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CHEST: an Application to Support Teachers in the use of Linked Open Data for Ubiquitous Learning

Pablo García-Zarza, Guillermo Vega-Gorgojo, Miguel L. Bote-Lorenzo, Vanesa Gallego-Lema, Juan I. Asensio-Pérez and Eduardo Gómez-Sánchez

***Abstract*—Ubiquitous learning (u-learning) leverages educational technologies to help students learn anywhere and anytime across multiple physical and virtual spaces. However, u-learning applications face a challenging trade-off: should they provide a predefined set of u-learning resources, thus saving time to teachers, but limiting their applicability to a wider range of u-learning situations? Or should they allow teachers to create their own u-learning resources, improving flexibility, but requiring a non-negligible effort from teachers that typically ends up in learning resources that cannot be reused by other teachers or by other u-learning applications? CHEST, the application presented in this paper, addresses this trade-off proposing the use (and reuse) of Linked Open Data (LOD) to support teachers in the design of u-learning situations in the Cultural Heritage domain. CHEST hides the complexity of LOD to teachers, thus reducing the effort in creating u-learning situations, while, at the same time, taking advantage of its reusable nature. CHEST allows teachers to create and reuse three types of learning resources in the form of LOD: spatial things, learning tasks, and itineraries (which group the other two types of resources). The paper elicits the requirements considered for the development of CHEST, describes its architecture, and presents the results of an evaluation study carried out with a CHEST prototype in the context of a University course involving two teachers and 14 students. The evaluation examines how CHEST supports teachers in the creation and reuse of u-learning resources based on LOD, paying attention to the balance between flexibility and required effort, while it also showcases how CHEST supports the enactment of u-learning situations in an authentic educational context. The study provides valuable insights into the applicability and effectiveness of CHEST within a specific educational context.**

***Index Terms*—LOD authoring, ubiquitous learning, learning tasks, itineraries, cultural heritage.**

I. Introduction

UBIQUITOUS learning [1], [2] (u-learning) is a type of learning supported by technology that can take place anywhere and at anytime across different spaces. For example, Art history teachers from Palermo, Italy, can explain the main characteristics of fountains and the evolution of this architectural element through history. They can use photographs and videos in class of some of the most important fountains in Europe such as the Trevi Fountain (Italy), the Fountain in the Garden of Versailles (France), and the Fountain of the Lions in The Alhambra (Spain). They can also ask their students to complete a test about monumental fountains with Moodle (virtual space). Then, these teachers can ask their students to visit some of the most representative fountains of Palermo. Teachers can create a series of learning tasks to be completed close to these ornamental structures (physical space), such as a task in which students must record a video explaining one of the sculptures of the Praetorian Fountain and another task in which they must write a comparative between the style of its sculptures with those of the Trevi Fountain (explained in class).

The benefits of u-learning such as accessibility, immediacy, and adaptability [3], together with the ubiquity of personal electronic devices (such as mobile phones, tablets, and laptops) and the evolution of telecommunications networks have brought the attention of teachers and researchers towards u-learning in recent years. As a result, many u-learning applications have been proposed (e.g., [4]–[7]). We can classify these applications into: (1) applications with learning resources (e.g., the description of a site like a fountain or a castle, a task in which students must record a video, a thematic route, etc.) that can be used in u-learning settings, but where teachers have little (or no) control over them; and (2) applications where teachers can make their own decisions about which learning resources to use in their u-learning situations.

The main problem with applications of the first type is the limited (or even lack of) personalization that teachers can carry out, heres for of the second type teachers must spend time authoring the learning resources from scratch, which requires significant effort. One way of reducing the workload associated with the creation of u-learning resources would be the reuse of already created resources, ideally across different u-learning applications (thus avoiding data silos [8]). Using a common (or at least public) schema for sharing data is one way to facilitate resource sharing across applications. Among the different ways of sharing data, the best practices proposed by the Linked Open Data (LOD) initiative [9] may bring important advantages for the field of u-learning.

LOD is a type of structured data which makes both the data and the schema public. There are important open multi-domain datasets, like Wikidata[1] and DBpedia,[2] that share their data as LOD (in fact, Wikipedia pages increasingly rely

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P. García-Zarza, G. Vega-Gorgojo, M.L. Bote-Lorenzo, J.I. Asensio-Pérez, and E. Gómez-Sánchez are with GSIC-EMIC, School of Telecommunications Engineering, Universidad de Valladolid, Spain (e-mail: pablogz@gsic.uva.es; guiveg@tel.uva.es; migbot@tel.uva.es; juaase@tel.uva.es; edugom@tel.uva.es).

V. Gallego-Lema is with GSIC-EMIC, Faculty of Education and Social Work, Universidad de Valladolid, Spain (e-mail: vanesa.gallego@uva.es).

[1]https://www.wikidata.org/
[2]https://www.dbpedia.org/

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on data from Wikidata [10]). LOD can be used by both humans (e.g., a teacher could retrieve data about the Palermo Cathedral from Wikidata)[3] and machines (a program could retrieve data about the Palermo Cathedral from Wikidata and format it nicely for the teacher inspection). Furthermore, an entity in a LOD dataset can link to other entities in the same or in different datasets (e.g., the Palermo Cathedral item in DBpedia[4] is connected to the item in Wikidata through the property `owl:sameAs`). This allows navigation between datasets, facilitates data reuse, and avoids duplication of information, thus promoting the evolution of the classic web (document-based) to a "web of data" [8].

In the case of u-learning, teachers could reuse data from these multi-domain LOD datasets to facilitate the design and setup of their u-learning situations. In addition, learning resources created by teachers could be shared as LOD. However, the main problem with using LOD is that it requires knowledge of Semantic Web technologies (such as SPARQL [11]), which teachers do not usually have. As a result, they may not take advantage of these existing LOD resources unless access to the data is simplified. Some previous works (e.g., [4], [6]) have explored the potential of using LOD to enact u-learning situations and have attempted to reduce the barrier to access these data. However, despite the fact that these applications simplify the access to LOD resources, they do not allow teachers to create and customize their own learning resources (e.g., allowing teachers to create their own itineraries for their students). This is again a limitation for some teachers [12].

In summary, in the current state of the art there are, on the one hand, u-learning applications that force teachers to design their situations from scratch, typically keeping all generated content in a data silo and, on the other hand, LOD-based u-learning applications that provide limited control when authoring or tailoring u-learning situations. From this gap arises the following research question: **How to support teachers to exploit LOD to author and enact u-learning situations?** This paper addresses this question for the Cultural Heritage (CH) domain by proposing a distributed application called CHEST (Cultural Heritage Educational Semantic Tool), to support teachers anywhere in the world in using LOD to author and enact their u-learning situations without the need to learn Semantic Web technologies.

The remainder of the paper is organized as follows. Section II reviews u-learning works, differentiating between applications with authoring and non-authoring support for the creation of u-learning resources. Section III introduces CHEST, a new application that supports teachers to exploit LOD to create and enact u-learning situations in the CH domain, presenting its architecture, main features, and how it was implemented. Section IV presents the method used to carry out the CHEST evaluation. This evaluation is based on an authentic experience, with two teachers creating an u-learning situation by reusing existing LOD, adding their own learning resources, and publishing them as new LOD for the eventual consumption of others. The findings of the research are presented in Section V. Next, the results of the evaluation are discussed in Section VI. Finally, in Section VII, we present the conclusions we have reached and the future work.

[3]http://www.wikidata.org/entity/Q1478407

[4]http://dbpedia.org/resource/Palermo_Cathedral

II. Related Work

While there are many applications that can be used for u-learning, only a few works were designed to support teachers in creating or customizing u-learning situations to their learners' needs. Some of these applications were already identified in a literature review [13]. We supplemented this analysis with some more recent applications.

U-learning applications support the creating and use of different types of learning resources. We have categorized these resources into three broad types: **spatial things**,[5] **learning tasks**, and **itineraries**. Going back to the initial example, our Palermo Art History teachers could author (or reuse) **spatial things** of the Trevi Fountain, the Fountain of the Lions, and the Praetorian Fountain of Palermo (adding the title, location, customized description for their students, etc.). Associated with these spatial things, they could author (or reuse) **learning tasks** (e.g., complete a quiz, take a photo, watch a video, etc.) that their students could carry out when visiting those spatial things in the virtual space (e.g., using a map on their laptops or mobile devices for the Fountain in the Garden of Versailles) and/or physical space (e.g., visiting the Praetorian Fountain in situ). In addition, these teachers can author (or reuse) an **itinerary** (e.g., going to the Praetorian and Garraffo fountains of Palermo and carrying out a set of tasks at these sites) in which they decide the order that should be followed for the completion of the tasks. In the following subsections we group existing u-learning applications into those that do not support the authoring and tailoring of u-learning resources (and, therefore, only allow the reuse of existing resources), and those that allow teachers to author new u-learning resources. Table I shows a summary of the existing u-learning applications analyzed.

U-learning applications without authoring support

There are applications that provide teachers with resources to implement u-learning situations but do not allow any kind of customization. These applications provide their own resources or use resources in open formats. In the first group, we find SWSMa [21]. In this application, students must complete a series of case studies in which they have to make decisions (learning tasks). Another application that uses its own resources is UoLmP [22]. This application aims to improve students' language skills by asking them (learning tasks) to listen to audio, take notes, read, etc. In addition, UoLmP takes into account the context of the students (needs, preferences, noise level, etc.) to adapt the tasks.

[5]According to [14], a spatial thing is "anything with spatial extent, (i.e. size, shape, or position) and is a combination of the real-world phenomenon and its abstraction (the feature). Examples are: people, places, or bowling balls". In the case of teachers, they often refer to this term as point of interest, beacon, or site. For this paper, we will use the term **spatial thing** from the point of view of the application design and **site** when it comes from the users (in the CH domain we are going to manage only this type of spatial thing). For example, the Cathedral of Palermo would be a spatial thing for us and a CH site for the teachers.

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TABLE I
SUMMARY OF U-LEARNING SUPPORT APPLICATIONS ADDING CHEST, THE APPLICATION USED IN THIS STUDY.

	Domain	Learning resource support			Task variability	Use of external data
		Spatial thing	Learning task	Itinerary		
Avastusrada [15]	Any domain	-	Author	Author	High	No
Casual Learn [6]	Cultural heritage	Support	Support	-	High	Yes
EducaWood [16]	Forestry education	Author	-	-	-	Yes
GLUEPS-AR [17]	Any domain	Author	Author	Author	High	No
MeLOD [4]	Cultural heritage	Support	Support	-	Low	Yes
PT Anywhere [18]	Telecommunication education	-	Support	-	Low	Yes
QuesTInSitu [5]	Any domain	-	Author	Author	Medium	No
SituLearn [19]	Any domain	Author	Author	Author	Medium	No
SmartZoos [20]	Environmental education	-	Author	Author	High	No
SWSMa [21]	Ethic social media	-	Support	-	Low	No
UoLmP [22]	Language education	-	Support	-	High	No
U-Physics [7]	Physics education	Author	-	-	-	No
CHEST	Cultural heritage	Author	Author	Author	Medium	Yes

There are not many applications that use LOD to support u-learning. One of them is MeLOD [4], an application for enacting learning situations in the CH domain that uses DBpedia. In MeLOD, students can choose the type of spatial things they want to receive. These students can carry out only two types of tasks at spatial things: commenting on the site and rating it. Teachers can monitor students while using MeLOD.

Casual Learn [6] is an application of our previous work that uses LOD resources. Students using Casual Learn can complete learning tasks linked to spatial things related to the CH of Castile and León (Spain). These learning tasks were generated semi-automatically using open data from different datasets and were then also published as LOD [23]. The variability of the type of these learning tasks is high: informative, free text (short and long), photo(s), video(s), the combination of free text and photo(s) or video(s), and multiple choice questions (MCQs).

An application that uses other types of open data is PT Anywhere [18]. This web application allows students to complete network simulations. The models for running these simulations are provided as OERs (Open Educational Resources). The application allows students to run network simulations, but it does not offer additional learning tasks.

The u-learning applications described in this subsection, which provide ready-to-use learning resources, reduce the effort required from teachers to create u-learning situations. However, we know from our previous experience that teachers may want to tailor learning situations to their students' needs [12]. Consequently, in those cases in which a greater degree of tailorability is needed, the described applications may fall short in satisfying teachers' requirements.

U-learning applications with authoring support

Some existing applications allow teachers to create or customize u-learning situations. These applications typically include a teacher tool for authoring the resources used in a u-learning situation, and a student tool to complete the tasks. An example is QuesTInSitu [5], an application that allows teachers to author geolocalized learning tasks and itineraries. Teachers can add three different types of tasks: multiple choice, multiple response, and yes/no questions. The itineraries are made up of the tasks chosen by the teachers. Students can use their mobile device to complete the learning tasks proposed by their teachers. Teachers are also able to monitor their students.

Other existing applications are Avastusrada [15] and SmartZoos [20]. Similarly to QuesTInSitu, teachers can author activity items (localized tasks) and activities (itineraries). The types of tasks that teachers can add are informative, multiple choice, free text, matching pairs, embedded content, and photos. To create itineraries, teachers must select the tasks, specify the difficulty level of the itinerary, and the maximum distance to the spatial thing at which students can complete the tasks. Teachers can track students while they follow the itineraries.

GLUEPS-AR [17] is a system that aims to support teachers in designing and enacting their u-learning situations. It uses multiple adapters to allow teachers to integrate learning resources from various tools (e.g., web pages, virtual worlds, etc.). As a result, the domain and types of tasks that can be completed in GLUEPS-AR are only limited by these external tools. Teachers can author spatial things in which to add other resources and monitor students when they use the system.

SituLearn [19] is a suite of applications. Teachers can author spatial things where they can add learning tasks. In addition, teachers can use the learning tasks and spatial things to author different types of itineraries. Teachers can reuse learning resources that other teachers have created with SituLearn. This data is stored in a private dataset. Teachers can monitor students while using their resources.

U-Physics [7] is an application that supports experimentation with various physical phenomena (such as inclined planes and pendulums) in real situations. When students carry out an experiment, the application stores its location (spatial thing) so that other students can find the site. In addition to the location, students can measure angles and annotate graphs.

EducaWood [16] is a web application that allows students to add descriptions (these descriptions are called annotations) in the forestry education domain. This data is stored as LOD. Annotations made by one student can be completed by other students. For example, a student can add a tree (spatial thing) to EducaWood just by identifying its location with an interactive map. Afterwards, other students can identify the tree species (according to a predefined taxonomy), add a photo, etc. EducaWood retrieves LOD data to provide additional information about tree species. Currently, it is focused on tree

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annotations and does not support other types of learning tasks.

QuesTInSitu, SmartZoos, Avastusrada, GLUEPS-AR, and SituLearn are good options because they allow teachers to enact educational situations, students to carry out learning tasks, and teachers to monitor the learning situation. Furthermore, these applications allow for a reasonable variety of learning tasks and support itineraries. However, they suffer from several problems. The first is that the resources created in these systems are not shared with other systems (acting as data silos). In addition, teachers must add all resources from scratch, which is not always an easy task. Another problem of applications whithout a clearly defined domain is the low specialization of the domain specific descriptions in which teachers want to work. U-Physics is another good option for students to learn physics and share their experiments with their classmates. However, teachers' decision making is low (e.g., the students can decide where they perform their experiments) and the generated resources are stored in a private dataset. Meanwhile, EducaWood allows the creation and reuse of LOD data of spatial things. This is particularly helpful in preventing users from having to annotate spatial things from scratch. However, it does not have a wide variety of learning resources (it does not support learning task completion or itineraries).

In this Section we have seen that there are applications that allow teachers to author learning resources, but that these resources must be created from scratch. We have also seen that there are applications in which teachers do not have to create learning resources, but neither can they modify them. Another problem with applications such as [21], [22] is that the resources they provide cannot be reused in other systems. Solutions such as those offered by [4], [18], which are based on open technologies (OER and LOD), can be more beneficial to the education community because the learning resources can continue to be used even if, for example, the applications are no longer available. We see more potential in the use of LOD than in other alternatives, as many governments and organizations publish their data as LOD. Although not originally intended for educational use, we can adapt to this content (e.g., [23]) so that it can be reused as a learning resource or as the basis for creating new ones. Moreover, efforts are being made to link educational institutions' repositories stored as OER with external LOD datasets [24].

III. CHEST

CHEST (Cultural Heritage Educational Semantic Tool) is a distributed application designed to support teachers to author and reuse spatial things, learning tasks, and itineraries by (re)using LOD related to CH. It also allows students to complete learning situations based on these resources. This application hides the complexity of using Semantic Web technologies by providing user interfaces based on maps and forms. In this way, CHEST overcomes the limitations found in existing tailorable u-learning applications by leveraging LOD for educational purposes. Thus, it facilitates the creation of new learning situations by allowing teachers to create and customize their own learning resources (spatial things, learning tasks, and itineraries) when needed. Teachers and students around the world can use CHEST as it retrieves global datasets.

A. Requirements

The requirements shown in this section have been defined based on ideas gathered from teachers through interviews, from the state of the art, and from our previous works [6], [12], [23]. The functional requirements (`FR`) of CHEST are:

- `FR0` Show the learning resources saved as LOD in formats that teachers are familiar with. They do not have to learn Semantic Web technologies to use CHEST.
- `FR1` Use map-based interfaces to show CH sites and itineraries. This is a common solution for u-learning applications in the literature (e.g., [5], [7]).
- `FR2` Use form-based interfaces to show the information of the different learning resources.
- `FR3` Show the provenance of the data. Teachers want to know where the data was obtained from. It also helps to credit the authorship of learning resources.
- `FR4` Save the learning resources authored by the teachers as LOD. These resources may be CH sites, learning tasks linked to CH sites, or itineraries (teachers should be able to prescribe a sequence of CH sites and tasks, or simply define a collection of them when designing a situation).
- `FR5` Provide LOD-based suggestions when teachers want to author a CH site. It prevents teachers from adding these learning resources from scratch.
- `FR6` Allow students to carry out learning tasks and itineraries created by teachers.

B. Datasets

CHEST uses different datasets to provide its users with information about spatial things. First, CHEST uses OpenStreetMap[6] open data. Its large community of authors add basic data such as the geometry of the spatial things. In addition, they can author others as the type of spatial thing (using tags). For example, they can say that a spatial thing is a castle or a fountain. CHEST employs these tags to show its users the spatial things of the CH domain. The OpenStreetMap community adds other interesting data such as labels, photographs, and links to other datasets. CHEST follows links to DBpedia[2] and Wikidata,[1] two projects that share its data as LOD. The application retrieves descriptions in multiple languages from DBpedia. In addition, CHEST offers suggestions to teachers when authoring spatial things based on information from this dataset. CHEST obtains from Wikidata labels and descriptions in multiple languages and photographs. In addition, in the region of Castile and León (Spain), CHEST also uses a local government repository to enrich the description of spatial things. This can be easily achieved because the dataset is linked from Wikidata through a property[7] for CH spatial things in the region. This way of retrieving information from local repositories following links

[6]https://www.openstreetmap.org/
[7]http://www.wikidata.org/prop/P3177

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TABLE II
SUMMARY OF THE FEATURES OF CHEST.

CLIENT			SERVER	
Client interaction	**Description**	**Allowed user**	**Server requests**	**Description**
C00	Display spatial things on the map view	Teachers & students	S00	The server checks the data of spatial things of a tile.
C01	Display a spatial thing	Teachers & students	S03	The server retrieves the data of a spatial thing from different datasets.
C02	Add a spatial thing	Teachers	S01, S02	The server retrieves data of the places near where the teacher wants to add the new spatial thing to make suggestions (S02) and facilitate the creation and storage as LOD of the place (S01).
C03	Remove a spatial thing	Teachers	S04	The server deletes the spatial thing from the CHEST triplestore.
C04	Display the list of learning tasks of a spatial thing	Teachers & students	S05	The server retrieves partial LOD from learning tasks of a place from the CHEST triplestore.
C05	Display a learning task	Teachers & students	S07	The server retrieves the LOD of a learning task stored in the CHEST triplestore.
C06	Add a learning task	Teachers	S06	The server stores learning task data linked to a site as LOD.
C07	Remove a learning task	Teachers	S08	The server deletes the learning task LOD from the CHEST triple-store.
C08	Display the list of all the itineraries	Teachers & students	S09	The server gets partial LOD from the itineraries.
C09	Display the data of a itinerary	Teachers & students	S11, S03, S07	The server retrieves the LOD of an itinerary (S11) with the spatial things (S03) and the learning tasks (S07) associated to this itinerary.
C10	Add an itinerary	Teachers	S10, S00, S01, S02, S05, S06	Before the server stores the LOD linked with an itinerary (S10) it will have provided the spatial things (S00) and tasks (S05) that they can be added to the itinerary. The server may receive requests to add other educational resources (S01, S02, S06).
C11	Remove an itinerary	Teachers	S12	The server deletes the itinerary LOD from the CHEST triplestore.
C12	Carry out a learning task	Students	S14	The server stores the answers' metadata in a private database.
C13	Sign in a teacher	Teachers	S13	The server stores teachers' ID and alias.

from global repositories could be extended to other places in the world.

CHEST also supports spatial things, learning tasks, and itineraries authored by teachers. A local dataset stores and shares the data of these learning resources as LOD. These resources are described using an ontology proposed by the authors, derived from the one presented in [25]. The ontology includes classes to represent the learning resources managed by the application (spatial things, learning tasks, and itineraries), and specifies the relationships among them. For example, it allows the creation of learning tasks that are linked to spatial things.

C. Design

We designed CHEST as a distributed application following the client-server architecture. Communication between the client and the server is done through a REST API [26] (Representational State Transfer application programming interface). Table II shows a list of the actions that users can perform on the client and the requests made to the server to perform them. On both the server and the client sides, we have created a set of managers for handling spatial things, learning tasks, and itineraries (Fig. 1).

The **spatial thing manager** receives and manages requests related to spatial things. This manager is responsible for retrieving data from different datasets and combining them according to a common schema. For this purpose, it uses a set of adapters. This component performs the retrieval of these data using the links it finds in the repository data. For example, the markers shown in Fig. 2a include spatial things retrieved from OpenStreetMap as well as those created by teachers (Table II, C00). Then, when a user taps on one of the markers (C01), the application prepares a representation like the one

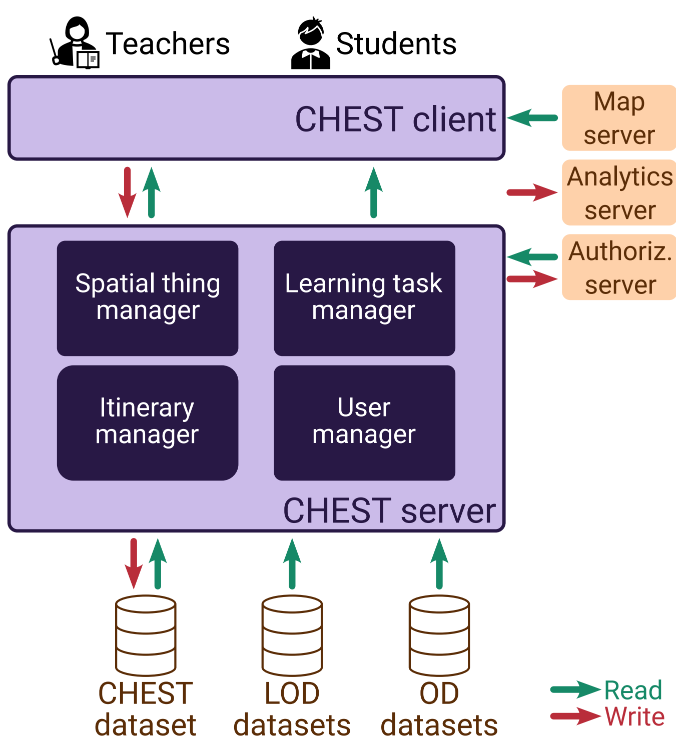

Fig. 1. Overview of CHEST architecture. In yellow we show the external services used by the application.

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TABLE III
OVERVIEW OF THE CHEST SERVER API.

Path	ID	Method	Query params.	Body request	Response	Auth.	Description
`/features/`	S00	GET	north, south, west, east	-	Spatial thing list	No	Discover spatial things in a bounding box
	S01	POST	-	Spatial thing data	Location of the spatial thing	Yes	Add a spatial thing
`/features/lod`	S02	GET	lat, long, incr	-	Spatial thing list	No	Get spatial thing suggestions
`/features/:st/`	S03	GET	-	-	Spatial thing data	No	Recover a spatial thing
	S04	DELETE	-	-	-	Yes	Delete a spatial thing
`/features/:st/ learningTasks/`	S05	GET	-	-	List of tasks	No	Get tasks of a spatial thing
	S06	POST	-	Task data	Location of the learning task	Yes	Add a learning tasks
`/features/:st/ learningTasks/:task`	S07	GET	-	-	Task data	No	Get a task of a spatial thing
	S08	DELETE	-	-	-	Yes	Remove a task
`/itineraries/`	S09	GET	-	-	List of itineraries	No	Get the list of itineraries
	S10	POST	-	Itinerary data	Location of the itinerary	Yes	Add an itinerary
`/itineraries/:it`	S11	GET	-	-	Itinerary data	No	Get the data of an itinerary
	S12	DELETE	-	-	-	Yes	Remove an itinerary
`/users/user`	S13	PUT	-	User data	-	Yes	Add or update an user
`/users/user/answers`	S14	POST	-	Answer	-	No	Save an answer

in Fig. 2b. For this, the spatial thing manager follows the links from the above repositories (local and OpenStreetMap) to other repositories (see Section III-B). Similarly, the **learning task manager** is responsible for responding to access (`C05`) and author (`C06`) requests regarding learning tasks.

The **itinerary manager** handles requests to create (`C10`) and access (`C09`) itineraries (Fig. 2e). It uses spatial thing and learning task managers to retrieve data about these learning resources. Therefore, when teachers add an itinerary, CHEST does not have to duplicate the information about spatial things and learning tasks. CHEST stores details of the itinerary as LOD: its name and description, the author, the time of creation, and the identifiers (as well as the relationships between these identifiers if teachers have decided to add an itinerary with order) of the spatial things and learning tasks.

The **user manager** is responsible for controlling what actions each user can perform. Users with a teacher role (`C13`) can add new learning resources, while users with a student role can only access them. Table III shows an overview of the main operations offered by the server API.

D. Illustrative scenario

Art teachers in Palermo can use CHEST to enact an u-learning situation guiding their students to visit some of the fountains in this city. They can center the map view on Palermo using its search engine. CHEST displays all the markers of the spatial things it has been able to retrieve in a map-based interface (Fig. 2a, `C00`).[8] We group the markers of spatial things into clusters according to the zoom level and the distance between them. Our Art teachers can turn on the fountain filter so that only spatial things of this type are shown. They can then access the sites they want their students to visit to find out what information will be shown to them.

Teachers want to access the information from the Praetorian Fountain. They click on its marker and CHEST displays a screen like the one in Fig. 2b.[9] This screen is divided into three tabs (Fig. 2b shows the first tab). In the first one, CHEST provides teachers with general information about a selected spatial thing (`C01`). In the second, teachers can find the learning tasks associated with this spatial thing (`C04`). The third tab indicates from which datasets CHEST retrieves the data shown in the first tab (`C01`). Teachers can use the second tab to add new learning tasks to CHEST (Fig. 2c, `C06`). The interface for adding tasks is adapted to the type of task that teachers want to add. For example, Fig. 2c shows the case of an MCQ type task. In this task, only one option is correct, but teachers can add as many incorrect answers as they want.

If teachers do not find one of the fountains they want to add to their learning situation, they can ask CHEST to add a new CH site. Using the “+” button CHEST shows a screen divided into three tabs (Fig. 2d shows the second tab). In the first, CHEST shows the spatial things that the teachers can find on the map as a list (`S00`). This is done to encourage the reuse of existing sites by facilitating their discovery and avoiding duplication. Clicking on an item on this list shows a screen as in Fig. 2b (`C01`). In the second tab (the one shown in Fig. 2d), CHEST shows suggestions of spatial things near the location where teachers want to add the site (`S02`). These sites are not yet displayed in CHEST. The suggestions are built with data that CHEST retrieves from DBpedia. With this option, teachers do not have to add data in case they decide to reuse one of the suggested sites and we encourage the reuse of data from other datasets. The last tab gives teachers the option to author the CH sites from scratch (`S01`). In our example, Palermo teachers do not need to use any of the options on this screen because CHEST already retrieves the spatial things they want to add to their students.

After authoring spatial things and learning tasks, Palermo teachers are ready to write an itinerary (`C10`). The process of creation of resources (spatial things (`C02`) and learning tasks (`C06`)) described above can also be carried out during the creation of the itinerary. Teachers select which spatial things (customizing their description if they want) and learning tasks (choosing only a few of those available on each site)

[8]https://chest.gsic.uva.es/home?center=38.115482,13.3620807&zoom=16
[9]https://chest.gsic.uva.es/home/features/osmw:926546483

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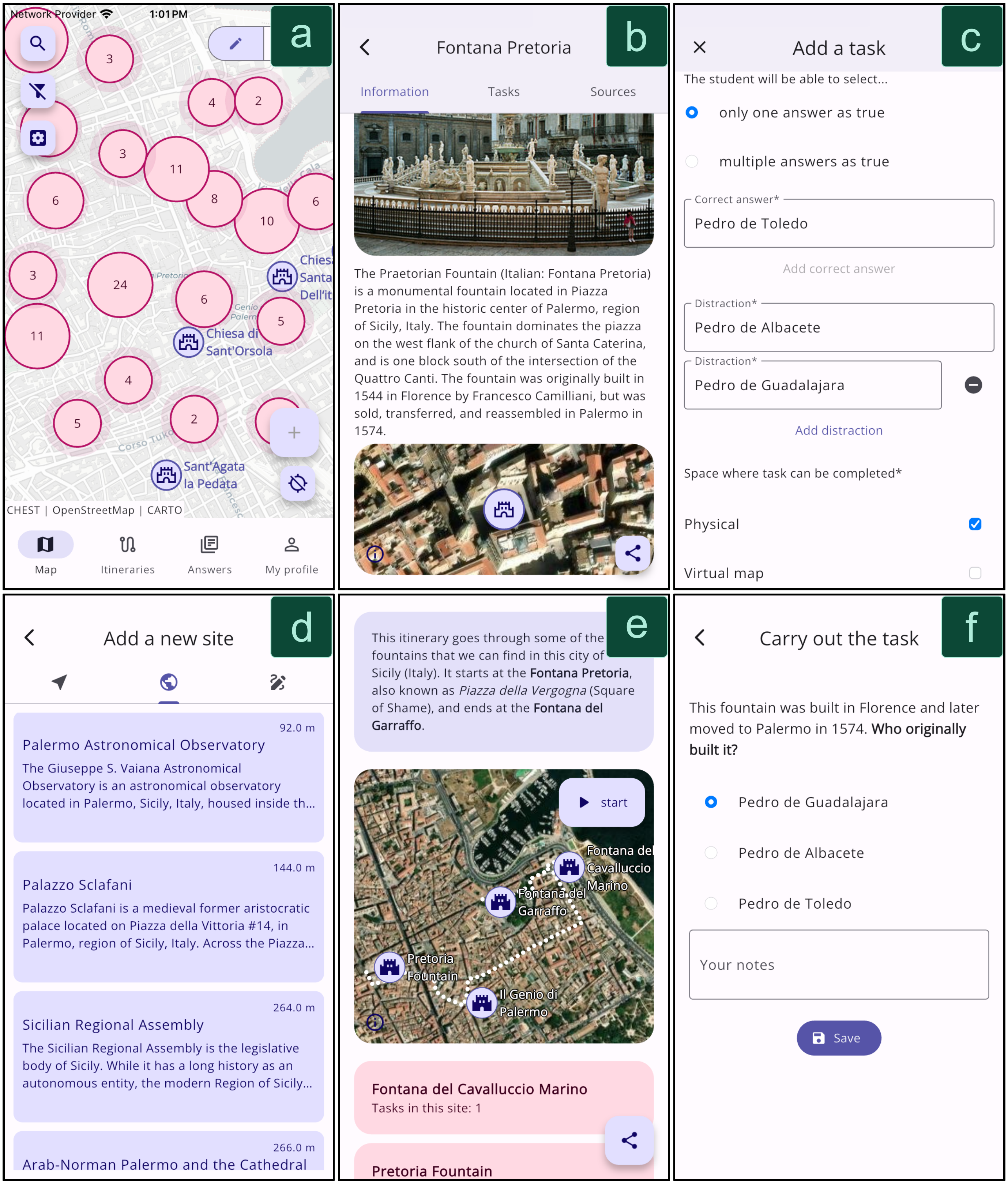

Fig. 2. Screenshots of CHEST. (a) Map interface showing a part of Palermo, Italy. (b) Screenshot of the "*Fontana Pretoria*" site. It is organized in 3 tabs showing: site information, linked tasks, datasets from which CHEST retrieves the data. (c) Screenshot for adding a MCQ task. (d) Screenshot with suggestions when teachers want to add a site. (e) View of an itinerary. (f) Screenshot to carry out the Fig. 2c task.

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they want to include in the itinerary. Palermo teachers can also add a track to guide students who want to complete the itinerary autonomously. When they have finished the creation of the itinerary, it automatically becomes available in CHEST.[10] Fig. 2e shows the screen with the previous itinerary information (`C09`). Students can complete this itinerary on site. They can see the tasks when they are near the site locations. For example, Fig. 2f shows a task that students must carry out (`C12`) close to the Praetorian Fountain.

E. Implementation

We have developed a multilingual (English and Spanish) CHEST client (Fig. 2) using Flutter.[11] CHEST is available for students and teachers as a web application[12] and on iOS[13] and Android[14] as an installable application. Students and teachers from all over the world can create a free account in CHEST (teachers must apply for accounts with editing permissions). CHEST server was developed using Node.js.[15] We use Virtuoso[16] to store the LOD added by the teachers. In Section III we show the latest prototype of CHEST. This version incorporates some enhancements derived from the feedback of teachers and students in the study described in Section IV, which employed an earlier prototype with minor differences (only web application). For example, although teachers could add itineraries, the interface that allows students to follow them was not finished so the teachers had to guide the students to complete it. Both versions of CHEST retain the core features of supporting teachers in the authoring and reuse of LOD-based learning resources, as well as supporting students by enabling them to visualize the previous resources and carry out the learning tasks.

IV. Method

The evaluation of CHEST is based on an authentic experience in which two teachers wanted to carry out a u-learning situation related to the CH of the city of Valladolid (Spain) and the development of digital competence in their students. However, they did not want to design this situation from scratch. Our goal was to help teachers author and enact their u-learning situations with little effort using LOD, a goal derived from the research question (RQ) "how to support teachers to exploit LOD to author and enact u-learning situations?".

The study follows a mixed-methods, embedded (concurrent-nested) design with qualitative priority. This choice is driven by the RQ which requires both an in-depth understanding of teachers' experiences and meanings (qualitative strand) and measurable evidence of use (quantitative strand). The qualitative component provides depth and understanding of the process, while quantitative data contributes to triangulation, helps clarify patterns, and supports the interpretation of the qualitative findings [27], [28]. This type of evaluation has been successfully employed in previous works, such as [12], [29], [30]. Our interpretive approach does not aim to provide a statistically generalizable answer to the RQ, but to illuminate it by obtaining a deep understanding of the particularities of the concrete phenomena under study.

A. Participants Recruitment

Two teachers participated in the study after providing informed consent. One of them is a teacher from the Department of Pedagogy at the Faculty of Education of Universidad de Valladolid, Spain. She has seven years of teaching experience at the university level. This teacher has a strong background and interest in the field of u-learning and, in the past, she had designed and enacted other u-learning situations. Her motivation to participate in the study stemmed from both professional curiosity and alignment with her teaching and research interests. The other participant was a pre-service teacher from the Master in Psychopedagogy of the same University. She agreed to participate in the study because she found the opportunity both interesting and relevant to her academic development. None of them had any knowledge about the Semantic Web or its related technologies. For the sake of simplicity, from now on we will refer to these two participants as "the teachers".

Both wanted to design and enact a u-learning situation for a group of students from the "University for Seniors"[17]. 14 of these students voluntarily participated in the u-learning situation. The students aged between 60 and 70 years were enrolled in the course "*Comunicación*" (Communication) to use geolocation technologies with this activity and others. At the beginning of the course, their knowledge of such technologies was either nonexistent or very basic. The students were totally unaware of Semantic Web technologies.

B. Data Collection

We gathered both qualitative and quantitative data to illuminate the topics of our study (see Section IV-C). Table IV shows the different techniques we used to collect this information. In addition, Fig. 3 summarizes which techniques were used in each of the stages and how they relate to each of the topics defined to answer the issue.

We divided the study into four stages. First, in **Stage 0**, we gave a demonstration of CHEST to the teachers for about an hour and a half. We showed them how to use CHEST to author learning resources (spatial things, learning tasks, itineraries). For spatial things, we showed them how to reuse CH data to simplify their creation. We also explained that these resources were stored as LOD and could be reused by other teachers. In addition, we showed how students could carry out the tasks. No data was collected at this stage.

Stage 1 started with the session to author LOD with CHEST for about two hours. One of the researchers attended this session. The session was a face-to-face meeting in which

[10]https://chest.gsic.uva.es/home/itineraries/md:caX6vNRhgSfrTMnsqtnreg
[11]https://flutter.dev/
[12]https://chest.gsic.uva.es
[13]https://apps.apple.com/es/app/chest-gsic/id6654914759
[14]https://play.google.com/store/apps/details?id=es.uva.gsic.chest
[15]https://nodejs.org
[16]https://chest.gsic.uva.es/sparql
[17]A special lifelong learning program, different from regular degrees, offered by Universidad de Valladolid for senior citizens.

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TABLE IV
TYPE OF TECHNIQUES TO COLLECT DATA DURING THE STUDY.

Label	Technique	Instruments	Description
INT	Interview	Recorder (mobile and microphone) and text files	Semi-structured conversation with teachers. These interviews were recorded (audio) or notes were taken (text) of the comments made by the teachers
OBS	Observation	Text files and screen recording	Textual notes taken while the participants carry out some action related to the u-learning experience and when we watched a video of teacher's computer screen while the teacher was adding the some learning resources
QUE	Questionnaire	Microsoft Forms	Participants' answers to questions in written form (electronically). These answers can be ratings (choosing one (or several) value(s) among several) or free text
LOG	Analytical data	Google Analytics for Firebase and CHEST server logs	Data collected automatically by the system

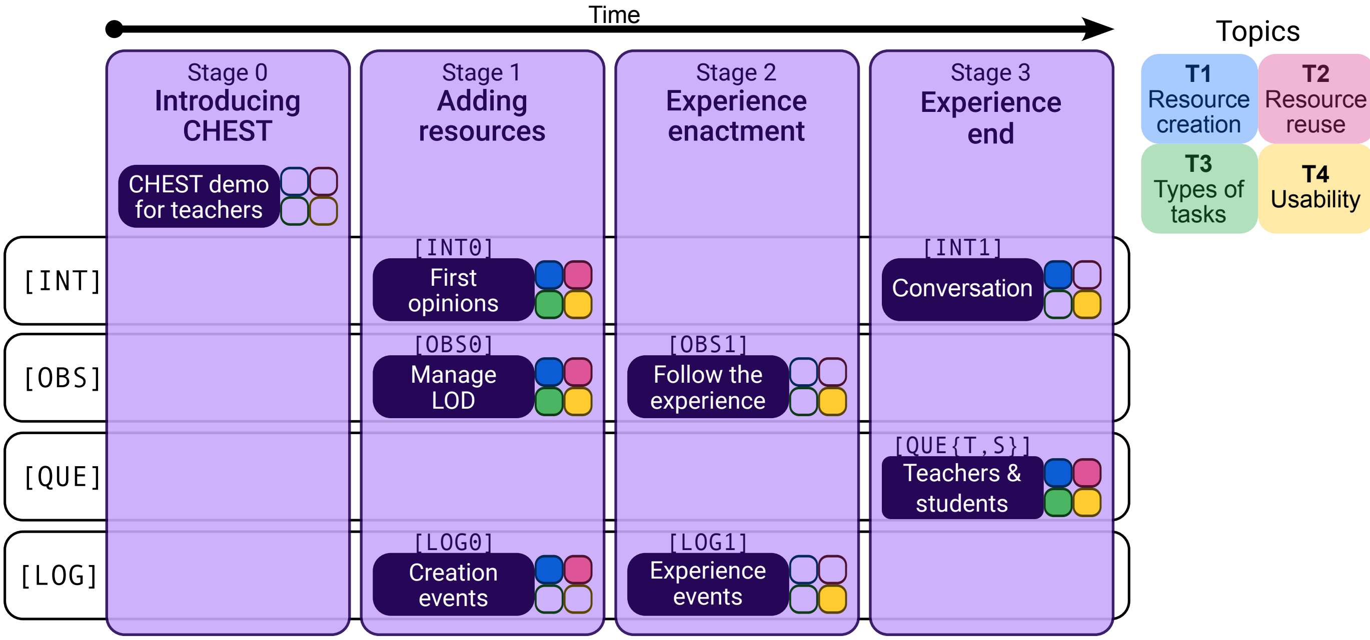

Fig. 3. Data collected at each stage of the pilot and its relationship to the topics (TN) with which the problem is to be addressed.

teachers used their computers to try to add the spatial things, learning tasks, and itineraries they needed. During the session, the teachers had the possibility of reusing spatial things and learning tasks (LOD) that already existed in CHEST. In addition to LOD reuse, teachers could also author other learning resources. We recorded the computer screen and the audio of the meeting, and the researcher attended this session to support the teachers and make observations (OBS0). After authoring the resources, the same researcher conducted and recorded a semi-structured interview with the teachers (INT0). During the days following the meeting, the teachers continued to add more learning resources. CHEST also logged events (LOG0) when a user performed an action (e.g., tapping a marker, answering a learning task, etc.).

Stage 2 was composed of two sessions (one of the researchers attended to them). In the first, the teachers conducted a voluntary training lesson (an hour) with the students who wanted to carry out the u-learning situation. The same researcher who attended the design session followed it. The teachers explained how to access and use CHEST and where they were going to start the activity. In the second, teachers and students completed the situation together (two hours) in the city of Valladolid using CHEST. The researcher also followed this activity and made observations stored as text files (OBS1). CHEST continued to automatically collect analytical data whenever a user (either a teacher or a student) interacted with the application (LOG1).

Stage 3 started as soon as the experience with the students was over. The researcher had a face-to-face conversation with the teachers (half an hour) to discuss how the learning situation had gone (INT1). In the following days, the teachers completed a voluntary questionnaire (QUET). In this questionnaire, we asked about the usability of the system (through the SUS survey [31]) and included open questions to find the teachers' opinions about the (positive/negative/desired) features offered by CHEST. We also wanted to give a voice to the students by providing them with a different voluntary questionnaire to find out what they thought of CHEST and the itinerary they had followed (QUES). Both teachers and eight students completed their questionnaires.

C. Data Analysis

The purpose of this subsection is to explain how we used the data to obtain the findings presented in Section V. In this way, we first contextualized the RQ introduced in Section IV in a specific issue that represents a potential tension to be

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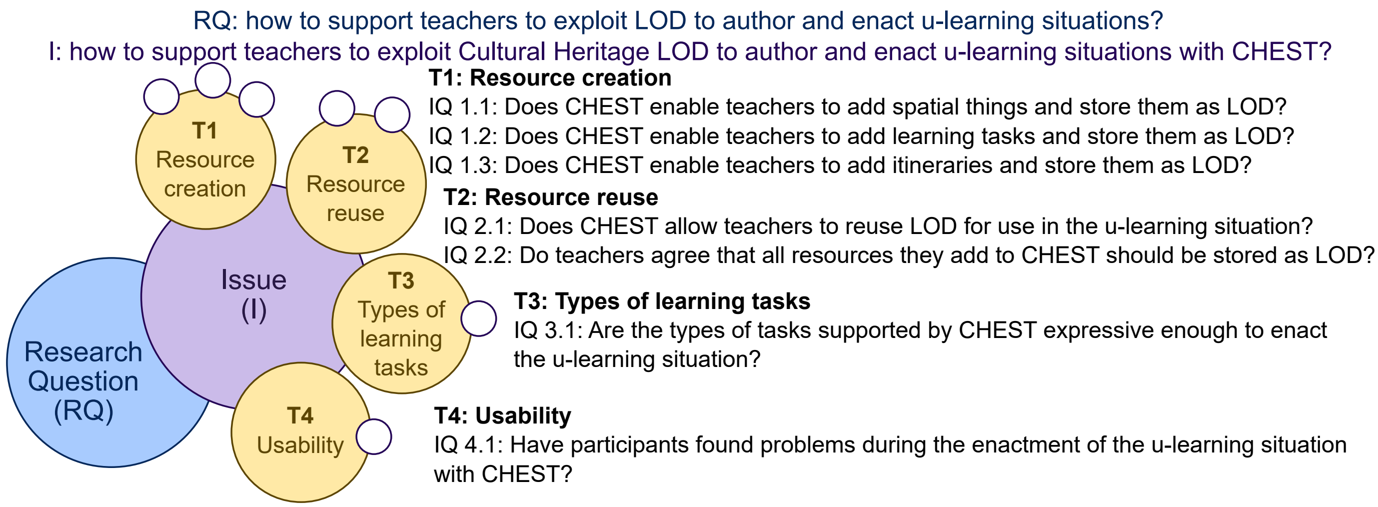

Fig. 4. Anticipatory data condensation schema. It shows how the RQ leads to the issue (I) with its topics (T) and informative questions (IQ).

assessed in a specific context or conditions: "how to support teachers to exploit CH LOD to author and enact u-learning situations with CHEST?" Then, we defined the topics and informative questions that can be seen in Fig. 4 to facilitate the data collection and analysis to answer the issue. The data were analyzed following a concurrent embedded strategy [32] where qualitative data is more important than quantitative data to provide a better understanding of the observed occurrences.

To extract qualitative data, we employed various techniques as outlined in Table IV. For the voice recordings, we first transcribed them all into text using the transcription tool integrated into Microsoft Word. One of the researchers then reviewed the transcripts to ensure their accuracy. Subsequently, one of the researchers (a Ph.D. student with prior experience in this task) conducted the coding of all textual sources, guided by the research topics (following a "solo coding" approach [33]). The topics of the data condensation process were employed as an initial set of deductive codes, and their interpretation was discussed together with the rest of the research team members. The data sources were triangulated to support our findings. In some cases, these findings were also supported by data automatically collected by CHEST.

D. Validity, Reliability, and Methodological Integrity

To ensure methodological integrity, we followed a systematic procedure throughout the study. To increase the credibility and transferability of the study we followed different techniques such as data and method triangulation, and peer debriefing. Data sources were coded based on the topics that would help illuminate the research issue. Although the initial coding was carried out by a single researcher, the process and results were reviewed by senior members of the research team (overcoming the limitations of "solo coding" [33]). Additionally, all authors participated in analyzing how the evidence supported the findings. Analytical data were reported without modification, as presented in the Google Analytics report.

Since the participants' native language was Spanish, all data were collected in that language. For reporting purposes, excerpts were translated into English using DeepL.[18] These translations were then reviewed by the authors to ensure that the original meaning was preserved. In addition, given that the study was conducted with Spanish-speaking participants, we assessed the perceived usability of CHEST using the SUS survey [31]. Specifically, we employed the Spanish version of the SUS, whose validity and reliability were established in [34]. The open-ended questions included in the different questionnaires were reviewed by the research team to assess their face validity. These questions were aligned with the research topics, which were derived from the RQ.

V. Findings

Table V shows the main findings of the study (labeled F0 to F8) and the main evidence supporting them (labeled according to the content of Table IV). The findings were structured using the topics of the anticipatory data condensation schema: (1) resource creation, (2) resource reuse, (3) types of learning tasks, and (4) usability.

The teachers wanted the students to learn about the CH of the city of Valladolid, Spain, which is part of their environment. This was a voluntary activity, so the teachers were unsure how many students would attend. To accommodate varying numbers, the teachers created two itineraries with CHEST that covered part of the historical center of the city. If the number of students had been large, they would have divided them into two groups, with each group completing one of the itineraries. However, since the number of student volunteers was relatively small (14), they decided that all of them would follow one of the itineraries together. This itinerary, approximately two kilometers long, included 10 CH sites and required the students to carry out 27 learning tasks (26 MCQs and one free text question). The teachers estimated that the students would take about 90 minutes to complete it.

[18]https://www.deepl.com

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TABLE V
STUDY FINDINGS AND SUPPORTING EVIDENCE

ID	Finding	Evidence	
T1. Resource creation			
F0	Teachers were able to create all the learning resources they needed using CHEST	E00-OBS0	In the first 12min they start to add a spatial thing
		E01-OBS0	Around 26 they start to create the task. On 34 they finish the creation of the first task
		E02-OBS0	Teacher: *Well, let's go to itineraries* [...] *Well, let is create.* Clicks on add button
		E03-LOG0	The teachers added 2 spatial things, 54 learning tasks, and 4 itineraries
F1	Teachers considered CHEST an intuitive application to add learning resources	E04-INT0	*I find that* (CHEST) *is very intuitive when generating a site, adding activities*
		E05-INT1	(Asking for task author) *The application is quite intuitive*
		E06-INT1	*The application is, in that sense* (task author)*, very intuitive, yes*
		E07-QUET	*Easy usability for locating resources*
T2. Resource reuse			
F2	Teachers reused learning resources and found that the reuse of learning resources was positive. They wanted to use data form other applications and websites	E08-INT0	*I am fine with an open and collaborative environment*
		E09-OBS0	They access: https://es.wikipedia.org/ (open data), https://www.arteespana.com/ (private data), and https://www.valladolid.es/ (government).
		E10-OBS0	They use Wikipedia categories to search for other eclectic buildings
		E11-LOG0	They linked 51 learning tasks to 15 spatial things from LOD
		E12-QUET	Pointing out positive aspects of CHEST: *Community tool, public environment*
F3	The teachers were able to reuse existing learning tasks by adapting their type to the learning situation	E13-INT0	*In this case, the design I want to do is to give you immediate feedback*
		E14-OBS0	They need feedback on tasks. Therefore, the open tasks do not work for them
		E15-OBS0	*Are there no choice tasks ? It is open text.* [...] *We should change everything if we want feedback*
T3. Types of learning tasks			
F4	The types of tasks were sufficient to realize the u-learning situation	E16-OBS0	They author open-text, yes/no, and MCQ learning tasks
		E17-QUET	(As a positive aspect) *Variety of resources/task type to integrate at each site*
F5	Teachers missed additional types of learning tasks	E18-INT0	*Activities such as drawing with the feet* [...] *Others for comparison* [...] *photo poem, photo story*
		E19-INT0	*It would also be nice to include a photograph*
		E20-QUET	*A field to obtain a reward, which may be in the form of points or other means*
T4. Usability			
F6	CHEST usability was good for teachers and students	E21-INT1	(Talking about how they would organize the creation of the itineraries) *but it is very intuitive!*
		E22-QUET	The SUS scores for the two teachers were 70.0 and 87.5 (out of 100)
		E23-QUET	Teachers would recommend the use of CHEST to their coworkers (10 out of 10 points)
		E24-QUES	*It uses geolocation and gives you an explanation of the point of interest and then asks you questions and then gives you the answers. This makes it very easy to learn*
		E25-LOG1	The day of the experience, 7 students completed 176 learning tasks (around 25 tasks per user), and 16 students accessed 296 spatial things (19 spatial things per user)
F7	Some aspects of the creation of learning resources needed to be improved	E26-INT0	Talking about the creation of an itinerary: *Intuitively, what it initially led me to do was to* [select the] *site and* [then] *select the tasks within the site*
		E27-INT0	[When asked "what other support would you have liked?"] *searches. We* (the teachers) *were thinking about an architectural style and maybe search for renaissance, baroque, or gothic. Palaces, houses, churches, etc.*
		E28-OBS0	*Is it possible insert a link to a website? What if we put the URL in parentheses?*
F8	The way CHEST stores answers and displays spatial thing markers needed to be improved	E29-OBS1	Students want to access their answers after the experience
		E30-QUET	*While students were completing the activity some of the answers were not saved*
		E31-QUES	*The map was not clear, there were several identical numbers, which was misleading*

Topic T1. Resource creation

Teachers were able to author all the learning resources (spatial things, learning tasks, and itineraries) they needed using CHEST (F0). They added two spatial things (E00-OBS0, E03-LOG0). Teachers also authored 54 learning tasks (MCQ, yes/no, and free-text) linked to 17 spatial things (E01-OBS0, E03-LOG0). These tasks were mostly MCQ-type (52 out of 54), so students could receive feedback on their responses if they completed the experience on their own. Finally, they added four itineraries (E02-OBS0, E03-LOG0) (two for a test and two for their students to use in this experience).

The teachers said that the process for authoring learning resources was "very intuitive" (E04-INT0, E07-QUET). Teachers only had to use interfaces they were used to working with (map and form-based) and they did not have to deal with the technologies associated with the Semantic Web (although they were aware that the data they aggregated were stored as LOD). For this reason, **teachers considered that CHEST is an intuitive application for adding learning resources** (F1).

Topic T2. Resource reuse

Teachers reused learning resources and found that the reuse of learning resources was positive (F2). They liked the idea that other teachers can reuse their work because they are using an "open and collaborative environment" (E08-INT0, E12-QUET). For the creation in CHEST of the u-learning situation, they used both information already included in the application and data collected by them from different websites (E09-OBS0, E10-OBS0). They only had to author 2 of 17 spatial things in their itineraries thanks to CHEST retrieving the rest of the spatial things from LOD datasets (E11-LOG0).

The teachers wanted to reuse the learning tasks that were already included in the spatial things shown in CHEST. Many of these tasks, which had been generated semi-automatically [23] for Casual Learn, did not have a correct answer associated (i.e., they were open-ended). As a result, the students would not receive feedback when they carried them out. As the teachers wanted "to give you immediate feedback" (E13-INT0) in their design, they decided to refactor these learning tasks as MCQs so that students would know which answer was correct once they had completed it. Therefore, teachers reused tasks from [23] by adapting them in CHEST to be of MCQ type (they added incorrect and correct answers). In conclusion, **the teachers were able to reuse existing learning tasks by adapting their type to the learning situation** (F3).

Topic T3. Types of learning tasks

The types of learning tasks that were included in CHEST allowed teachers to enact the learning situation they designed (F4). These teachers were satisfied with the variety of types of CHEST learning tasks (E17-QUET). They mostly used MCQ-type tasks (52 out of 54) because they needed their students to know the correct answer to the task as they completed the experience. They only added a free-text type learning task in the first spatial thing for their itineraries and another yes/no task. Teachers argued that the rationale of an initial free-text learning task was they were sure that they would be with the students at the beginning of the itinerary, so they could explain the correct answer directly to their students.

Although teachers employed only two types of tasks in the u-learning situation they designed, they could have used other types also available in CHEST. In addition, they identified other types of tasks that they would like to employ such as collage while completing the itinerary, photo poems, photo stories, etc. (E18-INT0). In addition, they wanted some tasks to have an image (E19-INT0) and provide rewords (E20-QUET). Tasks with images were not supported by the CHEST prototype employed in the study. Therefore, **teachers missed some additional types of learning tasks** (F5).

Topic T4. Usability

CHEST usability was good for teachers and students (F6). All of them were able to use the application to complete the u-learning situation. Both teachers responded to the SUS survey by filling out their voluntary questionnaire. The usability score was 70.0 and 87.5 out of 100 points (E22-QUET), which shows that, for these teachers, CHEST has good usability. In addition, in the questionnaires completed by the students, we can also see how they emphasized the ease of using CHEST in statements such as E24-QUES.

We detected that **some aspects of the creation of learning resources needed to be improved** (F7). The interface for adding descriptions to the different learning resources should be improved to allow teachers to add rich text. When teachers started to author learning resources, they asked if they could "insert a link to a website" (E28-OBS0). These teachers also noted that since they were not experts in the CH domain, they needed CHEST to help them quickly identify sites. These teachers indicated that they would like to have nice "searches" that allow to identify the "style and maybe search for renaissance, baroque, or gothic" or by the type of spatial thing such as "palace, house, churches" (E27-INT0). Finally, teachers did not find the process of itinerary creation natural (E26-INT0). In this version, teachers first had to select all sites and then the tasks of these sites. They thought it would be more natural if after selecting each site they could choose the tasks.

The way CHEST stores answers and displays spatial thing markers needs to be improved (F8). CHEST did not store the answers provided by the students outside of its client in order to avoid potential privacy issues. In this way, the students' answers were only kept on their devices as long as they did not leave the website. However, they could download their answers as an HTML file if they wanted to view them at other times. In these HTML files, students found the information of the spatial thing, the learning tasks, and the answer they had provided. However, the students wanted the answers to be saved in another way so that they could be accessed at any time through CHEST (E29-OBS1). In addition, some students had problems with the markers on the main map (E31-QUES) because they had numbers that indicated the number of sites grouped in them (group markers).

VI. Discussion

The aim of this study was to address the issue 'how to support teachers to exploit CH LOD to author and enact u-learning situations with CHEST?" The findings derived from this study respond directly to this issue and, therefore, contribute to illuminating our RQ. It should be noted that the participants in the study used an earlier version than the one presented in Section III. Nevertheless, both versions share the main features and differ primarily in that the newer version incorporates various solutions aimed at addressing the limitations identified by the study participants.

Findings F0 and F1 confirm that CHEST enables teachers to easily author learning resources. These resources are transparently stored as LOD following a public schema. This allows teachers to design u-learning situations and adapt them to their students' needs. The ability to author learning resources gives CHEST an advantage over other u-learning applications. CHEST authoring capabilities provide a distinct advantage over other u-learning applications (e.g., [4], [6]) that offer open learning resources but do not allow their customization.

Findings F2 and F3 indicate that teachers were able to reuse existing learning resources when designing their learning situations. This functionality provides a clear advantage over applications that enable teachers to design u-learning experiences (e.g., [5], [19]) yet require them to add all learning resources from scratch. In addition, this feature allows CHEST to avoid the cold-start problem [8]. The availability of CH LOD facilitated the implementation of the learning design conceived by teachers. In most cases, teachers only had to author the learning tasks, which were based on tasks stored as LOD (generated for another application [23]). The teachers adapted the learning tasks (converted them into MCQs) to align them with the need of immediate feedback in their learning design. Although not widespread, the use of LOD for sharing learning resources beyond spatial things (in our case, learning tasks and itineraries) is also positive. Thanks to their public scheme, it becomes easier for other applications to use these resources. In addition, it can foster the creation of a community of teachers who contribute these types of learning resources, knowing that their efforts may help the rest of the educational community.

The use of open data from different datasets (such as OpenStreetMap, Wikipedia, and DBpedia) allows CHEST to maintain a global scope. This is possible because the schemas of these repositories are shared openly. As a result, it is easier to know which property to query for links to the same entity (in our case spatial things) in several repositories, thus obtaining the most complete information available to be shown to the users. In addition, these projects benefit from many contributors who help keep the data up to date. It is also worth noting that there is a large amount of open data in the CH domain, which is a positive aspect.

`F4` shows that the teachers involved in this experience were able to enact their setting using or authoring the learning resources provided by CHEST. This may be related to the high variability of task types offered by CHEST (see Table I). However, Finding `F5` indicates that teachers desire a wider variety of learning tasks. Some of these tasks, such as photo poems and photo stories, could be seen as a combination of existing tasks (text and multiple photographs). Others stem from the feature of itineraries that these teachers started to use (for example, making a collage with all the photographs of an itinerary, which could be seen as a task of making multiple photographs that can be completed along the itinerary). While we aim to offer a generic set of tasks that many teachers can use, their originality may make some of the desired tasks challenging to implement.

Finding `F6` indicates that the level of usability perceived by the study participants was adequate. This may be attributed to our efforts to follow design guidelines such as Material Design when developing the CHEST client. As a result, participants' prior experience with other applications may have positively influenced their interaction with CHEST. Some limitations identified in the prototype used during the study have been addressed and resolved in the latest version. First, Finding `F7` shows that teachers were not comfortable with the way we designed some learning resources. Regarding the itineraries, we have also added the track feature so that teachers can indicate the recommended path. To help teachers, we have also added a rich text editor for the forms in which teachers must submit descriptions. Second, Finding `F8` indicates that the way markers were represented has been changed to avoid the confusion that some students had. Now, the group markers and the markers for different things have different colors. Also, we use the name of the spatial thing in the site markers. We allow users to decide what kind of spatial things are shown on the map (implementing one of the teachers' requests). We have finished implementing the functionalities that allow students to walk the itineraries, so it may be easier for them to walk the itineraries autonomously.

The number of participants who have used CHEST is too small to generalize our findings. However, the research methodology and the rich data collected allowed us to gain a deep understanding of the evaluation process. We concluded that CHEST effectively supported these teachers in using CH domain LOD in their u-learning context. In addition, the students completed this experience using LOD in a transparent way. Therefore, we can state that we provide an answer to the issue of this study and illuminate the research question. Of course, and to advance towards the generalization of the results obtained, it will be necessary to carry out additional experiences. On the one hand, we should carry out other experiences in the CH domain involving new teachers and students. But, on the other hand, we should also assess the possibility of distilling design guidelines from CHEST potentially applicable to other u-learning applications in different learning domains.

VII. Conclusions and Future Work

This paper introduced CHEST, a new u-learning application that allows the design and enactment of u-learning situations in the CH domain, supported by LOD. The design of its architecture balances the customization of learning resources with the reuse of existing data, thus offering a solution that addresses the limitations of existing u-learning applications. A prototype implementation of CHEST is available to support u-learning situations globally. This prototype is accessible via any device's web browser or through dedicated apps for Android and iOS devices. CHEST was evaluated observationally in an authentic learning situation with two teachers and 14 "University for Seniors"[17] students. Through this study, we have understanded that: (1) the author and reuse of LOD-based learning resources provides CHEST with an advantage over other u-learning applications; (2) the use of map- and form-based interfaces helps mask the complexity of semantic technologies, resulting in a good level of usability; (3) it is possible to offer a set of basic task types that teachers can customize; (4) students can engage effectively with the learning tasks using CHEST. In this way, the evaluation of CHEST not only demonstrates technical feasibility but also provides valuable insights into how semantic technologies can be effectively integrated into authentic learning environments. Our findings can inform the design and refinement of technological tools to support teachers and students, as well as pedagogical approaches that make such tools applicable in real educational settings. Nevertheless, further research with larger sample sizes is needed to better understand the conditions that mediate the utility of LOD to support u-learning.

In the near future, we aim to extend our experience in CH to other domains related to u-learning. For example, we have started working in the forestry education domain, following the same learning resources scheme as in CHEST but adapting the type of spatial things. We plan to explore using the same types of learning tasks (and possibly the tasks themselves) in multiple domains. In addition, we are working on including generative artificial intelligence (GenAI) for the automatic creation of learning tasks in spatial things where no teacher has yet authored any. These learning tasks could be based on LOD we retrieve and tasks that other teachers have included elsewhere. We also want this technology to be used to suggest to teachers, if they wish, different options to add itineraries.

Teachers could validate the GenAI itineraries or tailor them to the needs of their students. These tools, as well as the use of LOD, should be used to support teachers and try to reduce their workload.

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Pablo García-Zarza received his Master's degree in Telecommunications in 2021 from the Universidad de Valladolid, Spain. He is a PhD student in the Department of Signal Theory, Communications, and Telematics Engineering at the Universidad de Valladolid. His research interests include the use of linked open data (focusing on spatial data) and ubiquitous learning.

Guillermo Vega-Gorgojo received his PhD degree in Telecommunications Engineering from the Universidad de Valladolid, Spain, in 2011. He is a Full Professor in the Department of Signal Theory, Communications, and Telematics Engineering at the Universidad de Valladolid. His research interests include visual search interfaces, technology-enhanced learning, and the Semantic Web.

Miguel L. Bote-Lorenzo received his PhD in Telecommunications Engineering in 2005. He is currently a Full Professor of Telematics Engineering at the Universidad de Valladolid (Spain) and a member of the multidisciplinary research group GSIC/EMIC. His primary research interests include smart learning environments, learning analytics, and artificial intelligence in education. He also serves as an Associate Editor for IEEE Transactions on Learning Technologies.

Vanesa Gallego-Lema received her PhD degree in education from the University of Valladolid, Spain, in 2016. She is an associate professor of education at the University of Valladolid. She worked as a teacher in primary education and University, and she also collaborated in training and innovation tasks at the University of Valladolid. Her research interests include ubiquitous learning in physical activities in the natural environment, and how teachers learn.

Juan I. Asensio-Pérez received his PhD degree in Telecommunications Engineering from the Universidad de Valladolid, Spain, in 2000. He is a Full Professor in the Department of Signal Theory, Communications, and Telematics Engineering at the Universidad de Valladolid. His research interests include educational technology, computer-supported collaborative learning (CSCL), learning design, learning analytics, hybrid learning environments, and the application of artificial intelligence in education.

Eduardo Gómez-Sánchez received his PhD degree in Telecommunications Engineering from the Universidad de Valladolid, Spain, in 2001. He is a Full Professor in the Department of Signal Theory, Communications, and Telematics Engineering at the Universidad de Valladolid. His research interests include distributed computing, cloud computing, technology-enhanced learning, and learning analytics.