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LEARNING PERSONALISATION APPROACH BASED ON RESOURCE DESCRIPTION FRAMEWORK

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Abstract

The report is aimed to present a methodology of learning personalisation based on applying Resource Description Framework (RDF) standard model. Research results are two-fold: first, the results of systematic literature review on Linked Data, RDF "subject-predicate-object" triples, and Web Ontology Language (OWL) application in education are presented, and, second, RDF triples-based learning personalisation methodology is proposed. The review revealed that OWL, Linked Data, and triples-based RDF standard model could be successfully used in education. On the other hand, although OWL, Linked Data approach and RDF standard model are already well-known in scientific literature, only few authors have analysed its application to personalise learning process, but many authors agree that OWL, Linked Data and RDF-based learning personalisation trends should be further analysed. The main scientific contribution of the report is presentation of original methodology to create personalised RDF triples to further development of corresponding OWL-based ontologies and recommender system. According to this methodology, RDF-based personalisation of learning should be based on applying students' learning styles and intelligent technologies. The main advantages of this approach are analyses of interlinks between students' learning styles according to Felder-Silverman learning styles model and suitable learning components (learning objects and learning activities). There are three RDF triples used while creating the methodology: "student's learning style – requires – suitable learning objects", "student's learning style – requires – suitable learning activities", and "suitable learning activities – require – suitable learning objects". In the last triple, "suitable learning activities" being the object in the 2nd triple, becomes the subject in the 3rd triple. The methodology is based on applying pedagogically sound vocabularies of learning components (i.e. learning objects and learning activities), experts' collective intelligence to identify learning objects and learning methods / activities that are most suitable for particular students, and intelligent technologies (i.e. ontologies and recommender system). This methodology based on applying personalised RDF triples is aimed at improving learning quality and effectiveness.

Contents

1 Introduction

Personalised learning and application of Semantic Web and other intelligent technologies in education are important research areas of modern educational technology. Therefore, in recent years, researchers were extremely interested in such personalisation strategies (Kurilovas *et al.*, 2015; Spodniakova Pfefferova, 2015;; Juskeviciene *et al.*, 2016) and Semantic Web and other intelligent technologies (Lytras and Kurilovas, 2014; Lytras *et al.*, 2014; Kurilovas *et al.*, 2014a; Kurilovas and Juskeviciene, 2015). According to Kurilovas *et al.* (2014c), there has not been a concrete definition of personalisation so far. The main idea is to reach an abstract common goal: to provide users with what they want or need without expecting them to ask for it explicitly.

The main aim of the report is to analyse the problem of learning personalisation applying Resource Description Framework (RDF) standard model. The results of the performed systematic review on RDF and semantic description in learning and personalisation are discussed, and an original learning personalisation framework addressing student's learning styles and based on RDF and intelligent technologies is presented. The report in the extended version of the earlier authors' report (Jevsikova *et al.*, 2016) presented at ECEL 2016 conference. The report is enriched with review on Web Ontology Language (OWL) application in education and proposed methodology to personalise learning based on applying three RDF triples. There are the following RDF triples used while creating the methodology: "student's learning style – requires – suitable learning objects", "student's learning style – requires – suitable learning activities", and "suitable learning activities – require – suitable learning objects".

According to previous research, learning objects (LOs) (Kurilovas, 2009; Kurilovas and Dagienė, 2009; Kurilovas and Serikoviene, 2013; Kurilovas *et al.*, 2014b), learning activities (LAs) (Dagienė and Kurilovas, 2007) and learning environment (Kurilovas and Dagiene, 2016) are the main components of the whole learning units / scenarios (Kurilovas *et al.*, 2011; Kurilovas and Zilinskiene, 2013). Therefore, learning objects and learning activities are analysed in the report in more detailed way in order to create RDF triples-based learning personalisation methodology. Research on RDF-based personalised learning environment is out of scope of this report and should be the topic for further research.

RDF is a standard model for data interchange on the Web. RDF provides facilities for data merging even if the underlying schemas differ. It also supports the evolution of schemas over time without requiring all the data consumers to be changed. Therefore, RDF is a core model that can be used to support learning resource linking with student's learning styles. RDF extends the linking structure of the Web to use URIs to name the relationship between "subject" and "object" as well as the two ends of the link (this is referred to as a "triple"). Using this simple model, it allows structured and semi-structured data to be mixed, exposed, and shared across different applications (W3C Semantic Web, 2014). Visual representation of this triple model is a view of a directed, labelled graph with the resources, represented by the graph nodes, and named links between the resources represented by the graph edges. RDF is used to transform learning object metadata into semantic information with contextual relationships, what helps to achieve semantic metadata interoperability, improve learning object search and retrieval, according to the user's needs.

The Linked Data approach is closely related to RDF, and has and will have a strong impact on the educational field and has already started to replace the fragmented landscape of educational technologies and standards with a more unified approach, which allows to integrate and interlink educational data of any kind (Dietze et al., 2013a). The strongest side of the Linked Data approach is that it does not require particular schemas to be used, but instead, accepts heterogeneity and offers solutions on the links between schemas and datasets. The learning objects / resources, exposed as Linked Data, can be effectively enriched with metadata and interlinked.

OWL is standard ontology language which could use RDF triples to create ontologies linking students' learning styles, learning objects and learning activities. These ontologies should be the main part of personalised recommender system that should recommend learning components and scenarios suitable to particular students according to their learning styles.

The rest of the report is organised into following sections. Systematic literature review on RDF, Linked data and OWL application to personalise learning is presented in Section 2. Section 3 is aimed to discuss findings of the systematic review. Section 4 presents an original RDF triples based methodology to personalise learning. Section 5 concludes the report.

2 Systematic review

The main goal of the systematic review was to find out how RDF triples, Linked Data and OWL approaches can be used to identify suitable learning objects and learning activities for student to personalise learning in conformity with his/her learning styles.

1.1 Application of RDF and Linked Data to Personalise Learning

In order to identify scientific methods and possible results on Resource Description Framework (RDF) triples and Linked Data application in learning, systematic literature review method devised by Kitchenham (2004) has been used.

The following research questions have been raised to perform systematic literature review:

RQ1: How RDF and Linked Data approach are used to support learning, describe and link learning resources?

RQ2: How semantic web technologies, like RDF and Linked Data are used to support learning personalisation?

The protocol of search, conducted on January 15, 2017 in Clarivate Analytics (former Thomson Reuters) Web of Science database, including search keywords and search options used, corresponding research question and number of results found, are presented in Table 1. In order to obtain a wider view on semantic web technologies that can be used for our goal formulated above, we did not include "learning styles" into our search keywords.

Table 1. Search protocol in Thomson Reuters Web of Science

Set No.	Search phrase	Research Question	Results	Search options

1	TS=((RDF OR "Linked Data") AND learning)	RQ1	353	Language: English Document types: (Article OR Proceedings Paper OR Review) Timespan = 2009–2016
2	TS=((RDF OR "Linked Data") AND personalisation)	RQ2	27	

During the last years (2009–2016), 354 documents were found according the topic *(RDF OR "Linked Data") AND learning*, including 120 articles, 232 proceedings papers, 3 reviews and 1 book chapter; 27 documents were found according the topic *(RDF OR "Linked Data") AND personalisation*, including 9 articles, 17 proceedings papers, and 1 review.

After applying Kitchenham (2004) systematic review methodology, on the last stage 31 suitable documents were identified to further detailed analysis. The analysis results are as follows.

RDF proves to be a widely used semantic web framework to solve the problems we address in this report. The semantic web is a collection of working together components so that a machine is able to process and understand information. In order for this vision to be implemented, formal standards for representing and interpreting data are used, including RDF and machine processible ontologies (Algosaibi and Melton, 2014).

RDF as a recommended format for representing data is one of the most important contributions to the Semantic Web concept. It brings opportunity to develop new approaches to data analysis. The main idea is to represent each piece of data as a triple: “subject-proposition-object”, where the “subject” is an entity being described, “object” is and entity that describes the subject, and the “proposition” (or “predicate”) is a connection (a relation) between subject and object. A subject of one triple can be an object of another triple, and vice versa. This gives a network of interconnected triples (Chen and Reformat, 2014). RDF data can be analysed with various query languages, e.g. SPARQL. Teufl and Lackner (2011) expand the possibilities of such query languages and present a method to transform information presented in the RDF triples relations into activation patterns that are a basis for further analysis including semantic relation analysis, semantic search queries, unsupervised clustering, supervised learning or anomaly detection.

Svensson *et al.* (2009) argue that learning content repository based on RDF can be a flexible solution for digital content storage in terms of metadata expressivity, interoperability and data distribution. In their approach, the authors derive metadata that describe the context of the user through the built-in or attachable sensor capabilities of mobile devices. A learning content repository (Pinetree) is presented using RDF as a data model. Chen (2015) proposes an approach to transform metadata from equivalent lexical element mapping into semantic mapping with contextual relationships, based on RDF. RDF is used as a crosswalk model to represent the contextual relationships implicitly embedded between described objects and their elements. The semantic, hierarchical, granular, syntactic and multiple object relationships are included to achieve semantic metadata interoperability at the data element level. RDF-based expressions let manifest into a semantic representation the sets of shared terms, contextual relationships between described objects and their metadata elements. The author has developed nine types of mapping rules to achieve a semantic metadata crosswalk. By combining semantic descriptions already lying or implicit within the descriptive metadata, reasoning-based or semantic searching of these collections can be enabled and produce novel possibilities for content browsing and retrieval (Solomou and Koutsomitropoulos, 2015). The authors employ semantic searching techniques on digital repositories and introduce a methodology to pragmatically evaluate and get measurable results of the semantic searching in such scenarios.

Nakayama and Hoshito (2009) use an RDF-based ontology in support system for university students to create their own course schedules. The system provides course information, such as syllabus, students' assessment scores and reviews. The evaluation has shown that the number of courses selected increased significantly. Cimiano *et al.* (2011) argue that it is crucial to associate linguistic information with ontologies and that more expressive models beyond the label systems implemented in RDF, OWL and SKOS are needed to capture the relation between natural language constructs and ontological structures. Mu and Wang (2009) use the advantages of knowledge maps that can integrate the related digital learning resources. This allows looking for the resources and the relationship of knowledge in the form of map and increase content understanding by the learners. The authors use semantic web technologies standards, such as RDF, ontology language, and XML. Chen and Reformat (2014) suggest building categories based on similarity of entities contained in the data to provide more benefits in addition to properties indicating data type and subject, provided in RDF-based data.

There is a wide variety of technologies available to deal with exposing, sharing and integrating educational web data, but according to a number of publications in the recent years, it can be stated that Linked Data based approaches have gained a lot of attention and started realising the vision of highly accessible and Web-wide reusable learning resources by providing the standards, tools, and Web infrastructure to expose and interlink educational data at Web-scale (Dietze *et al.*, 2013a).

Semantic Web technologies and Linked Data are changing the way information is stored, described and exploited (Chicaiza *et al.*, 2014). The “Linked Data” term refers to a set of best practices for publishing and connecting structured data on the Web. Chicaiza *et al.* (2014) deal with improvement of the associations between learning subjects, areas and topics, including semantic relations and recommendations about resources for learners. The advantages of linked data web are used to support semi-automatic classification of educational resources. The relations of the resources are encoded in RDF language and stored in the repository, a query language is used to retrieve data, and the knowledge of organizational systems and linked data is used to classify the web resources according to the domain.

Dietze *et al.* (2013b) identify the existing problems of interoperability with a fragmented landscape of metadata schemas, such as IEEE LOM or ADL SCORM (e.g. large use XML and relational databases, often consisting of poorly structured text lacking formal semantics, leading to hard to interpret and process at machine-level ambiguous descriptions), and interface mechanisms, such as OAI-PMH, SQI and REST-ful services, and propose using Linked Data as the de facto standard for sharing data. The results of the European Commission-funded project “mEducator” demonstrate how the Linked Data principles are applied for semantic integration and social interconnecting of educational data, resources and actors. The metadata of educational resources, retrieved from different services, are transformed from their native (standardized or proprietary) formats into RDF, using a Linked Data-compliant educational resource schema and are made accessible via URIs (Uniform Resource Identifiers). A general approach based on automated enrichment and interlinking techniques to provide a rich and well-interlinked graph for the educational domain is based on already existing educational data on the web. The results of the experimental evaluation demonstrated improved interoperability and retrievability of the resource descriptions, presented as part of an interlinked resource graph.

The survey presented in (Dietze *et al.*, 2013a) is one of the first comprehensive surveys on the topic of linked data for education and provide an extensive overview of the Linked Data approaches for technology-enhanced learning. It aims to provide rich and well-interlinked data for the educational domain, using the existing technology-enhanced learning data on the web by allowing its exposure as linked data, and using automated enrichment and interlinking techniques.

Vega-Gorgojo *et al.* (2015) have performed a systematic literature review on usage of Linked Data proposals in learning domain, analysing in detail 33 studies published between 2009 and 2013. The authors state that Linked Data movement promises to significantly improve existing practices of system integration, resource sharing and personalisation to support learning. The proposals to use Linked Data in learning were classified into the technology-enhanced learning research areas: computer-supported collaborative learning, connection between formal and informal learning, contextualized learning, emotional and motivational aspects of technology-enhanced learning, games enhanced learning, improving practices of formal education, informal learning, interoperability, personalisation of learning, technology enhanced assessment, ubiquitous and mobile technology and learning, workplace learning. The majority of studies (52%) were assigned to the *interoperability* area. The authors have extracted RDF-compliant technological products, existing Linked Data vocabularies and RDF triple stores, mentioned in the analysed studies. Regarding personalisation, the authors stress new ways of contextualised and personalised learning practices that can be delivered through Linked Data by data reuse, such as quiz generation, enrichment of educational data or resource recommendation. However, Linked Data for personalisation according to the learning styles is not considered in the study, but the importance of use of Linked Data for improving the visibility of course offerings, recommendation of educational material or expert matching is mentioned.

New opportunities for relating learning resources identified by URIs combined with the usage of RDF as a lingua franca for describing them are arising with the emergence of Web of Data (Rajabi *et al.*, 2015). The authors present an approach for exposing existing IEEE LOM metadata as Linked Data. IEEE LOM elements (simple and structured, as well as with multiplicity) are transformed into XML representation and RDF triples (subject, predicate and object). The metadata are linked to the datasets in LOD (Linking Open Data), e.g. DBPedia. A case study and a reference implementation along with an evaluation have proved the concept of this mapping. Selected queries passed a performance testing on both relational database and triple store.

Eriksson (2015) presents a method of digitising steering educational documents (e.g. curricula, syllabi, subject plan) using RDF and Linked Data. To create digitally usable versions of the syllabi, their content was divided into meaningful chunks of text. Each chunk was regarded as resource and was assigned with an URI. To represent the hierarchical structure of the documents, the predicates “hasChild”, “isChildOf”, “isPartOf” and others were used for making the structure traversable by positioning the statements within the document. RDF triples like “Methods for solving equations” – “is a” – “core content” have been used. The approach may be successfully used for individual development plans. The author also states that by adding steering document chunk connections to learning resource metadata, it would be possible to search for learning resources relevant to specific knowledge requirements or core contents.

Chung and Kim (2015) design an ontological semantic model of achievement standards (the standards, providing guidelines about what has to be taught and assessed by teachers and what has to be studied and achieved by students). Mapping rules are defined to formalise the semantic model to RDF/OWL specification. The approach is based on Linking Open Data. The proposed semantic model is used to create Linked Data profile searching and browsing, sharing, modification history tracing, learning resource linking.

Dessi and Atzori (2016) address the problem of ranking among properties of the entities used in RDF datasets, Linked Data and SPARQL endpoints. The authors provide applications for property tagging and entity visualisation, and propose to apply Machine Learning to Rank techniques to the problem of ranking RDF properties. The major advantages of the approach are: flexibility/personalisation, speed, effectiveness.

Yu *et al.* (2012) introduce educational online video resource annotation, adopting Linked Data technology. The tools, presented by the authors enable users to semantically annotate video resources using vocabularies defined in the Linked Data cloud and browse semantically linked video resources, enriched with information from various online resources. The suggested approach deals with the lack of semantic connections between isolated annotation of educational video resources and enhances the exploration, sharing, reuse, and linking of videos for better e-learning experiences.

Otero-Garcia *et al*. (2011) present a context-based algorithm to semantically annotate e-learning resources. This algorithm uses both syntactic and semantic analysis techniques to identify the RDF triples which annotate the relevant terms that characterise the educational content. The algorithm was used on Linked Data to explore the DBpedia graph.

Hogan *et al.* (2011) propose an architecture and implementation of the Semantic Web search engine. The search engine consists of crawling, data enhancing, indexing and user interface components for search, browsing and retrieval of information (these components correspond to the traditional search engine architecture); unlike traditional search engines, the proposed semantic web search engine operates over RDF Web data (Linked Data). The authors discuss how current semantic web standards can be tailored for use on web data.

Vert and Andone (2014) suggest using Linked Data principles to discover, integrate and reuse online learning resources, using standards and principles proven to foster web interoperability, like RDF and SPARQL. The authors concentrate on the solutions for open educational resources (OERs). The publishing of resources as

Linked Data is done in several steps: selection of data sources, usage of vocabularies and ontologies to model the data, conversion to the RDF data model, including cleaning of the data, publishing the semantic-enriched data to linked learning resources repositories and consuming the data, usually through SPARQL endpoints. One more study on the OERs in MOOCs (Massive Open Online Courses) proposes to combine the description of OERs with Linked Data approach in order to improve integration of repositories and materials (Piedra *et al.*, 2015). This would lead to a new generation of OERs (described in machine-readable formats), that would facilitate automatic processing tasks. Researchers present a 9 component architecture (OER collecting; OER metadata quality assurance; generation and publication of linked OER data; contextualization, classification and enrichment of OER; seeker of resources (selector of items from OER universe based on SPARQL); getting course preference data and attributes; resources collecting, transformation and graph loading from social network; OER discovering via social network analysis; OER filtering) and validate it with Java introductory online course.

Linking Open Data (LOD) cloud is a collection of linked RDF data with over 31 billion RDF triples. Accessing linked data is a challenging task due to ontology schema specifics in each data set (Zhao and Ichise, 2013). To solve this issue, the authors propose an automatic method to integrate different ontology schemas: Mid-Ontology learning approach that can automatically construct an ontology linking related ontology predicates (class or property) in different data sets. The approach consists of three main phases: data collection, predicate grouping, and Mid-Ontology construction. Experiments show that our Mid-Ontology learning approach successfully integrates diverse ontology schema, and effectively retrieves related information.

While personalisation, adaptation and recommendation are central features of Web-based educational environments, recommender systems apply information retrieval techniques to filter and deliver learning resources according to user preferences and requirements (Taibi *et al*., 2013). The authors state that, however, the suitability of possible recommendations is fundamentally dependent on the available data, i.e. metadata about learning resources and data about the users. To solve the limitation in quantity and quality of both types of data, the Linked Data movement has become very active over the recent years. Taibi *et al*. (2013) propose a large-scale educational dataset, generated by exploiting Linked Data methods and applying clustering and interlinking techniques to extract, import and interlink a wide range of educationally relevant data.

Research work, presented in (Morshed *et al*., 2013) is aimed to develop knowledge recommendation system for the Linking Open Data Cloud using semantic machine learning approach. Knowledge is stored in a triplestore using RDF triples format (subject, predicate, and object) along with the complete metadata. The authors argue that such a RDF representation made the developed intelligent knowledge base very flexible to integrate with the Linking Open Data (LOD) cloud.

One of the most popular Linked Data applications in personalisation area is a recommendation of resources, based on the user interests or past activities. Zeng *et al.* (2010) discuss resource recommendation method where FOAF (Friend of a Friend) formal vocabulary and RDF/OWL standards has been used to describe user interests. Dojchinovski and Vitvar (2014) suggest a method to personalised access to Linked Data, basing on the similarity of user interests. In their method, authors concentrate on the algorithms of computing resource similarity and relevance in a Linked Data graph. Nasraoui and Zhuhadar (2010) use RDF/OWL technologies to represent the content and the user profiles in order to achieve personalised search of learning resources. The researchers use cluster-based semantic search and utilise two different types of ontologies, a global ontology model that represents the whole e-learning domain, and a learner model that represents the learner profile. The implementation of the ontology models in this approach is separate from the design and implementation of the information retrieval system. However, the authors consider only learner's past activities to personalise search.

Figueroa *et al.* (2015) have conducted a systematic literature review on Linked Data based recommendation systems for diverse domains and grouped selected contributions into discussing algorithms (graph-based, statistical algorithms), similarity measures, ontologies, information aggregation and enrichment. The authors did not analyse learning recommendation systems in particular, but conclude that one of the most promising directions for future work is personalisation of recommendations.

2.2 Application of Web Ontology Language (OWL) to Personalise Learning

The W3C Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be exploited by computer programs, e.g., to verify the consistency of that knowledge or to make implicit knowledge explicit. OWL documents, known as ontologies, can be published in the World Wide Web and may refer to or be referred from other OWL ontologies. OWL is part of the W3C's Semantic Web technology stack, which includes RDF, RDFS, SPARQL, etc.

In Maffei *et al.* (2016), the chosen modelling language is OWL: this provides the possibility to describe in a computer understandable way a higher education courses to an unprecedented level of detail. OWL enables also the creation of a specific knowledge base by populating the model.

Kozibroda (2016) has built the ontology of Information System domain knowledge. This enables to combine a huge amount of existing information into a single knowledge base that combines several disciplines. It has been shown in the process of investigation that Protege OWL programming product is the best for the creation of computer system ontology in preparing future engineering teachers and makes it possible to describe not only concepts, but also specific objects.

Srisa-an *et al.* (2016) paper aims to understand a user preference in adopting courseware service in an ontology form. An association rule (Data Mining) is applied to find out factors and conditions that lead to decision to choose a service. Due to its benefit to search engine, OWL format is chosen as a file format for this paper. Experimental results show high percentages of confidence and lift values above 80% and greater than 1 respectively. From the relationship, the authors construct an ontology for user preference using OWL format. The relationship between ontology knowledge management with user preferences is that knowledge representation represented in Ontology form and then knowledge is organised and acquired via user preference web-based application.

Rabahallah *et al.* (2016) consider that the choice of the e-learning web services depend, generally, on the pedagogic, the financial and the technological constraints.

The Learning Quality ontology extends existing ontology such as OWL-S to provide a semantically rich description of these constraints. However, due to the diversity of web services customers, other parameters must be considered during the discovery process, such as their preferences. For this purpose, the user profile takes into account to increase the degree of relevance of discovery results. Rabahallah *et al.* (2016) also present a modelling scenario to illustrate how our ontology can be used.

The main purpose of (Luz *et al.*, 2015) is to present the importance of Interactive Learning Objects to improve the teaching-learning process by assuring a constant interaction among teachers and students, which in turn, allows students to be constantly supported by the teacher. The paper describes the OWL ontology that defines the Interactive Learning Objects available on the Internet.

Alomari *et al.* (2015) developed a tool that represents course content graphically with illustrations and semantic meaning. The proposed model is an automated semantic e-learning system based on BNF rules and the OWL ontology language that is capable of representing course contents using ontology.

Szilagyi *et al.* (2015) present an evaluation mechanism based on ontologies used for learner evaluation in the context of a serious game. The authors concentrate on the conception of these ontologies, which are used to represent competences as learning outcomes, learning tasks in the context of serious games, learner traces and other specific elements. The entire model makes highly use of semantic web technologies, notably the OWL and RDF(S) (Resource Description Framework Schema).

The objective of (Alsobhi *et al.*, 2015) was to propose an ontology that will facilitate the development of learning methods and technologies that are aligned with dyslexia types and symptoms. The paper commences with a discussion of domain ontology and examines how learning objectives that take into consideration a student's capabilities and needs can be matched with appropriate assistive technology in order to deliver effective e-learning experiences and educational resources that can be consistently employed. The ontology employed within this study was developed using OWL, an information processing system that allows applications to handle both the content and the presentation of the information available on the web. Two characteristics were employed within this research to describe each resource: dyslexia type and the features of assistive technologies that were deemed to be most appropriate for educational experiences targeted at each dyslexia type.

3 Findings of the Systematic review

The results of systematic review have shown that many authors agree that “pure” metadata approaches to describe learning objects lack flexibility to address the issues of personalisation. Therefore, metadata of learning resources, conforming the widely used metadata specifications and schemas (e.g. IEEE LOM) are enriched with ontologies to include semantic information on learning resources and student information and to enhance learning object categorisation, search and retrieval.

Regarding Research Question 1, the review has revealed that Linked Data and triple-based RDF standard model could be successfully used in education.

The range of applications of these semantic web technologies is very wide and includes questions of design of LO repositories and transformation of LO metadata into semantic mappings using RDF triples and Linked Data principles to ensure interoperability, scalability, and semantic search. There are approaches to expose existing IEEE LOM metadata as RDF and Linked Data. IEEE LOM elements are transformed into RDF triples (subject, predicate and object) (Solomou and Koutsomitropoulos, 2015; Chen, 2015). The metadata are linked to the datasets in Linking Open Data Cloud (e.g., Rajabi *et al.*, 2015).

The Linked Data approach is a promising approach to establish relationships between learning resources and student's personal characteristics (unless, this point was not discussed in studies we examined). It is based on a set of well-established principles and (W3C) standards, e.g. RDF, SPARQL, aiming at facilitating Web-scale data interoperability (Taibi *et al*., 2013).

Through the last years, vast amounts of educational metadata collections and university data have been provided according to Linked Data principles. In addition, the Linked Data approach allowed to provide knowledge and offers significant potential for its exploitation in educational contexts (cross-domain datasets, e.g. DBpedia, as well as formal descriptions of domain knowledge provide in domain-specific vocabularies, e.g. Europeana).

Several studies describe interlinking and mapping study documents (e.g. steering documents, achievement standards) representation as RDF and Linked Data. Many utilise open educational resources (OER) and Linked Data cloud to enrich online courses, reuse and recommend open resources for users.

RDF and Linked Data technologies are used to annotate and classify resources according to similarity and other criteria, building categories of learning resource.

Although Linked Data approach and RDF standard model are already well-known in scientific literature, only few studies have analysed its application to personalise learning process. Usually, user modelling and past experience, interests are used to provide personalisation. We did not encounter sound studies dealing with these technologies application for personalisation according to student's learning styles. This addresses our *Research Question 2*, posed in the previous section. In their systematic review on recommendation systems using Linked Data, Figueroa *et al.* (2015) state that one of the most promising directions for future work is personalisation of recommendations. We follow this direction in our model presented in the next sections of this report.

Literature analysis on OWL application in education has shown that OWL is widely and successfully used in education but only few studies that employed OWL to personalise learning were found: in (Rabahallah *et al.,* 2016), the user profile was taken into account to increase the degree of relevance of discovery results, and in (Srisa-an *et al.*, 2016), knowledge was organised and acquired via user preference web-based application.

According to literature review, we identify three RDF triples used while creating learning personalisation methodology: "student's learning style – requires – suitable learning objects", "student's learning style – requires – suitable learning activities", and "suitable learning activities – require – suitable learning objects". In the last triple, "suitable learning activities" being the object in the 2nd triple, becomes the subject in the 3rd triple.

4 Learning Personalisation Approach Applying RDF triples

4.1 Learning Personalisation Framework

According to Kurilovas *et al.* (2014c), learning software and all learning process should be personalised according to the main characteristics / needs of the learners. Learners have different needs and characteristics i.e. prior knowledge, intellectual level, interests, goals, cognitive traits (working memory capacity, inductive reasoning ability, and associative learning skills), learning behavioural type (according to his / her self-regulation level), and, finally, learning styles.

According to Kurilovas (2016), future education means personalisation plus intelligence. Learning personalisation means creating and implementing personalised learning units / scenarios based on recommender system suitable for particular learners according to their personal needs. Educational intelligence means application of intelligent (e.g. Semantic Web) technologies and methods enabling personalised learning to improve learning quality and efficiency.

In personalised learning, first of all, integrated learner profile (model) should be implemented based on students' learning styles.

After that, interlinking of learning components (learning objects, learning activities, and learning environment) with learners' profiles should be performed, and ontologies-based personalised recommender system should be created to suggest learning components suitable to particular learners according to their profiles (Kurilovas *et al.*, 2014c).

According to Kurilovas (2016), after interlinking and ontologies creation stage, recommender system should be created to link students' personal data in their profiles, relevant LOs according to corresponding metadata fields, and learning activities and tools suitable to particular students according to their learning styles and other profiles' data.

Interlinking and ontologies creation should be based on the expert evaluation results. Experienced experts should evaluate learning components in terms of their suitability to particular learners according to their learning styles and other preferences / needs.

Recommender system should form the preference lists of the learning components according to the expert evaluation results. Probabilistic suitability indexes should be identified for all learning components in terms of their suitability level to particular learners. Probabilistic suitability indexes could be easily calculated for all learning components and all students if one should multiply learning components' suitability ratings by probabilities of particular students' learning styles (Kurilovas *et al.*, 2016a). These suitability indexes should be included in the recommender system, and all learning components should be linked to particular students according to those suitability indexes. The higher suitability indexes the better learning components fit the needs of particular learners.

Thus, personalised learning units / scenarios (i.e. personalised methodological sequences of learning components) could be created for particular learners. An optimal learning unit / scenario (i.e. learning scenario of the highest quality) for particular student means a methodological sequence of learning components having the highest suitability indexes (Kurilovas *et al.*, 2016a).

A number of intelligent technologies should be applied to implement this approach, e.g. OWL-based ontologies, recommender systems, intelligent agents, decision support systems to evaluate quality and suitability of the learning components, personal learning environments etc.

The main advantages of this framework are analysis of interlinks between students' learning needs e.g. learning styles and suitable learning components based on using pedagogically sound vocabularies of learning components, experts' collective intelligence to evaluate suitability of learning components to particular learners' needs, and application of intelligent technologies.

This pedagogically sound learning units / scenarios personalisation framework is aimed at improving learning quality and effectiveness. Learning unit / scenario of the highest quality for particular student means a methodological sequence of learning components with the highest suitability indexes.

Thus, the level of students' competences, i.e. knowledge / understanding, skills and attitudes / values directly depends on the level of application of high-quality learning units / scenarios in real pedagogical practice (Kurilovas *et al.*, 2016a).

In order to implement presented learning personalisation framework, first of all, RDF triples-based OWL ontologies should be created to interlink all learning components with students' learning styles.

4.2 Linking students' Learning Styles and Suitable Learning Objects

In order to create RDF triples "student's learning style – requires – suitable learning objects", the author propose to apply probabilistic suitability indexes presented in (Kurilovas *et al.*, 2016a) to identify LOs that are the most suitable for particular students according to their learning styles.

For this purpose, after identifying probabilistic learning styles of particular students (Kurilovas *et al.*, 2016a), we should ask the experts' opinion on suitability of particular LOs to learning styles.

In (Kurilovas *et al.*, 2014c), the authors have applied Honey and Mumford learning styles model and interlinked these learning styles with suitable LOs according to Massart and Shulman (2011) LOM AP metadata field 'Learning Resource Type'.

In (Dorça *et al.*, 2016), the authors have applied Felder-Silverman learning styles model to interlink these learning styles with suitable LOs according to LOs Structure, Format, Interactivity Type, Learning Resource Type, and Interactivity Level.

After identifying particular students' learning styles and particular LOs suitability indexes, one could create a number of the aforementioned RDF triples "student's learning style – requires – suitable learning objects" and corresponding OWL-based ontologies. Finally, a recommender system could be created based on the aforementioned ontologies to recommend the most suitable LOs for particular students according to identified LOs probabilistic suitability indexes.

4.3 *Linking Students' Learning Styles and Suitable Learning Activities*

In order to create RDF triples “student’s learning style – requires – suitable learning activities”, the authors propose to apply probabilistic suitability indexes presented in (Kurilovas *et al.*, 2016a) to identify LAs that are the most suitable for particular students according to their learning styles.

In (Jasute *et al.*, 2016), the authors have applied Felder-Silverman learning styles model to interlink these learning styles with suitable Inquiry-Based Learning activities and sub-activities using expert evaluation results.

After identifying particular students’ learning styles and particular LAs suitability indexes, one could create a number of the aforementioned RDF triples “student’s learning style – requires – suitable learning activities” and corresponding OWL-based ontologies. Finally, a recommender system could be created based on these ontologies to recommend the most suitable LAs for particular students according to identified LAs probabilistic suitability indexes.

4.4 *Linking Suitable Learning Activities to Learning Objects*

The last but not the least – one should interlink suitable LAs and LOs and thus create the third RDF triple “suitable learning activities – require – suitable learning objects”. This triple is necessary because not all LAs are suitable to particular LOs and vice versa.

When suitable LAs have been linked to learning styles, the third component of learning, i.e. learning objects, should be linked to suitable learning activities. These links correspond to the set of RDF triples “suitable LA requires suitable LO”, i.e. <LA_i> <*requires*> <LO_j>, where $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$. Each component of an RDF triple, i.e. subject (LA_i), predicate and object (LO_j), is assigned with International Resource Identifiers (IRI).

In order to present our approach, we select one of the learning scenarios developed by iTEC project, called “A breath of fresh air”[1] as an example (European Schoolnet, 2014). This scenario implements the ideas of situated and collaborative learning.

The essence of the scenario is that students go out of the school to explore other learning spaces tasked with a problem or challenge. They have to either capture authentic data, or explore how concepts can be applied in the real world. When students come back to class, they work together to create outputs (artefacts), usually in digital format. This output is then shared with other students, classes, parents, etc. One of the examples of application of this scenario in iTEC project was a cross curricular science and geography activity in order to develop students’ understanding of the local natural environment and wildlife. The class was set with challenge of finding out why the population of ladybirds has decreased in the school grounds over the last year. The students are divided into groups and go out to take pictures, measure temperature and survey habitats. They analyse numerical data in groups and create a video which they then share within and outside the school.

[1] Detailed scenario descriptions can be found at http://itec.eun.org/c/document_library/get_file?p_l_id=18097&folderId=18123&name=DLFE-737.pdf and http://itec.eun.org/c/document_library/get_file?p_l_id=18097&folderId=17991&name=DLFE-717.pdf

In order to link learning activities to learning objects student use or may need to use, we decompose the above described learning scenario into smaller learning activities. Using the example scenario described above, we have identified these core learning activities students are involved into (Table 2). The decomposition has been done collaboratively by the authors. The table also includes examples of LOs uses with and appropriate composite learning activity. We list only student activities, e.g. problem statement in this scenario is done by the teacher and therefore is not included in the table below.

The learning scenario represent blended learning activities, however for each LA students may use digital LOs using their mobile phone when they are outside the school, carry activity or prepare for the certain activity with appropriate LOs in the classroom.

Table 2. Scenario decomposition into learning activities and examples of LOs uses

Learning activity	**Example of LO uses by the students**
LA1. Learn preliminary information on the basic concepts, related to the problem	Explore pictures of Ladybirds, read dictionary definitions, watch video
LA2. Set specific group goals	Use mind mapping tools to express group goals
LA3. Capture data outside the school using digital devices	Learn basics on how to take good photos, measure temperature, e.g. short manuals
LA4. Share findings within a group	Post findings on a group wiki or shared document using mobile device
LA5. Use software tools to analyse data	Watch video tutorials or read short manual how to use software tools (e.g. spreadsheet) to analyse data collected outside the school, create diagrams, and use this tool
LA6. Analyse and process digital data	Learn or recall elements of statistics, e.g. read webpages, textbooks, see example videos
LA7. Draw conclusions from the group's data	Use digital tools to present conclusions, e.g. mind mapping software
LA8. Create a short film	Use a simple web-based film-maker tool
LA8.1.Process images	Use image editing tools, e.g. collage makers on the web
LA8.2. Write a script	Read a web page, a textbook or a manual on how to compose a good script, use text processor
LA9. Share film on a learning platform	Use one of the learning platforms (e.g. Moodle or Mahara) to share the video
LA10. Reflect (comment on other group's output)	Create a blog entry or record an audio file to reflect on the group work and product, use learning platform's features to post comments on other group results

Dorça *et al.* (2016) use certain IEEE LOM standard fields to create relations between LO and student's learning style. These LO metadata fields are: structure, format, learning resource type, interactivity type, and interactivity level. We propose to use the same fields (except "format" field) and corresponding vocabularies of Learning Resource Exchange Metadata Application Profile (Massart and Shulman, 2011) to create RDF triples "suitable LA *requires* LO". We do not include "format" field as LRE AP we use has an extended vocabulary of learning resource types, and format can be derived from this field. The values for LO structure are: atomic, collection, networked, hierarchical, linear. The LO type is grouped into learning assets, learning resource and social media. Interactivity type includes active, expositive, mixed. Interactivity level ranges from very low to very high.

In Table 3, the mappings of learning activity denoted by the code we have assigned in Table 2, and suitable LO metadata field values are presented. The mapping was done independently by three experts, and the results have been discussed and combined. These mappings are used to form RDF triples.

Table 3. Mapping learning activity to LO metadata fields

Learning activity code	**Structure**	**Learning resource type**	**Interactivity type**	**Interactivity level**
LA1	Atomic Collection Linear	Audio Video Image Text Demonstration Glossary Presentation Reference Textbook	Expositive Mixed	Very low Low Medium High
LA2	–	Application Tool Website	Mixed Active	Medium High Very high
LA3	Collection Networked Hierarchical Linear	Video Demonstration Presentation Guide (advice sheets) Reference Simulation Textbook Website	Expositive Mixed Active	Very low Low Medium High Very high
LA4	–	Application Image sharing platform Reference sharing platform Tool Weblog	Mixed Active	Medium High Very high

		Wiki		
LA5	Atomic Collection Linear	Application Video Demonstration Presentation Guide (advice sheets) Reference Simulation Textbook Tool Website	Expositive Mixed Active	Very low Low Medium High Very high
LA6	Atomic Collection Linear	Video Demonstration Presentation Glossary Guide (advice sheets) Reference Simulation Textbook Website	Expositive Mixed Active	Very low Low Medium High Very high
LA7	–	Application Tool Website Wiki	Mixed Active	Medium High Very high
LA8	–	Application Tool Website	Mixed Active	High Very high
LA8.1	–	Application Tool Website Image sharing platform	Mixed Active	High Very high
LA8.2	–	Application Tool Website Reference sharing platform Audio Video Image Text Demonstration Glossary Presentation Reference Textbook	Expositive Mixed Active	Very low Low Medium High Very high

LA9	Networked	Application Tool Video sharing platform Website Weblog Wiki	Mixed Active	Medium High Very high
LA10	Networked	Application Sound sharing platform Tool Website Weblog Wiki	Mixed Active	Medium High Very high

The LOs, required by the LA, are additionally concretised by using specific search term, e.g. "Ladybird" for LA1, as well as appropriate grade, age, etc. The items that are presented in the same cell for metadata field in Table 3, are combined using OR operator (e.g. interactivity type is "mixed" OR "active"), the items, representing metadata fields and presented in the same row of the Table 3, are combined using AND operator (e.g. LO's structure is "atomic" AND type is "image" AND interactivity type is "expositive" AND interactivity level is "low").

For learning activities, indexed in the LO metadata repository, e.g. as learning resource of type "Lesson plan", "Case study", "Enquiry-oriented activity", "Experiment", "Exploration", "Open activity", "Project", "Role play", the metadata field "Relation" is used. The "Relation" field is an optional metadata field. Therefore, we cannot totally rely on it. But, given this field is used and relation types are defined in a vocabulary, this can be treated as one of the possible ways to form RDF triples. LRE metadata AP (Massart and Shulman, 2011) uses a vocabulary that defines a relation called "requires" that is totally suitable for the approach we present in this report.

5 Conclusion

In the report, both systematic review results and methodology on applying RDF triples to personalise learning are presented.

While creating learning personalisation methodology, the author has identified three RDF triples used: "student's learning style – requires – suitable learning objects", "student's learning style – requires – suitable learning activities", and "suitable learning activities – require – suitable learning objects". In the last triple, "suitable learning activities" being the object in the 2nd triple, becomes the subject in the 3rd triple.

According to presented methodology, after identifying particular students' learning styles and particular learning components' (learning objects' and learning activities') suitability indexes, one could create a number of analysed RDF triples and corresponding OWL-based ontologies. Finally, a recommender system could be created based on these ontologies to recommend the most suitable LOs and LAs for particular students according to identified LOs and LAs probabilistic suitability indexes.

Limitations and future work: In Section 4.4, the author presented his approach using one of the learning scenarios as an example. However, learning activities, the author has decomposed this scenario to, may become composite learning activities of other scenarios as well. Creation of a vocabulary of learning activities should be researched in more detail, finding balance between universal learning activities and the specific ones. This is positioned as future work.

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