

Conceptual Knowledge Representation: a semantic model for Smart Learning Environments in an IoT-enabled Smart Campus

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(submitted: 16/8/2024; accepted: 31/8/2025; published: 27/10/2025)

Abstract

Smart learning environments (SLE) have been greatly enhanced lately by the adoption of cutting-edge technologies such as Internet-of-Things (IoT), Artificial Intelligence, Augmented Reality, Cloud Computing and Learning Analytics among others. Huge amounts of heterogeneous data are being exchanged between numerous devices, sensors and “things” used by students, educators and educational institutions. This heterogeneity hinders seamless communication among different systems pertaining to SLE. A smart campus is an example of a smart learning environment involving different systems such as smart learning management system, personalized learning, e-learning, assessment, smart classroom and smart library system among others. These systems often need to collaborate to enhance the teaching and learning process. To allow seamless communication among these systems, semantic interoperability has to be tackled by the adoption of a shared common data model. Ontologies are viewed as a potential way to ensure semantic interoperability. Several ontologies exist in the smart learning domain. However, none of them represents a smart learning environment for an IoT-enabled smart campus. This paper presents a semantic model entitled *SmartLearningOnto* that aims to model different aspects of a smart learning environment in a smart campus. The proposed ontology facilitates exchange of data among several systems in a smart campus by defining the concepts related to smart learning in an appropriate way. Furthermore, it infers new knowledge to enrich the learning experience of learners. SPARQL queries have been used to answer competency questions. Furthermore, several metrics along with expert evaluation have been used to evaluate *SmartLearningOnto*.

KEYWORDS: Smart Learning Environment, Smart Learning, IoT, Semantic Interoperability, Ontology.

DOI

<https://doi.org/10.20368/1971-8829/1136004>

CITE AS

Nagowah, S., Ben Sta, H., & Gobin-Rahimbux, B. (2025). Conceptual Knowledge Representation: a semantic model for Smart Learning Environments in an IoT-enabled Smart Campus. *Journal of e-Learning and Knowledge Society*, 21(2), 44-60. <https://doi.org/10.20368/1971-8829/1136004>

1. Introduction

With the emergence of ICT in education, learning has changed considerably in the past years. The usage of advanced technologies such as mobile devices and IoT in learning has reshaped the learning and teaching process and has given rise to SLE. With the adoption of digital, context-aware and adaptive devices supported

by proper tools and AI techniques, the learning process is enhanced (Tabuenca et al., 2024). SLE further allows appropriate adjustments with respect to the learner’s knowledge and ability, facilitating student-learning experience (Kavashev, 2024). A smart campus is an example of a SLE where smart education services are delivered to students to nurture innovative skills and talents (Dong et al., 2020). The smart campus promotes smart learning where usage of cutting-edge technologies predominates to allow learners to acquire knowledge and gain a richer learning experience (Çelik & Baturay, 2024).

Several systems in the Smart Learning domain collaborate to support learning and make the learning and teaching process more efficient. Based on a systematic literature review, Muhamad et al. (2017) classify the following systems under the Smart Learning domain: Smart Learning Management, Personalized Learning, Assessment, Smart Classroom

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and Smart Library. Smart Learning management refers to activities that help to support the teaching process such as course syllabus, meeting schedule and student attendance among others (Iqbal et al., 2020). Personalized learning refers to education tailored and adjusted based on an individual learner's conditions, abilities, preferences, background knowledge, interests, goals, evolving skills and knowledge (Shemshack & Spector, 2020). Personalized learning aims to increase the learner's motivation and engagement. Assessment refers to the evaluation of the learner's work and make appropriate judgement regarding the quality of work (Nagowah & Nagowah, 2009). Smart classroom represents a transition from the traditional ways of working to a digital way of working using classroom resources (Hossenally et al., 2022). Smart libraries support the teaching and learning process by providing additional resources such as books and other materials (Sungkur et al., 2019). Both smart classrooms and smart libraries have the capability of capturing the needs of the users to promote personalized learning. These different systems in the Smart Learning domain are inter-connected. Therefore, they need to collaborate to share data in order to take proper decisions.

Interoperability is reported as one major challenge to be addressed to ensure seamless communication among the different systems in SLE (Chituc, 2020). Semantic interoperability is one type of interoperability linked with the meaning of data that is being exchanged by communicating parties (Kiljander et al., 2014). Different vocabularies are used to represent data in different systems. Therefore, to achieve semantic interoperability, it is of paramount importance that the exact meaning of the data be precisely understood so that the data can be exchanged and translated among systems (Heflin & Hendler, 2000). Ontology-based models can be used to represent knowledge and promote semantic interoperability (Ghawi & Cullot, 2007).

Developing an ontology is the first step in the journey for interoperability (Scrocca et al., 2021). An ontology plays an important role in providing a common shared data model of a particular domain where the whole knowledge of the domain can be represented (Carbonaro, 2020). Gruber (1993) define an ontology as an "explicit specification of a conceptualization". Ontologies are capable of resolving semantic heterogeneity of the information coming from underlying devices in SLE due to the agreed vocabulary and common understanding they provide (Elsaleh et al., 2020). Furthermore, ontologies provide numerous benefits such as reasoning, reusability, sharing and machine-understandable (Ouf et al., 2017). This paper thus suggests an ontology that represents the

smart learning domain in an IoT-enabled smart campus environment to allow data from different systems to be interconnected in that environment.

The remaining part of the paper is structured as follows: Section 2 describes related ontologies developed in the domain of smart learning. Section 3 describes the materials and methods section where the methodology to come up with a new semantic model to represent the knowledge in the smart learning domain along with rules adopted for reasoning is detailed. In section 4, results and discussions are presented along with the evaluation of the ontology. Finally, section 5 presents the conclusion of the paper and elaborates on future work.

2. Background

Ontologies are viewed as the future of learning environment (Ouf et al., 2016). To come up with an ontology for the smart learning domain, this section reviews existing ontologies in the learning/smart learning domain. Figure 1 shows a summary of ontologies related to Smart Learning domain.

Kultsova et al. (2015) have proposed an ontology-based content management system to manage the learning process. Ouf et al. (2017) made use of ontologies namely the *Learner Model Ontology*, the *Learning Object Ontology*, the *Learning Activities Ontology* and the *Teaching Methods Ontology* to personalize learning environments based on the preferences and needs of learners. Yu et al. (2007) have proposed three ontologies in the context of e-learning namely the *Learner Ontology*, the *Learning Content Ontology* and the *Domain Ontology*. Castellanos-Nieves et al. (2011) have proposed an ontology entitled *OeLe*. The ontology defines vocabulary for concepts such as course, teacher, student, exam, questions, answers and so on. Litherland et al. (2013) have used *OeLe* for e-assessment of the accounting domain. Both summative and formative assessment were tackled. Khmour (2020) presented the *Expanded Course Ontology* where concepts like Course, Student, Teacher, Exam and Question are described. A number of ontologies have been developed to represent course information. One example is the *OLOUD* ontology proposed by Fleiner et al. (2017). *OLOUD* represents course information such as curricula, subjects, courses, semesters, personnel, buildings and events in a university campus, based on Hungarian concepts. *CURONTO* is another ontology designed for Curriculum Representation (Al-Yahya et al., 2014).

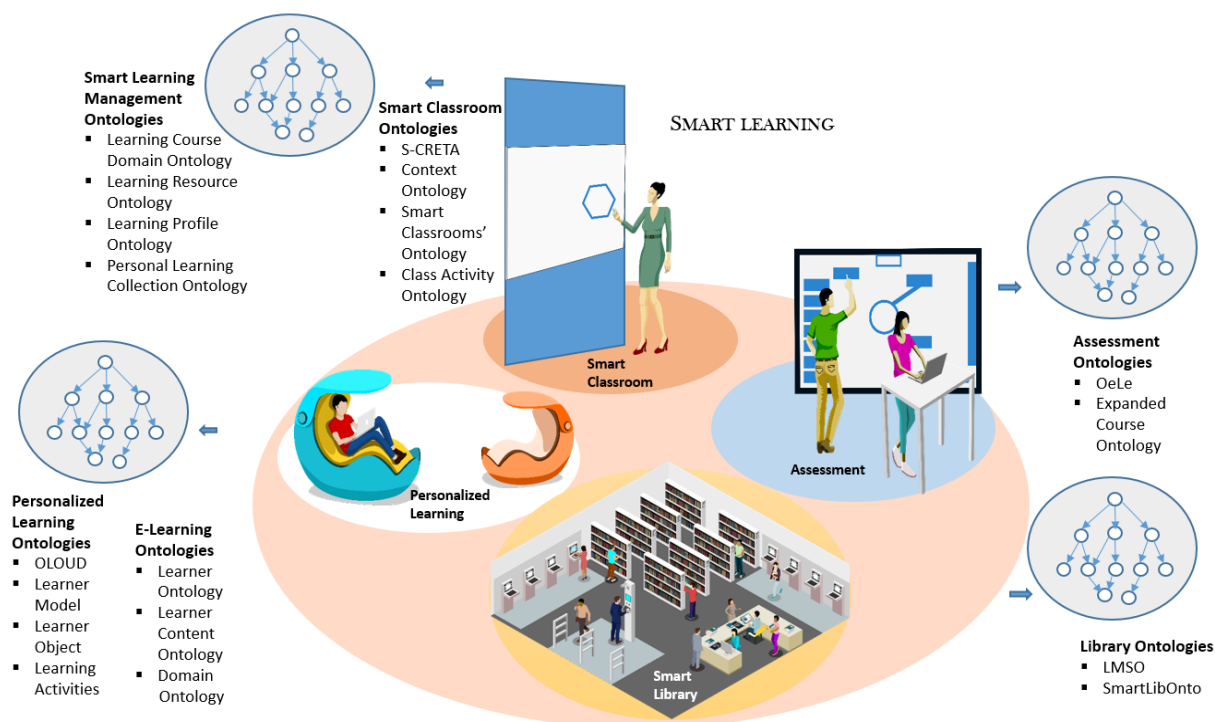


Figure 1 - Ontologies in the Learning/Smart Learning domain.

Several ontologies have been proposed in the context of smart classroom namely *S-CRETA* (Maria et al., 2012), *Context Ontology* (Shi et al., 2010), *Smart Classrooms' Ontology* (Uskov et al., 2015) and *Class Activity Ontology* (Martinez et al., 2024). While *S-CRETA* and *Class Activity Ontology* focus mainly on activity detection in a smart classroom and laboratory respectively, *Context Ontology* lays emphasis mainly on capturing contextual information to promote reasoning. Uskov et al. (2015) proposed the *Smart Classrooms' Ontology* but did not implement the ontology. Nagowah et al. (2019) proposed the Smart Classroom ontology that fits the context of an IoT-enabled smart classroom. Banu et al. (2013) presented *LMSO*, which stands for a Library Management System Ontology. The semantic model defines concepts for library personnel, library member, library resources and library services. Nagowah et al. (2021) have proposed *SmartLibOnto* to cater for a smart library system.

It can be observed that the different ontologies developed tackle one particular aspect of a smart campus. None of the existing ontologies cover several (if not all) aspects related to smart learning such smart learning management, personalized learning, e-Learning, assessment, smart classroom and smart library, thus hindering information exchange through the different inter-connected systems in the Smart Learning domain. Since these ontologies have all been developed to address a particular aspect of the Smart Learning domain, it is likely that the ontologies have some commonalities. Certain concepts will exist in

different ontologies, for example, the Course and Teacher concepts exist in both *OLOUD* and *OeLe* ontologies. A student who follows a particular Course in the *OLOUD* ontology will have to be assessed at some point to get an insight of his performance. The *OeLe*, on the other hand, includes assessment details for a student following a particular course but lacks details regarding the programme, the attendance pattern of the student or where the course is being held. Thus by integrating *OLOUD* and *OeLe*, each ontology will complement the lacking functionalities of the other one.

Vast amounts of data in SLE originate from different systems and devices used by students, tutors and educational institutions. This data being heterogeneous in nature, hinders seamless communication among various systems in SLE. The data has to be semantically enriched to enable automation of activities between the systems. With the usage of a common data model for the Smart Learning domain, the knowledge about the different systems can be properly represented in order to resolve semantic heterogeneity of the information coming from underlying devices and systems. This paper thus proposes an ontology entitled *SmartLearningOnto* that aims firstly to integrate data from inter-connected systems in the Smart Learning domain and secondly to facilitate flow of information among these systems allowing for informed decision-making.

3. Materials and Methods

This section details the methodology to develop the proposed ontology.

3.1 Methodology

To be able to properly develop an ontology and define a knowledge base, it is fundamental to follow a proper methodology. Several methodologies exist for ontology development and maintenance such as TOVE Methodology (Gruninger & Fox, 1994), METHONTOLOGY methodological framework (Fernández-López et al., 1997), Uschold and King methodology (Uschold & King, 1995), Noy and McGuinness methodology (Noy & McGuinness, 2001) and NeOn Methodology (Suárez-Figueroa et al., 2012) amongst others.

The NeOn Methodology framework is a highly flexible framework. After reviewing the existing methodologies for ontology development, the NeOn Waterfall Model has been selected for developing the *SmartLearningOnto* for the following reasons: This model favours projects where several different domains are involved. These domains might not be well understood and there are possibilities that the requirements change during the development process. For the development of *SmartLearningOnto*, some of the sub domains are already known while some might be incorporated later on during the development process. The NeOn methodology also encourages the reuse of both ontological and non-ontological resources. The different phases of the methodology are described in detail in the following sections.

3.2 Initiation Phase

The initiation phase of the NeOn methodology consists of spotting the essential requirements for the ontology. A motivation scenario justifying the need for an ontology for Smart Learning domain and an ontology requirement specification document (ORSD) are produced in this phase.

A. Motivation Scenario

Rita James is a student enrolled for a study programme offered by a faculty at the university. Once enrolled on a study programme, she will belong to that faculty. The programme will consist of a curriculum, which specifies how the programme will be completed. The curriculum consists of several subjects.

Courses which are based on a subject will have temporal attributes and can be delivered by one or more teachers either online, on campus or hybrid. The teacher can be a full-time staff belonging to a faculty or a part-timer. To follow a course, Rita first needs to register for the course. The course will be evaluated based on assessment such as class tests, assignment/

project, presentation and/or written examinations. The teacher creates questions for the assessment consisting of open-ended questions, closed questions and problem solution questions. Rita is given her performance details and feedback on her performance during the course.

Some courses are held in smart classrooms. The classrooms are equipped with sensors, which observe the environmental conditions of the classroom. The room conditions are automatically adjusted. For instance, lights are switched off when nobody is present in the room, air conditioner is adjusted with respect to room temperature and projector is switched on upon the entrance of an instructor. The smart classroom is equipped with an RFID reader sensor that keeps track of when someone is entering and leaving the room.

Upon registration of a particular course, Rita is recommended resources based on the subject matter from the smart library to help her in her studies. She can query about availability of resources and reserve the resources via an online reservation system. She additionally receives suggestions regarding resources based on her user profile, which includes her preferences.

B. Ontology Requirements Specification Document (ORSD)

The ORSD defines several elements such the purpose, the scope, the implementation language among others of the proposed ontology. Table 1 shows the ORSD.

3.3 Reuse and Reengineering Phase

Rather than developing an ontology from scratch, ontology reuse promotes the adoption of existing ontologies or knowledge models as input to new ontologies or knowledge representations (Katsumi and Grüninger, 2016). A number of ontologies exist for the different systems in Smart Learning domain as described in Section 2. However, not all are available online, hindering reuse of the ontologies. To demonstrate integration and interoperability among the interconnected systems and to show how the ontologies can “talk to each other”, one candidate source ontology is selected from each of the different sub domains as discussed in the following sections.

A. Smart Learning Management/Personalized Learning

From the motivation scenario, it is clear that one ontology in the field of smart learning management is required. The *OLOUD* ontology describes vocabulary for course information such as curricula, subjects, courses, semesters, personnel, buildings and events in a university campus. Some of the main concepts of the *OLOUD* ontology are described as follows (Fleiner et al., 2017):

- **Curriculum:** A student enrolls on a Study Programme in a university and the Study Programme has a Curriculum, which specifies how the Study Programme will be completed.
- **Specialization:** The Curriculum specifies Specializations, which comprise of a number of compulsory and optional Subjects.
- **Degree:** Following the Curriculum will result in a Degree (BSc, BA, MA, MSc, MRes, MPhil, PhD).
- **Attendance Pattern:** The Curriculum has a specific Attendance Pattern, which refers to the mode in which the Curriculum will be followed (full-time, part-time, correspondence).
- **Course:** A Course is based on a particular Subject. It is taught by one or more Teachers. It is offered at a particular time and in a particular Location. The Course has a CourseType which refers to the type of the Course, whether an ExamCourse, Seminar, Laboratory or Practice.

The *OLOUD* ontology partially fits the motivation scenario described. The ontology models courses that are delivered at a particular location while the motivation scenario describes three delivery modes for courses: online, face-to-face or hybrid. An additional concept *DeliveryMode* is the required. While *OLOUD* models the different aspects related to *Course*, it lacks concepts with respect to assessment of the *Course*.

B. Assessment

The *Expanded Course Ontology* can be considered to model the assessment components. It caters for concepts related to assessment such as Exam and Exam questions (Open-ended questions, Multiple Choice questions and problem solving questions) along with their answers. According to Davis (2002), the term '*Exam*', '*Test*' and '*Quizzes*' are used interchangeably as they all test the students' knowledge with a series of questions but they are limited in scope. Other modes of evaluation include assignments, projects, seminars, orals among others. These evaluation methods will also include questions, though projects and orals emphasize more on the demonstration capability. *Teacher* refers to the individual who teaches a particular *Course* and who sets *Questions* for *Exam*.

Ontology transformation

Izza (2009) defines on ontology transformation as "*changing the structure of the ontology to make it compliant with another*". To fit the motivation scenario defined, the '*Exam*' concept is changed to '*Assessment*' and the latter will consist of several subclasses such as Exam, Test, Quizzes, Assignments, Projects, Seminars and Presentations.

Table 1 - Ontology Requirements Specification Document.

Ontology Requirements Specification Document	
1	Purpose
The need for developing the Smart Learning Ontology is to represent knowledge among different collaborating systems in the smart learning domain.	
2	Scope
The ontology will focus on different aspects such as Smart Learning Management, Assessment, Smart Classroom, Smart Library and Personalised Learning.	
3	Implementation Language
OWL 2 will be used as the implementation language for developing the proposed ontology.	
4	Intended End-Users
The intended set of end-users for the ontology will include students, academic staff, non-academic staff and visitors of a smart campus.	
5	Intended Uses
Users of a smart campus will use the semantic model to find out about services offered by a panoply of applications in the smart learning domain.	
6	Ontology Requirements
a. Non-Functional Requirements	
Appropriate standards related to smart learning should be used for the development of the ontology.	
b. Functional Requirements: Set of Competency Questions	
The competency questions will be those targeting more than one sub domains. Some examples are listed as follows:	
- Smart Learning Management System - For which programme, did a particular student enroll? - Which faculty is offering which programme? - To which subject is a particular course related to? - When will the course be delivered? - What is the delivery mode of a particular course? - When did a particular student register for a particular course? - Course Assessment - List the assessments and the assessment types related to a particular course. - List the exams questions for a particular course. - List the performance details for a particular student with respect to a course assessment. - Smart Classroom - Which sensors are placed in a particular smart classroom? - List the observable properties and their results that are observed in the SmartClassroom1 at a particular time and by which sensors? - Who attended a particular event in a particular SmartClassroom and when? - Smart Library - Who are the users of the smart library? - List services provided by the smart library. - List the sensors deployed in the smart library. - Is a particular resource available in the library? - Inter-connected systems (Some examples) - List the exam questions and answers set by teacher '<i>Smith</i>' for the subject '<i>Knowledge Engineering</i>'. - What are the observable properties such as noise and temperature of the smart classroom where the teacher '<i>Smith</i>' is teaching the '<i>Database Systems</i>' course and at what time were the observable properties captured? - Which study books from the smart library could be used by students following the courses under subject '<i>Knowledge Engineering</i>' taught by teacher '<i>Smith</i>' in SmartClassroom1?	

Teacher sets the *Assessment* which will be taken by *Student*. *Assessment* consists of *Question* and each *Question* has *Question_Annotation*. *Question* has *Answer* and each *Answer* has *Answer_Annotation*. The transformed assessment ontology is shown in Figure 2.

C. Smart Classroom

As described in the Introduction section, IoT has turned the traditional classroom to smart classroom which is enhanced by technology to facilitate the learning process. The *Smart Classroom Ontology* from Nagowah et al. (2019) is considered to model the motivation scenario. The main concepts are described as follows:

- **Classroom:** *Classroom* represents the class where a particular lecture or event will be held. It has a *Location* and it is reserved for a particular time duration.
- **Activity:** *Activity* represents a particular event involving a *User* occurring at a particular *Location* and *Time*.
- **Context:** *Context* represents an observable property that can be observed by a *Sensor*.
- **Platform:** *Platform* represents a computer resource (hardware or software) present in the classroom or used by the User. It can be an RFID reader for tracking attendance or a software used to generate a *LearnerProfile* consisting of *Performance* details, *Attendance* details and *Learning Analytics*.
- **Service:** Based on context information, different services such as adjusting room conditions can be triggered.

- User: The *User* represents anyone using the smart classroom such as the Teacher/Lecturer or the Student.
- Sensor: The smart classroom is deployed with sensors, which are modelled by SOSA: Sensor.

D. Smart Library

A smart library uses IoT to capture real-time data about the library resources and its users. The *SmartLibOnto* from Nagowah et al. (2021) is considered to model the motivation scenario. The main classes are listed as follows:

- Academic Library: An *Academic Library* provides *Services* to its *Users* and manages different *Resources*.
- Services: The services consists of *General*, *Educational* and *Scientific* services.
- Resources: *Resources* include Study Book, Thesis, Manuscript, Newspaper among others.
- Platform: *Platform* refers to a computer resource that is used by Users and *the Academic Library*.
- Sensor: The smart library is dispersed with sensors, which are modelled by SOSA: Sensor.

In this phase we thus started by reusing the *OLOUD* ontology (which is available online) and transformed *Expanded Course Ontology* (Khdour, 2020). However, both ontologies *OLOUD* and *Expanded Course Ontology* do not include concepts of smart communities such as smart classroom and smart library. *Smart Classroom Ontology* defines vocabulary for context and sensor information in a smart classroom while *SmartLibOnto* include concepts such as resources and services for a smart library as well as sensor concepts.

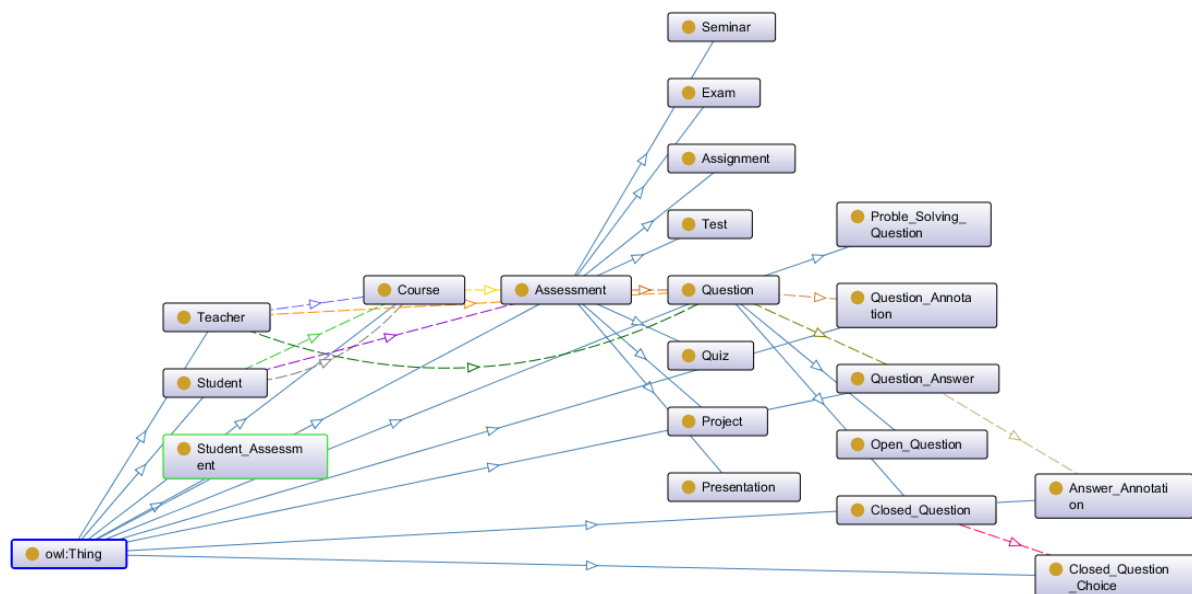


Figure 2 - Transformed Expanded Course Ontology.

3.4 Merging and Modelling Phases

Ontology merging is a method that fuses two ontologies to produce a third one (Guzmán-Arenas & Cuevas, 2010). According to Chatterjee et al. (2017), ontology merging can be performed accurately only after aligning the concepts of the source ontologies. Prior to alignment and merging, ontology mapping is performed. Mappings are computed after an analysis of similarity between concepts in compared ontologies (Bagüés et al., 2006). Semantic similarity refers to the “degree of relatedness” (Rhee et al., 2009). The semantic matches/mappings can represent relations of equivalence (is-a) and specialization and/or generalization (part of) (Amrouch & Mostefai, 2013).

Correspondence or Mapping

Given the ontologies O_1 and O_2 , a correspondence or mapping among the entities e_1 and e_2 from ontologies O_1 and O_2 is defined as $\langle id, e_1, e_2, r, n \rangle$

Where id is a unique identifier,

r is a relation for example $=, >, <, \neq$,

n is a confidence measure (typical in the range of (0,1)) holding for the correspondence between e_1 and e_2 (Euzenat, 2007). Matching ontologies promote interoperability of the knowledge and data expressed in the matched ontologies (Shvaiko & Euzenat, 2008). LogMap (<http://krrwebtools.cs.ox.ac.uk/logmap/>) is an example of a matching system that can handle semantically rich ontologies comprising of tens (and even hundreds) of thousands of classes (Jiménez-Ruiz & Cuenca Grau, 2011). For the purpose of matching and merging ontologies in this work, two tools namely Protégé 5.5.0 and LogMap were used. Both tools provide GUI based ontology merging. The tools promote pairwise ontology integration. Manual intervention was also carried out to match the classes.

Step 1

For a start, *OLOUD* ontology was first merged with the transformed *Expanded Course Ontology* (Figure 2) as they define vocabulary for *Course* (as highlighted in yellow in Figure 3). *Expanded Course Ontology* adds the assessment elements in the *OLOUD* ontology. Concepts from *OLOUD ontology* are shown in green in Figure 3 while concepts from *Expanded Course Ontology* are shown in blue in Figure 3. The concepts ‘*Course*’ and ‘*Teacher*’ are common in both two ontologies and the relationship ‘course teacher’ from *OLOUD* and ‘teaches’ from *Expanded Course Ontology* is equivalent. Grey lines model relationships while black lines illustrate ISA relationships.

By merging the two ontologies, assessment of the course is modelled. A new concept *DeliveryMode* has been introduced to model the delivery mode of the course. The two ontologies merged together can now answer the competency question 5.a listed below,

which could not be answered by the ontologies separately:

Competency Question 5.a List the exam questions and answers set by teacher ‘*Smith*’ for the subject ‘*Knowledge Engineering*’.

Step 2

As a second step, *Smart Classroom Ontology* has been merged with *OLOUD Expanded Course Ontology*. Concepts from *Smart Classroom Ontology* are shown in orange in Figure 4. The following mappings have been made:

- *Context* from *Smart Classroom Ontology* has been mapped to *ObservableProperty* in *SOSA*.
- *Student* from *Smart Classroom Ontology* has been mapped to *Student* in *OLOUD Expanded Course Ontology*.
- *Lecturer* from *Smart Classroom Ontology* has been mapped to *Teacher* in *OLOUD Expanded Course Ontology*.
- *Time* from *Smart Classroom Ontology* has been mapped to *Course time* in *OLOUD Expanded Course Ontology*.

The merged together can now answer the following competency question 5.b:

Competency Question 5.b. What are the observable properties such as noise and temperature of the smart classroom where the teacher ‘*Smith*’ is teaching the ‘*Database Systems*’ course and at what time were the observable properties captured?

Step 3

As the last step, *OLOUD Expanded Course Ontology Smart Classroom Ontology* was merged with *SmartLibOnto* to form the *SmartLearningOnto* as shown in Figure 5. Concepts from *SmartLibOnto* are shown in purple and the common concepts between ontologies are shown in yellow color. *SmartLearningOnto* represents a common model where concepts of a smart learning domain are modelled. The following mappings have been made:

- *User* from *Smart Library ontology* has been mapped to *User* in *OLOUD Expanded Course Ontology Smart Classroom Ontology*.
- *Services* from *Smart Library ontology* has been mapped to *Services* in *OLOUD Expanded Course Ontology Smart Classroom Ontology*.
- *KPI* from *Smart Library ontology* has been mapped to *KPI* in *OLOUD Expanded Course Ontology Smart Classroom Ontology*.
- *Platform* from *Smart Library ontology* has been mapped to *Platform* in *OLOUD Expanded Course Ontology Smart Classroom Ontology*.

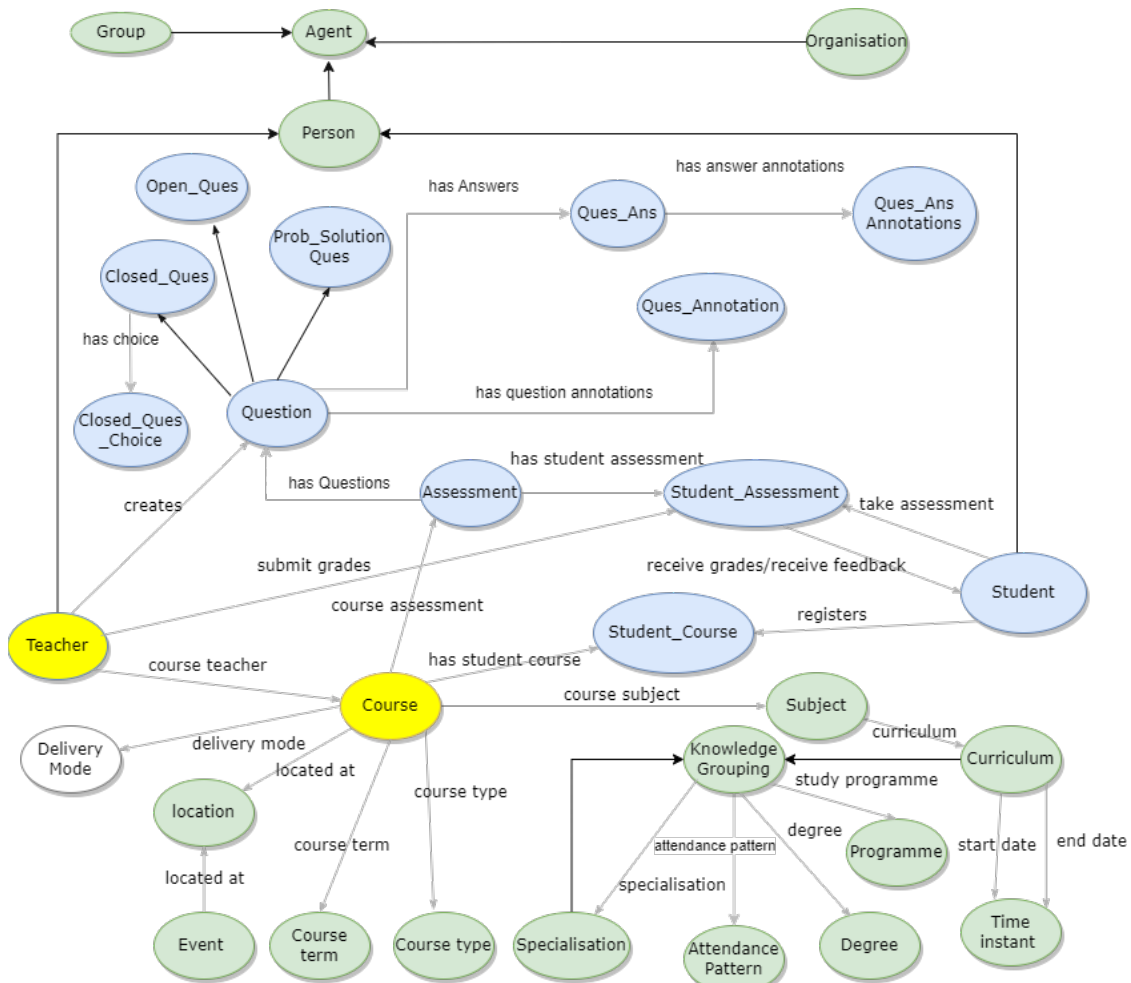


Figure 3 - Concept Mapping –OLOUD_Expanded Course Ontology.

A new concept *SmartCommunity* has been introduced to group Smart Classroom and Smart Library. A new relationship *Categorisation* has been created to categorise *Resources* based on *Subject*.

The four ontologies merged together can now answer the following competency question 5.c, which could not be answered by the ontologies separately:

Competency Question 5.c. Which study books could be used by students following the courses under subject 'Knowledge Engineering' taught by teacher 'Smith' in *SmartClassroom1*?

3.5 Implementation Phase

In this phase, the conceptual model from the previous phase is implemented in OWL using Protégé tool. Protégé 5.5.0 and Logmap are used to merge the four ontologies described in section 3.2. Both tools yielded to more or less the same merged ontology. Anomalies identified were manually corrected to yield best results. The taxonomy of *SmartLearningOnto* is formalized,

whereby the class hierarchy, object property hierarchy and data property hierarchy are developed as shown in Figure 6. Classes model concepts in the domain while object property model relationships between concepts. Data properties represent features and attributes of the concepts. Individuals represent instances of classes.

Semantic Reasoning

Semantic reasoning enables the transformation of low-level data into high-level knowledge, promoting informed decision-making (Bonte et al., 2017). Protégé 5.5.0 includes a number of reasoners in its standard distribution. Reasoners such as Pellet (Sirin et al., 2007) and HermiT (Glimm et al., 2014) are two examples available that can be adopted for effective reasoning. Knowledge can be expressed in the form of rules using the Semantic Web Rule Language (SWRL, <http://www.w3.org/Submission/SWRL/>). SWRL is an expressive OWL-based rule language, which supports more powerful deductive reasoning capabilities than OWL alone (Zhang et al., 2013).

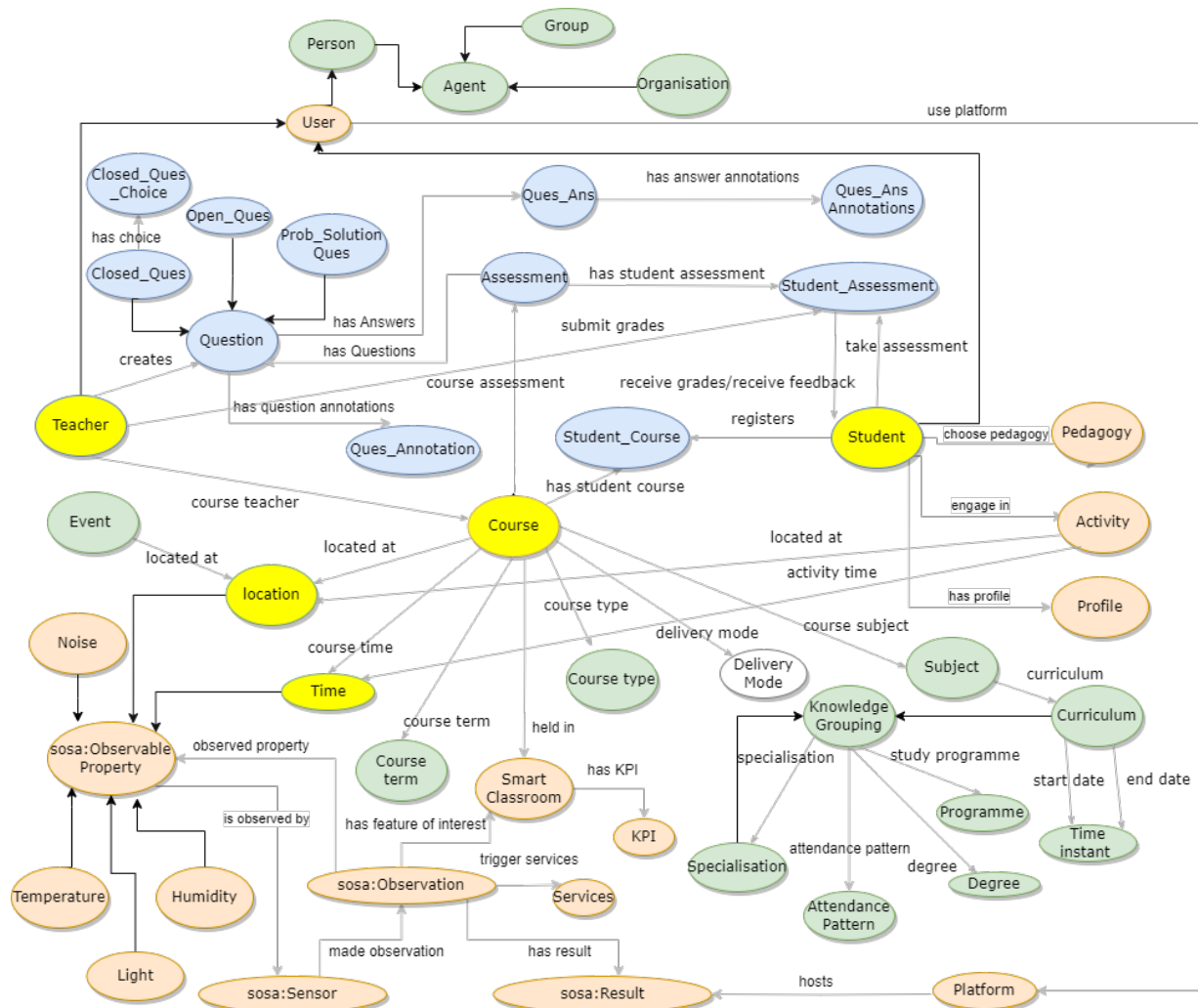


Figure 4 - Concept Mapping –OLOUD Expanded Course Ontology Smart Classroom Ontology.

Reasoners adopt rule-based reasoning where they interpret the defined rules along with asserted facts from knowledge bases to extract new knowledge (De Farias et al., 2016). Reasoners such as Pellet and Hermit use forward chaining inference method to infer the new facts to the knowledge base based on defined facts and the rules (Sherimon et al., 2020).

Some rules are defined as follows.

Rule 1

When a student registers for a course, she is recommended a number of resources from the smart library related to the subject.

$$\text{Student}(?x) \wedge \text{Course}(?y) \wedge \text{Student_Course}(?z) \wedge$$

$$\text{Subject}(?a) \wedge \text{Resources}(?b) \wedge \text{registers}(?x,?z)$$

$$\wedge \text{hasStudentCourse}(?y,?z) \wedge \text{oloud:courseSubject}(?y,?$$

$$a) \wedge \text{categorisation}(?b,?a) \rightarrow \text{recommendResources}(?$$

$$x,?b)$$

Figure 7 shows student Rita has registered for the *Database Systems* course and as per Rule 1 she is recommended resources (the study book entitled “*Fundamentals of Database Systems*”) for the course.

Rule 2

A student is recommended a number of resources from the smart library related to her preference set.

```
Student(?x) ^ Profile(?y) ^ hasProfile(?x, ?y) ^
Subject(?a) ^ SameAs (?y, ?a) ^ categorisation(?b, ?a)
-> recommendResources(?x, ?b)
```

Figure 8 shows student Sarah has set her preference *Semantic Web* in her profile and as per Rule 2 she is recommended resources (the study book entitled “*An Introduction to Ontology Engineering*”).

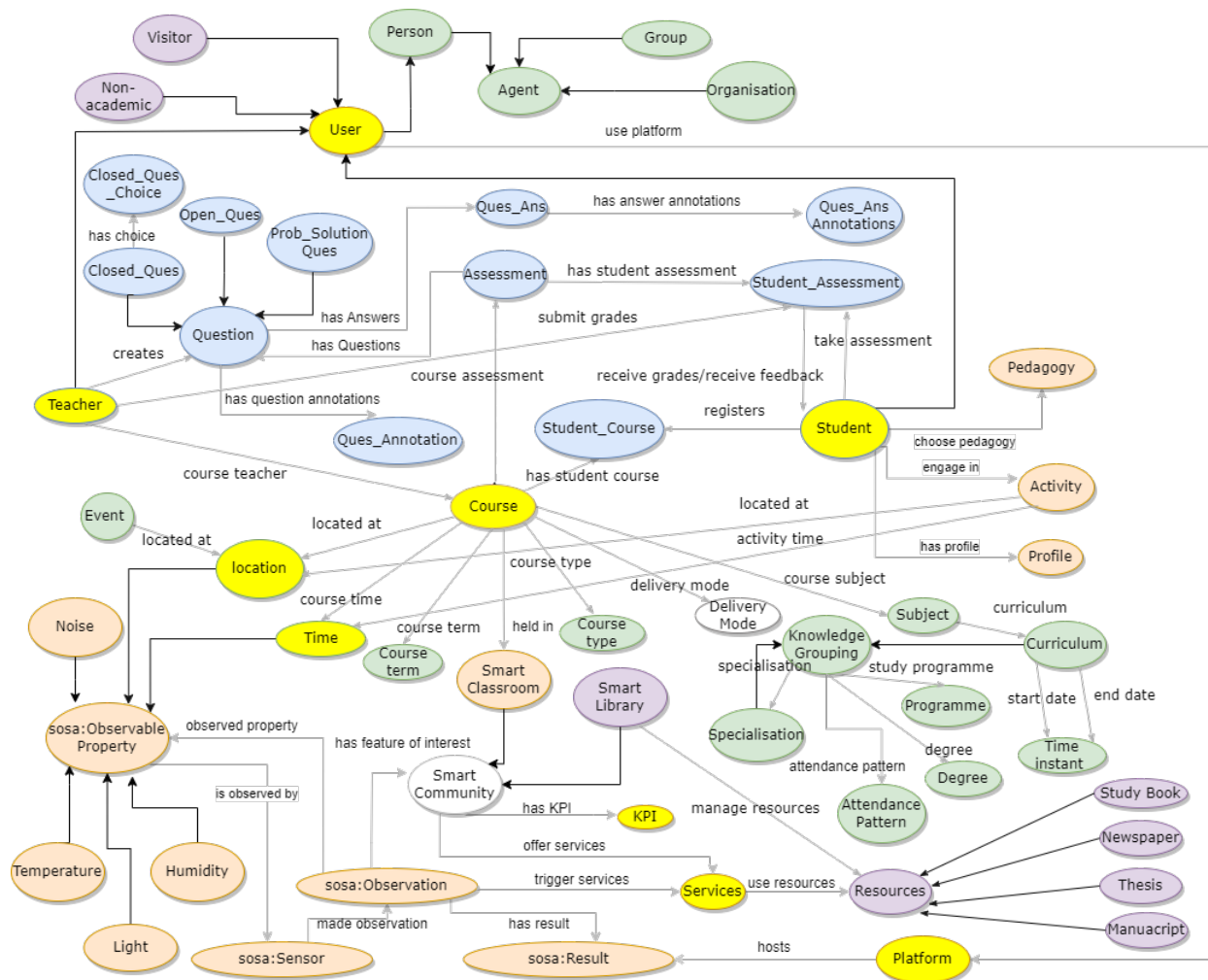


Figure 5 - SmartLearningOnto Concept Mapping.

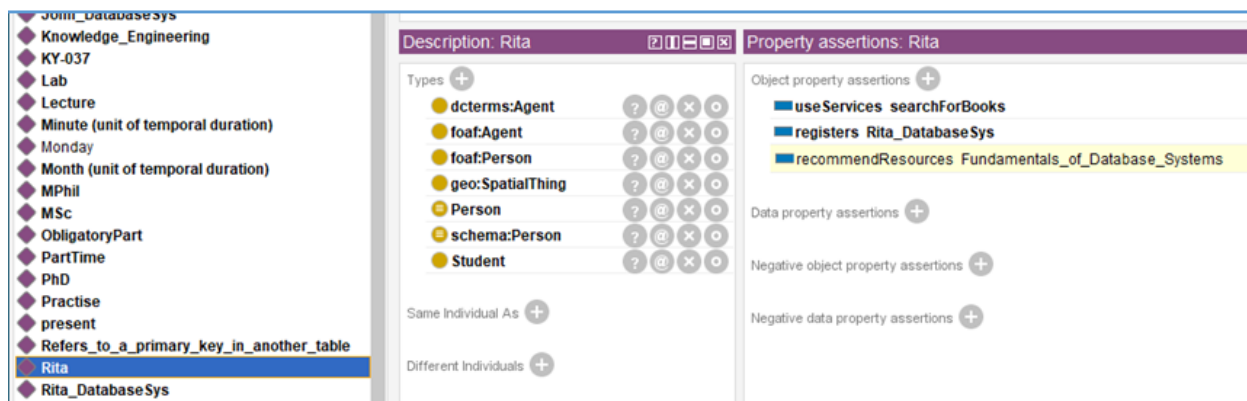
Figure 6 - Concepts, Object and Data Properties of *SmartLearningOnto*.

Figure 7 - Semantic Reasoning using Rule1.

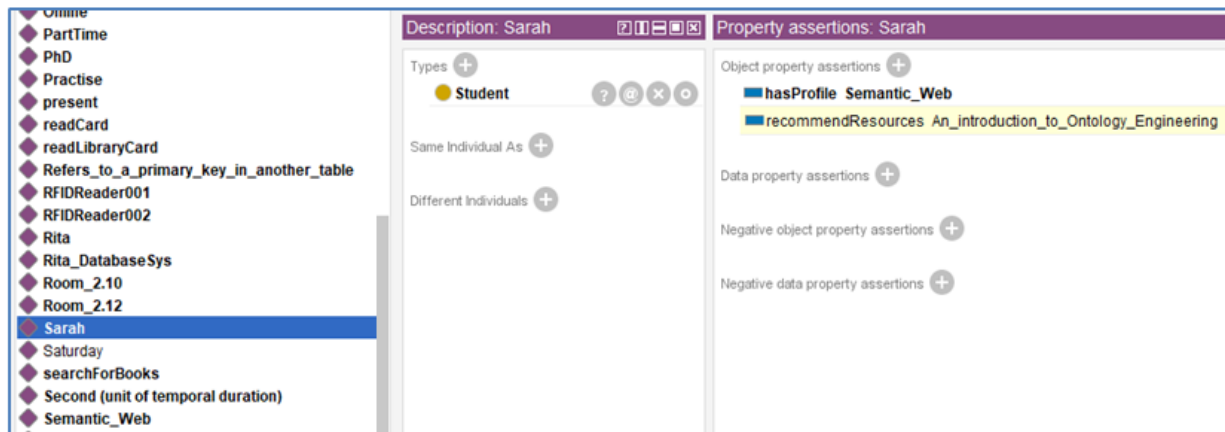


Figure 8 - Semantic Reasoning using Rule 2.

4. Results and Discussions

The developed ontology has been evaluated using (1) semantic querying with respect to competency questions set, (2) domain expert evaluation and (3) a set of metrics.

4.1 Evaluation of Requirements based on Semantic Querying

Query languages are used for retrieving information from ontology repositories (Sheeba & Krishnan, 2015). The SPARQL has been proposed by the World Wide Web Consortium (W3C) and it is used to service an OWL query (O'Connor & Das, 2009). The different Prefixes used are listed as follows:

Prefix:

PREFIX owl: <http://www.w3.org/2002/07/owl#>
 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
 PREFIX oloud: <http://lod.nik.uni-obuda.hu/oloud/oloud#>
 PREFIX ta: <http://ontology.ihmc.us/temporalAggregates.owl#>
 PREFIX time: <http://www.w3.org/2006/time#>
 PREFIX sm: <http://www.semanticweb.org/snagowah/ontologies/2021/10/sm#>
 PREFIX sosa: <http://www.w3.org/ns/sosa/>

The following listings show the SPARQL queries implemented in in Protégé. The result for competency question 5c is shown in Figure 9. The data obtained by executing the SPARQL queries validates the purpose fulfillment of the ontology.

(i) Smart Learning Management System

Competency question 1a	SPARQL
For which programme, did a particular student enroll?	<code>SELECT ?x ?p where { ?x sm:enrollProgramme ?p }</code>

Competency question 1b	SPARQL
Which faculty is offering which programme?	<code>SELECT ?f ?p where { ?f sm:offers ?p }</code>

Competency question 1c	SPARQL
To which subject is a particular course related to?	<code>SELECT ?c ?s where { ?c oloud:courseSubject ?s }</code>

Competency question 1d	SPARQL [Query taken from http://lod.nik.uni-obuda.hu/]
When will the course be delivered?	<code>SELECT DISTINCT ?course ?day ?beginhour ?beginminute ?durationhour ?durationminute WHERE { ?course oloud:courseTime ?ct . ?ct ta:hasTemporalAggregateDescription ?tad . ?tad ta:hasithTemporalUnit ?day ; ta:hasStart ?start . ?start time:hasDurationDescription ?dd ; time:hasBeginning ?begin . ?dd time:hours ?durationhour ; time:minutes ?durationminute . ?begin time:inDateTime ?begindatetime . ?begindatetime time:hour ?beginhour ; time:minute ?beginminute . }</code>

Competency question 1e	SPARQL
What is the delivery mode of a particular course?	<code>SELECT DISTINCT ?c ?dm where { ?c sm:delivery_mode ?dm }</code>

Competency question 1f	SPARQL
When did a particular student register for a particular course?	<code>SELECT DISTINCT ?s ?sc ?registrationdate where { ?s sm:registers ?sc . ?sc sm:registrationDate ?registrationdate }</code>

(ii) Course Assessment

Competency question 2a	SPARQL
List the assessments and the assessment types related to a particular course.	<pre>SELECT ?c ?a where {?c sm:course_assessment ?a}</pre>
Competency question 2b	SPARQL
List the exams questions for a particular course.	<pre>SELECT ?e ?q ?a where {?e sm:hasQues?q. ?q sm:has_question_annotations ?a}</pre>
Competency question 2c	SPARQL
List the performance details for a particular student with respect to a course assessment.	<pre>SELECT ?c ?a ?s ?totalmarks ?marksscore where {?c sm:course_assessment ?a. ?a sm:hasAssessment ?sa. ?s sm:takeAssessment ?sa. ?a sm:assessmentTotalMarks ?totalmarks . ?sa sm:marks_scored ?marksscore}</pre>

(iii) Smart Classroom

Competency question 3a	SPARQL
Which sensors are placed in a particular smart classroom?	<pre>SELECT ?SmartClassroom ?sensor where {?SmartClassroom sosa:isFeatureOfInterestOf ?Observation. ?Observation sosa:madeBySensor ?sensor}</pre>
Competency question 3b	SPARQL
List the observable properties and their results that are observed in the SmartClassroom1 at a particular time and by which sensors?	<pre>SELECT ?ObservableProperty ?Sensor ?Result ?Resultime where {?Observation sosa:hasFeatureOfInterest ?SmartClassroom. ?SmartClassroom owl:sameAs sm:SmartClassroom1. ?Observation sosa:observedProperty ?ObservableProperty. ?ObservableProperty sosa:isObservedBy ?Sensor. ?Observation sosa:hasResult ?Result. ?Observation sosa:resultTime ?Resultime}</pre>
Competency question 3c	SPARQL
Who attended a particular event in a particular SmartClassroom and when?	<pre>SELECT ?SmartClassroom ?Result ?User ?Resultime where {?SmartClassroom sosa:isFeatureOfInterestOf ?Observation. ?Observation sosa:observedProperty ?ObservableProperty. ?ObservableProperty owl:sameAs sm:classroomPresence. ?ObservableProperty sosa:isObservedBy ?Sensor. ?Observation sosa:hasResult ?Result.</pre>

```
?Result sm:is_owned_by ?User.
?Observation sosa:resultTime
?Resultime
}
```

(iv) Smart Library

Competency question 4a	SPARQL
Who are the users of the smart library?	<pre>SELECT ?User where {?User sm:useServices ?SmartLibrary}</pre>
Competency question 4b	SPARQL
List services provided by the smart library.	<pre>SELECT ?Services where {?Services sm:servicesOfferedBy ?SmartLibrary}</pre>
Competency question 4c	SPARQL
List the sensors deployed in a particular smart library.	<pre>SELECT ?SmartLibrary ?Observation ?ObservableProperty ?Sensor where {?SmartLibrary sosa:isFeatureOfInterestOf ?Observation. ?SmartLibrary owl:sameAs sm:SmartLibrary1. ?Observation sosa:observedProperty ?ObservableProperty. ?ObservableProperty sosa:isObservedBy ?Sensor.}</pre>
Competency question 4d	SPARQL
Is a particular resource available in the library?	<pre>SELECT ?Resources ?AvailabilityStatus where {?Resources sm:resourceAvailability ?AvailabilityStatus}</pre>

(v) Interconnected Systems

Competency question 5a	SPARQL
List the exam questions and answers set by teacher 'Smith' for the subject 'Knowledge Engineering'.	<pre>SELECT ?Course ?Question ?Annotation ?Answers ?AnsAnnotations WHERE {?Question rdf:type sm:Question . ?Question sm:has_question_annotations ?Annotation . ?Question sm:hasAnswers ?Answers . ?Answers sm:has_answer_annotations ?AnsAnnotations . ?Question sm:isCreatedBy sm:Smith. sm:Smith oloud:courseTeacher ?Course. ?Course oloud:courseSubject sm:Knowledge_Engineering.}</pre>
Competency question 5b	SPARQL
What are the observable properties such as noise and temperature of the smart classroom where the teacher 'Smith' is teaching the	<pre>SELECT ?SmartClassroom ?Noise ?resultTimeNoise ?Temperature ?resultTimeTemperature WHERE {?Noise sosa:observedProperty sm:estimateSound. sm:estimateSound sosa:resultTime ?resultTimeNoise.</pre>

'Database Systems' course and at what time were the observable properties captured?	<pre> ?Temperature sosa:observedProperty sm:estimateTemperature. sm:estimateTemperature sosa:resultTime ?resultTimeTemperature. ?SmartClassroom sosa:isFeatureOfInterestOf sm:estimateTemperature. ?SmartClassroom sosa:isFeatureOfInterestOf sm:estimateSound. ?SmartClassroom sm:holds sm:DatabaseSystems. sm:Smith oloud:courseTeacher sm:DatabaseSystems. } </pre>
---	--

Competency question 5c	SPARQL
Which study books could be used by students following the courses under subject 'Knowledge Engineering' taught by teacher 'Smith' in SmartClassroom1?	<pre> SELECT ?Study_Book WHERE { ?Study_Book sm:used_Resources ?Services. ?Services sm:used_Services ?Student. sm:Student rdfs:subClassOf sm:User. ?Student sm:follows ?Course. ?Course oloud:courseSubject sm:Knowledge_Engineering. sm:Smith oloud:courseTeacher ?Course. ?Course sm:held_in sm:SmartClassroom1} </pre>

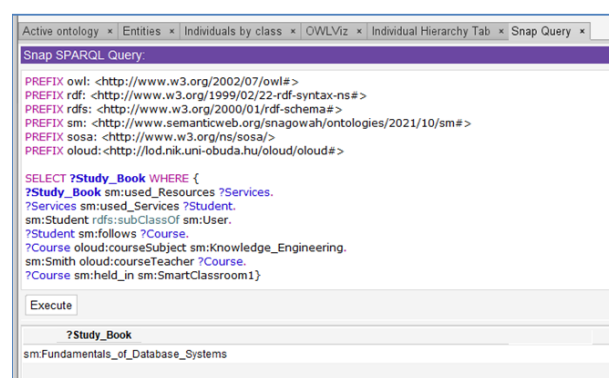


Figure 9 - Execution of SPARQL for competency question 5c.

4.2 Expert Evaluation

A logical evaluation was carried out by two domain experts who have PhD degrees in the field of Computer Science/AI and who have more than 10 years of teaching experience in the field of Information Engineering/Semantic Web. The domain experts have provided critical reviews and after finalizing the ontology, they were in the opinion that

(i) *Ontology Coverage(Completeness).*

SmartLearningOnto describes the main concepts related to smart learning management and assessment (with respect to the motivation scenario).

(ii) *Consistency.*

All relevant concepts have been modelled related to smart learning management and assessment (with respect to the motivation scenario).

(iii) *Accuracy*

SmartLearningOnto correctly captures and represents aspects of the motivation scenario with respect to smart learning management and assessment.

4.3 Metrics and Formal Validation

McDaniel et al. (2018) list a number of criteria that can be used for ontology quality assessment. As shown in Table 2, *SmartLearningOnto* meets all the evaluation criteria defined in the Table 2.

Table 2 - Evaluation Criteria.

Metric	Measure
Adaptability	<i>SmartLearningOnto</i> has been developed by integrating several ontologies. To cope with changes in future, additional ontologies can easily be mapped and integrated. The concepts have been described to ease mapping of new concepts in future.
Cohesion	<i>SmartLearningOnto</i> has reused several existing ontologies such as SOSA. Given that <i>SmartLearningOnto</i> models different elements of the same domain, these elements have some commonalities and are comprehensible and coherent with each other, facilitating the merging process.
Completeness	<i>SmartLearningOnto</i> includes all relevant concepts in the smart learning domain as confirmed by domain experts. <i>SmartLearningOnto</i> could answer the competency questions defined.
Computational Efficiency	Computational efficiency was assessed by the Pellet reasoner. The processing time of the ontology is 1197 ms by Pellet. Defined SWRL rules have been executed properly and have appropriately performed logical inference.
Consistency	No sign of inconsistency is shown by Pellet reasoner, implying that there are no contradictions. Furthermore, SPARQL queries were successfully executed to answer all competency questions.
Coupling	<i>SmartLearningOnto</i> was developed by merging several ontologies and they all worked well when integrated as demonstrated by the SPARQL queries.
Coverage	All relevant concepts have been covered, avoiding redundancy as confirmed by domain experts. A number of sub domains have been covered in <i>SmartLearningOnto</i> .

4.4 Discussion

Technology has transformed the education environment. Several systems are in place to enhance the learning and teaching process in an innovative way. This paper suggests a semantic model that represents data emerging from different systems (Smart Learning Management, Personalized Learning, Assessment, Smart Classroom and Smart Library) in SLE. By integrating data from these systems, the ontology allows the exchange of data and promotes reasoning based on the data, enhancing semantic interoperability.

Such collaboration among the different systems have the following pedagogical implications:

(i) Active and collaborative Learning

By aligning ontologies from different sub domains in SLE, the proposed ontology allows for semantic querying across the different domains. For example, learners following a particular course, get access to exam questions set for a particular subject to enhance the learning process. This query was possible due to alignment between an ontology from the Personalized Learning domain and one from the Assessment domain.

(ii) Personalized Learning

The proposed ontology infers new knowledge about resources available from the Smart Library upon course registration and based on student preference. The learner can then use the resources to learn about a topic at his own pace, thus enriching his learning experience. Such inference was possible due to ontology alignment between the Personalized Learning domain and the Smart Library Ontology.

(iii) Continuous monitoring of student engagement and performance

Observations from real-time environmental data from the Smart Classroom and Smart Library captured by the proposed ontology provide educators with information about contextual factors like location and noise. Such information can be used to monitor student engagement. Teachers also get details about student progress, learning behaviors and performance and can thus adapt their teaching style with respect to learner needs.

5. Conclusions and Future Works

Smart learning domain has evolved in the past years with the advent of advanced technologies such as IoT. Several systems have cropped up to make learning more pleasant and to enhance SLE. This paper presents an ontology for the smart learning domain entitled *SmartLearningOnto*. It regroups knowledge from several sub domains in smart learning namely personalized learning, assessment, smart classroom and smart library. By defining a common data model in the domain, cross-domain communication is now possible across these sub domains and data can be shared to promote semantic interoperability. The proposed ontology was formally validated using metrics and was evaluated based on domain expert feedback. It has fulfilled all requirements defined in the ORSD and has answered all competency questions set. As future works, the proposed ontology will be further extended by incorporating more sub domains in the field of smart learning.

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