

A Survey of Semantic Web Based Recommender Systems for E-Learning

Cevat Aktas[1] and Birol Ciloglugil[2(✉)]

[1] Institute of Natural Sciences, Department of Computer Engineering, Ege University, 35100 Bornova, Izmir, Turkey
cevataktas61@gmail.com

[2] Department of Computer Engineering, Ege University, 35100 Bornova, Izmir, Turkey
birol.ciloglugil@ege.edu.tr

Abstract. Recommender systems have been widely used in various domains such as e-commerce, e-learning and the entertainment sector especially for movie and music recommendation. E-learning has gained more attention recently, as the Covid-19 pandemic forced a mandatory shift from face-to-face education to online education. In this regard, taking into consideration the individual differences of learners such as learning styles, prior knowledge level, and motivation level play a vital role in acceptance and usage levels of e-learning systems by the learners and academic success levels of students using these e-learning systems. Semantic web technologies enable modeling these individual differences with ontologies and provide a valuable foundation for knowledge based recommender systems. Various learning resource or learning object ontologies that model learning materials and learner model ontologies that model learner profiles have been developed and used successfully in different educational recommender systems. These ontologies and interaction data of learners with e-learning systems provide valuable data for recommender systems to operate on. Collaborative filtering and content based filtering approaches have been used to analyze these data and implement educational recommender systems. Therefore, in this paper, we provide a review of semantic web based recommender systems conducted at the e-learning domain. We surveyed different aspects of educational recommender systems such as the data sources used for recommendations and the approaches utilized for implementation. Finally, we present the implications, limitations and future work directions in the field of educational recommender systems.

Keywords: E-Learning · Recommender Systems · Semantic Web · Ontology

1 Introduction

Recommender systems have been successfully adopted to various domains that are widely used in daily life, especially in the e-commerce field and for recommendation of movies and music. The usage of recommender systems in the e-learning

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domain is relatively new compared to its usage in the aforementioned domains. There have been numerous educational recommender systems developed in the last decade; however, with the shift from face-to-face education to online education because of the Covid-19 pandemic, the popularity of recommender systems in e-learning has increased [1].

Modeling of the individual differences between learners such as learning styles, prior knowledge level, and motivation level has a significant importance in adoption and usage level of e-learning systems by the learners [2,3]. These individual differences are essential for the personalization support of the e-learning systems [4,5]. Thus, personalization of the recommendations provided to learners effect the academic success levels of students [6–8].

Semantic web technologies enable modeling individual differences of learners with ontologies [9,10] and provide a valuable foundation for knowledge based recommender systems [11,12]. Various learning resource or learning object ontologies that model learning materials and learner model ontologies that model learner profiles have been developed and used successfully in different educational recommender systems [13–17]. These ontologies and interaction data of learners with e-learning systems provide valuable data for recommender systems to operate on [18–20].

Collaborative filtering, content based filtering and knowledge based recommendation are the main approaches for implementing recommender systems [21–23] and have been used to analyze the learner generated data and implement educational recommender systems [22,24]. Other artificial intelligence techniques such as data mining, fuzzy logic and sequential pattern mining are also widely used for implementing recommender systems [25–27].

Therefore, semantic web techniques, recommender system approaches and artificial intelligence methods provide opportunities to facilitate learning progress and enhance learning experiences of learners [13–15]. With this motivation, in this paper, we present a review of other survey studies with similar aims and focus on providing a detailed view of the semantic web based recommender systems conducted at the e-learning domain. We examined different aspects of educational recommender systems such as the data sources used for recommendations and the models and approaches utilized for implementation.

The rest of the paper is organized as follows; Sect. 2 provides a comparison of other surveys conducted to analyze recommender systems and artificial intelligence approaches in general that are applied in the e-learning domain. Section 3 presents a detailed analysis and discussion of recent educational recommender systems that incorporate an ontological component. Section 4 includes a discussion of the implications observed and possible future work directions in the field of educational recommender systems, and lists the limitations of this study. Finally, Sect. 5 concludes the paper.

2 A Review of Surveys Conducted on Personalized E-Learning Systems

There are a lot surveys conducted at the literature that focus on personalized e-learning systems and particularly on the usage of different artificial intelligence techniques in the educational domain. Table 1 presents a brief summary of these survey studies by listing the main aim of each survey paper.

Table 1 contains surveys conducted at a wide range of areas; however, the main aspects considered as inclusion criteria for the examined surveys can be listed as given below:

- "Semantic web, ontology and linked data technologies which are quite related to each other"
- "Recommender system methods"
- "Personalized e-learning systems and usage of artificial intelligence techniques on the educational domain"

Thus, the selected surveys cover a selection of these three criteria; with some surveys meeting at least one of them, while some of them involves both of the criteria listed above. Table 2 presents an analysis of focussed research areas of the recent survey papers examined in Table 1. The studies listed at Table 2 can be categorized in groups as given below:

- "Papers focussing on personalization or usage of artificial intelligence techniques on e-learning systems" [4,6,24–27]
- "Surveys that emphasize the application of recommender systems in the e-learning field" [18–22]
- "Papers discussing the semantic web, ontology and linked data technologies in e-learning systems"[16,17]
- "Review of different recommender system techniques applied in various domains including education"[23]
- "Surveys that cover both semantic web, ontology and linked data related technologies, recommender system methods which are applied in an educational environment"[13–15]

Only three survey studies, namely [13–15] listed in Table 2 are involved with both of the three research areas focussed in this paper. Table 3 provides a more detailed analysis of each survey paper by listing publication year, the publication year interval of studies covered in the survey, and the number of examined studies in each survey.

The number of studies covered by [14] can seem relatively high, that is because this survey also contains studies that do not involve ontologies and focus on other recommender system approaches. When the findings of [14] are anaylzed in detail, it can be seen that only 6 publications were covered when ontology methodologies were investigated, only 10 publications applied ontologies as part of conventional recommender systems, and only 15 publications involved hybrid recommendation approaches, of which only 8 studies involved ontologies as part

Table 1. Surveys Conducted on Personalized E-Learning Systems.

Reference	Year	Main Aim of the Survey
[4]	2015	Focusses on the usage and integration of different learning style models on adaptive e-learning systems.
[6]	2015	Provides content analysis of articles that present adaptive e-learning environments implemented by using learning styles.
[13]	2022	Presents a systematic literature review on ontology usage for implementing recommender systems in the e-learning domain.
[14]	2019	Reviews ontological recommender systems implemented in the e-learning field; however, also provides a review of other machine learning techniques applied for e-learning.
[15]	2018	Knowledge based recommender systems developed by using ontologies are analyzed to present a survey.
[16]	2015	Focusses on ontology usage in e-learning environments; however, the focus of the surveys was not only on recommender systems.
[17]	2018	Provides a systematic mapping study of how ontologies are applied to enhance higher education; thus, the application domain is narrowed down from the e-learning domain in general to higher education context only.
[18]	2015	Presents a more general survey on the usage of recommenders systems on the e-learning domain.
[19]	2022	Reports the state of the art on application of recommender systems on MOOCs (Massive Open Online Courses).
[20]	2022	Provides a more specialized review of the recommender system implementations only for learning path recommendations.
[21]	2020	Dicsusses machine learning based recommender systems implemented in the e-learning domain systematiccally.
[23]	2021	Examines the applications of content-based and context-based recommendation systems; however, not focusses on a particular domain.
[22]	2020	Reviews educational recommender systems by focussing on how to support the learners' agency.
[24]	2015	Surveys the educational content design and learner adaptation aspects of e-learning systems and not focusses on the recommender system related components.
[25]	2022	Presents a more general review of artificial intelligence based personalized e-learning environments and not focusses on recommender systems.
[26]	2020	Discusses the applications and open issues related to artificial intelligence usage in educational systems.
[27]	2020	Provides a survey of the challanges and open research issues of the research field "artificial intelligence in education"

Table 2. Analysis of Focussed Research Areas of Recent Surveys.

Survey Paper	Focussed Research Areas		
	Semantic Web	Recommender System	AI/Personalization in E-Learning
[4]	No	No	Yes
[6]	No	No	Yes
[13]	Yes	Yes	Yes
[14]	Yes	Yes	Yes
[15]	Yes	Yes	Yes
[16]	Yes	No	Yes
[17]	Yes	No	Yes
[18]	No	Yes	Yes
[19]	No	Yes	Yes
[20]	No	Yes	Yes
[21]	No	Yes	Yes
[23]	No	Yes	No
[22]	No	Yes	Yes
[24]	No	No	Yes
[25]	No	No	Yes
[26]	No	No	Yes
[27]	No	No	Yes

Table 3. Details of Surveys Conducted on Usage of Ontologies in Educational Recommender Systems.

Reference	Publication Year	Publication Year Interval of Studies Covered in the Survey	The Number of Examined Studies
[13]	2022	2010–2020	28 journal articles
[14]	2019	2010–2018	108 publications in total (91 journal articles, 10 conference papers, 5 books)
[15]	2018	2005–2014	36 publications

of hybridization strategy (with 3 formal and 5 domain ontologies). Therefore, it can be concluded that when ontologies are considered as the main focus, the number of investigated studies at each survey listed in Table 3 are quite close to each others.

As the most recent survey listed in Table 3, [13] includes only one article from the year 2020, which points out that there is a need for a new survey which will cover more recent research on this topic. With this motivation, this survey focusses on more recent related work on ontology usage in educational recommender systems.

3 Semantic Web Based Recommender Systems Implemented for E-Learning

Some of the pioneering research studies in the field of ontology based educational recommender systems covered by previous systematic literature reviews [13–15] can be listed and briefly discussed as given below:

- [28] : Presents a semantic web based solution to provide personalized feedback to students based on their learning goals for self assessment in lifelong learning environments. It is stated that semantic web technologies are useful to provide more effective learning experiences to students and to make online learning environments more student-oriented.
- [29] : Proposes a smart learning system for the law domain by using knowledge discovery and cognitive computing approaches. The findings of an experimental study conducted with the proposed system show that students achieve higher success when they work with personalized learning materials.
- [30] : Provides a student modeling approach by using ontologies and diagnosis rules. The proposed method is a diagnostic rule-based system that is based on detecting students' mistakes during the learning process to help personalize learning materials.
- [31] : Presents a student modeling approach based on non-monotonic diagnostic methods for training in intelligent virtual environments. The performances of students are continuously monitored to identify students' incorrect answers, and then, the student models are utilized to identify the causes of these errors.
- [32] : Proposes an ontology based personalized feedback generator called "OntoPeFeGe" that takes into account students' learning styles and prior knowledge levels. In this study, student profiles and learning materials are modeled based on an educational domain ontology. The experiments conducted to evaluate the effectiveness of OntoPeFeGe conclude that it improves students' learning performance and helps develop learning strategies.
- [33] : Designs and develops a BDI agents based solution for intelligent tutoring systems. The BDI agents monitor students' performance and offer customized learning plans by taking into account students' learning goals and prior knowledge levels. Experiments conducted to analyze the impact of the proposed system show that students' learning performance was improved significantly and the use of customized learning materials increased students' motivation levels.
- [34] : Provides a problem based learning approach for the IP addressing topic of computer networks course. It is stated that the proposed approach can increase students' motivation and problem-solving skills by offering a more active learning experience.
- [35] : Presents an educational recommender system based on semantic analysis of social networks. With customized recommendations according to students' interests and skills that utilize the semantic analysis of data in learning environments, the learning process of students can become more efficient.

- [36] : Proposes an ontology for representing learners' characteristic features by utilizing different learning style models. It is discussed that learning styles models can be used more effectively by including other characteristics of learners, such as motivation levels, and learning goals.
- [37] : Presents the "ACCESIBILITIC" ontology that supports accessibility of ICT users. The design and development of the ontology that offers solutions to accessibility problems by taking into account the activities and needs of disabled users is explained in detail.
- [38] : Proposes a solution called "OntoSakai" to support learning management systems with semantics and user profiling. The ontology which includes various features of users such as learning styles, preferences, skills, interests and other characteristics is utilized to customize the learning management system and improve learning experiences of students.
- [39] : Provides a personalized social network for academic purposes by using a fuzzy recommender system. The proposed approach collects data through a feedback mechanism that allows users to rate recommended materials, and then, adjusts the recommendations by adapting to the users' preferences and interests to provide more efficient social learning experiences.
- [40] : Presents an adaptive e-learning environment that is based on utilization of semantic web, agents and cloud computing technologies. The ontology-based approach provides a foundation that defines relationships of e-learning materials, and software agents use data mining and data analysis techniques to identify students' strengths and weaknesses. By combining ontologies and software agents, the learning materials are more accurately categorized and presented to students in a more appropriate way.
- [41] : Utilizes semantic web technologies to propose automatic feedback generation for online assessment. In this study, responses of students are automatically evaluated by using semantic web technologies. It is pointed out that these technologies can help provide students with more detailed and personalized feedback and improve their learning processes.
- [42] : Proposes an advisor system that takes into account cultural differences in instructional design processes to provide students more effective learning experiences. This system is used to evaluate the impact of cultural differences on the learning process and to provide students with appropriate learning materials and methods.
- [43] : Presents a hybrid educational recommender system that utilizes ontologies and sequential pattern mining to make recommendations by taking into account students' learning preferences and previous learning experiences. The relationships between learning materials are also analyzed to provide more personalized recommendations.
- [44] : Proposes an agent based context-aware adaptive e-learning system which takes into account the learning needs and characteristics of the students and personalizes the learning materials. It also monitors the learning progress of students and provides feedback to students during their learning processes.
- [45] : Provides the "On-smmile" student model which is based on ontology networks to integrate multiple e-learning systems. This study presents an

interesting approach for creation of student models and personalization of learning materials by using ontology networks.

In this paper, more recent research studies that were not covered by [13–15] are also analyzed. Table 4 presents a summary of more recent journal articles by focussing on the main aim of each research paper.

Table 4. Analysis of more recent research articles conducted as ontology based educational recommender systems.

Reference	Year	Main Aim of the Survey
[46]	2021	Addresses the cold-start problem of content recommender systems for the e-learning domain by offering an ontology-based solution.
[47]	2021	Provides a semantic web based hybrid content recommender system for e-learning that alleviates the cold-start problem.
[48]	2023	Presents a personalized e-learning system that supports adaptive access to digital libraries by using ontologies and collaborative filtering.
[49]	2022	Proposes an e-learning recommender system which uses a dynamic ontology.
[50]	2021	Provides a recommender system based on usage of ontologies and machine learning approaches for recommendation of lifelong learning courses.
[51]	2023	Presents a hybrid recommender system that is based on linked data technologies, and description and dialetheic logic.
[52]	2023	Proposes a solution for prediction of students' behaviors based on usage of personalized ontologies and neural networks

4 Discussion of Ontology Usage in Educational Recommender Systems

Implications identified after analyzing previous systematic literature reviews and more recent research articles can be grouped as given below:

- Semantic web technologies and ontologies can be useful for problems such as cold-start, sparsity of ratings, and overspecialization in recommender systems [13,15,46,47].
- Ontologies are generally used for representation of domain knowledge and learner modeling in educational recommender systems [16]. However, there are other areas for using ontologies such as curriculum modeling, data integration among different domains [17].
- The most commonly recommended items to students in educational recommender systems are learning objects [13,14]. Besides that, learning paths [20], feedback [28,32,41], learning devices [37] and pedagogical scenarios [42] can also be recommended to learners.

- Most of the educational recommender systems were evaluated in higher education settings, with only one study reported at pre-school setting [13]. In addition, most of the studies conducted at higher education level are involved with programming and computer/software engineering courses. This is an expected finding, because most of the recommender systems are developed by computer/software engineers and tested in courses of these departments.
- Most of the studies are evaluated as part of a single course [13]. A more diverse evaluation setting is needed to assess the effectiveness of the proposed educational recommender systems.
- Standards for ontology development and engineering are generally not followed or reported in research studies [13,14].
- Semantic web technologies are frequently used together with software agents [33,40,44,53,54]. Therefore, more research can be conducted in this area to take advantage of recent technological advancements in this research area.
- There are limited number of studies based on linked data technologies like [51]. More research can me conducted to utilize and combine various technologies.
- Research studies focus more on the technological advancements; however, educational/pedagogical aspects are as important as the technological aspects to provide better learning experiences and to improve the quality of the recommender systems [13].

Future work directions for further research studies can be listed as given below:

- Possible combinations of different recommendation approaches to provide hybrid recommender systems need to be supported with more research [14]. In this regard, traditional recommender system techniques like content-based filtering, collaborative filtering, and knowledge based (ontology based) recommendation can be supported with deep learning and machine learning approaches such as neural networks, support vector machines, and random forest to propose more enhanced hybrid recommendations [13,55].
- More research should be conducted on methodologies for ontology evaluation. Since most of the studies do not report whether or how they evaluate the ontologies they have developed, there exist a gap in this direction [13].
- The proposed e-learning systems are generally evaluated with runtime performance analysis, simulation studies (with nonreal students), and sometimes quantitative and qualitative observations (in face to face or online classroom settings) [13,15]. Thus, evaluation aspects of recommenders systems needs more attention in future studies.
- There are recent research studies that focus on providing explainable recommendations to students in personalized e-learning systems [56]
- Utiling new technological advances such as AR/VR technologies and the Metaverse can also facilitate providing more enhanced learning experiences [57].

There are also limitations of this paper. First of all, a systematic approach is not followed, which may effect the findings presented. However, the snowball

approach is followed in this paper by checking the citations of other survey articles. Thus, it can be claimed that the overall quality of the papers examined in this paper is relatively high.

5 Conclusion

In this paper, a detailed analysis of previous surveys conducted at the e-learning field by focussing artificial intelligence and personalization, recommender systems, and semantic web/ontology/linked data technologies have been given. Also, a comparison with three other surveys that focus on semantic web based recommender systems in e-learning domain like this review has been provided. A summary of major studies covered by previous surveys is presented and more recent research studies conducted as semantic web based recommender systems in the e-learning field are discussed.

Ontology usage as part of recommender systems provide a huge potential for implementation of future personalized e-learning systems. However, in order to reach the full potential of educational recommender systems, both educational and technological aspects as well as the cultural differences should be considered. In this regard, a diverse set of stakeholders including computer/software engineers, learning content designers, institutional representatives should come together and work in tandem to produce more efficient educational recommender systems, preferably with international collaborations.

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