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Semantic models in Web based Educational System integration

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Abstract: Web based e-Education systems are an important kind of information systems that benefited from Web standards for implementation, deployment and integration. In this paper we propose and evaluate a semantic Web approach to support the features and interoperability of a real industrial e-Education system in production. We show how ontology-based knowledge representation supports the required features, their extension to new ones and the integration of external resources (e.g. official standards) as well as the interoperability with other systems. We designed and implemented a proof of concept in an industrial context that was qualitatively and quantitatively evaluated and we benchmarked different alternatives on real data and real queries. We present a complete evaluation of the quality of service and response time in this industrial context and we show that on a real-world tesbed Semantic Web based solutions can meet the industrial requirements, both in terms of functionalities and efficiency compared to existing operational solutions. We also show that an ontology-oriented modelling opens up new opportunities of advanced functionalities supporting resource recommendation and adaptive learning.

1 Introduction

E-education systems are often at the intersection of information systems and Web based systems. They leverage state of the art results of information sciences and technologies (IST) as well as the Web architecture and resources to support educational processes and the management of their users (learners and teachers), pedagogical resources (courses, exercises, etc.), regulations (e.g official reference standards) and integration across different systems and actors in particular to ensure compatibility and seamless user-experience.

Since education is under the responsibility of public authorities, educational solutions developed by public or private organizations must comply with the public authorities specifications. Taking the example of France, as part of the Education Code (Ministère de l'éducation nationale, 2018), the Ministry of Education has defined and published in the French Official Journal a common reference base of knowledge and skills[1]. It standardizes the content of courses by specifying knowledge and skills that a student must acquire at each step of her school curriculum. Additionally, the French Ministry of Education specifies a format for digital pedagogical resources description called ScoLOMFR (Réseau Canopé, 2011). It is based on the IEEE standard Learning Object Metadata (LOM) (committee, 2002) and its French version, LOMFR[2]. ScoLOMFR specifies a description schema and a common vocabulary for all online pedagogical resources for their indexing and sharing among different e-Education actors in France. As a result, any learning environment developed by public institutions or private companies must meet these standards and norms to ensure a wide dissemination, whatever the educational context. Moreover, they must have updating capabilities to adapt to the possible evolution of these standards. Semantic Web technologies stand as a solution to achieve these goals, offering open standards for ontology-based knowledge representation, with extensible schemata, and data integration and interoperability.

In this paper, we show benefits of Web Information systems and technologies in e-Education context. We present the results of an ontology-based educational knowledge modelling and management experience in a real e-Education environment: the learning solution developed by the Educlever company. We address the following questions: (1) can an in-

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[1] original name: *Socle commun de connaissance, de compétences et de culture*

[2] http://www.lom-fr.fr

dustrial educational system in production rely on semantic Web technologies? (2) Does semantic Web ontology-oriented modelling effectively support educational system integration? (3) Does a semantic Web educational system support additional features? In order to answer these questions, we provide a proof of concept by implementing ontology-based integration and augmentation of different systems, sources and actors of e-Education and benchmarking them in an industrial real-world context.

Our proposed solution relies on EduProgression ontology (Rocha et al., 2016) which is modelling the official common base of knowledge and skills, and which we extended to meet the specific needs of the Educlever solution. Starting from the technical solution originally adopted by Educlever, mainly based on a relational database of educational resources and a graph database of educational concepts and skills indexing these resources, we developed an alternative Semantic Web based solution with (1) an ontology of educational concepts and skills, (2) a repository of semantic annotations of pedagogical resources, and (3) a base of queries on this repository implementing the functionalities offered by the existing solution and additional ones. We show the feasibility of our solution in a real industrial context by implementing it within four off-the-shelf triplestores: *Allegrograph*, *Corese*, *GraphDB* and *Virtuoso*. We benchmark the existing and new solutions on real data and queries and perform evaluation of the quality of service and response time. The results of our evaluation show that the semantic Web based solution meets the industrial requirements, both in terms of functionalities and efficiency. Moreover, we show that our ontology-based modelling opens up new opportunities of advanced functionalities supporting resource recommendation and adaptive learning.

This paper is organized as follows: Section 2 presents state-of-the-art Educational ontologies and triple stores. Section 3 presents our proposed Semantic Web based modeling of educational systems which meets public standards. Section 4 proposes a Semantic Web architecture for educational systems and show how it improves the Educlever solution. Section 5 evaluates and compares Web based integration propositions. We perform this evaluation in the Educlever context, providing data and queries which implement real industrial requirements, on different triplestores and we compare them to each other and to the existing Educlever solution. Section 6 summarizes our contributions and provides several perspectives.

2 Related Work

2.1 Educational Ontologies

The interest of ontologies in the domain of e-Education has been repeatedly pointed out during the last decade. In (Jaffro, 2007), the author analyses the reasons and ways to use ontologies in e-Education and for which goals. Many ontologies have been proposed and designed for dedicated applications. Among them CURONTO (Al-Yahya et al., 2013) is an ontological model dedicated to curriculum management and to facilitate program review and management.

In (Rani et al., 2016) the authors propose an e-learning management system based on an ontology modelling all the dimensions of the system. Other works on ontology modelling deal with the production of pedagogical resources: (Gueffaz et al., 2014) and (Rocha et al., 2016) propose ontologies built from French official texts describing curriculum and populate such ontology. Finally, ontology engineering can support the management of the learning process. In (Gascueña et al., 2006), the authors use an ontology to describe the learning material that compose a course, to provide adaptive e-learning environments and reusable educational resources. In a similar way, (Hyun-Sook and Jung-Min, 2012) and (Hyun-Sook and Jung-Min, 2014) have as primary objective to develop an ontology-based learning support system which allows the learners to build adaptive learning paths through the understanding of curriculum, syllabuses, and course subjects. In OntoEdu (Guangzuo et al., 2004), the authors propose to use Semantic Web technologies to implement a service layer which will allow an automatic discovery, invocation, monitoring and composition of learning paths.

(Al-Yahya et al., 2015) and (Alsultanny, 2006) presented a review and overview of works on ontologies in the domain of e-Education. They map works to different needs that ontologies can address. (Al-Yahya et al., 2015) classify ontologies in E-learning context into four categories: (1) curriculum modelling and management, (2) describing learning domains, (3) describing learner data and (4) describing e-Learning services. But, to the best of our knowledge, none of the ontologies reported in the literature has been used in an industrial context, or evaluated on the data of an EdTech company. Moreover, the proposed ontologies do not integrate public authority recommendations or standards model. This is precisely what we will focus on in this paper: We propose and evaluate an ontology-based solution modeling public recommendations to answer the requirements of Edtech company Educlever. Our solution relies on the Eduprogresion (Rocha et al., 2016) ontology which models the *Common base of knowledge, skills and culture* published by the French ministry of national education in 2016. It specifies the set of knowledge and skills that must be mastered by students to build their personal and professional future and succeed in life in society. It also specifies the positioning of knowledge and skills in the different cycles of primary and secondary school, and therefore the learning progression.

Figure 1 presents the main concepts of the Eduprogression ontology. The key concept is that of element of knowledge and skill (EKS), which should be acquired by a learner in his curriculum in a given course at a given cycle. Each element has at least one learning domain among the five defined by French ministry of education: languages for thinking and communicate, methods and tools to learn, formation of the person and the citizen, natural systems and technical systems, representation of the world and the human activities. The concept of Progression is another key concept which represents the program of study for a subject (*course*) at a particular level (*cycle*). In the last version of the recommendation, a progression is defined for an EKS and a learning domain. Our ontologies in this paper will start from the Eduprogression ontology and extend it to cover the needs of a specific actor of e-eductation.

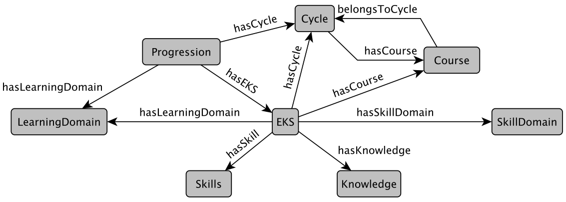

Figure 1: Ontology Eduprogression

2.2 Off-the-shelf Triplestores

Triplestores or RDF store systems are software solutions to store data represented in RDF format. These last years, development of triple stores has flourished. Today there are more than 20 systems available[3]. In order to help developers make the right choice among all these systems, many benchmarks have been designed (Wu et al., 2014; Mironov et al., 2010). But these benchmarks have some limitations: most of them rely on artificial data and/or hypothetical use cases while using target data improves benchmarking and helps for the right choice (Jean et al., 2012).

In order to conduct a comparative evaluation on the Educlever use cases and data, we first chose several triplestores by distinguishing between native RDF triplestores, designed and dedicated to store RDF data, and non native RDF triplestores, designed for another type of data (e.g. relational data) but adapted to store RDF data. Among native RDF triplestore, we distinguished between in-memory triplestores and triplestores with persistent storage. As a result, we chose the four following triplestores: *Corese* is an in-memory triplestore; it loads all the ontologies and RDF data when starting the application and saves it in an RDF file when exiting it. *Allegrograph* and *GraphDB* (*OWLIM*) both are native RDF triplestores with persistent storage capabilities. Finally, *Virtuoso* is a non native RDF triplestore.

As detailed latter in the paper, for the benchmarking of these triplestores we translated the Educlever dataset into RDF, relying on a dedicated ontology and we considered the Educlever requirements and we implemented them with SPARQL. In the next section we present our Semantic Web based modeling of the Educlever data and needs.

3 Ontology based Modelling of Skills, Knowledge and Pedagogical Resources

In this section, we propose an ontology-based model to represent knowledge and skills referential and also pedagogical resources. Beforehand, the Educlever solution relied on relational and graph databases to store them and had limitations to integrate heterogeneous data without losing information and to infer new information from it. The ontology-based model of skills, knowledge and pedagogical resources presented in the following has been setup in the Educlever software infrastructure.

Our solution relies on two linked datasets. The first one is called *Referential*, it describes and contains all the elements of knowledge and skill available through the e-Education solution, Educlever for our case study. The main concept is *Cocon*, which stands for *"COmpétences et CONnaissances"* in French (skills and knowledge). The second dataset is called *Corpus*, it describes and stores all pedagogical resources available through the e-Education solution. *Corpus* is described using a specific vocabulary, with *OPD* as key concept, which stands for *"Objet Pédagogique"* in French (Pedagogical Object). We formalized this vocabulary and underlying concepts into an ontology which reuses and extends EduPro-

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[3] `https://fr.wikipedia.org/wiki/Triplestore` and `https://db-engines.com/en/ranking/rdf+store`

gression.

3.1 Knowledge and Skills Modelling

The concept of *Cocon* is the keystone of the *Referential* modelling. It represents an atomic element of knowledge or skill learnt by students on the e-Education solution. An example of *Cocon* is the *multiplication of two integers* identified with URI `educlever:MultiplyTwoIntegers`[4] in the Educlever system. We formalize this concept as a class equivalent to *EKS* from the ontology Eduprogression, thus integrating public standards description. Figure 2a presents the Educlever *Referential* ontology. Each *Cocon* can be described by indicating its learning domain(s), course and cycle using respectively properties *hasLearningDomain*, *hasCourse* and *hasCycle* defined on class *EKS* in ontology Eduprogression. For instance, the learning domain of the *multiplication of two integers* is the first domain of French education standards, languages for thinking and communicate, its course is Mathematics and its cycle is the second cycle.

There are two others classes: *Knowledge* and *Status*. *Knowledge* specializes *Cocon*, and gathers abstract elements of knowledge. For example, *Arithmetic* is an instance of *Knowledge*. *Status* specifies the current state of an instance of *Cocon* in its life cycle in an e-Education solution; its instances are *in creation*, *in updating* or *deleted*.

Referential comprises two mains properties: *hasStatus* to associate a status to a cocon, and *isRelatedTo* to link two cocons. The latter is specialized into five properties specifying the nature of the relation: *skos:broader* (in particular any instance of *Knowledge* is related to other cocons representing more specific elements of knowledge or skill), *isComplexificationOf* states that a cocon goes more in depth than another, *isFollowedBy* expresses a progression between two instances of *Cocon*, *isPrerequisiteOf* and *isUnderstandingLeverOf* states that a cocon helps to understand another.

The uses of the *Referential* ontology in the Educlever platform are twofold: (1) It enables to describe the knowledge and skills developed by the company for learners and to link them to the standard published by the French education ministry. (2) It is used in combination with the ontology of pedagogical resources described in the following, to evaluate the acquisition of elements of knowledge or skill by learners and to recommend them relevant pedagogical resources. Moreover, by relying on semantic Web models and technologies we can reuse, extend and align with existing vocabularies to increase interoperability. The adopted solution is compliant with linked data Web architecture and principles such as derefenceable URIs.

3.2 Pedagogical Resources Modelling

Figure 2b presents the *Corpus* ontology. The concept of *pedagogical object (OPD)* is the keystone of *Corpus*. It represents a pedagogical resource created to learn and acquire knowledge or skills. It is formalized as a class which is the range of all the properties declared in the ontology.

There are two key properties: Property *worksOn* enables to link an instance of *OPD* and an instance of *Cocon* from the *Referential* ontology, representing an element of knowledge or skill tackled in the pedagogical resource. It is specialized into three properties specifying the nature of the relation, the role of the *OPD* relatively to the *Cocon*: *isLearningOf*, *isTrainningOf*, and *isEvaluationOf*). The other key property is *hasOPD*, linking two *OPD*s. It enables to represent partonomies, expressing how some pedagogical resources are composed as a combination of other resources, which may be reused for composing different other pedagogical resources. *AutonomousOPD* is the subclass of *OPD* gathering the resources which do not need any other resources to be used. Three other properties enable to associate a pedagogical resource to a course, a learning domain and a status in the life cycle of Educlever resources. Thanks to *Corpus* model, e-Education company could provide pedagogical resources annotated on public standards and so, could be evaluated by the public authority. Moreover, based to this model, private companies could share pedagogical resources mainly when theses pedagogical resources allow to learn or evaluate many different skills and knowledge.

4 Semantic Web based Architecture for e-Educational System

In this section we propose a Semantic Web based architecture, relying on triplestores, to manage the above described ontology-based modelling of skills, knowledge and pedagogical resources. We use this architecture to upgrade the existing software architecture of the Educlever solution. We first briefly describe the initial industrial architecture before explaining the proposed evolution.

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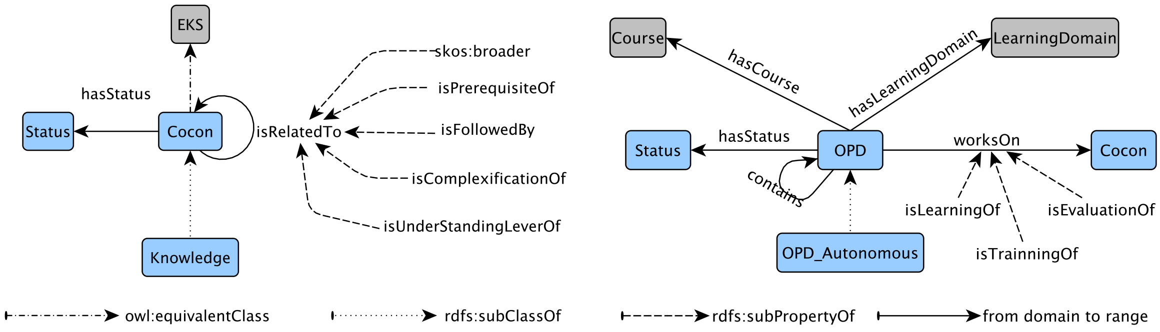
[4] educlever: `http://www.educlever.fr/edumics/refeduclever#`



(a) Referential Ontology.

(b) Corpus ontology.

Figure 2: Educlever Ontology

4.1 Case of a real e-Education Information System in Production: the Educlever Solution

The first version of the Educlever system was built on top of a relational database storing the pedagogical resources. Two tables were used: the first one storing *OPD*'s attributes like *status*, *title*, *author* and *type*; the second one storing the *course* and *cycle* of each *OPD* and the partonomic relations between them. Based on this relational database, the three main functionalities implemented are: (i) find *OPDs* relative to a particular *course* and/or *cycle*, (ii) find *OPDs* contained in a given *OPD* and (iii) find *OPDs* by combining the two previous criteria. The *tree* structure storing the partonomy of *OPDs* is also useful for interactive exploration of the dataset of pedagogical objects by users through a dedicated web interface.

A second version of the Educlever platform was built to enable the implementation of new functionalities exploiting *Cocons*, to support the construction of learning paths and the evaluation of learners, e.g. the computation of the accessiblility of a *Cocon* by a learner, based on the evaluation of the acquisition of prerequisite *Cocon*, or the computation of the degree of understanding of a *Cocon* by a learner. To represent property chains on *Cocons* a relational database was not efficient, obliging to perform joins between table *Cocon* and itself. Then, Educlever upgraded its platform by adding a graph database (*OrientDB*) to represent the relations between *Cocons*. Based on this graph database, the two main functionalities implemented are: (i) find all the prerequisites of a given Cocon and, recursively, the prerequisites of prerequisites, (ii) find all narrower Cocons of all direct prerequisites of a given Cocon.

The overall architecture of the Educlever solution is depicted in Figure 3. What this description of a real industrial system also stresses is that there is a need for approaches taking into account the existence of legacy information systems and their integration, extension and evolution.

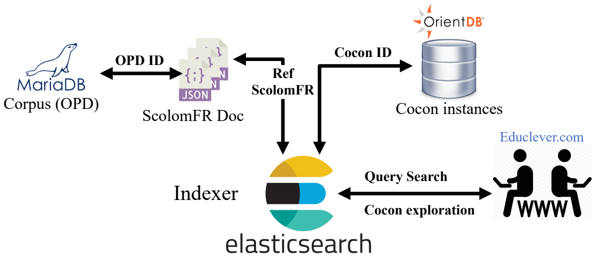
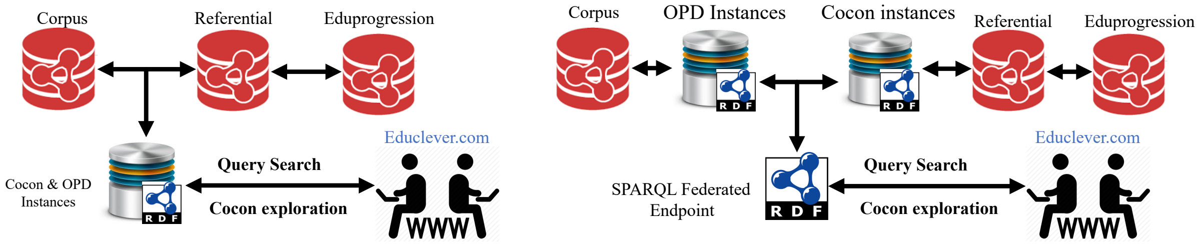


Figure 3: Existing Architecture of the Educlever Solution

4.2 e-Education System Architecture based on Semantic Web Technologies

We propose two architectures based on Semantic Web technologies to design an e-Education system. They are built on top of triple stores to store and process RDF data from the *Referential* and *Corpus* datasets: after mapping the Educlever relational and graph databases into RDF datasets, we chose to materialize the RDF data (and not only offer a virtual access to it). Our aim is to provide a basis for future versions of the Educlever solution natively based on semantic Web models and technologies.

In the simple architecture we used a triplestore to store both *Referential* and *Corpus* datasets into a single graph. As depicted in Figure 4a, the Educlever solution relies on a SPARQL endpoint Web service queried with HTTP requests. Let us note that with this architecture each functionality is implemented by a single SPARQL query, whereas with the current architecture (Figure 3) some functionalities are imple-



(a) Simple Architecture.

(b) Federated Architecture.

Figure 4: Semantic Web based Architecture of e-Education solution

mented by combining the results of several queries to different database systems, with different query languages.

In the current solution, the Educlever data relative to Cocons and OPDs are separated in two databases. This decision was motivated by the fact that these two databases can support different functionalities and are used in different processes. The graph database on Cocons is used for learning path design and *Cocon* evaluation while the relational database on OPDs is used for *OPD* creation by the pedagogical team and for learners training, learning and evaluation. So, a failure of one database does not affect the processes exploiting the other one which can continue their execution. With this architecture, the impact of a failure in exploitation is limited on one database. In order to add this flexibility in a semantic Web based architecture, we proposed a federated architecture relying on a *SPARQL federated Endpoint*. As depicted in Figure 4b this federated endpoint allows us to separate the two datasets, *Referential* and *Corpus*, thus preventing failure while continuing to query them as a single dataset. This context and scenario is typical of the need to take into account legacy software, information system and organizational constraints from real industrial contexts as well as the service quality constraints, etc.

5 Evaluation of the Semantic Web Integration Efficiency

We led some experiments to evaluate the two proposed e-Education system architectures based on Semantic Web technologies. For this evaluation we implemented real use cases from the Educlever company, with its real data stored in the *Referential* and *Corpus* datasets. Here we report the results of (i) a qualitative evaluation of the proposed semantic Web based solution consisting in comparing the number of use cases that can be implemented within this solution to the number of them that are implemented in the current Educlever solution (section 5.1); and (ii) a quantitative evaluation of the proposed solution, focusing on the execution cost time of the queries implementing the use cases (section 5.2).

5.1 Qualitative Evaluation: Implementability of the Use Cases

The existing Educlever system has been designed to address the company use cases. Here we present these use cases classified into four categories: (i) use cases exploiting dataset *Referential* only, from C_1 to C_5, (ii) use cases exploiting dataset *Corpus* only, from C_6 to C_8, (iii) use cases exploiting both datasets, from C_9 to C_{11}, and (iv) use cases requiring querying property paths between cocons on dataset *Referential*, from C_{12} to C_{14}. The SPARQL queries we wrote to implement these use cases are given in Table 3 in Appendix; each use case C_i is implemented by a query Q_i.

1. **Find all direct prerequisites of a given *Cocon*** *c*: this is used to check whether a learner is ready to work on *c* or if he needs to work on some prerequisites before.
2. **Find all direct narrower cocons of a given *Cocon*** *c*: this is mainly used for the exploration of the *Referential* dataset, starting with high level *Cocons* and iteratively going down by following the *broader/narrower* relations.
3. **Find all the *Cocons* such that a given *Cocon* *c* is in their prerequisites**: this is used to identify the candidate *Cocons* for the next learning step after working on *Cocon* *c*.

Table 1: Implementation of the use cases depending on the tested architectures

	Referential					Corpus			Both datasets			Path queries		
	`R1`	`R2`	`R3`	`R4`	`R5`	`R6`	`R7`	`R8`	`R9`	`R10`	`R11`	`R12`	`R13`	`R14`
educ-v2	✔	✔	✔	✔	✖	✔	✔	✖	✖	✖	✖	✔	✖	✖
all other implementations	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

4. **Find all direct prerequisites of a given *Cocon* c and of its direct narrower cocons**: this is used to score all these *Cocons* when a learner has successfully validated c.
5. **Find all prerequisites of all the *Cocons* which are understanding levers of a *Cocon* c_i which is a complexification of a given *Cocon* c**: this is used to find alternative (longer) learning paths to learn a *Cocon* c which seems to be complex.
6. **Find all *OPDs* which evaluate a given *Cocon* c**: this is used to build an evaluation *OPD* of c.
7. **Find all the information about a given *OPD* o**: status, course and learning domain.
8. **Find all *OPDs* which are all useful to evaluate and learn a given *Cocon* c**: recommend evaluation *OPDs* for learning. The goal of this use case is used to prepare the learners to an evaluation session by using evaluation *OPDs* during learning stage.
9. **Find all *OPDs* useful to evaluate both a given *Cocon* c and all its prerequisites**: this supports the recommendation of *OPDs* in order to speed up the study.
10. **Find all evaluation *OPDs* more simple than a given *OPD* o**, considering the complexification relations between the *Cocons* these *OPDs* are related to: this is used to recommend *OPDs* to evaluate a learner.
11. **Find all *OPDs* useful to understand a given *Cocon* c**: these *OPDs* are related to c with an instance of relation *isTrainingOf* or linked to *Cocons* c_i related to c with relation *isUnderstandingLeverOf*.
12. **Recursively find all direct or indirect prerequisites of a given *Cocon* c**: this involves evaluating learning paths of property *isPrerequisiteOf*.
13. **Find all *Cocons* within a prerequisite path between two *Cocons* c_1 and c_2.**
14. **Infer implicit prerequisite paths between two *Cocons* c_1 and c_2**: find the simplest *Cocons* associated to more complex *Cocons* in the path.

As Table 1 shows it, the semantic Web based proposed solutions implement all of the use cases while the current version of the Educlever solution implements only eight of them. The functionalities which are difficult or impossible to be implemented in the current solution are those requiring to jointly exploit the two databases, and those requiring a recursive traversal of the graph base. These can seamlessly be implemented with semantic Web models.

5.2 Quantitative Evaluation: Analysis of the Query Execution Times

For the evaluation of the execution times of the queries implementing the use cases, we performed a two-step benchmarking. First, we evaluated and compared the proposed solution deployed in a local environment. Second we evaluated it when deployed in the Educlever industrial environment. We compared the execution times with those of the current version of the Educlever solution based on a relational database and a graph database. For the deployment of the semantic Web based solution, we compared the performances of four triplestores. In the following, we describe the experimental environment, protocol and results.

5.2.1 Experimental Environment and Protocol

Hardware : In the first step of our benchmarking, we used a MacBook Pro with processor 3,3 GHz Intel Core i7, 16 GB for RAM and 1 To for hard disc. We used VirtualBox through Docker virtualization. We used only one Docker container at a time. In the second step, used a virtual Linux server host on a remote machine. The remote VMWare virtual machine has a processor AMD Opteron 3.1 GHz, 6 GB of RAM and 85 GB for hard disc.

DataSet : We used the exploitation data of Educlever for the experiments. Table 2 summarizes the characteristics of the datasets *Corpus* and *Referential*: the number of triples and the number of instances of *Cocon Referential* and of *OPD* in *Corpus*. Let us note that the size of *Corpus* is much greater than that of *Referential*, therefore the execution times of queries on *Corpus* may be higher than that of queries on *Referential*.

Table 2: Dataset statistics

Dataset	Number of triples	Number of instances
Referential (Local vs Remote)	60 306	8 643 / 17
Corpus (Local vs Remote)	2 390 274	557 094 / 72 467

- **Queries** : We implemented the Educlever use cases by writing a base of fourteen SPARQL queries, each one corresponding to one use case. They are given in Table 3 in Appendix.
- **Triplestores** : We tested four triplestores: (i) *Allegrograph (alleg-cent)*, (ii) *Corese (corese-cent)*, (iii) *GraphDB (graphdb)* and (iv) *Virtuoso (virt)* where we stored together the *Referential* and *Corpus* datasets, as described in the first proposed architecture 4a. We also setup two SPARQL Federated Endpoints with *Allegrograph (alleg-fed)* and *Corese (corese-fed)* storing *Referential* and *Corpus* datasets separately as proposed in the second proposed architecture 4b. The *Allegrograph* SPARQL Federated Endpoint uses two SPARQL Endpoints, each built with an *Allegrograph* repository. Similarly, the *Corese* SPARQL Federated Endpoint uses a *Corese* server for each SPARQL Endpoint. We compared the execution times of the SPARQL queries implementing the Educlever use cases with the execution times of the queries or codes in the current Educlever Information System described in 3 (*educ-v2*).
- **Protocol** : We observed two indicators: (i) the SPARQL query execution times and (ii) the SPARQL query answers themselves. The first one measures the performance of the solution and the second one checks its correctness. Since all the configurations returned the same sets of answers, in the following we focus on the evaluation of the performance. For each tested triplestore, we executed each query ten times and stored all the execution times. For a deep analysis of the query execution behaviours, we considered three indicators: (i) the first execution (*1st Ex*), (ii) the average execution time *(Av)* and (iii) the median *(Med)* execution time of the next nine queries.

5.2.2 Results

Use cases on dataset *Referential*. Figure 5 shows the query execution times of SPARQL queries on *Referential* for the four chosen triplestores deployed in a local context. First, we can observe that query execution time of first execution is greater than the average time and the median time. This is due to the use of cache memory for this execution. For the specific case of Q_1, its execution time is very important (2s for *graphdb*) because it is the first query of the benchmark and cache is not efficient yet. The chart also shows that *graphdb* and *virt* got the best query execution times, and that the execution times of *alleg-fed* are better than those of *alleg-cent*, This is because only one dataset (*Referential*) is queried with alleg-fed while both datasets are stored together and queried with *alleg-cent*. The same can be observed and explained when comparing the results of *corese-cent* and *corese-fed*. All execution times are below 200 ms. According to (Zhou et al., 2012), this is an acceptable response time for a Web application.

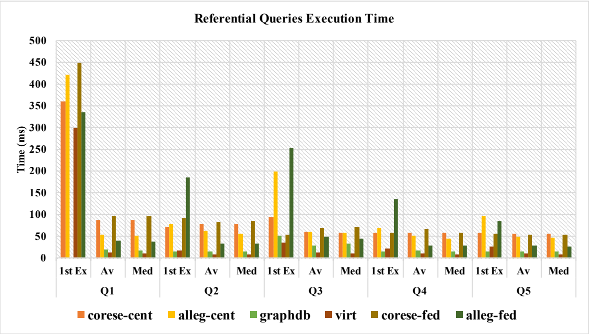


Figure 5: Execution times of SPARQL queries on Referential with a local deployment

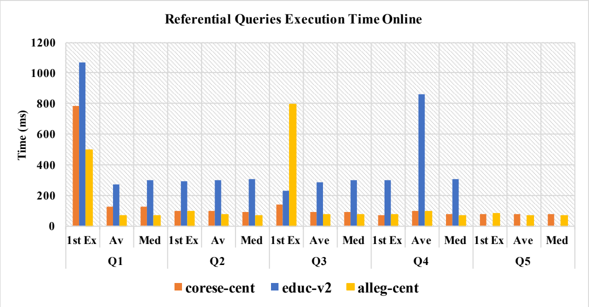


Figure 6: Execution times of SPARQL queries on Referential with a remote deployment

Figure 6 shows the execution times of the same queries on *Referential*, for the four triplestores this time deployed in the industrial context of Educlever; it also shows the execution times of the current Educlever solution *educ-v2*. It confirms the results observed on the local deployment and it shows that the execution time of *educ-v2* is greater than *corese-cent* and *alleg-cent* for use cases C_1 to C_4. *educ-v2* does not implement C_5.

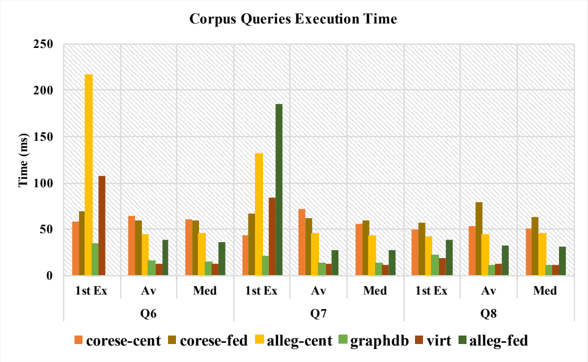


Figure 7: Execution times of SPARQL queries on Corpus with a local deployment

Use cases on dataset *Corpus*. Figure 7 shows the query execution times of SPARQL queries on *Corpus* for the four chosen triplestores deployed in a local context. Their observation confirms our previous comparative analysis on *Referential*: *graphdb* and *virt* get the best query execution times. We also get confirmation that, in average, a federated architecture is better for queries on a single dataset.

In comparison to Figure 5, we can note that the execution times of queries on *Corpus* are much lower than those of queries on *Referential* whereas the size of the *Corpus* dataset is much greater than that of the *Referential* dataset (see Table 2). This can be explained by the fact that the queries on *Corpus* have simple star patterns while the queries on *Referential* have heterogeneous and more complex patterns (Arias et al., 2011). All the execution times remain below 200 ms which is acceptable for a response time of a Web application (Khan and Amjad, 2016).

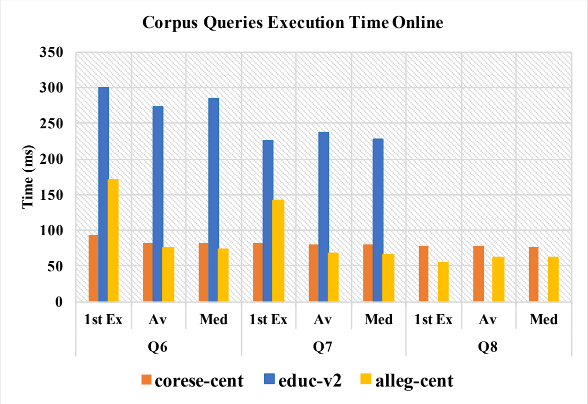


Figure 8: Execution times of SPARQL queries on Corpus with a remote deployment

Figure 8 shows the execution times of the same queries on *Corpus*, for the four triplestores this time deployed in the industrial context of Educlever; it also shows the execution times of the current Educlever solution *educ-v2*. It confirms our previous results, and *corese-cent* and *alleg-cent* outperform the current Educlever system *educ-V2*. Use case C_8 does not have an execution time for *educ-v2* because it cannot be implemented with only one query.

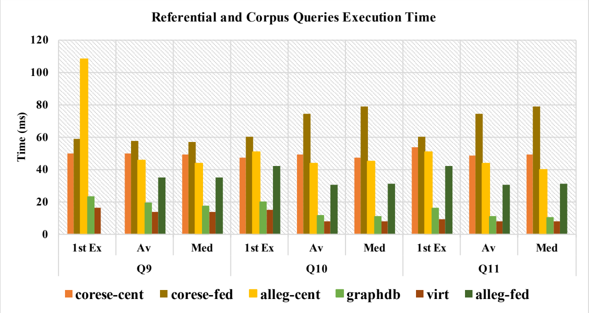


Figure 9: Execution times of SPARQL queries on Referential and Corpus with a local deployment

Use cases on both datasets. Figures 9 and 10 show the execution times of the queries on both *Referential* and *Corpus*, for the four chosen triplestores deployed respectively in a local and remote context. The trends are the same and the execution times does not exceed 200 ms for all the queries on all triplestores in a local context. Figure 10 does not show the execution times for *educ-v2* since it does not implement these use cases with a single query.

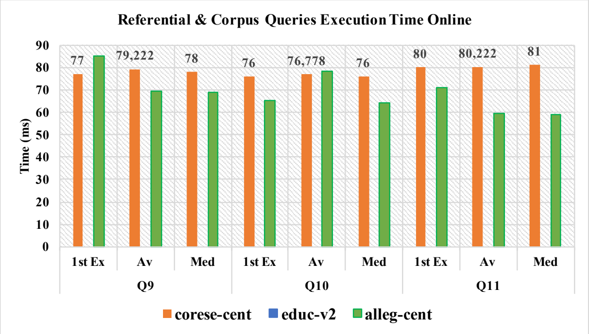


Figure 10: Execution times of SPARQL queries on Referential and Corpus with a remote deployment

Use cases implemented by queries with property paths. Property paths are a key feature for implementing high value use cases for Educlever. Figures 11 and 12 show the execution times of such queries on the four triplestores deployed respectively in a local and a remote context. For readability, we use the logarithmic scale to draw the chart in Figure 11. Figure 12 confirms that with *corese-cent* or *alleg-cent* in

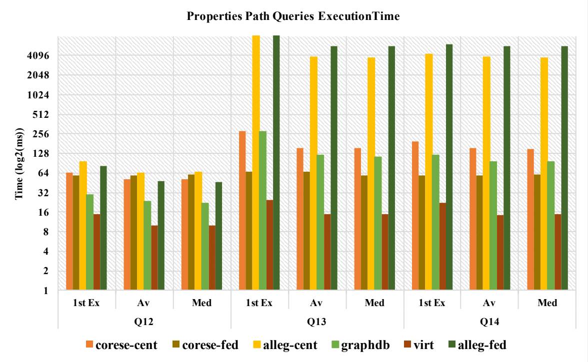


Figure 11: Execution times of SPARQL queries with property paths on Referential with a local deployment

the Educlever industrial context, the execution time of queries with a few property paths in the graph pattern, like it is the case for Q_{12}, remains under 200 ms in average, which is acceptable for a Web application. But, for more complex queries, like Q_{13} and Q_{14}, the execution time can reach up to to 4000 ms (4s), which is not acceptable in the Educlever industrial context. This is among our next challenges to find a convenient architecture to handle such queries, with pre-processed results.

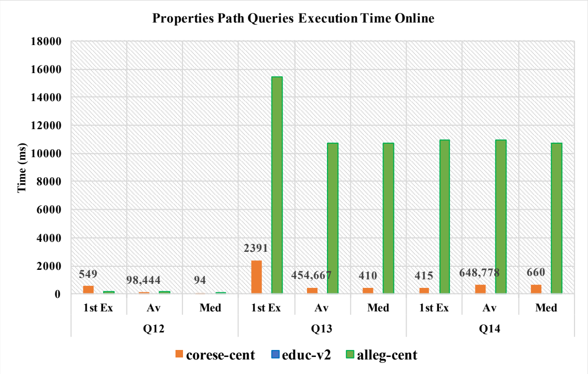


Figure 12: Execution times of SPARQL queries with property paths on Referential with a remote deployment

6 Conclusions

In this paper, we reported a knowledge modelling experience in an industrial context to propose an e-Education solution compliant with public education specifications based on semantic Web models and technologies. We briefly presented the ontology Eduprogression which describes a shared conceptualization of knowledge pieces and skill in the educational context and we showed how we used it and extended it to model the specific needs of a company (Educlever) for the E-Education solution they develop. Then we described the proof of concept we developed and deployed in the real industrial context of Educlever. It relies on two ontologies, *Referential* populated by all the elements of knowledge and skill (*Cocons*) available on the Educlever learning platform, and *Corpus* populated by all the pedagogical resources available on the Educlever platform. We developed a base of SPARQL queries to implement the Educlever uses cases and we proposed two software architectures based on Semantic Web technologies designed for an e-Education systems. We upgraded the Educlever software architecture following these propositions and implemented these architectures with four triplestores *Corese*, *Allegrograph*, *GraphDB* and *Virtuoso* in order to benchmark them and compare them to the existing solution on real data and real queries.

We presented a complete evaluation of the quality of service and response time in an industrial context with a real-world tesbed showing that the Semantic Web based solution meets the industrial requirements, both in terms of functionalities and efficiency compared to existing operational solutions. Moreover, by relying on semantic Web we can reuse, extend and align with existing vocabularies to increase interoperability. We showed this by implementing the introduction of the standard ScolomFR with links to the Educlever ontologies. With our propositions, it is also now possible to share *OPD*s and integrate *Cocons* with other e-Education systems, provided that they comply with the Eduprogression modeling.

In this context we also showed that an ontology-oriented modelling opens up new opportunities. One of the next challenges for us is the modeling of learner profiles as an additional populated ontology integrated with *Referential* and *Corpus* and the development of SPARQL queries and rule-based reasoning mechanisms for resource recommendation and adaptive learning. We also plan to link pedagogical resources from several educational organizations in order to build an integrated educational solution offering the learner a coherent learning path across a set of educational systems, based on dynamically federated endpoints.

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APPENDIX

Table 3 presents the SPARQL queries implementing the Educlever use cases. These are templates of queries where *Cocon* and *OPD* must be replaced by the URI of an instance of respectively class *Cocon* or class *OPD*.

Label — SPARQL Queries

Q1

```
SELECT ?prerequis WHERE {?prerequis referential:isPrerequisiteOf cocon .}
```

Q2

```
SELECT ?child WHERE {cocon referential:isParentOf ?child .}
```

Q3

```
SELECT ?next WHERE {cocon referential:isPrerequisiteOf ?next.  }
```

Q4

```
SELECT ?prerequisite ?child ?childPrerequisite
WHERE {?prerequisite referential:isPrerequisiteOf cocon .
       cocon referential:isParentOf ?child .
       ?childPrerequisite referential:isPrerequisiteOf ?child .}
```

Q5

```
SELECT ?simple ?helper ?helpPrerequisite
WHERE {cocon referential:isComplexificationOf ?simple .
       ?helper referential:isUnderstandingLeverageOf ?simple .
       ?helpPrerequisite referential:isPrerequisiteOf ?helper .}
```

Q6

```
SELECT ?opd WHERE {?opd corpus:isEvaluationOf cocon .}
```

Q7

```
SELECT ?status ?course ?learningDomain
WHERE {opd corpus:hasStatus ?status .  opd corpus:hasCourse ?course .
       opd corpus:hasLearningDomain ?learningDomain .}
```

Q8

```
SELECT ?opd ?status
WHERE {?opd corpus:isEvaluationOf cocon .  ?opd corpus:isLearningOf cocon .
       ?opd corpus:hasStatus ?status .}
```

Q9

```
SELECT ?opd
WHERE {?opd corpus:isEvaluationOf cocon .?opd corpus:isEvaluationOf ?prerequiste .
       ?prerequiste referential:isPrerequisiteOf cocon .}
```

Q10

```
SELECT ?opd
WHERE {opd corpus:isEvaluationOf ?cocon .  ?opd corpus:isEvaluationOf ?simple .
       ?cocon referential:isComplexificationOf ?simple .  }
```

Q11

```
SELECT ?opd
WHERE {{?opd corpus:isTrainningOf cocon .}
       UNION
       {?cocon referential:isUnderstandingLeverageOf cocon .
       ?opd corpus:isTrainningOf ?cocon .}}
```

Q12

```
SELECT ?prerequis WHERE {?prerequis referential:isPrerequisiteOf+ cocon .}
```

Q13

```
SELECT ?source ?dest (count(?counter) as ?edgeposition
WHERE {c1 refeduclever:isPrerequisiteOf* ?counter .
       ?counter referential:isPrerequisiteOf* ?source .
       ?source referential:isPrerequisiteOf ?dest .
       ?dest referential:isPrerequisiteOf* c2 .}
GROUP BY ?source ?dest .  ORDER BY ?edgeposition .
```

Q14

```
SELECT ?sourceSim ?destSimp (count(?counter) as ?edgeposition
WHERE {c1 refeduclever:isPrerequisiteOf* ?counter .
       ?counter referential:isPrerequisiteOf* ?source .
       ?source referential:isPrerequisiteOf ?dest .
       ?dest referential:isPrerequisiteOf* c2 .
       ?sourceSim referential:isComplexificationOf* ?source .
       ?destSimp referential:isComplexificationOf* ?dest .
       NOT EXISTS {?sourceSim referential:isComplexificationOf ?otherS .}
       NOT EXISTS {?destSim referential:isComplexificationOf ?otherD .}}
GROUP BY ?sourceSim ?destSimp .  ORDER BY ?edgeposition .
```

Table 3: SPARQL queries implementing the Educlever use cases