Deploying learning designs across physical and web spaces: Making pervasive learning affordable for teachers

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Abstract

Pervasive computing devices and communication infrastructures enable learning situations that occur in both the physical and the virtual world. However, deploying these pervasive situations is still a challenge for teachers. This paper presents GLUEPS-AR, a system for deploying learning designs across physical and web spaces, using mainstream Virtual Learning Environments, Web 2.0 artifacts and Augmented Reality applications. GLUEPS-AR has been evaluated through a mixed methods study on the deployment of three authentic pervasive learning situations. Results highlight that GLUEPS-AR supports teachers in deploying their pedagogical ideas on pervasive learning environments, overcoming main limitations of existing approaches.

Keywords: Pervasive learning environment, Virtual learning environment, Augmented reality, Ubiquitous learning, Across spaces

1. Introduction

Learning is not tied to the walls of a classroom or the limits of a Virtual Learning Environment (VLE). Learning may occur at every location and time [56]: in the classroom, in a fieldtrip, in a museum, at home, in the streets of a city, in Wikipedia, etc. Learning may happen within one of these spaces[1], but also *across* them [8, 34, 56]. When these learning spaces overlap, forming a single entity, they constitute *pervasive learning environments* [64, 67].

Augmented Reality (AR) [4, 69] is a technology that can facilitate the creation of pervasive learning environments, allowing the overlapping of virtual information in a physical environment. The affordances of AR for learning have been explored in multiple research initiatives [75, 28, 49, 13]. For example, AR can be used to convert a playground into a virtual savanna

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[1] We consider a "space" as the dimensional environment in which objects and events occur, and in which they have relative position and direction [19]. This definition is not limited to the physical world, also the virtual (computerized) one is considered. Thus, a space would be a container for individuals and their tasks [9], and also for artifacts.

[15], or to foster spatial skills in mathematics and geometry by interacting with 3D virtual objects [28]. The evolution of mobile devices during the last years has made AR widely available. Moreover, such mobile devices currently allow the capture of information from physical spaces (e.g. taking pictures), which can be used in subsequent activities, e.g., in a web learning space [34, 59].

Despite the ubiquitous presence of information and communication technologies (ICT) that could facilitate pervasive ways of learning [67, 26], these pervasive learning environments are not at all widespread among teachers. One likely reason for this lack of adoption is the complexity of implementing such pervasive technologies in a way that supports their concrete pedagogical ideas and restrictions, which is very demanding and error-prone. The pragmatic restrictions of authentic educational settings (e.g. time restrictions, class management issues, etc.), together with the fact that an average teacher is not an expert in ICT, further limits the acceptance [65] of these technologies in educational practice.

Multiple research initiatives have strived to support the implementation of pervasive learning environments [34, 68, 16, 55, 74, 66]. These systems enable teachers to define the learning activities to be performed through pervasive technologies, using some kind of authoring tool. However, these initiatives are limited in one or more of the following aspects: they are usually tied to particular enactment systems (e.g. a concrete AR application to be used by students when performing the learning activities); they support a very narrow variety of learning activities and/or pedagogical approaches; they are not compatible with enactment systems that are currently widespread in authentic educational settings; and they do not support the flow of learning artifacts between activities conducted in different spaces of the pervasive environment. Such limitations restrict the range of learning situations to which the initiatives are applicable, thus affecting their adoption and use in authentic teaching practice.

An alternative to these ad-hoc approaches for the transformation of teachers' ideas into pervasive learning environments that support them, would be to explicit those ideas in a way that is independent of the enactment system, as it is often done, e.g., in the field of learning design [35, 32]. There exist multiple authoring tools that enable the definition of pedagogical ideas for a set of activities (also called "learning designs" generically) in a variety of formats, and for different pedagogical approaches[2]. These representations of the pedagogical intentions could then be semi-automatically transformed into different enactment systems as required by each educational context. This kind of approach has been applied most commonly to web-based learning activities, now dominated by the use of VLEs (e.g. Moodle[3], Blackboard[4], LAMS[5] or Sakai[6]) and Web 2.0 artifacts (e.g. blogs, wikis or Google applications) [10]. Indeed, there exist systems that support the semi-automatic implementation (also called "deployment" [50]) of multiple formats of learning designs throughout multiple distributed (web-based) learning environments (DLEs) [40] that encompass widely-used VLEs and Web 2.0 artifacts. Thus, we could consider how this kind of approach could be used also beyond web-based learning environments, supporting teachers in the deployment of pervasive learning environments.

This paper presents the architecture and prototype implementation of GLUEPS-AR, a system to support teachers in the deployment of pervasive learning environments. GLUEPS-AR

[2] See, for example, the tools registered in the Learning Design Grid website (http://www.ld-grid.org/resources/tools, Last visit 10/2012).

[3] https://moodle.org Last visit 10/2012.

[4] http://www.blackboard.com Last visit 10/2012.

[5] http://www.lamsfoundation.org Last visit 10/2012.

[6] http://www.sakaiproject.org Last visit 10/2012.

semi-automatically deploys learning designs defined in a variety of authoring tools, into multiple kinds of pervasive learning environments (formed by web-based DLEs and AR-enabled physical spaces). AR is used as a bridge between spaces (or between different moments within a same physical space), allowing the flow of learning artifacts between web and physical spaces, in a controlled way, defined by the teacher in the learning design. Such a bridge allows the consideration of the pervasive learning situation as a whole (holistic). GLUEPS-AR reuses existing technologies (learning design authoring tools, widespread VLEs, Web 2.0 artifacts and AR applications), in order to keep at bay the technological complexity of the environment teachers face (rather than proposing new authoring or enactment tools). By overcoming the aforementioned limitations of current pervasive learning environment implementation efforts, GLUEPS-AR provides a more general approach that we expect can be more easily accepted by teachers in authentic educational situations. As a consecuence, we expect in addition that such an approach would foster a wider adoption of pervasive learning environments in real practice.

This paper also presents the evaluation of GLUEPS-AR in three authentic learning situations, involving a non-ICT-expert teacher in the design and deployment of a pervasive learning environment that supports those situations. This evaluation aims to assess whether GLUEPS-AR enables teachers to deploy authentic pervasive learning situations involving different physical (AR-enabled) and web spaces, with a reasonable amount of effort.

The structure of the paper is as follows: in the next section, a review of alternatives available for the deployment of pervasive learning environments is presented, including a categorization of their main limitations; section 3 describes in detail the GLUEPS-AR architecture, its data model and a prototype implementation of the system. Afterwards, the methodology and results of the evaluation study are explained in section 4, followed by a discussion of the results and implications (section 5). Finally, section 6 contains the main conclusions and future work in this line of research.

2. Systems supporting the deployment of pervasive learning environments

There exists an increasing corpus of research work dealing with ICT-enhanced learning situations that go beyond the walls and times of the physical classroom [15, 60, 31, 13, 23, 24, 47]. However, most of these works do not tackle the issue of how costly it is for an average teacher (one that is not an expert in ICT) to put these situations into practice in authentic educational settings. Only very recently research is starting to consider the deployment of these kind of pervasive learning situations by teachers (mainly in physical spaces), by means of authoring tools that enable teachers to design and deploy such pervasive learning activities. We review these works below in chronological order, emphasizing their features related to the deployment of pervasive learning situations by teachers.

2.1. Authoring tools for pervasive learning environments

Kurti, Milrad and colleagues [34, 33] studied how to support learning situations conducted across different contexts, focusing on the use of mobile devices and learning situations that involve indoor and outdoor activities. They developed a system (the Learning Activity System, or LAS) that facilitates the design and enactment of learning situations across contexts. LAS allows to capture information from physical contexts by means of different sensors, and presents such information in a web platform integrating different web APIs (such as Google Maps[7]). However, the deployment of the learning situations requires an ICT expert, since LAS lacks a proper authoring tool (i.e., the definition of a scenario requires programming expertise). In this line, the same authors have integrated LAS with the CeLS system (a web-based VLE, see [54]), to support learning design and enactment using scripts [43]. They have also explored the transitions of learning situations across contexts, including the flow of certain artifacts between spaces, as well as the use of AR [59].

Tissenbaum and Slotta have proposed a "smart classroom" approach [58, 68], which includes multiple technologies and devices, which are guided by a learning design, and which features means of automatic deployment. Thus, instead of studying multiple contexts (e.g. outdoor and indoor), this approach studies a classroom as an ecosystem of technologies, transforming such a classroom into a multi-space learning environment with projectors, computers, software applications, tabletops and mobile devices.

ARIS [16, 22] and Gymkhana [53] are systems aimed at creating and playing gymkhana-like games with AR. Albeit independent, these efforts are similar to each other, and to precursor works such as MIT-AR [30] or ROAR[8], focused on game-based learning. However, while MIT-AR and ROAR only supported variations in a specific game, ARIS and Gymkhana provide an advanced authoring tool that enables the creation and deployment of different games by non-ICT expert teachers.

QuestInSitu [55] is a system for the definition and deployment of assessment activities based in geolocated questionnaires. With this system, teachers may use a web platform to create and position questions along a route. Students, virtually using the web platform, or physically with mobile devices and GPS, have then to follow the route and answer the questions in the corresponding geographical locations (*in situ*). QuestInSitu supports different types of positioning (e.g. geoposition and markers).

Yiannoutsou and Avouris [74] have improved previous game-based learning approaches based on AR, which were not originally focused on teachers [57]. Now, different actors (e.g. museum visitors, students, teachers, etc.) may design games using an authoring tool wherein AR artifacts are defined and positioned using different technologies (geolocation, RFID, etc.). An example of learning situation created with such authoring tool is the CityScrabble game [38].

Finally, ARLearn [66] is a system to create and run learning games featuring geolocated AR and Augmented Virtuality (AV) [42]. ARLearn provides an authoring tool, and two runtime environments: a mobile application (for the AR version), and a user interface based on Google Street View[9] (for the AV version). The authoring tool and the AR version of the system are very similar to the ones in ARIS, with the AV version of the games being the main difference with existing approaches.

2.2. Limitations of existing systems for authentic educational practice

The research work presented above tackles, in one way or another, the problem of deploying learning situations in pervasive learning environments. However, some limitations may restrict their use by teachers in authentic settings:

[7] https://maps.google.com Last visit 10/2012.
[8] http://gameslab.radford.edu/ROAR/ Last visit 10/2012.
[9] http://www.google.com/streetview Last visit 10/2012.

- All the described approaches provide teachers with **authoring tools tied to specific enactment technologies and/or a narrow variety of learning activities** (with the pedagogical restrictions that this imposes): a specific game in a city in CityScrabble, gymkhanas in Gymkhana, or geopositioned questionnaires in QuestInSitu. Furthermore, a learning design defined using one of these authoring tools cannot be deployed in a different proposal's enactment system (e.g. to use a LAS design in the "smart classroom", or viceversa). This lack of a general approach to deployment forces teachers to learn a new authoring and enactment tool for each new kind of activity to be incorporated, thus limiting the potential acceptance of these systems.

- In general, existing approaches **break with enactment technologies that are currently widespread in authentic educational settings**, such as VLEs (e.g. Moodle, Blackboard) or Web 2.0 artifacts (e.g. blogs, wikis, Google Docs). Most of the reviewed approaches propose their own enactment technologies. Only ARLearn uses a mainstream tool like Google Street View, but is limited to only *that* implementation of virtual environment. The system proposed by Kurti and colleagues is the only one in which a VLE (CeLS) is introduced – but then again, the system is limited to using just that (not very widespread) implementation of VLE. This restriction to one specific enactment technology may hamper teacher acceptance due to institutional restrictions (e.g. enforced institution-wide usage of a concrete VLE implementation) or, if such a technology is completely new, due to a lack of experience with it [70, 39, 8].

- Most proposals described above have a limited support to the connection of learning activities across spaces. This connection is exemplified fundamentally by the **flow of artifacts between activities conducted in different spaces** (e.g. creating a document about a topic in the classroom, and reviewing it in a different, more meaningful physical space). Such connection of learning activities across spaces facilitates a holistic view of the learning situation and a more seamless learning [8, 56], contributing to the continuity of the learning experience across the learning spaces [8], and therefore, to the continuity of the learning objectives. All described approaches, except for LAS and smart classroom proposals, have a very limited support (if any) for this flow of artifacts. Indeed, Kurti and colleagues studied the connection of outdoor and indoor contexts, and thus their system allows to capture information from an outdoor physical context (e.g. taking pictures, videos, etc.), presenting it in a subsequent activity in another context through a web platform. Later research by the same group combines the use of AR in a classroom, relating it with prior activities done in a different context [59]. However, although related conceptually with previous activities, the AR artifacts (3D models) do not flow automatically between different activities.

Therefore, to the best of our knowledge, none of the aforementioned approaches supports the usage of multiple different enactment technologies, and the support for a wide variety of learning activities is quite limited in most of them. In addition, none of these approaches use widespread enactment technologies (such as broadly-used VLEs, Web 2.0 tools or AR applications), with the sole exception of ARLearn, that implements Google Street View. Finally, only LAS and smart classroom support (with restrictions) the flow of learning artifacts between spaces. Tackling all these limitations may contribute to making the deployment of pervasive learning situations affordable for teachers, thus contributing to the acceptance of pervasive learning environments.

3. GLUEPS-AR

In order to overcome these limitations, we present the Group Learning Unified Environment with Pedagogical Scripting and Augmented Reality support (GLUEPS-AR). GLUEPS-AR is a system for the semi-automatic deployment of learning designs in different pervasive learning environments composed by web-based DLEs and AR-enabled physical spaces. The system extends an existing proposal (GLUE!-PS [50]), aimed at supporting the deployment of learning designs defined using multiple authoring tools, in different kinds of web spaces. GLUEPS-AR extends such an approach, considering not only web spaces, but also physical ones, therefore extending the scope of the target settings from (web-based) DLEs to pervasive learning environments. GLUEPS-AR uses AR in mobile devices (e.g., tablets and smartphones) as the main technology to connect these web and physical spaces, allowing the flow of learning artifacts between them, achieving a single, pervasive learning environment.

3.1. Architecture of the system

Fig. 1 shows the basic GLUEPS-AR architecture. The system's architecture prioritizes the extensible integration of existing systems, in the same way that its precursor (GLUE!-PS) did for web environments. It is based on a central element (GLUEPS-AR Manager) and a set of adapters that enable a low coupling between the external elements (authoring tools, enactment technologies) and the central component. The GLUEPS-AR Manager translates learning designs created using different authoring tools (which may use different data models to represent designs) to the native GLUEPS-AR data model. Then, these translated designs are deployed into the different pervasive learning environments. The GLUEPS-AR Manager has a Graphical User Interface (GUI) for the teacher, to particularize and configure the designs (e.g. assigning specific students to groups, or tools to be used in each activity). The multiple learning design (LD) authoring tools are integrated through LD-adapters (Fig. 1, left) that handle the specifics of translating from each authoring tool format to the common one used by GLUEPS-AR. Conversely, multiple web-based DLEs (composed of VLEs and third party tools) may be integrated with DLE-adapters (Fig. 1, right), and multiple AR applications may be integrated using AR-adapters that handle the abstractions and data formats of each specific AR implementation.

The architecture of GLUEPS-AR has been designed to overcome the described limitations of the approaches reviewed in the previous section:

- In GLUEPS-AR, authoring tools are not tied to specific enactment technologies and/or specific kinds of learning activities, since the system allows the integration of multiple authoring and enactment tools (even those not specifically designed for activities in multiple spaces). A learning design defined in any of the integrated authoring tools could be deployed in any of the enactment technologies integrated with GLUEPS-AR. This multi-to-multi approach makes the solution extensible, adaptable, and not coupled with specific technological implementations or pedagogies. The average effort required for integrating new authoring or enactment tools is relatively low: by developing only one new adapter, multiple new combinations of design and enactment tools are added to system.

- GLUEPS-AR enables reusing existing technologies, rather than breaking with currently widespread enactment technologies. Thus, successful VLEs, Web 2.0 artifacts or AR ap-

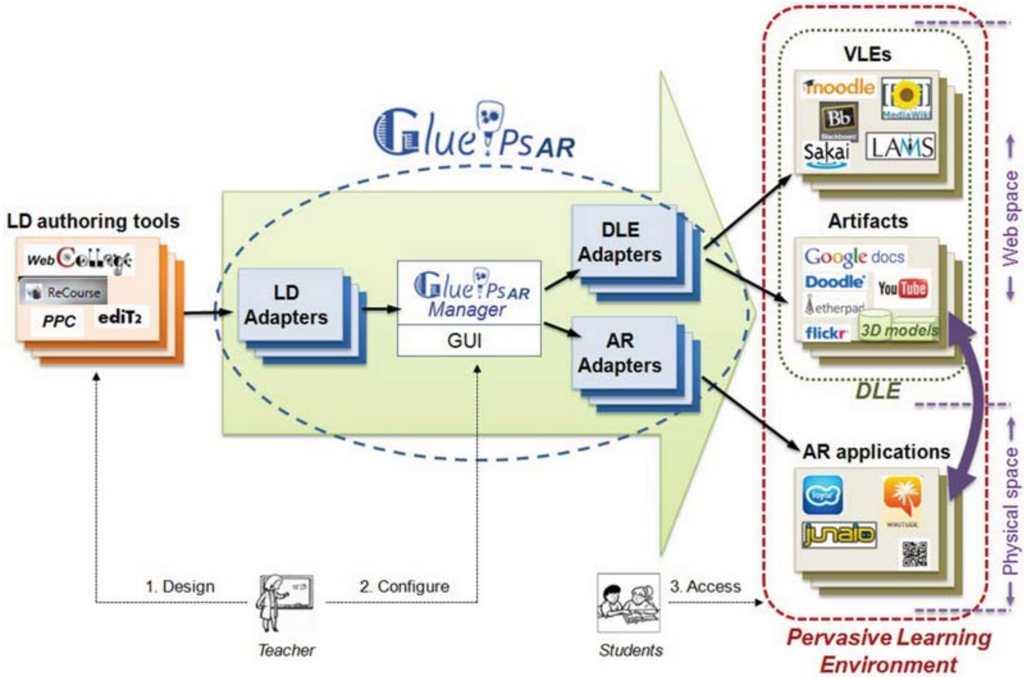

Figure 1: GLUEPS-AR system architecture.

plications (e.g. general purpose AR browsers such as Junaio[10], Layar[11] or Wikitude[12] [6]) can be used within GLUEPS-AR. This has a positive effect in the adoption of the overall proposal, since teachers will be able to use familiar tools in their scenarios.

- Augmented reality is used in GLUEPS-AR, not only to show virtual objects over physical environments (e.g. 3D models, questionnaires or related information), but also to enable the flow of learning artifacts between spaces. Thus, the same learning artifact (e.g. a Google Docs document) may be used in an activity performed in a physical space by a particular group, and be reused simultaneously or in a subsequent activity, in a different space (e.g. a VLE), or within the same space by another group. This flow, guided by the teacher's pedagogical intentions captured in the learning design, thus serves as a scaffold for seamless, across-spaces learning [8, 56].

3.2. *GLUEPS-AR data model*

At the data level, the process of deploying learning designs through GLUEPS-AR implies two data translations: a first one from the output format of the authoring tool to the GLUEPS-AR data model, and a second one from the GLUEPS-AR data model to the DLE and AR application

[10]http://www.junaio.com Last visit 10/2012.
[11]http://www.layar.com Last visit 10/2012.
[12]http://www.wikitude.com Last visit 10/2012.

data models. Thus, the GLUEPS-AR data model is a key element of the system. GLUEPS-AR extends the GLUE!-PS data model, also known as its Lingua Franca [50], to include the necessary elements to represent physical spaces and AR-related concepts.

Commonly, AR applications handle the concept of POI (Point of Interest) [6] to refer to a virtual artifact situated in a certain physical position. However, each AR application has a different data model for POIs (i.e. they model them using different attributes). Since GLUEPS-AR aims to deploy learning designs in pervasive learning environments, potentially featuring multiple AR applications, we have analyzed existing, publicly available data models for representing artifacts in physical locations, in order to define a generic data model for POIs. This analysis followed a hybrid approach: (1) we studied existing positioning data models and standards not defined for a specific software application or tool (we could call it a top-down approach); and (2) we analyzed data models of different existing AR software applications (i.e. a bottom-up approach). After this analysis (see Fig. 2), we defined a generic POI data model, giving priority to most commonly appearing features and attributes, that are at the same time useful for positioning learning artifacts in physical environments (using AR). The resulting model should be complete enough to adapt from GLUEPS-AR to any AR application data format, while avoiding unnecessary detail that would complicate the development of AR-adapters.

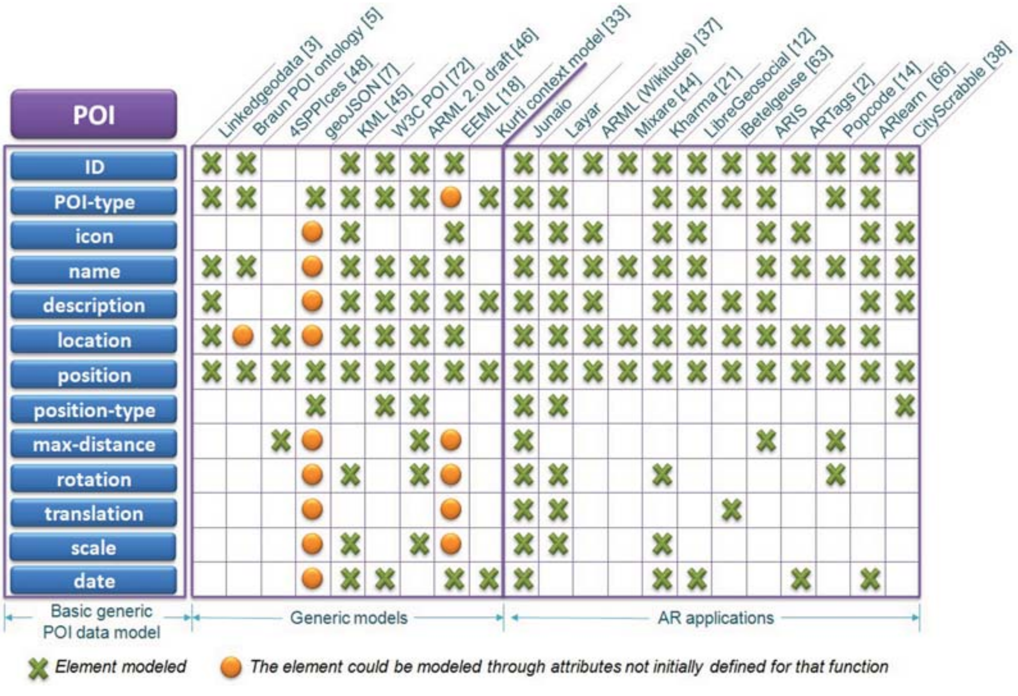

Figure 2: Basic generic POI data model, and table representing the analysis of their presence in existing positioning data models.

Fig. 2 (left) shows the basic generic POI data model proposed, and whether its attributes are modeled or not by the analyzed data models. In this generic model, a POI has a unique *ID*, an associated *icon* (an image to represent the POI in the AR application), a *name* and a *description*.

There may be different types of POIs (e.g. 3D models, images) that the AR browser needs to identify (e.g., for different rendering methods in AR), marked in the *POI-type* attribute. Since POIs denote virtual artifacts, the POI also includes the *location* of the artifact (usually a URL). Given that the POI denotes an artifact augmenting a physical space, the POI definition will also need a *position* in the physical space. The POI may be positioned in the physical space by different mechanisms, such as geolocation, by using markers, or by image recognition. Therefore, the POI will also have a *position-type* to identify the mechanism to be used. In learning scenarios it is sometimes interesting to show the POI only if the students are within a certain range of the POI (denoted using the *max-distance* attribute). The *date* attribute provides timing information (e.g., when was the POI created, showed or updated). Finally, the representation of the virtual artifact in the physical space may also be configured, rotating (*rotation* attribute), moving (*translation* attribute) or scaling (*scale* attribute) such an artifact. Fig. 3 illustrates how GLUEPS-AR implements this basic generic POI data model, converting the positioned learning artifacts to generic POIs, and offering the POIs to each AR application supported in their own specific format, by using different AR-adapters.

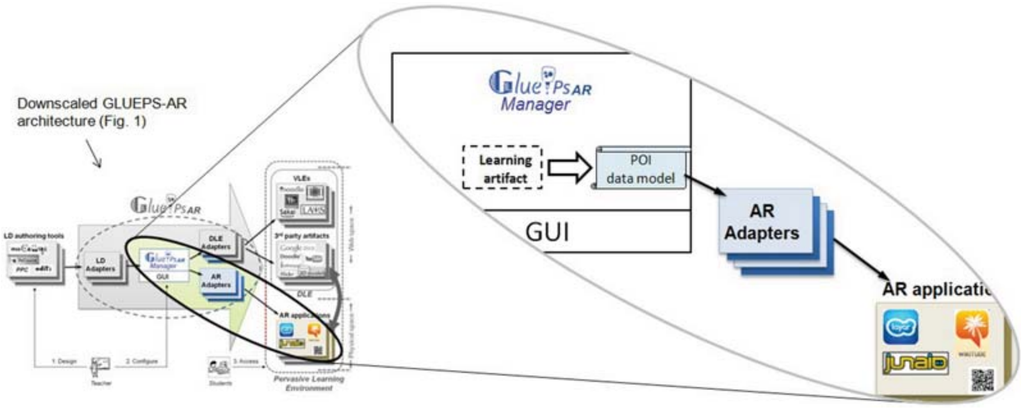

Figure 3: Integration of AR applications in GLUEPS-AR using the basic generic POI data model.

Fig. 4 shows the GLUEPS-AR data model in relation to the data format of its predecessor (GLUE!-PS), marking in red the modifications over the GLUE!-PS data model. The GLUE!-PS Lingua Franca is based around the modelling of a learning *design* (formed by different learning *activities*). This design can be particularized, configured and deployed within a *course* of a *learning-environment* installation (e.g. a Moodle server). Such a particularization of a design (called a *deploy*) contains data about the concrete *participants* (e.g. the students who perform the activities), their *roles* and grouping (*groups*). In this model, learning activities are mediated by *resources* (e.g. learning materials, tools), which can be static in design-time (*objects*), or instantiable during the deployment (*tools*). In the latter case (e.g., if it is needed that each group of students uses a different Google Docs document), a different *tool-instance* can be assigned to different groups or students.

As in pervasive learning environments *deploys* are no longer restricted to a single virtual learning environment, the GLUEPS-AR data model includes a new relationship between *instanced-activity* and *learning-environment*. Thus, each *instanced-activity* (i.e. an activity conducted by a

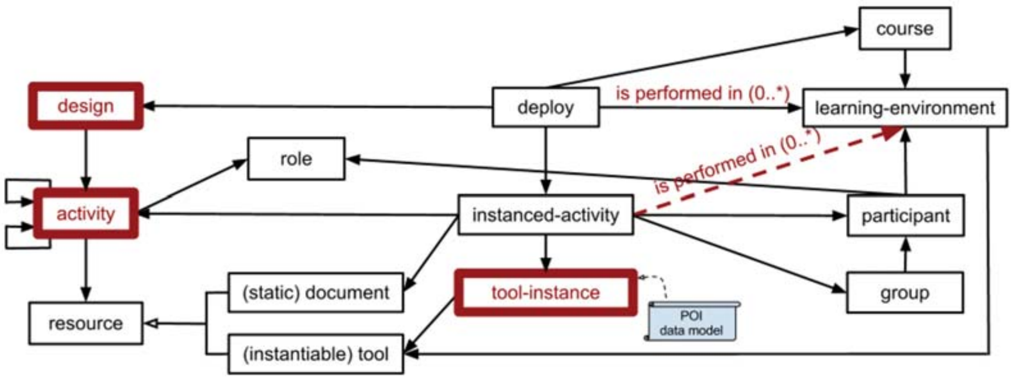

Figure 4: GLUEPS-AR data model, with the modifications over the GLUE!-PS Lingua Franca [50] indicated through thick-lined boxes.

specific group of students) could be deployed in a different *learning-environment*. Consequently, a *design* may be deployed across multiple *learning-environments*. A new *environmentType* attribute has also been added to the *design* and *activity* information elements, in order to allow for a generic definition of the intended target learning environments during the authoring of the learning design. The *tool-instance* element (which basically represents a virtual learning artifact) has also been modified in order to include attributes related to its representation in a physical space: this element now includes the aforementioned generic POI model attributes.

3.3. GLUEPS-AR prototype

A GLUEPS-AR prototype has been developed, extending the existing GLUE!-PS prototype [52] with the architecture and data model modifications described in previous subsections. As it happens with the GLUE!-PS prototype, GLUE! [1] is used to implement the integration of external Web 2.0 tools into existing VLEs, to form web-based DLEs. However, this prototype includes the implementation of the basic generic POI data model, and integrates the Junaio AR browser and any QR code [25] reader through the corresponding AR-adapters. Also, 3D models and AR images (images superimposed to physical environments) have been integrated as new types of artifacts that can be used in the particularization of learning designs. Consequently, GLUE!-PS's Moodle and MediaWiki DLE-adapters, as well as the system's GUI, have been modified to take into account all these new functionalities. All developments have been realized in Java and Javascript.

Using this prototype, pervasive learning designs can be defined using authoring tools already supported by the GLUE!-PS system, such as WebCollage[13] [71] and the Pedagogical Pattern Collector[14] (PPC) [36]. These designs may be deployed in two web-based VLEs (Moodle and MediaWiki), and into physical environments augmented using Junaio or any QR code reader. Web 2.0 artifacts (such as Google Docs, W3C widgets [73], or web pages), 3D models and AR images can be used as learning artifacts in both spaces (web and AR-enabled physical). All these

[13] http://pandora.tel.uva.es/wic2/ Last visit 10/2012.

[14] http://thor.dcs.bbk.ac.uk/projects/LDSE/Dejan/ODC/ODC.html Last visit 10/2012.

kinds of artifacts can be configured through the GLUEPS-AR GUI, including the space wherein the artifact is going to be deployed (i.e. into a VLE vs. through AR), and other space-dependent attributes: the positioning type (currently, by markers or geoposition), the specific marker to be used, or the geographical coordinates where the artifact should appear.

Also, the GLUEPS-AR prototype supports the flow of artifacts between web and physical spaces, and between the same space in different moments. For example, a learning artifact that is used by a group of students in a certain activity may be reused in subsequent activities in different spaces, by the same or a different group. This feature also enables the flow of multimedia information generated by students *in situ* (e.g. taking photos or videos) between activities in different spaces (e.g., by taking pictures and copying them in a Google Docs document positioned in a physical environment using AR, which is afterwards reviewed in class). This kind of artifact flow, along with the capability of the GLUEPS-AR data model to represent groups of students and their artifacts (e.g. offering different artifacts to different students, even at the same time and place, or viceversa), open up multiple pedagogical possibilities, especially for collaborative and constructivist pedagogical approaches.

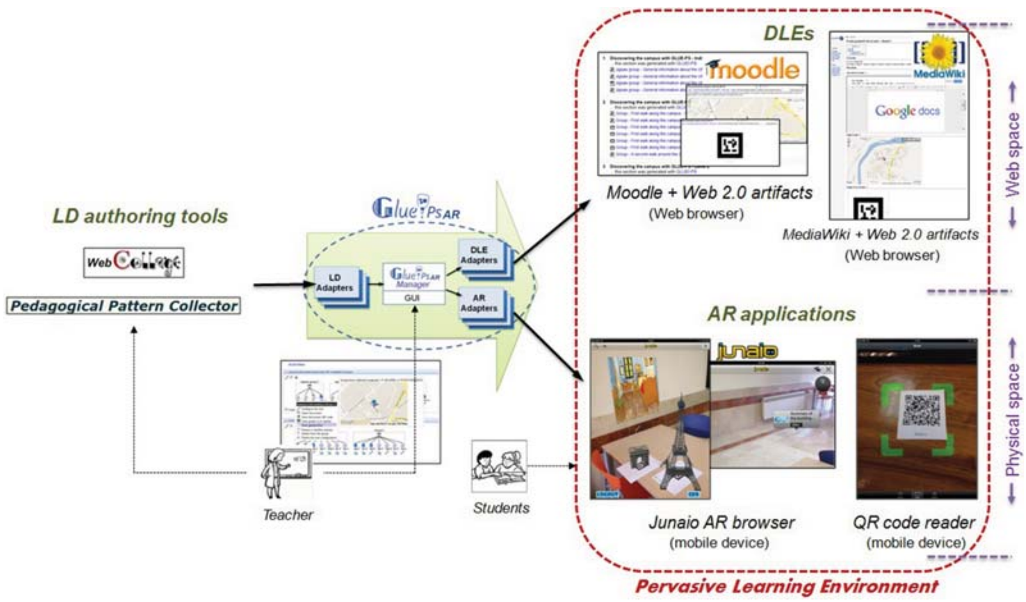

Figure 5: GLUEPS-AR prototype deployment process in a pervasive learning environment. The current implementation supports two LD authoring tools (WebCollage and Pedagogical Pattern Collector), and pervasive learning environments composed by two DLEs (Moodle and MediaWiki, plus a variety of embedded web artifacts) and two AR applications (Junaio and any QR code reader).

Fig. 5 represents the process of deploying a learning situation with the current GLUEPS-AR prototype. In the figure we see how a teacher can use a generic learning design authoring tool (WebCollage or the Pedagogical Pattern Collector), and deploy her designs in a pervasive learning environment composed by a web space (using Moodle or Mediawiki and Web 2.0 artifacts), and a physical space augmented with Junaio and/or QR codes.

3.4. *General characteristics of the approach*

Several general characteristics of the GLUEPS-AR proposal could be replicated in the design of systems that use existing technologies for the creation of pervasive environments: (1) The usage of central data models (e.g., GLUE!-PS's Lingua Franca, or GLUEPS-AR's POI model), abstracting the most common concepts used by related technologies, in a simple manner. This allows the transformation between concepts handled by the different technologies through these central data models. (2) Using adapter-based architectures to separate the common functionality and data from the specific aspects of the technologies to be integrated. This kind of architecture can help reduce the development effort for the integration of new systems, since the common functionality is already implemented in the central element; the integration thus would just require the development of a (relatively small) adapter to deal with the specifics of the new system to be integrated. (3) Use AR to create seamless connections between physical and virtual spaces, since the advances in ICT and computing devices now allow for widespread use of AR, which has inherent affordances for connecting physical and virtual objects.

4. Evaluating the deployment of pervasive learning situations with GLUEPS-AR

An evaluation study (a case lasting 2 months and involving the design and deployment of three learning situations devised by a university teacher) has been carried out to illuminate the research question driving our work: *Does GLUEPS-AR make the deployment of authentic pervasive learning situations affordable for teachers, overcoming the limitations of the existing approaches?* In the following subsections we describe the context of the study, the evaluation methodology followed and, finally, its main results.

4.1. *Context*

The study has been conducted within the educational context of "Physical education in the natural environment", a mandatory course corresponding to the 4^{th} year (out of 4) of the Preservice Primary School Teacher degree at the University of Valladolid, Spain, during 2012. In this course, the faculty conducts a series of learning situations related with orienteering in a physical environment. The pedagogical approach in these learning activities models the one that primary school teachers will have to follow in their teaching practice, in which the whole curriculum evolves from "nearby" subjects (e.g. their neighbourhood) to "far away" ones (e.g. their region). Thus, in this course the teacher starts with learning activities in the classroom, explaining basic orienteering techniques and letting students carry out simple tasks and games related to the topic (e.g. drawing a sketch of the classroom). Afterwards, the students move outdoors, in the area around the Faculty of Education building, conducting other orienteering learning activities there. Finally, the teacher prepares learning activities in a natural environment (spanning a whole day, or a weekend), not only related to orientation skills, but also to the knowledge of such environment and its relation with the rural surroundings. Each of these three phases (classroom, campus, natural environment) feature multiple learning activities, including tasks performed in the virtual space of the institutional learning platform (Moodle). The Moodle representation of the activities, alongside a set of third-party web tools, is used as the main reference guide of the course. The orienteering activities themselves are realized using pen and paper, markers and a compass, although additional technologies are being integrated progressively, such as QR codes and mobile devices (for picture taking and the scanning of QR codes).

The following subsections detail the design of an evaluation case related to this learning context. In the evaluation, the teacher of the described course was involved in the co-design and co-deployment (i.e. together with the evaluation team), using GLUEPS-AR, of the aforementioned and inter-related learning situations (classroom, campus, natural environment).

4.2. Method

For the design of the evaluation study we have followed the Computer-Supported Collaborative Learning (CSCL) Evaluand-oriented Responsive Evaluation Model (CSCL-EREM) [27], an evaluand-centered framework to guide evaluators of CSCL innovations. This model recommends the use of a profuse set of quantitative and qualitative data gathering techniques in a mixed method approach [11]. The CSCL-EREM model is deeply inspired in a responsive approach to evaluation [62], and it assumes that the authenticity of the learning scenario in which a tool is evaluated increases the accuracy and usefulness of its evaluation. This approach also underscores the importance of responding to participants' needs (rather than describing, measuring or judging them) as a way of better understanding the setting, and to facilitate the adoption of the evaluated technology in real practice. Hence, GLUEPS-AR has been evaluated through the in-depth study of the practice of one faculty member of this course, its particular contextual characteristics, pedagogical constraints and needs. This kind of evaluation process does not pursue statistically-significant results, rather aiming to understand the particularity and the richness of concrete phenomena [17], in this case provided by the holistic evaluation of GLUEPS-AR in an authentic setting.

4.2.1. Research question

To give plausible answers to the research question featured at the beginning of this section, an issue or tension [61] can be defined as a conceptual organizer of the evaluation process ("Does GLUEPS-AR make the deployment of the participant's authentic pervasive learning situations affordable?"). Following Miles and Huberman's anticipated data reduction approach [41], our main issue is divided into various topics, which help to illuminate its multiple dimensions (see Fig. 6). In turn, each topic has been explored through a set of informative questions that help us understand it. More concretely, we have defined topics regarding the affordability (for the teacher) of the deployment of the concerned pervasive learning situations using GLUEPS-AR (Topic 1); the support offered by GLUEPS-AR to overcome the limitations of existing approaches, as well as the meaningfulness (for the teacher) of such features (Topic 2); and the alignment of the concepts used throughout the process (i.e. those of the learning situation designs and technological tools used in the deployment), with the teacher's current practice and concepts (Topic 3). Fig. 6 represents this anticipated data reduction structure.

Following the advice of the CSCL-EREM model, a profuse set of data gathering techniques have been used, in order to collect and triangulate evidence answering our informative questions. Such techniques are observations, time measurements, audio, video and screen recordings, questionnaires, interviews, and artifacts generated by the teacher (e-mails and other documents). All these different data sources provide valuable information to illuminate our evaluative issue (see Table 1). The analysis of these data has been further complemented with a feature analysis by which we aimed at a systematic comparison between GLUEPS-AR and the related works discussed in section 2. More concretely, we have followed a combination of the screening and experimental methods of the DESMET evaluation methodology [29]. DESMET defines a set of steps and tools to define and assess a set of features relevant for the purposes of an evaluation.

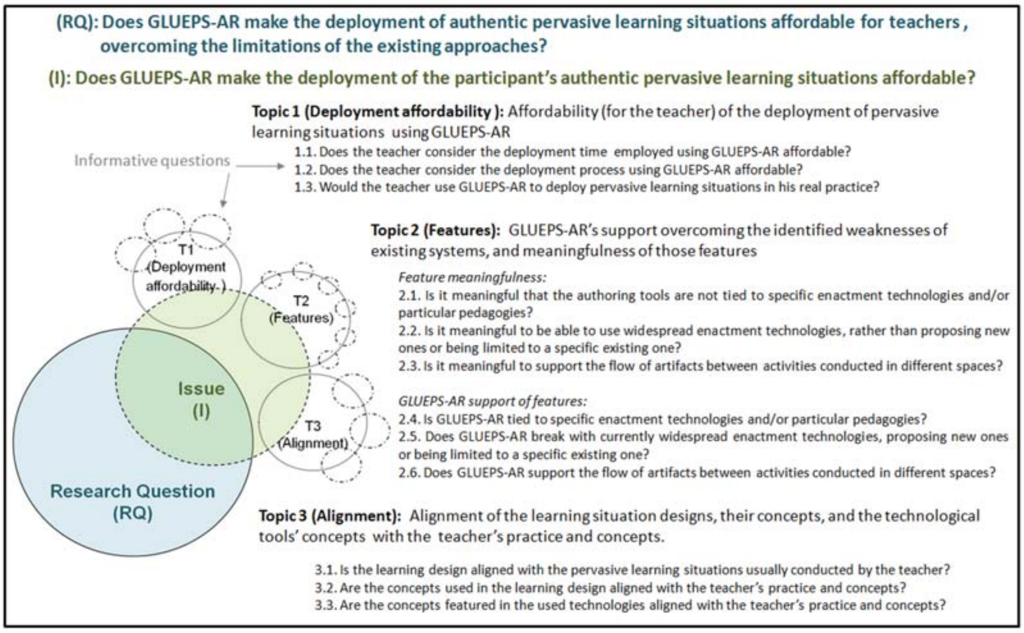

Figure 6: Structure of the research question, issue, topics and informative questions of the evaluation study.

In the proposed evaluation schema, these features match the informative questions of Topic 2 of our study (see Fig. 6), and serve to complement and triangulate the rest of our data on that topic, in order to increase the credibility of our findings.

4.2.2. Description of the intervention

Fig. 7 illustrates the evaluation flow and the data gathering techniques used throughout the process. As the figure shows, different techniques were used for the illumination of each topic, in order to answer the informative questions, triangulating the data from different sources and methods.

We carried out an iterative design process, wherein the participant teacher was involved in varying degrees. In a first stage (*Previous steps* in Fig. 7), the teacher was interviewed about his pervasive learning practice in the course [Int 1], without describing the affordances of AR or GLUEPS-AR (to avoid biasing him towards those possibilities). Based on the information gathered during this first interview, the evaluation team designed collaboratively a series of learning situations for the course. An ICT-expert member of the evaluation team defined such a learning design in the WebCollage authoring tool, and deployed it in a pervasive learning environment (using Moodle, Junaio and QR codes readers) with GLUEPS-AR. The time employed in this first deployment of the learning situations was measured [Time 1]. A tabular/graphical representation of the evaluators-produced learning design was sent to the teacher with the aim of getting an initial assessment of its alignment with his practice. His response to this learning design was essentially positive, in the ensuing communication with the evaluation team [Teach 1].

Then, in a second interview [Int 2], the evaluation team and the teacher jointly co-designed a

Table 1: Data sources for the evaluation and labels utilized to quote them along the text.

Data source	Type of data	Label
Interviews	Qualitative interviews with teacher (recorded and transcripted), to capture the opinions of the teacher in depth.	[Int]
Observations	Audio/video recordings and observation notes taken during the sessions with the teacher, to capture his reactions and other emergent issues while interacting with the system.	[Obs]
Questionnaires	Numerical ratings, qualitative explanations of the answers realized by teacher, and scoring of GLUEPS-AR's features. Used to get the initial opinions of the teacher over a wide range of matters.	[Quest] [Score]
Teacher-generated artifacts	Artifacts generated by the teacher (emails and documents), used in the co-design of the learning situations.	[Teach]
Time measurements	Quantitative deployment time measurements, to study the required effort and the affordability of the deployment process.	[Time]
Screen recordings	Qualitative and quantitative information about the design and deployment processes, to analyze them in detail.	[Screen]

new version of the pervasive learning activities, using the previous learning design as a basis (*Co-design* phase in Fig. 7). Afterwards, the teacher worked alone improving the design, sending back a series of modifications to the co-designed activites [Teach 2]. Then, the evaluators, following the teacher's instructions, generated a final learning design for the course (comprising the three learning situations with a total of seventeen collaborative activities expected to span more than twenty seven hours of course work). Such final learning design was then expressed in computer-interpretable form using the WebCollage authoring tool, and deployed with GLUEPS-AR by the same ICT expert evaluator, recording the screen [Screen 1] and measuring the deployment time of the whole process [Time 2] (*Intermediate steps* in Fig. 7).

Afterwards, the teacher and the evaluation team deployed jointly this final version of the learning situations (*Co-deployment* phase in Fig. 7). In particular, the teacher deployed by himself (supported by the evaluation team) the third learning situation regarding the rural environment, using GLUEPS-AR. The resulting pervasive technological setting was reviewed by the teacher. During this co-deployment session, one of the evaluators took observation notes [Obs1], while the computer screen was recorded [Screen 2] and the deployment time was measured [Time 3]. Fig. 8 shows the user interfaces of GLUEPS-AR and Junaio.

After this final deployment, the teacher was interviewed (*Final steps* in Fig. 7) [Int 3]. Then, he answered a web-based Likert-type questionnaire [Quest 1], and finally, he was interviewed again [Int 4] to gain a better understanding of the answers in the questionnaire.

In parallel to this process (although represented within *Previous steps* in Fig. 7), a feature analysis in screening mode (i.e. the features are identified and scored by the evaluation team [29]) was conducted [Feat 1]. The identified limitations of existing approaches to the deployment of pervasive learning environments (section 2) were categorized as features and subfeatures. Each approach, as well as the GLUEPS-AR system, was assessed by the evaluation team, scoring the different subfeatures in a 0 to 5 scale, using a score sheet (as the method recommends). In order to provide these scores, some of the existing approaches were tested (QuestInSitu, ARLearn, ARIS and GLUEPS-AR), while the rest were analyzed studying their specifications and/or related literature. Also, in order to triangulate with the judgement of a relevant actor external to the evaluation team, a feature analysis of GLUEPS-AR was conducted by the teacher as a tool assessor [Feat 2]. This feature analysis was based in the experiment mode [29] of DESMET, in

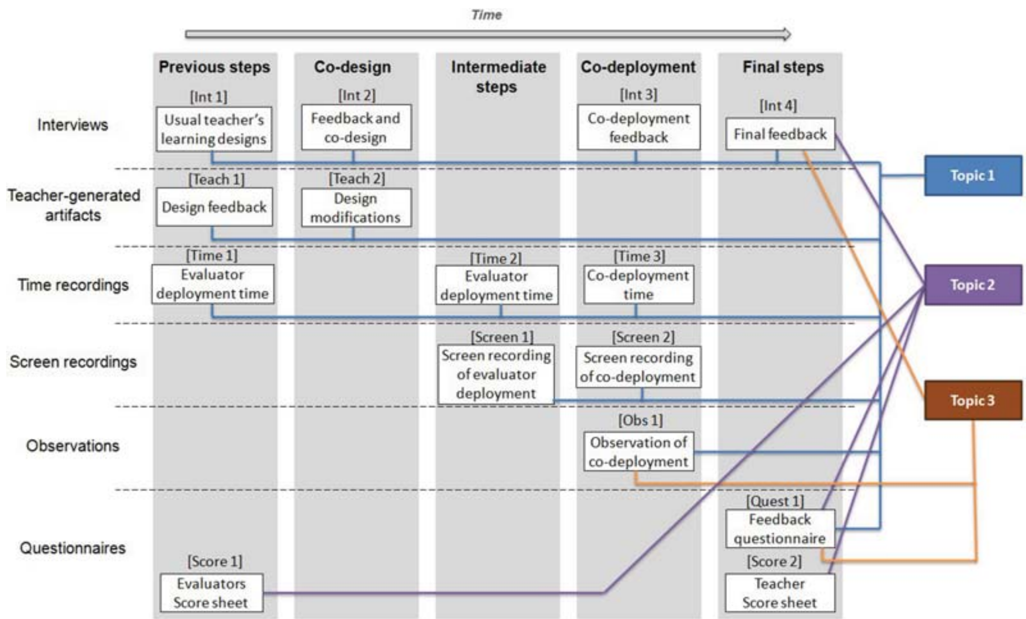

Figure 7: Data gathering and evaluation flow of the study.

which the teacher scored the identified subfeatures for GLUEPS-AR using the same scale of 0 to 5 in a score sheet [Score 2] (represented within *Final steps* in Fig. 7).

4.3. Results

This section summarizes the main results obtained in the evaluation of GLUEPS-AR. The results are organized according to the three topics defined to analyze our research question (see Fig. 6). The findings are illustrated with excerpts of the qualitative and quantitative data that support them.

4.3.1. Deployment affordability (Topic 1)

Topic 1 deals the affordability for the teacher of deploying pervasive learning situations using GLUEPS-AR. This topic has been explored by measuring the time needed for each deployment performed, and by analyzing the teacher's opinions on the system's complexity and his expectations about the future use of the system.

Table 2 shows the time employed for the definition of the learning design using the WebCollage authoring tool. The table also accounts for the time it took to deploy the learning designs of the three learning situations into a pervasive learning environment using GLUEPS-AR. As described in the previous subsection, there were three rounds of deployment throughout the evaluation process: the first two were done by an ICT-expert member of the evaluation team, while the last one was done by the teacher (with occasional help from the researchers). As the table shows, the deployment time of the third learning situation took the teacher only three minutes longer than the ICT expert (18 vs. 15 minutes). In the answers to the first questionnaire [Quest 1], the teacher regarded positively a total definition and deployment time below three hours (the

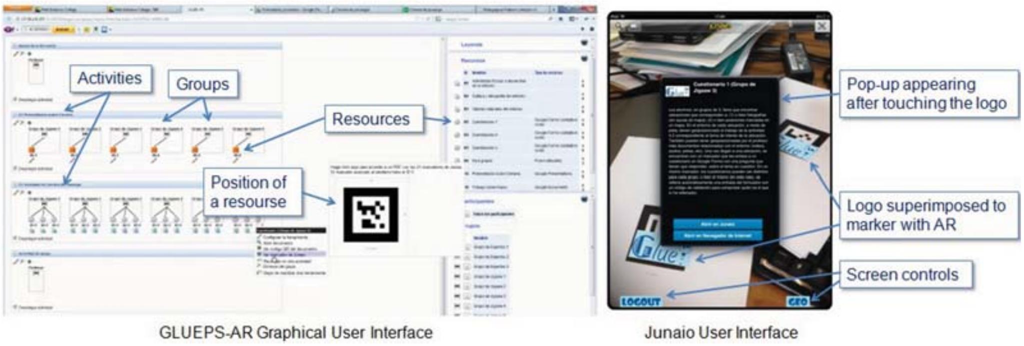

Figure 8: Screenshots of the GLUEPS-AR GUI in a desktop web browser (left) and Junaio user interface in a tablet (right).

Table 2: Time (in minutes) devoted to the definition and deployment of the learning situations, using WebCollage and GLUEPS-AR, respectively.

	Learning situation 1 (classroom)		Learning situation 2 (campus outdoor)		Learning situation 3 (natural environment)	
	WebCollage	GLUEPS-AR	WebCollage	GLUEPS-AR	WebCollage	GLUEPS-AR
Initial proposal (evaluator)	15	16	14	24	24	16
Final design (evaluator)	38	28	15	19	16	15
Final design (co-deployment)	-	-	-	27	-	18

whole process took 109 and 131 minutes in the first two rounds done by the expert, respectively). This judgement was also confirmed at the interview ("*I think that three hours, with the explanations you did, is acceptable. Perfectly, yes*" [Int 4]). Also, the teacher considered that the deployment process with GLUEPS-AR was easy ("*I see this part very easy*" [Int 3]), although he was mainly concerned about the time required for the definition of the learning design in WebCollage ("*I see it easy. But... to deploy. Not all teachers will have somebody which have set up the rest of the architecture [referring to the learning design in WebCollage]*" [Int 3]). Despite this concern, he appeared to be very motivated to use GLUEPS-AR to conduct these or other different learning situations, not only related with orienteering [Quest1] ("*[...] It would be very useful. I would like to use it.*" [Int 3]; "*I can think of many more possibilities for applying these things. Trekking, active tourism, ...*", "*[The teacher] volunteers to try it by himself in order to see if he is able to design something, and to think in philosophical/educational applications of these technologies*" [Obs 1]).

4.3.2. Features (Topic 2)

Topic 2 deals with the support for the identified features limiting teacher adoption (see section 2), and the meaningfulness of such features. This topic has been studied mainly through the comparative feature analysis of GLUEPS-AR and the other existing approaches, combined with interviews and questionnaires with the teacher. This feature analysis targets identified limitations in the deployment of pervasive learning situations very narrowly; thus, it should not be taken as an indicator of the overall quality of the systems. Table 3 shows the evaluation profile obtained in the feature analysis conducted by the evaluation team [Score 1]. As it can be seen, GLUEPS-AR obtains significantly better scores than most of the alternative approaches. Such score has been triangulated with the GLUEPS-AR feature analysis conducted by the teacher after his use of GLUEPS-AR in the co-deployment experience (last column in Table 3) [Score 2]. Only two sub-features ("*The system allows different pedagogical approaches*" and "*Inside a same pedagogic approach, the system allows to use different techniques (questionnaires, games, collaborative writing, debate, etc)*") were scored 3 by the teacher (in a 0-5 scale; 3 corresponds to "*The system has a partial support to this feature*"). The interview data showed that the teacher was purposefully cautious about the pedagogical effects of the technology, at least until he could see it in action with students ("*By now, I will put my score here [at 3], so as not to exaggerate. I have to see how it fares in the enactment, combining the technology with the pedagogy, in order to have further elements of judgement*" [Int 4]). All the identified sub-features were valued as meaningful by the teacher [Quest 1], although always considering technology in a lower level of meaningfulness than pedagogy ("*[technology] depends on the person, and her thoughts as a teacher, the course, etc. That is the drawback I see in almost every point in the questionnaire. That's why I don't put the maximum score to anything. I think, based in what I have seen, that it [GLUEPS-AR] enables and helps you [...] [to a question about whether he found the pedagogical part missing from the score sheet:] Yes, that's it. That [the pedagogy] is the most important aspect*" [Int 4]).

Table 3: Evaluation Profile of the different approaches: LAS, Smart classroom (SmCl), ARIS, Gymkhana (Gym), QuestInSitu (QIS), CityScrabble (CiSc),ARLearn (ARL), GLUEPS-AR (G-AR).

SubFeature	Conformance score obtained								
	Evaluation team								*Teacher*
	LAS	SmCl	ARIS	Gym	QIS	CiSc	ARL	G-AR	G-AR
Allow multiple technologies	0	0	0	0	0	0	0	4	4
Can use existing systems	4	4	1	1	1	1	3	4	4
Share and reuse designs in different enactment technologies	0	0	0	0	0	0	0	3	4
Deploy in different spaces	4	4	3	3	4	3	4	4	4
Allow different pedagogical approaches	4	4	2	2	2	1	3	4	3
Allow different techniques	4	4	2	2	2	0	3	4	4
Learning artifacts produced by students may be used from different spaces	4	4	1	1	3	1	3	4	4
Holistic view (related activities in different spaces)	4	4	1	1	3	1	3	4	4
System support groups in different spaces	5	5	0	5	0	0	5	5	4
Total	29	29	10	15	15	7	24	36	34
% over the total possible	66	66	22	33	33	16	53	80	76

4.3.3. Alignment with the teacher's practice (Topic 3)

To explore the alignment of the learning situation design, its concepts, and the technological tools' concepts with the teacher's own practice and notions, we gathered feedback from the teacher after the co-deployment process, through an interview and a questionnaire. Such data was combined with observations of the co-deployment, to strengthen the credibility of the results.

Results were positive regarding the alignment of the learning design to the teacher's usual pervasive learning situations and to the learning objectives of the course ("*[to a question about whether there was a connection between the learning situations and his pedagogical objectives:] Yes, I think so. It always can be fine-tuned a little more, and I am a little afraid [...] the technology dazzles you so much, that you end up doing things that are not strictly necessary for the pedagogical line that you want to follow*" [Int 4]). The teacher understood the concepts of the learning design and the different technologies involved [Quest 1] ("*You mean [whether I understand it] at a methodological level, what is a pyramid, or a jigsaw? Yes, I know all that*", "*[to a question about whether he understands the way GLUEPS-AR represents resources:] Yes, I think so*" [Int 4]). The Junaio AR application, although valued positively (4 in a 1 to 6 scale), proved to be the most challenging technology for the teacher [Quest 1]. This was probably due to a lesser understanding of the pedagogical possibilities of AR ("*[Referring to AR] It is difficult to see its applicability and usefulness. Maybe [...] because it is more difficult. Maybe I am less familiarized with this kind of gadgets*" [Int 4]). However, despite these difficulties with AR concepts, the teacher was perfectly capable of deploying an AR-enabled learning situation using GLUEPS-AR.

5. Discussion

Overall, the data from different quantitative and qualitative sources suggest that the deployment of different pervasive learning situations using GLUEPS-AR is affordable for the teacher (Topic 1). Also, the evaluation evidence shows how GLUEPS-AR overcomes the aforementioned limitations of existing approaches in deploying pervasive learning situations (Topic 2). Furthermore, the concepts handled by the different technologies involved in the deployment process appear to be aligned with the teacher's own practice and concepts (Topic 3). Therefore, the evidence indicates that GLUEPS-AR made the deployment of the participant teacher's authentic pervasive learning situations *affordable*. This provides a first exploration of our main reseach question ("Does GLUEPS-AR make the deployment of the participant's authentic pervasive learning situations affordable?"), with encouraging results.

The course fragment featured in our evaluation, composed by three learning situations and multiple interrelated activities in various physical and web spaces, highlights some of the limitations for adoption of existing pervasive learning approaches, in the context of authentic educational settings. It also has served to show how GLUEPS-AR overcomes such limitations: it is able to interoperate with multiple widespread technologies (including the Moodle VLE already in use in the course); it supports flows of learning artifacts across web and augmented physical spaces (which was used, e.g. for *in situ* peer review activities across different learning situations in our evaluation); and it supports deploying multiple kinds of learning activities (such as blended work through Web 2.0 artifacts embedded in a VLE, collaborative work in a classroom, or outdoor orienteering tasks – all featured in the teacher's learning design).

However, the evaluation, as a process to confront our proposal with real actors and learning situations, helped us to also identify limitations in the current GLUEPS-AR prototype, such as the scalability problems that appear when the number of students is very high. In our evaluation study, we defined a learning situation with eighteen students, while the participant teacher usually has more students in his courses (as an example, he conducted in 2012 a similar learning situation in the university campus with about seventy students). Trying to deploy this kind of complex learning design for such large cohorts, using the current GLUEPS-AR prototype would prove quite tedious and time-consuming. This is due to the fact that student grouping and tool configuration currently requires a certain amount of repetitive (albeit easy) operations. Thus, in the future, the GLUEPS-AR GUI should be modified to improve the scalability in the number of students and groups whose activities can be deployed (by automating or randomizing such configuration). Also, although our focus in this study was the deployment (as opposed to the enactment) of pervasive learning situations, the evidence hints that the relationship between system features and their pedagogical implications needs to be analyzed in depth. New studies that not only cover the deployment, but also the enactment of pervasive learning situations, are among our plans for future research.

An interesting emergent finding was the need for greater flexibility in what students are able to do during the enactment, such as letting them take decisions about the type of learning artifacts they can create and their location (e.g., allowing students to create orienteering routes by themselves during the enactment). The participant teacher in our study usually resorted to this kind of strategy so that students helped him in the organization of the tasks, as well as for pedagogical reasons. Since current research approaches supporting the deployment of pervasive learning environments are somewhat rigid in what students are allowed to do during enactment, this is an interesting matter for further research.

As mentioned before, it is important to note that the feature analysis conducted as part of the evaluation provides scores just on the basis of the limitations identified for teacher adoption in authentic settings, and not other features or functionalities. Such scores should not be interpreted as a global measurement of the quality of each system, or a comparison of the pervasive learning experiences they provide. Rather, it represents the relative degree of support for certain features relevant to the acceptance of systems for deploying pervasive learning situations, by teachers operating in authentic educational settings.

6. Conclusions and future work

Learning has always been naturally pervasive and ubiquitous, but only recently mobile and web technologies have reached the point where they can pervasively support learning, connecting the learning experiences in different contexts. Even if specific tools exist for the implementation of such pervasive learning environments, their limited range of applicability makes it challenging for non-technical users (such as most teachers) to develop a wide range of pervasive learning experiences. In this paper we have presented a more general approach to the deployment of such learning situations, overcoming this limitation. The results from the evaluation of a first prototype suggest that GLUEPS-AR is able to support multiple pervasive learning situations, making the deployment of such situations affordable for teachers. Even if the other approaches could adapt better to specific situations or pedagogies, GLUEPS-AR provides a general-purpose alternative, that we expect could be more easily accepted by practitioners in their everyday practice (since it integrates widespread technologies that many of them already know and use).

The positive results of this first evaluation motivates us to continue the exploration of the deployment of multiple pervasive learning situations by non-ICT-expert teachers. We intend to enact the pervasive learning situations described in the presented evaluation study with real students, and to repeat the process across different kinds of spaces, learning situations and teachers profiles. These studies will evaluate also whether teachers are able to complete the whole cycle of designing, deploying and enacting the learning situations with their students. In addition, we plan to incorporate in the approach new enactment technologies to support the orchestration [51] of the learning situations, such as ambient displays [20] and monitoring processes. Another line of future work is the extension of the generic POI model and the architecture presented here to other types of AR devices (e.g., head mounted displays such as Google Glass[15]) and to different types of spaces beyond the physical and web domains, including also environments such as tabletop computers and 3D virtual worlds. Finally, further research is necessary to provide increased flexibility to students during the enactment of pervasive learning situations (e.g. the selection and production of artifacts of their choice in run-time).

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