SLEek: An Ontology For Smart Learning in the Web of Data

***Abstract*—This paper presents SLEek, an ontology for the context-aware recommendation of learning activities in Smart Learning Environments (SLEs). SLEek relates students, activities, and topics. Thus, it creates an actor-artifact network that is especially suitable for the context-aware recommendation of activities across contexts in formal and informal environments. SLEek implementation reuses vocabularies from the Web of Data, so it facilitates the reuse of data -and data structures- from third parties. SLEek is currently used in [Anonymized application], which includes a dataset of nearly 17K learning activities related to 2K physical and virtual contexts, and 16K topics obtained from DBpedia. All these data are available as Linked Open Data.**

***Index Terms*—Smart Learning Environment, Semantic Web, recommender system, informal learning, ontology**

I. Introduction

Smart Learning Environments [1] emerged as a new trend in the Technology Enhanced Learning field. SLEs promise to adapt the learning experience offering personalized support to the learner taking into account her context and her own needs [2]. Thus, SLEs allow to design and enact new learning scenarios across contexts and spaces. As an example, if a student is learning Gothic Art at high-school (formal space), the SLE may suggest her visit a Gothic church nearby when she is walking around (informal space).

SLEs offer this kind of personalization by coherently integrating very different tools. These tools may differ in the technology they use (e.g., web, mobile [3]); in the type of learning they support (e.g., formal or informal [2]); and in the providers that offer them. An SLE should provide coherent access to learners through all these disparate tools. Hence, they should be integrated in a way that lets them be aware of the learner's progress and her relationship with the learning activities.

As part of this integration problem, the SLE and the tools integrated into it should count with a shared data model. Such a data model should allow describing students, learning contexts, and learning artifacts. This way, the learner could get recommendations of learning activities through different tools taking into account her context and interests.

This paper proposes SLEek, an ontology for the context-aware recommendation of learning activities in SLEs. SLEek defines the main concepts needed for the recommendation of activities in SLEs and enables to relate learners and contextualized activities. Further, the use of semantic technologies lets SLEek reuse vocabularies and datasets available on the Web [4] and offers the extensibility needed to adapt it to specific scenarios.

A preliminary version of SLEek was published in [5]. This paper extends our previous work by proposing a refined version of SLEek and describing how it is currently used. Indeed, we employed SLEek in [Anonymized application] [6], a mobile application that suggests learning tasks depending on the physical context of the learner and is used together with [Anonymized SLE] SLE [7], [8]. [Anonymized application] also uses SLEek to publish on the Web a registry of nearly 17K learning tasks contextualized in physical and virtual learning contexts called [Anonymized SPARQL endpoint] [9], [10].

The rest of the paper is structured as follows. Section II offers and overview of the use of ontologies to support smart learning. Section III presents a scenario to illustrate the requirements of SLEek, which is defined in section IV. Then, section V describes the current use of SLEek in real settings. Finally, section VI summarizes the most important conclusions of the paper.

II. Ontologies for Smart Learning

SLEs make extensive use of ontologies [11]. In many cases, SLEs use ontologies to support formal learning processes. These are typically complex and highly expressive ontologies that structure the SLE knowledge domain. These ontologies are then exploited to offer recommendations of artifacts [12], personalize learning support [13], or analyze learning processes [14].

A few other cases focus on informal learning. These SLEs use simpler and less expressive ontologies. Thus, they offer the flexibility needed to deal with the spontaneous and emerging nature of informal learning processes [15]. These ontologies typically define the context where learning artifacts are used, as such context is key to support or analyze informal learning processes [15]. Again, we can find multiple uses of these ontologies, including understanding learning needs [16], building portfolios [17] or learning analytics [15].

Regarding the Web of Data, its potential for educational purposes has already been deeply explored [18]. Although SLEs have not extensively exploited it yet, we can still find a few proposals that leverage the Web of Data. Some authors reuse Web vocabularies to improve the interoperability of their dataset [13]. Others relate their ontology to DBpedia entities to enrich the description of their own entities, thus increasing their discoverability [12]. Finally, we can cite our previous job, where we gather data from the Web to automatically generate contextualized learning content [9], [10].

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All in all, we can see that the research community is starting to explore the potential of semantic technologies to support smart learning. However, the ontologies proposed for SLEs do not take into account the need of bridging formal and informal learning contexts and the recommendation of learning tasks across contexts and spaces.

III. Scenario

This section describes a scenario that exemplifies the requirements of a data model for an SLE. This scenario is based on the literature about SLE [1], [2], as well as on interviews with nine secondary-school teachers of History of Art from the Spanish region of Castile and Leon. We carried out two rounds of semi-structured interviews in order to build and validate this scenario with the teachers.

John teaches History of Art in a secondary-school. In his classes he uses Moodle, and he tells his students to use the mobile application [Anonymized application], so they can also learn History of Art during their daily life. In his school, the SLE [Anonymized SLE] integrates both Moodle and [Anonymized application]. [Anonymized SLE] can retrieve activities organized according to topics (e.g., Romanesque Architecture) from [Anonymized SPARQL endpoint], in order to propose them in personalized suggestions through either Moodle or [Anonymized application]. These activities may include one or several resources (e.g., text, images, videos, questionnaires...).

This week, John started the topic of Romanesque Art. So he asks his students to access the corresponding Moodle unit. Mary is one of the students in the course. When she is at home, she accesses Moodle and she finds several activities proposed by John. After watching a video about Romanesque vaults, she answers a questionnaire where she has to distinguish between barrel vaults and groin vaults. Her answers are correct. [Anonymized SLE] monitors Mary's progress and updates the topics Mary is interested in (”Romanesque Art”, ”barrel vault” and ”groin vault”). With this information, [Anonymized SLE] queries [anonymized SPARQL endpoint] for tasks that meet the selected topics of a kind suitable for Mary. It then selects the most appropriate ones around the town where Mary lives. Finally, it tells [Anonymized application] that these particular activities are a good recommendation for Mary.

Two days later, Mary is walking around her city. She passes by a Romanesque church and [Anonymized application] suggests Mary an activity related to Romanesque Art. This activity invites her to take a photo of the modillions of the church and reflect on the images that they represent (see Figure 1). After doing the task, Mary rates the activity with 5 stars and asks [Anonymized application] to propose another one. This new activity is proposed because Peter (a colleague of Mary) rated, two days ago, with 5 stars both the task previously done by Mary and the one that is now proposed. This other activity asks Mary to get into the church and identify the type of vault it has. After doing the task, Mary rates it with two stars and continues with her walk.

Fig. 1. An activity represented in [Anonymized application]. The texts says in Spanish: ”If you find a modillion in the Hermitage of San Pedro de Tejada, describe it and say its functionality. You can also take a photo to the modillion”.

When Mary arrives home she accesses Moodle. In her portfolio of Mahoodle[1] she finds the activities she carried out at the church together with her answers. She also discovers that [Anonymized SLE] added two new optional activities to her personal space in Moodle (the selection and deployment of these tasks is similar to the one previously described for [Anonymized application]). Both of them are related to her experience in the church: one of the activities asks her to draw a Romanesque modillion, while the other asks her about the name of a church she has visited (Figure 2).

The following week John accesses Moodle and visualizes the activities done by his students using [Anonymized application]. He is happy to see that several students carried out some activities. However, he realizes that some of them confuse the terms “frontispiece” and “lintel”. Hence, he will explain these terms again in the classroom. He also finds out that Rose made an interesting comment about the

[1] https://manual.mahara.org/en/20.04/mahoodle/mahoodle.html

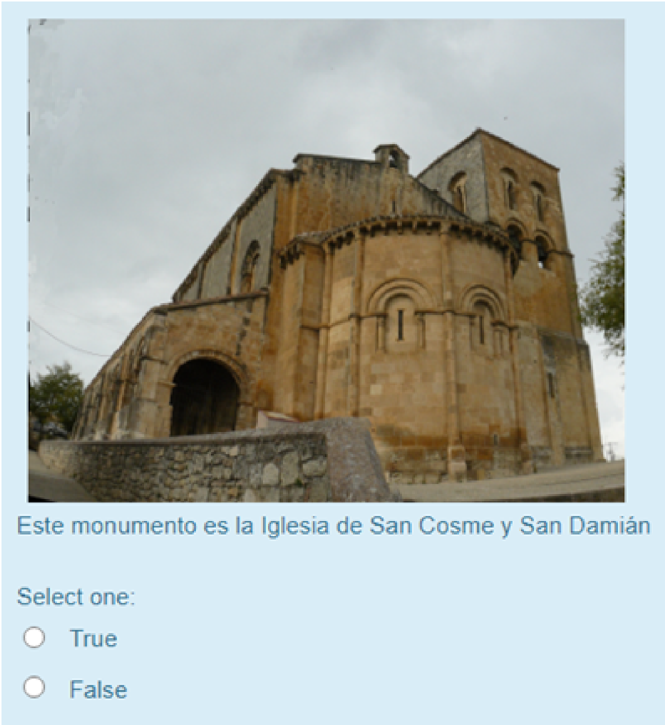

Fig. 2. An activity represented in Moodle. The texts says in Spanish: "Is this monument the church of San Cosme and San Damián?"

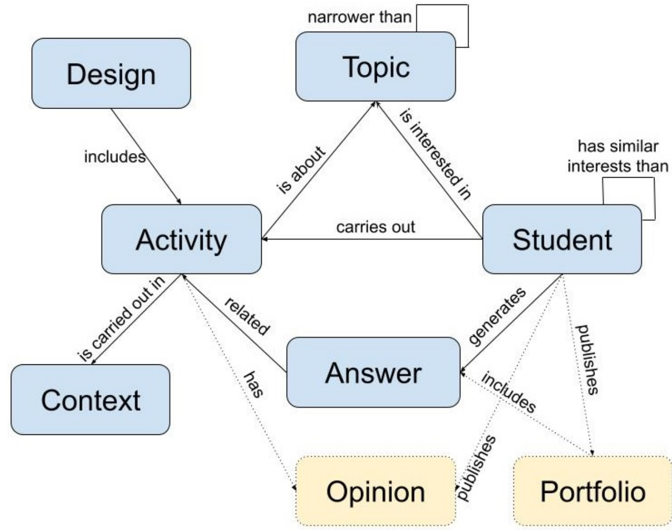

Fig. 3. Overview of SLEek classes. Concepts in blue are core concepts; concepts in yellow are the extension needed to support the scenario in section III.

modillions of a local church, so he will invite her to comment on it to her classmates.

IV. SLEek Ontology

This section proposes SLEek, an ontology that supports the modelling of scenarios similar to the one described above. SLEek should relate `activities` and `students` through their `topics` of interest, even if these `activities` are carried out in different `contexts`.

The `activity` recommendation by the SLE is improved if there are relationships among `students` (e.g., Peter and Mary have similar `opinions` regarding the `activities`) and `topics` (e.g., "modillions" and "Romanesque Architecture" are related). Hence, SLEek should be able to define a social network of `students` and arrange the `topics` in thesauri. It thus enables to generate an artifact-actor network, which is especially suitable for the recommendation of learning activities in informal contexts [15].

Taking all this into account, we derived the SLEek data model as depicted in Figure 3. We took as a basis the data model proposed by [19], which is suitable for the enactment of learning activities in multiple environments. This data model has already been extended to support competence-based evaluation using portfolios [20]. This model defines concepts like `Design`, `Activity`, `Answer` and `Student`. However, it does not consider concepts that are important for SLEs, such as `Topic` and `Context`. All these are core concepts of our SLEek as they are expected to be shared with any SLE. SLEek is extensible, so it can be adapted to the needs of specific SLEs or scenarios.

As an example, for the scenario described in section III, we included two additional concepts: `Portfolio` and `Opinion`. Note that these two concepts are only needed if users are allowed to rate `activities` and if `portfolios` are used to report or assess the `activity` results.

SLEek was implemented as an ontology to enhance its extensibility and its integration with other registries available in the Web of Data. Table I lists the main attributes of each class, while Table II relates the namespaces used with their corresponding URIs.

For the implementation of SLEek we used several well-known ontologies. Some of them, such as Dublin Core (`dc:` and `dcmi:` in Tables I and II), have been widely used to describe learning resources. Others are general-purpose ontologies used in the Web of Data [4]: RDF, FOAF, Review (`rev:`), DBpedia (`db:`) or SKOS. When needed, we defined new classes (`cl:ontology/task`) or properties (`clp:bloom`).

By using these vocabularies, we facilitate the integration of our data model and others used in the Web of Data. Thus, we can leverage the data available on the Web. More specifically, we took advantage of DBpedia, which defines a wide variety of thesauri that relate categories of elements. As an example, DBpedia thesauri relates the terms `db:Romanesque_architecture` and `db:Modillion`. These relationships are offered as Open Data, so we can extract them to define the relationship between topics in our data model.

V. SLEek in use

SLEek is currently used by [Anonymized SPARQL endpoint] (available at [AnonymizedURL]/sparql). In its current

TABLE I
CLASSES AND MAIN PROPERTIES DEFINED, TOGETHER WITH EXAMPLES OF INSTANCES.

	Activity	
	cl:.../photoModillions	cl:.../sanCosmeyDamian
rdf:type	cl:ontology/task	cl:ontology/task
rdfs:label	”Photograph modillion”	”Romanesque churches”
dc:creator	cl:researchers	john@teachers.com
dc:subject	db:modillion	db:Rom...architecture
clp:textResource	”Photograph modil...”	”Is this monument...”
foaf:depiction	dbf:San_PedroT02.JPG	dbf:San_Cosme.JPG
clp:hasContext	clc:SaintJohn	clc:Moodle
rv:hasReview	cl:review/rev001	
clp:bloom	cl:.../remember	cl:.../remember
	Student	
	mary@student.com	peter@student.com
rdfs:type	foaf:Person	foaf:Person
foaf:interest	db:modillion	db:Rom...architecture
rev:Review	cl:review/rev001	cl:review/rev100
clp:carriesOut	cl:.../photoModillions	cl:.../RomanesqueChurches
clp:generates	cp:answer1	cp:answer2
	Topic	
	db:modillion	db:Rom...architecture
rdfs:type	cl:topic	cl:topic
rdfs:label	”Modillion”	”Romanesque Architecture”
skos:broader	db:Rom...architecture	
skos:narrower		db:modillion
	Context	
	cp:context/SanPedroT	db:Moodle
rdfs:type	dbo:Location	cp:vle
rdfs:label	”San Pedro de Tejada”	”Moodle”
geo:long	”-4.3128”	
geo:lat	”42.2736”	
	Design	
	cp:design1	cp:design2
rdfs:type	cp:design	cp:design
dc:creator	john@teachers.com	john@teachers.com
	Answer	
	cp:answer1	cp:answer2
dc:type	dcmi:Image	dcmi:Text
dc:creator	mary@student.com	mary@student.com
dc:related	cl:.../photoModillions	cl:.../nameStyle
	Opinion	
	cp:review/rev001	cp:review/rev002
rdfs:type	rev:Review	rev:Review
rev:Rating	5	2
	Portfolio	
	cp:portfolio/portfolio1	cp:portfolio/portfolio2
dc:type	dcmi:Collection	dcmi:Collection
dc:autor	mary@student.com	peter@student.com
dc:hasPart	cp:cActivity1	cp:cActivity2

TABLE II
NAMESPACES USED IN THE ARTICLE AND THEIR CORRESPONDING URI.

Prefix	URI
cl:	[AnonymizedURL]
clp:	[AnonymizedURL]/property/
foaf:	http://xmlns.com/foaf/0.1/
db:	http://dbpedia.org/resource/
dbc:	http://dbpedia.org/resource/Categoría:
dbf:	http://commons.wikimedia.org/wiki/Special:FilePath/
dbo:	http://es.dbpedia.org/ontology/
dc:	http://purl.org/dc/elements/1.1/
dcmi:	http://purl.org/dc/dcmitype/
geo:	http://www.w3.org/2003/01/geo/wgs84_pos#
rdfs:	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rev:	http://purl.org/stuff/rev#

version, [Anonymized SPARQL endpoint] is a registry of activities of History of Art. This registry currently publishes 10,793 activities contextualized in physical locations of the Spanish region of Castile and Leon. These activities were semi-automatically created out of descriptions of historical buildings available in the Web of Data [9]. An example is described in the first column of Table I. Additionally, [Anonymized SPARQL endpoint] also contains 6,128 Moodle activities that were also semi-automatically created from the same data sources [10]. All these activities are related to a context and a set of topics. In the case of Moodle activities, they are all contextualized in the virtual environment Moodle. The rest of the activities are contextualized in 2,197 different physical contexts (i.e., the locations of the historical buildings they refer to). All these activities are also related to 16,732 topics obtained from DBpedia. Table I includes example descriptions of activities, topics, and contexts.

Table I shows the descriptions of two contextualized activities: one contextualized in Moodle and the other one geolocalized in a physical environment. They are both described using the same attributes, so the SLE can handle them in the same way. Their attributes include the textual and image resources related to these activities. Both of them are also related to topics `db:modillion` and `db:RomanesqueArchitecture`, which are later on described in Table I. These two topics, defined as DBpedia concepts, are related: `db:modillion` is a narrower concept of `db:RomanesqueArchitecture` (as defined in a DBpedia thesaurus). Hence, there is an indirect relationship between both activities. Similarly, the student Mary is related to the topic `db:modillion`, which makes her indirectly related to `db:RomanesqueArchitecture` and the two activities.

These relationships among topics, students, and activities weave a context-aware semantic actor-artifact network [15]. [Anonymized application] exploits this network to recommend activities to the students. For example, taking that Mary is interested in modillions and is located in a certain physical environment (such as in the scenario of Section III), [Anonymized application] can submit the following query to [Anonymized SPARQL endpoint] in order to retrieve all the tasks related to the topic ”modillion” located near her.

```
SELECT ?task ?cont ?lat ?long ?aTR ?rT ?img
WHERE {
    ?cont geo:lat ?lat ;
          geo:long ?long .
      FILTER (
        (xsd:decimal(?lat) > 41.64889) &&
        (xsd:decimal(?lat) < 41.65539) &&
        (xsd:decimal(?long) > -4.73183) &&
        (xsd:decimal(?long) < -4.72533) ) . {
    SELECT ?cont ?task ?aTR ?rT ?img ?aT
    WHERE {
    ?task clp:hasContext ?cont ;
          clp:answerType ?tRes ;
          clp:associatedTextResource ?aTR ;
          dc:subject dc:modillion
    OPTIONAL {?task foaf:depiction ?img .}
    OPTIONAL {?task clp:answerType ?aT .}}}.}
```

VI. Conclusions

This paper presents SLEek, an ontology for SLEs that allows personalizing learning processes offering activities in formal and informal environments. Its implementation using semantic technologies enables the integration of this ontology with others in the Web and the reuse of third-party data. This ontology is currently used in [Anonymized SPARQL endpoint], which contains 16,921 learning activities, and [Anonymized application], a smart application that exploits such registry in the context of [Anonymized SLE] SLE.

One of the main characteristics of SLEek is that it allows defining a context-aware semantic actor-artifact network, which is especially suitable for the recommendation of learning activities. Additionally, the activities described are related to a context and a set of topics, so they can be recommended to people interested in their topics that are in certain physical or virtual contexts.

The research work presented should be seen as a new iteration in our Design-Based Research methodology. Following this methodology, in the near future, we will use SLEek to integrate [Anonymized application] and [Anonymized SLE]. Then, we will carry out some pilot studies with secondary-school students to support scenarios similar to the one presented in Section III.

References

[1] B. Gros, "The design of Smart Educational Environments," *Smart Learning Environments*, vol. 3, no. 15, pp. 1–11, 2016.

[2] G. Hwang, "Definition, framework and research issues of Smart Learning Environments - A context-aware ubiquitous learning perspective," *Smart Learning Environments*, vol. 1, no. 4, pp. 1–14, 2014.

[3] J. Dron, "Smart Learning Environments, and not so Smart Learning Environments: A systems view," *Smart Learning Environments*, vol. 5, p. 25, 2018.

[4] T. Heath and C. Bizer, *Linked Data: Evolving the Web into a global data space*, J. Hendler and F. van Harmelen, Eds. Morgan & Claypool, 2011, URL: http://linkeddatabook.com/editions/1.0/, last visited January 2021.

[5] Anonymized publication.

[6] Anonymized publication.

[7] Anonymized publication.

[8] Anonymized publication.

[9] Anonymized publication.

[10] Anonymized publication.

[11] T. Hoel and J. Mason, "Standards for smart education – towards a development framework," *Smart Learning Environments*, vol. 5, 2018, DOI: https://doi.org/10.1186/s40561-018-0052-3.

[12] N. Capuano and D. Toti, "Experimentation of a smart learning system for law based on knowledge discovery and cognitive computing," *Computers in Human Behavior*, vol. 92, pp. 459–467, 2019.

[13] S. Ouf, M. Ellatif, S. Salama, and Y. Helmy, "A proposed paradigm for Smart Learning Environment based on Semantic Web," *Computers in Human Behavior*, vol. 72, pp. 796–818, 2017.

[14] D. Boulanger, J. Seanosky, V. Kumar, Kinshuk, K. Panneerselvam, and T. Somasundaram, *Theory Principles and Design of Magnetic Circuits*. Heidelberg (Germany): Springer Berlin, 2015, pp. 289–296.

[15] A. Ruiz-Calleja, S. Dennerlein, D. Kowald, D. Theiler, E. Lex, and T. Ley, "An infrastructure for workplace Learning Analytics: Tracing knowledge creation with the Social Semantic Server," *Journal of Learning Analytics*, vol. 6, no. 2, pp. 120–139, 2019.

[16] B. Dobreski and Y. Huang, "Ontology informed design to advance developers' informal online learning," *Educational Technology Society*, vol. 21, no. 3, pp. 23–34, 2018.

[17] K. Rezgui, H. Mhiri, and K. Ghédira, "Ontology-based e-portfolio modeling for supporting lifelong competency assessment and development," *Procedia Computer Science*, vol. 112, pp. 397–406, 2017.

[18] Anonymized publication.

[19] L. Prieto, J. Asensio-Pérez, Y. Dimitriadis, E. Gómez-Sánchez, and J. Muñoz-Cristóbal, "GLUE!-PS: A multi-language architecture and data model to deploy tel designs to multiple learning environments," in *Proceedings of the 6th European Conference on Technology Enhanced Learning*. Heidelberg, Germany: Springer, 2011, pp. 285–298.

[20] A. Lozano-Alvarez, J. Asensio-Pérez, G. Vega-Gorgojo, and A. Martínez-Monés, "Helping teachers align learning objectives and evidence: Integration of eportfolios in distributed learning environments," *Journal of Universal Computer Science*, vol. 21, no. 8, pp. 1022–1041, 2015.