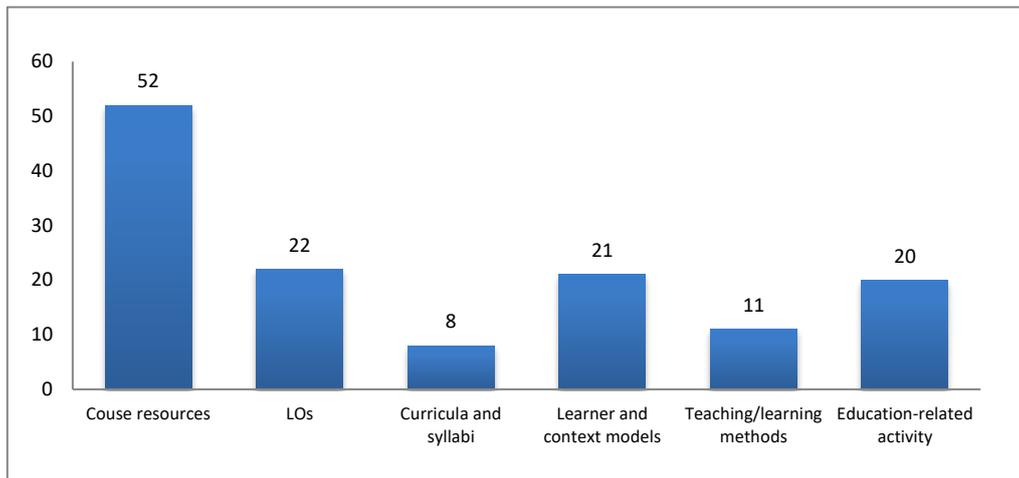


Figure 1 Ontology use in e-learning environments⁴

3.1 Course Resource Modeling

Much attention has been paid to modeling course resources as ontologies for the purposes of learning resource reuse, adaptive and personal content selection, and adaptive learning pathways. We further identified the following four types of STO-based ontology use in course resource modeling.

Course knowledge base Constructing high-quality course knowledge repositories based on STO is an important research problem in the e-learning field. Many studies have addressed this issue [23–48]. For example, Lubliner and Widmeyer [24] focused on designing and realizing a knowledge repository, with the objective of helping people learn by exploring interconnected concepts. Five design goals were specified for that knowledge repository. In [26], the authors used Text2Onto to extract concepts from textbooks and slides into OWL ontologies. Then, the knowledge represented by the OWL ontologies was modeled and organized according to three concepts and two relations. Similarly, concept maps were extracted from documents and converted into domain ontologies specified in OWL by identifying classes, properties, and instances [29]. Colace and De Santo [28]

⁴ A paper may fall under more than one type of ontology use.

introduced a novel algorithm for building a lightweight course ontology using a Bayesian network. Different from the abovementioned approaches, Gaeta et al. [48] constructed domain ontologies using the ontology extraction technique (i.e., extracting concepts and their relationships from existing ontologies or semistructured documents such as slides and DOC files).

Concept map A concept map represents knowledge structure according to concepts and relations. Concept maps can be regarded as ontologies since they both identify domain concepts and relationships. Many studies [15–22] examined how to construct concept maps from educational materials, such as lecture slides. For example, Atapattu, Falkner, and Falkner [15] extracted concept maps in the form of XML from lecture slides using natural language processing (NLP) algorithms. Lau et al. [16] proposed a way to automatically construct concept maps with the objective of alleviating excessive information in e-learning environments. Specifically, concept maps were generated from messages posted on blogs, e-mails, websites, and so on using NLP techniques.

LOD for educational resources: Bansal and Kagemann [54] presented an extract-transform-load semantic framework to integrate data sources and publish data as LOD. STO was used in the transform phase by creating ontologies for further use. Fernandez, D’Aquin, and Motta [55] focused on LOD related to video lectures in the educational domain. The authors created RDF descriptions of video lectures extracted from YouTube and Videlectures.net. Various properties of video metadata were specified using standard existing semantic vocabularies, such as Dublin Core, FOAF, and W3C. LOD was used to generate natural language questions in [56]; for this purpose, a history domain ontology was created.

Annotation Ontologies can be used to annotate educational resources to improve information retrieval and search results [57–60]. Pattanasri and Tanaka [58] proposed an entailment ontology

based on textbook information, which was intended to improve the efficiency of learning material retrieval. In [59] and [60], light-weighted ontologies were defined using SKOS and used to annotate educational resources. Dealing with educational document retrieval, Ahmed-Ouamer and Hammache [61] created domain ontologies to index educational resources. Shih, Yang, and Tseng [62] also indexed learning resources based on domain ontologies to support content retrieval in a grid computing environment.

3.2 LO Description

LOs are resources accessible on the Internet. We differentiate LOs from course resources since learning object metadata (LOM) is an IEEE standard for specifying LO characteristics. Because of the XML format of LOM, an interoperability problem still exists for LO reuse and searching. Studies have focused on enriching LOs using STO with the objective of improving LO interoperability [63–69], LO search and retrieval [70–76], and adaptable learning content and pathways [77] [78], as well as related issues such as LO display [79], automatic course content construction [80] [81], and LO repository construction [82] [83].

Kalogeraki et al. [63] proposed an ontology-based model to solve the interoperability problem of LOs. The LOM is enriched with semantic annotation by the developed ontology. Hsu [64] also dealt with the interoperability issue in Los, presenting a multilayered semantic LOM framework consisting of URL, XML, ontology, and rule layers to facilitate LO interoperability and reuse.

Paramartha, Santoso, and Hasibuan [70] focused on LO searching. They defined an LO ontology using the FOAF vocabulary and IEEE LOM standard; the search engine used SPARQL to perform LO searches. Brut, Sedes, and Dumitrescu [73] extended the LOM standard with

ontological annotations to improve the efficiency of LO searching. Lee, Tsai, and Wang [75] proposed an ontological approach for LO retrieval. The query expansion algorithm could automatically aggregate a user's original short query and remove ambiguity in the query. Solomou, Pierrakeas, and Kameas [76] defined an ontology for LO discovery in distance learning. Various characteristics of Los, such as title, description, and aggregation level, were specified as either classes or properties in the ontology.

Abech et al. [77] proposed a model called EduApdapt, which adapted LOs according to students' contexts, including their learning styles, devices, and so on. The core part of the model is a set of ontologies such as LO ontology and user context ontology. Kontopoulos et al. [80] proposed a system called PASER to automatically construct course plans based on AI planning and semantic technologies. LOs were stored and composed by PASER with metadata defined as SKOS ontology. The key module in PASER is the planning engine, which aims to provide the learner with personalized curricula from educational resources.

In the context of mobile learning, [79] investigated the LO display problem on mobile devices. That study proposed enabling LOs in the form of SCORM to display on different mobile phones; two ontologies were defined, and Microsoft's SharePoint Learning Kit was used to process the format of LOs. Lama et al. [83] proposed a way to automatically classify large-sized repositories of LOs. Their classification mechanism was based on the ontological relations between the semantic LO repositories and DBpedia.

3.3 Curriculum and Syllabus Modeling

A curriculum specifies how learning content is organized and sequenced to create a

planned and systematic program of learning and teaching. A syllabus is an outline of the topics to be taught in a course. STO has been applied to model curricula and syllabi to automatically and adaptively guide e-learning processes [84–91]. Fernández-Breis et al. [84] introduced an educative curriculum management system called Gescur based on semantic platforms and ontologies. Teachers can use it to create, access, and analyze curricula. For example, Gescur supports detecting nonconformities in curriculum execution and helping teachers define corrective tasks and procedures. Gueffaz, Deslis, and Moissinac [87] modeled the French curriculum using ontology to better index and rank educational resources. The curriculum was in the form of textual documents, which were first annotated in XML format and then extracted to populate the base ontology. The ontologies were also enriched by external data resources such as DBpedia. In [86], a software platform was presented for comparing informatics curricula based on ontology matching. In [90], an ontology of pharmacy competency was developed to solve interoperability and cooperation problems in pharmacy competency management in the cloud. That ontology could be used by pharmacists for curriculum building and by educational institutions for educational materials management. Petiwala and Moudgalya [91] proposed a semantic open syllabus ontology, which can be used to assist automated textbook generation.

3.4 Learner and Context Modeling

A learner model normally includes information such as learning styles, personal information, background knowledge and performance, learning goals, and preferences. In addition, context information, such as network conditions and mobile devices, is also considered in learner models [6] [92]. A rich and accurate definition of the learner profile is key to achieving personalized and

adaptive learning [78]. Premlatha and Geetha [4] identified various levels of adaptation for learning content in e-learning environments. Specifically, five levels of adaptation were identified, including content level and link level. LO processes and learner parameters were also discussed. STO is an important means for modeling learner profiles [27] [31] [34] [35] [45] [49] [78] [93–97] and context information [98–104] in e-learning systems to achieve personalized e-learning.

In [78], an e-learning framework based on a set of ontologies and SWRL (Semantic Web Rule Language) was proposed to realize a costumed learning model and learning style. The authors classified learner models into seven categories (e.g., personality, knowledge, behavior), which were defined as ontologies. Gavriushenko, Kankaanranta, and Neittaanmaki [103] presented an STO-based approach to decision support for learning management. The knowledge base of the decision-support system contained an ontology to model learner and teacher information; SWRL rules were constructed to perform recommendations. Yago et al. [94] proposed a student model called ON-SMMILE, defined as an ontology network containing information such as student knowledge and assessment. In [95], a Learner's Characteristics Ontology was proposed, containing information such as learning styles. Muñoz et al. [34] defined users' profiles as an ontology model called OntoSakai; it modeled different aspects of the learning process such as competences and learning tools. The ontological student model proposed by [97] described dynamic learning styles by monitoring students' actions during the learning process.

Capuano et al. [99] proposed a learning context ontology to improve the efficiency of selecting proper learning resources. Rimale, Benlahmar, and Tragha [79] also dealt with learning content display problems in mobile learning environments. Mobile users' context information was modeled by the "ontology of use." Gamalel-Din [51] proposed a smart e-learning knowledge base (SELK)

for adaptive and personalized learning that contained ontologies related to student background knowledge and course material. In [104], a learner model based on ontology and SWRL rules was defined for personalized learning pathways in the EDUC8 system. In [100], a context-based ontology was defined that contained information such as student, device, and location. The aim of that ontology was to realize a context-aware e-learning environment.

3.5 Teaching/Learning Method

Many studies have investigated teaching/learning methods [78] [105–108] [111] [112] and instructional theory modeling [68] [109] [110] [113].

Ouf et al. [78] proposed a teaching method ontology in which methods such as online discussion, peer-to-peer teaching, and reflection were defined as OWL classes. Chahbar, Elhore, and Askane [111] improved the PERO system—a computing environment supporting machine teaching—by replacing the relational database with domain ontologies; a teaching ontology in the domain of electricity was defined. Oprea [112] presented a collaborative ontology development framework that could be used in educational applications. That educational ontology aimed to cover the lifecycle of university courses, which consisted of three parts: teaching activity, learning activity, and examination activity. Algorithms were specified to develop ontologies using ontology mapping methods. Dobreski and Huang [107] presented LILO, an ontological model that defines developers' learning strategies, learning resources, and learning objectives. That model could be used to aid the design of informal learning systems.

Instructional design theories provide guidelines for designing learning activities and arranging associated resources. Ontologies can be used to model these theories, which are normally expressed

in natural languages. In [109] [110], STO was used to model instructional design theories. In addition, SWRL rules were created to specify constraints between the elements of the instructional models. Lu and Hsieh [68] defined an instructional ontology that contained 15 relations, including “law,” “process,” and “procedure.” Mizoguchi and Bourdeau [113] introduced the use of ontology engineering in AIED (artificial intelligence in education) problems. The authors discussed the development of a system involving OMNIBUS, an ontology of learning/instructional theories, and SMARTIES, a theory-aware authoring system.

3.6 Education-Related Activity

In addition to the abovementioned uses, STO has been applied to other education-related activities and aspects, such as e-assessment and competency management, as well as teaching/research activity modeling.

A number of studies focused on the use of semantic ontologies for assessment-related tasks [114–126]. An e-learning application was developed for the semiautomatic e-assessment of academic credentials and competencies [114]. The core part of the application was a university–course–credit–grade ontology and a set of rules for credit–grade conversions. Marzano and Notti [116] also presented an ontology-based assessment environment called EduOntoWiki that provided a tool for consultation, discussion, and learning to academic communities. Romero et al. [117] defined ontologies of assessment and assessment instruments in e-learning environments to realize the semiautomatic generation of tests. Mouromtsev et al. [120] proposed an approach to estimate students’ knowledge in the ECOLE system. Specifically, an ontology of knowledge rate was created, and formulas to calculate students’ knowledge rates based on learning results were defined. [121]

dealt with the feedback generation of online assessments based on ontologies, semantic annotation, and NLP algorithms. The automatic feedback algorithm took questions and answers as inputs and generated feedback by calculating similarities between annotations. Puustjärvi and Puustjärvi [90] and Gasmi and Bouras [122] used STO to address competency management. For example, [90] dealt with pharmacy competency management. To solve interoperability and cooperation problems in pharmacy competency management, the authors developed a competency ontology in OWL to unify the terms and concepts used in the domain and then proposed using a community cloud to aid cooperation between pharmacy and healthcare authorities.

Munoz et al. [124] proposed an ontology-based virtual education framework consisting of four layers (e.g., knowledge management and education process). The ontology layer is a transversal layer that defines the concepts, instances, and properties for the other three layers. [125] described the process of building a reference ontology for higher education using the NeOn methodology. A reference ontology can be used to create a specific ontology and thus avoid having to build a domain ontology from scratch. The authors first identified 81 competency questions in the specification phase, and then, in the conceptualization phase, they identified concepts and their relationships using the data–dictionary–concepts hierarchy, attributes classification tree, and object properties table. An ontology for modeling teaching and research activities was defined in [126] to achieve better cooperation and to monitor cooperation status. VIVO ontology is based on a set of Web ontologies, including Bibontology, Dublin Core Elements, and FOAF (Friend of a Friend). The proposed ontology AcademIS extends VIVO with elements emphasizing such as teaching collaboration and monitoring.

Web services and applications have been developed based on e-learning platforms to provide

various learning services [127–132]. Gutiérrez-carreón, Daradoumis, and Jorba [128] proposed using semantic Web services to integrate a cloud service API with an educational system. As a case study, features of the Google Apps Cloud were integrated with a learning management system called Chamio. In [129], a set of popular online document editors was selected, including Google Drive and Microsoft’s OneDrive. Then, the authors proposed an ontology consisting of generic vocabulary for the interoperability of the online document editors used in e-learning environments. Zhuhadar and Nasraoui [130] and Wongthongtham et al. [131] studied the problem of learning resource selection based on ontologies and semantic annotation. Wu, Mao, and Chen [132] defined an ontology called subO for integrating e-learning databases and facilitating resource reuse.

3.7 Discussion of Ontology Use in e-Learning

Section 3 has addressed RQ1: “What are the major uses of ontology in e-learning systems?” Among the six identified types of ontology use, course resource modeling is the major one, accounting for 42% of research efforts. We further identified four subtypes of ontology use in course resource modeling: concept map, course knowledge base, LOD for educational resources, and annotation. Among these four subcategories, studies paid more attention to course knowledge base. We can observe from this review that STO is an ideal technique for solving the problems of modeling e-learning resources, improving the interoperability of learning resources, enriching LOs, and personalizing educational content.

The above review shows that ontology is widely used in e-learning systems. However, most of these studies proposed defining their own ontologies from scratch, while not taking advantage of the Semantic Web standard to reuse existing resources. As such, sharing and reusing high-quality

educational ontologies is important for improving the efficiency of developing STO-based learning systems. Furthermore, ontology evaluation, as an essential part of developing ontology-based systems, has not received sufficient attention in the e-learning field. While a few studies addressed ontology evaluation, most educational ontologies were not evaluated by any criteria. Therefore, evaluation techniques for educational ontologies should be emphasized in the design and development of e-learning systems. Lastly, as [9] and [10] pointed out, an integrated method of intelligent computing and STO can result in more advanced learning systems. Although STO provides an ideal means to support e-learning resource management, we advocate a combination of other intelligent computing methods, such as machine learning, to develop better adaptive and personalized e-learning systems.

4. Educational Ontology

In the previous section, we summarized how STO can be used to support adaptive e-learning, thus answering RQ1. In this section, we aim to answer RQ2 (“What is the state of the art in educational ontology?”) by reviewing educational ontologies in the 123 selected papers from the following five aspects: *level of semantic richness*, *ontology language*, *editing tools*, *design principles*, and *building routine*.

4.1 Level of Semantic Richness

The concept of *ontology spectrum* was proposed to classify ontologies by semantic richness [5]. Ontologies can range from simple and inexpressive to highly complex and precise: *catalogs*, *glossaries*, *thesauri*, *formal taxonomies*, and *proper ontologies*. The more expressive an ontology

is, the more intelligent and complicated applications it can support. A *catalog*-type ontology (Type 1) refers to a list of the IDs of entities. A *glossary*-type ontology (Type 2) refers to a set of definitions of terms. A *thesaurus*-type ontology (Type 3) includes a set of terms with a number of predefined relations between them. A *formal-taxonomy*-type ontology (Type 4) refers to a set of concepts with subsumption relationships. Finally, a *proper ontology* (Type 5) is an ontology with all possible axioms, such as OWL restrictions and SPIN rules. We applied the ontology spectrum to classify the reported educational ontologies reviewed in section 2. Figure 2 shows the levels of semantic richness for current educational ontologies. Among the 123 educational ontologies, only one is Type 2 (glossary), 30% belong to Type 3 (thesaurus), 22% belong to Type 4 (formal taxonomy), 40% belong to Type 5 (proper ontology), and 7% could not be judged from the papers. Obviously, most educational ontologies are richer than the glossary type (Type 2).

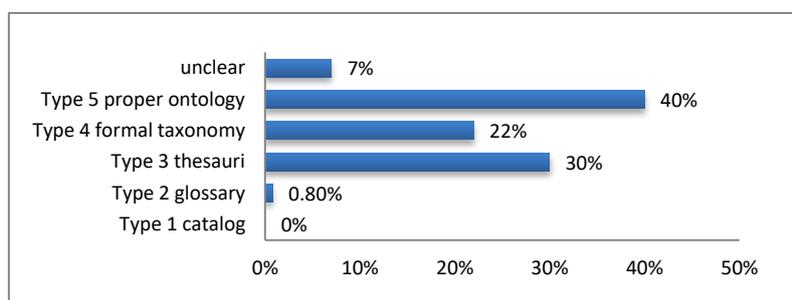


Figure 2 Semantic richness of educational ontologies

4.2 Ontology Language

Sets of ontology languages have been proposed since the 1990s, including CycL⁵, F-logic⁶, and W3C-standard OWL. It is beneficial for ontology developers to understand the use of ontology languages in educational ontology modeling. Figure 3 summarizes the ontology languages used for ontology creation in e-learning environments. Four languages—XML (only), RDF(/XML), RDFS,

⁵ <https://en.wikipedia.org/wiki/CycL>.

⁶ <https://en.wikipedia.org/wiki/F-logic>.

and OWL—are the major ontology languages used in educational ontology modeling. As shown in Figure 3, among the 123 educational ontologies, 3% were in XML (only) and RDFS, 5% in RDF/XML, 59% in OWL, and 2% in other languages (e.g., description logics) while 28% were unspecified in the literature. It is obvious that OWL is the dominant ontology language for creating educational ontologies.

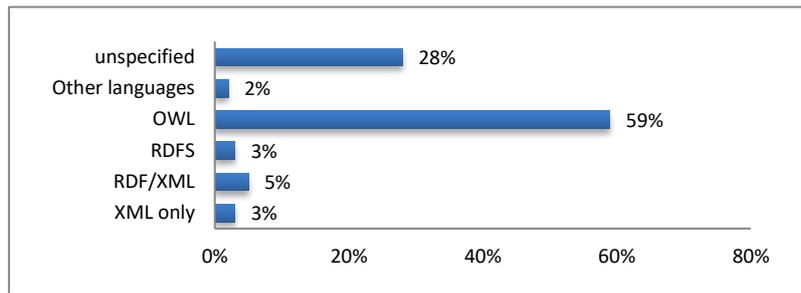
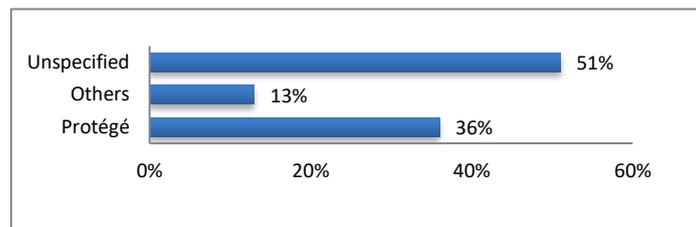


Figure 3 Ontology languages used in educational ontologies

4.3 Editing Tool

Widely used ontology editing tools include Protégé⁷, Ontolingua⁸, OntoEdit⁹, Neon Toolkit¹⁰, and TopBraid Composer¹¹. Figure 4 shows the editing tools used in the 123 educational ontologies; 36% of the ontologies were developed using Protégé, and 13% were created by other tools, such as abstract domain model [99] and Hozo [53] editors. Meanwhile, the editing tools were unclear for 51% of the ontologies. Obviously, Protégé is the dominant ontology editor, while other tools such as Ontolingua and OntoEdit were not used at all in e-learning systems.



⁷ <https://protege.stanford.edu/>.

⁸ <http://www.ksl.stanford.edu/software/ontolingua/>.

⁹ <http://www.semafora-systems.com/>.

¹⁰ <http://neon-toolkit.org/>.

¹¹ <https://www.topquadrant.com/tools/ide-topbraid-composer-maestro-edition/>.

Figure 4 Editing tool

4.4 Design Principle

Ontologies can be developed from scratch or by reusing existing data resources. To understand the design principles used in e-learning environments, we summarized the design principles as either *from scratch* or *reusing ontology*. *From scratch* refers to creating ontologies without using any existing resources. *Reusing ontology* refers to creating ontologies by reusing existing ontological resources such as classes, properties, and instances. Reusing existing data resources is advocated by the Semantic Web since related standards such as RDF and OWL are designed for reuse and integration. As shown in Figure 5, 69% of the educational ontologies were created from scratch, while only 21% were developed by reusing existing ontologies. In 10% of the research works, details of the design principle are not provided.

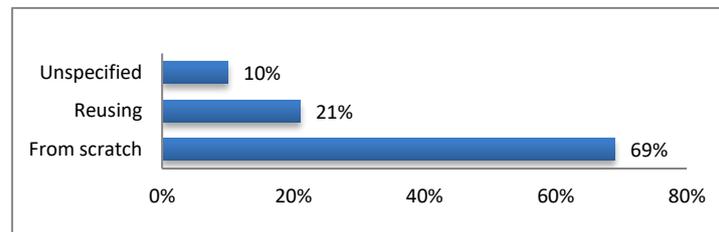


Figure 5 Design principle

4.5 Building Routine

An ontology can be created manually, semiautomatically, and automatically. Automatically creating a high-quality ontology is a challenging task. Simple ontologies such as Type 1 or Type 2 can be constructed automatically by defining generation or transformation algorithms [133]. For complex ontologies such as Type 5, manual approaches are normally used to ensure quality. However, when the scale of ontologies becomes large, manual development requires a great deal of

time and effort. As a compromise, a semiautomatic approach can solve the low efficiency of manual approaches and the poor quality of fully automatic methods. Figure 6 shows the statistics for the building routines (i.e., manual, semiautomatic, or automatic) used in the educational ontologies. Among the 123 educational ontologies, 74% were constructed manually, while only 4% were automatically created; 7% were created semiautomatically, while 15% of the papers did not specify the building routine.

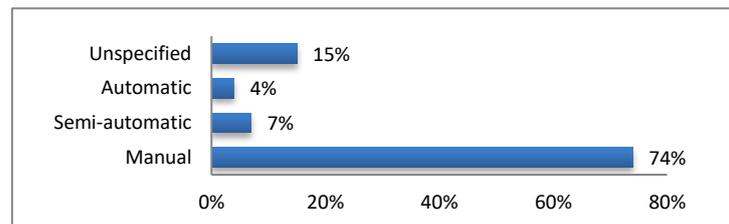


Figure 6 Building routine

4.6 Discussion of Educational Ontologies

From our review of the five abovementioned aspects, we can answer RQ2: “What is the state of the art in educational ontology?” Figure 2 shows that 40% of the ontologies are proper ontologies, indicating a high level of semantic richness. Since educational systems are mostly knowledge-intensive systems that require rich, high-quality knowledge bases to realize adaptive e-learning functions, the richer the ontology, the more complex applications a system can support. For this reason, the semantic richness of educational ontologies is important. In Figure 6, we observe that 74% of the ontologies were manually constructed, while only 4% were built automatically. The cost and effort of manually developing and maintaining educational ontologies were not mentioned in the reviewed literature. Manually developing large-scale ontologies is both time consuming and error prone. In the field of ontology engineering, researchers have worked on ways to automatically create high-quality ontologies. The statistics shown in Figure 6 suggest that the educational domain

needs to take advantage of the techniques obtained in the ontology engineering field to improve the efficiency of ontology development.

As already mentioned, manual ontology development requires considerable effort. Thus, ontology reuse is a solution for improving the efficiency of ontology engineering. The W3C standards, such as RDF, RDFS, and OWL, advocate Web resource sharing and reuse. As such, ontologies defined in these languages are easy to reuse and integrate. Figure 3 shows that only 2% of the ontologies were defined in languages other than XML, RDF, RDFS, and OWL. Moreover, 59% of the ontologies were defined in OWL. This indicates that educational ontologies have a good basis for reuse. However, Figure 5 shows that only 21% of the ontologies were developed by reusing existing ontologies, while 69% were created from scratch. These statistics indicate the low efficiency of ontology development in the educational domain. Research should therefore pay more attention to platforms and approaches for facilitating ontology reuse in the educational field.

5. Ontology-Based Educational Application

In this section, we focus on STO-based applications in e-learning environments, aiming to answer RQ3: “What are the various applications of STO-based learning systems?” Studies dealing only with the development of educational ontologies were omitted here. We classified papers related to ontology-based e-learning into four categories: *adaptive/personalized learning*, *curriculum management and instructional design*, *educational resource management*, and *automatic assessment*. As shown in Figure 7, among the 106 included research papers, most focused on adaptive/personalized learning, accounting for 42%, while 34% focused on educational resource management. Meanwhile, 8% and 16% of the papers concerned curriculum

management/instructional design and automatic assessment, respectively. In addition to the classification of applications, Table 2 summarizes the educational systems and tools reported in the literature. Studies only involving approaches or algorithms but with no implementations were omitted from the table.

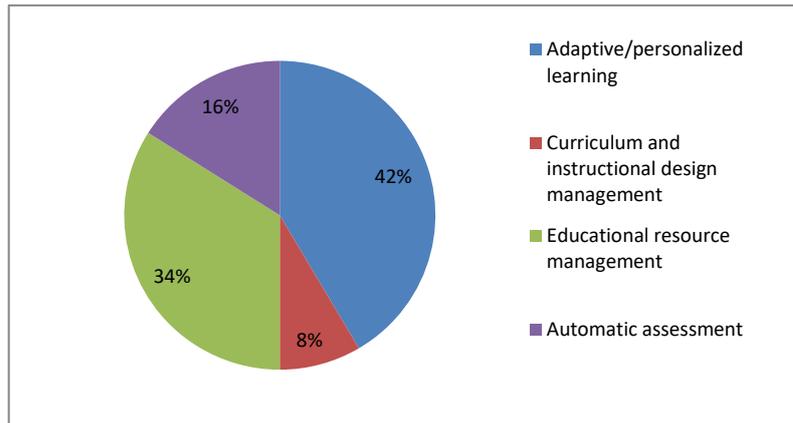


Figure 7 Ontology-based educational applications

Table 2 e-Learning systems and applications

Category of application	System/tool	Function/feature
Adaptive learning	PRINTEPS [53]	Knowledge-based reasoning; quiz editing module based on ontology and rules
	Adaptive e-learning system [49]	Felder-Silverman learning style model; cloud-based ontology storage
	PASER [80]	Ontology-based planning system for adaptive course plans
	Intelligent recommendation module [17]	Course ontologies; measuring a student's understanding level; personal learning suggestions
	Decision-support tool [107]	Ontology of users, teachers, courses, and specializations; recommendation system based on semantic knowledge base
	EDUC8 [104]	Learning process execution engine supported by a semantic framework; personalized learning pathways
	Smart Learning system [32]	Automatically classifies textual legal cases using NLP; generates learning paths based on legal ontologies
	PROTUS [47]	Web-based programming tutoring system; recommends personalized links and actions for students
Curriculum management	Gescur [84]	Curriculum management system based on ontologies; monitors the execution of a curriculum
Instructional design	CHOCOLATO [106]	Intelligent authoring tool based on semantic technologies; selection of interaction patterns, learning strategies, etc.

Course resource creation	DOM-Sortze [46]	Semiautomatic construction of domain modules from textual documents
	Prototype system [16]	Automatically generates concept maps from online messages with NLP
Information retrieval	LOFinder [64]	Retrieves LOs based on multilayered semantic LOM framework
Automatic exercise creation	GAMES [77]	Automatically generates math exercises based on ontology
Online assessment	ECOLE [120]	Assesses students' knowledge rates based on ontologies
	OeLE [121]	Automatic feedback generation of online assessment based on STO

5.1 Adaptive/Personalized Learning Applications

The goal of adaptive/personalized learning is to improve educational outcomes by adjusting learning content and methods according to learners' background knowledge and preferences. Much effort has been made to apply STO to adaptive or personalized learning. The main idea in such research is to use ontologies to model learning content, student background knowledge, and context information, thereby achieving adaptable learning content and learning paths for different students. STO can transform learning content into computer-understandable resources, and thus, can be intelligently adjusted.

Course content recommendation A number of studies have realized adaptive learning content based on ontologies and semantic rules. For instance, Rani, Nayak, and Vyas [49] and Perišić, Milovanović, and Kazi [97] presented ontology-based mechanisms to realize learning personalization according to learning style. Zeng, Zhao, and Liang [50] focused on personalized course content recommendations based on course ontology according to users' knowledge requirements. An algorithm was presented for determining a learner's knowledge status by reading behavior logs. The adaptive learning approach presented in [52] could adjust content presentation, navigation, or content selection according to user situations, such as task and preference. Kontopoulos et al. [80] proposed a system called PASER to automatically construct course plans based on AI planning and STO. LOM was processed and selected using deductive rules.

Context-aware learning Context information has been modeled by ontologies to support learning-resource selection for personalized e-learning [20] [21] [32] [45] [77] [79] [98–100] [128]. For example, Gutiérrez-carreón, Daradoumis, and Jorba [128] studied e-learning service applications based on cloud computing and Owl ontologies. The Google Apps cloud and Chamilo were integrated for learning management application development. Rimale, Benlahmar, and Tragha [79] focused on the LO display problem on mobile devices in the context of mobile learning. Gómez, Huete, and Hernandez [100] developed a context-aware system that could deliver adaptable learning content according to time, location, date, and so on.

Personalized learning path Some adaptive systems have focused on personalizing learning paths. Iatrellis, Kameas, and Fitsilis [104] proposed a system called EDUC8 to perform personalized learning pathways. Chen [90] defined a competency ontology to unify terms and concepts used in pharmacy. The cloud-based approach aims to realize individual learning paths and aid cooperation between pharmacies and healthcare authorities.

5.2 Curriculum and Instructional Design Management

STO has also been used to manage curricula and instructional design practices. By formalizing curricula and instructional models with ontologies, the reuse of curriculum and instructional designs can be realized [84] [86] [87] [106] [109] [110] [112] [126] [135]. For example, Fernández-Breis et al. [84] introduced a software tool, Gescur, which is an educative curriculum management system. Teachers can use Gescur to create, access, and analyze educative curricula. Gescur supports detecting any nonconformity in the execution of curricula and can help teachers define corrective tasks and procedures. Triperina, Sgouropoulou, and Tsolakidis [126] proposed an ontology for

modeling teaching and research activities in higher education. [112] presented an educational ontology for covering the lifecycle of a university course; the ontologies were categorized into three types: teaching activity, learning activity, and examination activity. Isotani et al. [106] developed an authoring tool called CHOCOLATO that can help teachers design collaborative learning scenarios.

5.3 Educational Resource Management

Educational resources need to be formally defined and managed to support adaptive learning. STO has been used to integrate educational data, manage course materials, and realize learning content retrieval.

Data integration LOD- and ontology-based methods have been proposed to address the interoperability and integration of learning resources [2] [54] [55] [67] [81] [82] [124] [125] [132]. In [55], video lectures were extracted from YouTube and Videolecuture.net and then transformed into RDF descriptions using Dublin Core and FOAF, among others. Bansal and Kagemann [54] proposed an extract–transform–load semantic framework to integrate various data sources and publish data as LOD. Al Fayez and Joy [132] integrated medical educational content in the form of online articles based on biomedical ontologies into one linked data set. In [124] and [125], ontology-based approaches were used to reconstruct educational resources. Zemmouchi-Ghomari et al. [125] built a reference ontology for higher education based on the NeOn methodology. Reference ontologies can be used to create specific ontologies, thus helping developers to avoid building domain ontologies from scratch.

Course resource construction Lubliner and Widmeyer [24] developed a disciplinary knowledge repository for concept learning. Lau et al. [16] automatically generated concept maps

from online messages using NLP techniques; this could help instructors understand students' learning progress and thus improve learning outcomes. Similarly, Zouaq and Nkambou [29] semiautomatically transformed textual LOs into concept maps first and then into domain ontologies. Larrañaga et al. [46] developed an ontology-based system called DOM-Sortze to support the semiautomatic construction of domain modules from textbooks. Matteo Gaeta et al. [48] also extracted concepts and relationships from text documents and created domain ontologies. A profile for LOM was proposed by [76] to characterize educational resources used in distance-learning courses. Lama et al. [83] dealt with the construction and maintenance of large-sized LO repositories by classifying LOs using the categories of DBpedia.

Information retrieval Researchers have also focused on content retrieval and LO searching for e-learning based on ontology indexing. In [58] [59] [63] [64], ontologies were used to enrich LOs, aiming to solve the interoperability problem and facilitate LO reuse. Cerón-Figueroa et al. [65] dealt with the matching of educational repositories using ontology-matching algorithms. In [75], ontologies were used to rewrite and improve users' queries in LO searches.

5.4 Automatic Assessment

Automatically generating high-quality exercises or test questions is a challenging problem in e-learning. STO can provide solutions to this problem [19] [36] [44] [56] [77] [88] [114–117] [119–121] [136]. In [114], RDFS ontologies were applied to a semiautomatic e-assessment system for evaluating learners' credentials and competencies. Mouromtsev et al. [120] proposed an approach to estimate students' knowledge based on the ontology of knowledge rate. Sánchez-Vera et al. [121] presented the automatic feedback generation of online assessment based on semantic technology,

including ontology and semantic annotation. Vinu and Kumar [44] developed a prototype called Automatic Test Generation that could generate multiple-choice questions based on domain ontologies.

5.5 Discussion of Ontology-Based Application

This section addressed RQ3 by reviewing ontology-based e-learning systems according to four categories: *adaptive/personalized learning*, *curriculum management and instructional design*, *educational resource management*, and *automatic assessment*. Figure 7 shows that the majority of the studies (42%) focused on adaptive/personalized learning. This is reasonable because STO has the advantage of modeling learning resources, and adaptable content and learning pathways can thus be realized based on ontologies. STO standards such as OWL make it an ideal means of learning resource sharing and merging. We also observed that 34% of the studies focused on STO-based educational resource management. Fewer studies have investigated curriculum and instructional design, as well as automatic assessment based on STO. We suggest that more attention should be paid to these two applications since they are important in e-learning environments.

Comparing the number of studies (106) with the systems/tools (16) listed in Table 2, we observe that the implementation of the proposed approaches and algorithms in recent research is inadequate. Most of the studies focused on methodologies, frameworks, and algorithms without implementing prototype tools and systems. Therefore, we suggest that more attention should be paid to developing and improving ontology-based e-learning systems and tools.

6. Conclusion

This study reviewed papers (134 of 3,039 retrieved papers) from the last 10 years related to STO in e-learning contexts. The survey was guided by three research questions. First, we analyzed and classified six types of ontology uses in 123 studies (excluding 11 survey papers). Then, we reviewed educational ontologies in terms of five aspects: level of semantic richness, ontology language, editing tool, design principle, and building routine. Finally, we summarized STO-based educational applications and sorted out the systems/tools developed in these studies. In addition to those findings, we identified four issues in existing studies that should be addressed. First, the quality of educational ontologies needs to be guaranteed by ontology evaluation, which was not considered in most of the studies. Second, the low rate of reusing ontological resources (21%) suggests that learning resource sharing should be encouraged. In addition, (semi)automatic ontology engineering approaches remain immature; specifically, 74% of the ontologies were manually constructed, while only 4% were built automatically. Finally, we suggest that more attention should be paid to the development of ontology-based e-learning systems and tools, which could help improve the comparison of systems/tools. The findings provided by this survey can therefore be used to guide future research in e-learning environments.

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