Supporting Teacher Orchestration in Ubiquitous Learning Environments: A Study in Primary Education

Juan A. Muñoz-Cristóbal, Iván M. Jorrín-Abellán, Juan I. Asensio-Pérez, Alejandra Martínez-Monés, Luis P. Prieto, and Yannis Dimitriadis, *Senior Member, IEEE*

Abstract—During the last decades, educational contexts have transformed into complex technological and social ecologies, with mobile devices expanding the scope of education beyond the traditional classroom, creating so-called Ubiquitous Learning Environments (ULEs). However, these new technological opportunities entail an additional burden for teachers, who need to manage and coordinate the resources involved in such complex educational scenarios in a process known as "orchestration". This paper presents the evaluation of the orchestration support provided by GLUEPS-AR, a system aimed to help teachers in the coordination of across-spaces learning situations carried out in ULEs. The evaluation, following an interpretive research perspective, relied on a study where a pre-service teacher designed and enacted an authentic across-spaces learning situation in a primary school. The situation, which illustrates the orchestration challenges of ULEs, was aimed at fostering orienteering skills. It spanned five sessions taking place in the classroom, in the school's playground and at a nearby park, using multiple technologies and devices. The evaluation showed that GLUEPS-AR helped the teacher in the multiple aspects of orchestration, including implementation of his pedagogical ideas, adaptation in runtime, and sharing of orchestration load with students. Teacher awareness during outdoor activities was the main aspect to improve upon.

Index Terms—Artificial, augmented, and virtual realities, computer uses in education, education, ubiquitous computing, mobile environments

1 Introduction

Technological advances in the last decades, such as laptops, digital blackboards, Virtual Learning Environments (VLEs) or Web 2.0 tools, are transforming educational contexts into heterogeneous ecologies of technological and social resources [1]. In addition, mobile devices provide new opportunities for learning, both within and beyond the classroom [2]. The use of mobile devices may engage students in knowledge discovery, facilitating the incorporation of pedagogical approaches like active and experiential learning [3]. However, at the same time, these new opportunities for learning are creating even more heterogeneity, generating new barriers or discontinuities across the different learning spaces [4]. Some authors use the metaphor of a "seam" to refer to these discontinuities [5]: a spatial, temporal or functional constraint that forces the user to shift between a variety of spaces or modes of operation [6], [7]. However, technology may also help reduce such seams and transform them into opportunities for learning. Thus, for instance, VLEs may reduce technological, social and pedagogical discontinuities in classrooms and blended learning [8], mobile devices may help connect classrooms with other physical places [4] and augmented reality (AR) may aid to link virtual and physical spaces [6]. Reducing the discontinuities between different physical and virtual spaces may favor seamless learning, i.e., a continuous learning experience across different spaces [9]. This way, the seamless combination of independent physical and virtual learning spaces constitutes a so-called Ubiquitous Learning Environment (ULE) [10], [11].

The difficulties for teachers to put into practice learning activities in technology-supported classrooms and blended environments have been profusely studied in the recent years under the umbrella of the "orchestration" metaphor [12], [13], i.e., the coordination of learning activities in complex authentic educational settings. However, the across-spaces extension of learning situations beyond the classroom generates additional orchestration challenges for teachers [14]. Although there is a growing interest in the orchestration of ULEs [15], [16], [17], there is still a dearth of studies regarding the support provided by systems to the orchestration of across-spaces learning situations in ULEs.

The GLUEPS-AR system [18] aims to support teachers in the deployment[1] and runtime management of learning

- *J.A. Muñoz-Cristóbal, J.I. Asensio-Pérez, A. Martínez-Monés, and Y. Dimitriadis are with the GSIC-EMIC Group, School of Telecommunications Engineering, Universidad de Valladolid, Paseo de Belén 15, 47011, Valladolid, Spain. E-mail: juanmunoz@gsic.uva.es, juaase@tel.uva.es, amartine@infor.uva.es, yannis@tel.uva.es.*
- *I.M. Jorrín-Abellán is with the Department of Secondary and Middle Grades Education, Bagwell College of Education, Kennesaw State University, 1000 Chastain Road, MD 0122, Kennesaw Hall, Bldg. #1, Kennesaw, GA 30144-5591. E-mail: ijorrina@kennesaw.edu.*
- *L.P. Prieto is with the CHILI research lab, École Polytechnique Fédérale de Lausanne, RLC D1 740 (Rolex Learning Center), Station 20, CH-1015, Lausanne, Switzerland. E-mail: luis.prieto@epfl.ch.*

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1. Throughout this paper, we will use the word "deploy" to mean the setting up of the technological environment.

designs, defined using multiple authoring tools [19], in different ULEs. Such ULEs may be composed of widespread web-based VLEs (e.g., Moodle[2]), popular Web 2.0 tools (e.g., Google Drive[3]), and physical spaces augmented with existing mobile AR clients (e.g., Junaio[4]). Previous to the study presented in this paper, GLUEPS-AR had only been used by a teacher to design and deploy an across-spaces learning situation [18]. This design was not put into practice with actual students, and the evaluation focused on the a priori planning/preparation of the scenario, and the systematic comparison of GLUEPS-AR features with other technological alternatives. This comparison showed that GLUEPS-AR was able to overcome existing limitations of the reviewed approaches, mainly due to its ability to be employed with multiple authoring and enactment tools, and the support it provides to the flow of learning artifacts between activities conducted in different spaces. To extend such initial evaluation, we present in this paper a study that evaluates, following an interpretive research perspective [20], [21], the support provided by GLUEPS-AR to the *orchestration of a ULE* throughout a complete authentic learning scenario (from its initial conception to the enactment with real students). Such orchestration evaluation is the main contribution of the paper.

Thus, the research question we explore in this paper is: *how does GLUEPS-AR help teachers orchestrate their across-spaces learning situations conducted in ULEs?* In order to illuminate it, we evaluate the teacher orchestration support provided by GLUEPS-AR, in a study involving the design, deployment and enactment of an authentic across-spaces learning situation performed in a primary school and its surroundings. The situation aimed to foster orienteering skills in physical education. It spanned multiple sessions in a ULE formed by different spaces (a wiki-based VLE, a classroom, the school's playground and a nearby park) and using different technologies (an interactive whiteboard, laptops, tablets, Web 2.0 tools, AR, as well as paper and pencil).

The structure of the paper is as follows. In the next section, the learning situation in which GLUEPS-AR was evaluated is described in order to illustrate the complexity and richness of the wide ecology of technological and social resources that shapes ULEs. Section 3 deals with the orchestration metaphor and the GLUEPS-AR system. After that, Section 4 describes the evaluation performed, and Section 5 discusses the results of the evaluation.

2 ORIENTATE!: AN AUTHENTIC ACROSS-SPACES LEARNING SITUATION

Orientate! Is an authentic across-spaces learning situation conceived and conducted by a pre-service teacher during his *practicum*, involving a sixth-grade class (18 students, about 12 years old) in a public primary school in Valladolid (Spain) and its surroundings. This pre-service teacher worked under the supervision of the in-service teacher responsible for the class. The learning situation was framed within the official prescriptive Spanish curriculum. Since

2. https://moodle.org. Last access October 2014.
3. http://www.google.com/drive. Last access October 2014.
4. http://www.junaio.com. Last access October 2014.

	Spaces	Tools	Activities	Snapshot
1 (1,5h)	Classroom Wiki	Smartboard, tablets, wiki Google Slides, webwhiteboard	Introduction to orienteering and sketch of the classroom	
2 (2,5h)	Park Classroom Wiki	Tablets, wiki, Line Brush (digital map), paper & pencil, Picasa	Select elements in a park and place them in map and sketch	
3 (2h)	Playground Classroom Wiki	Tablets, map, AR markers, Junaio, paper & pencil, Google Docs, images, Smartboard, wiki	Orienteering race in playground	
4 (1h)	Classroom Wiki	Paper & pencil, smartboard, wiki, Google Docs, laptops	Prepare questions for final race	
5 (2h)	Park Classroom Wiki	Tablets, wiki, Line Brush (digital map), AR markers, Junaio, paper & pencil, Google Docs, laptops, Picasa	Orienteering race in park	

Fig. 1. The five-session learning plan.

the aforementioned in-service teacher had to assess the pre-service teacher in his practicum, the in-service teacher participated in the learning situation having the main role of an observer, and assisting the pre-service teacher when needed. The main learning objectives of Orientate! were to help students understand orienteering concepts, develop orienteering skills, and use orienteering instruments.

During the learning situation students collaborated in three physical spaces: the classroom, the school's playground, and a nearby public park. Moreover, students were also asked to collaborate through a web space consisting on a VLE in the form of a wiki-site integrating multiple Google Drive documents and other Web 2.0 artifacts. AR and mobile devices were used to bridge physical and virtual spaces, enabling the access, in specific locations of a physical space, to virtual artifacts created in a web space. Thus, the five sessions in which the activity was divided (see Fig. 1) used resources across all these physical and virtual spaces.

The *first session* was devoted to a general introduction to orienteering. The pre-service teacher, using the wiki and Google Drive Slides in the interactive whiteboard, as well as the traditional blackboard, explained some initial issues on how to read maps, use a compass, or the way contour lines are represented in a topographic map. After a 35-minute lecture students were asked to apply what they just learned, in the generation of a classroom sketch-map representing all its physical elements (in three groups of six students). Each group used a tablet and a web whiteboard embedded in the wiki to create the sketches. Afterwards, the pre-service teacher reviewed each sketch with its authors using the interactive whiteboard, and finally the group returned to their desk to revise the sketch using the tablet.

The *second session* took place in a nearby public park. The objectives of the session were to put into practice some of the

theoretical concepts seen, and to prepare an orienteering race for a subsequent activity in the park (session 5). Groups were given a tablet, wherein they could access an orienteering map of the park loaded into a drawing application. A different area of the park was assigned to each group. Then, they were asked to select five elements of special interest for them in the assigned zone (e.g., a fountain or a small house to store boats) and to prepare a question regarding each element, to be answered by a different team in the final orienteering race (session 5). They were also asked to draw a paper & pencil sketch-map of the park to situate the chosen elements, as well as to position them in the digital map in the tablet. Back in the classroom, the pre-service teacher took pictures of the sketches, uploading them to Picasa[5] and the wiki.

The *third session* consisted of an augmented reality orienteering race within the playground of the school. The session was intended to let students practice with orienteering skills and AR in a nearby environment, before the final, more difficult to control, race in the park. Divided in the same groups, students were provided with an orienteering map (in paper). Groups were asked to locate seven AR markers indicated in the map, which were placed all over the playground. Each marker contained a question regarding the orienteering contents seen in the previous sessions. Questions were prepared previously by the pre-service teacher, and were of two kinds: textual (using a Google Drive document linked to the marker) or graphical (using AR to overlay an image onto the marker). Groups also carried tablets with the Junaio AR application, in order to access the questions. Afterwards, in the classroom, the students accessed the wiki using the tablets and the interactive whiteboard, to read a Google Drive document with the correct answers and compare them with their own responses.

The *fourth session* took place in the school classroom, and it was dedicated to the preparation of the final session in the park. Students used laptops to access the wiki and generate a set of questions (each one in a different Google Drive document) regarding the points of interest previously selected in session 2 (e.g., "Which is the color of the roof of the small wooden house near the riverbank?"). These questions were intended to be answered *in situ* by the other groups in the last session.

In the *fifth and last session*, students went back to the park for the final orienteering race. The questions created by the students in session 4 were linked to corresponding AR markers, which were positioned all over the park in the places previously selected by the students in session 2. Group 1 was asked to find markers created by group 2; group 2 had to find the ones posed by group 3, and group 3 had to find markers defined by group 1. Each group used a tablet with the map indicating the location of the markers, and Junaio to read the AR markers and access the questions created in Google Drive documents. Students were also asked to take a picture of the elements found. Each picture was uploaded to Picasa and to the wiki as an evidence of the group having been there. After the race, back in the classroom, the students used laptops to compare their own responses with the correct answers (placed in the wiki by the teacher).

5. http://picasa.google.com. Last access October 2014.

The learning situation presented above was created, deployed and enacted by a non-ICT-expert pre-service teacher. The scenario involved a web space (a wiki) and three different physical spaces (indoor and outdoor) evolving from the "nearby" classroom to a more "far away" park in the city. This formal learning situation was integrated in the official curriculum and conducted during the official lesson hours. The situation included multiple existing enactment technologies: an interactive whiteboard, laptops, tablets, paper and pencil, a wiki used like a VLE, Web 2.0 tools, a drawing mobile application and a mobile AR client. In the scenario, AR was used to connect the different spaces, e.g., the same Web 2.0 artifacts could be accessed from the wiki (web space) and from different physical spaces using mobile AR. These artifacts were to be created from within different spaces by the teacher and the students.

These characteristics differentiate this learning situation from others reported in the ubiquitous learning literature. There are studies where researchers or ICT-experts set up partially or completely the scenario [22], [23], [24], [25], [26], [27], [28]. There are also cases based in a single physical space (e.g., a classroom) [29], [30] or similar kinds of spaces (e.g., multiple indoor ones) [31], [32], [33]. Other studies involve informal and/or extra-curricular activities (e.g., performed with volunteers out of the official hours) [17], [34], [35], [36]. Yet other scenarios enable the access to artifacts only from certain spaces (e.g., an artifact can be accessed only from a web space, or only from a physical space) or involve collecting data from a physical space to be accessed from a web one [14], [24], [37], [38]. The Orientate! Scenario, on the contrary, was designed by a non-ICT expert teacher, taking into account the constraints of the official curriculum. The scenario spans multiple physical and virtual spaces, and involves accessing artifacts from all these spaces. It illustrates the complexity and richness of a formal scenario integrated in a prescriptive primary education curriculum, involving several spaces and multiple existing technologies. Therefore, we consider the Orientate! scenario itself a second contribution of the paper.

3 GLUEPS-AR: A System for the Orchestration of across-Spaces Learning Situations in ULEs

This section introduces the orchestration metaphor and presents the orchestration challenges that scenarios like Orientate! pose. This section also outlines GLUEPS-AR, the orchestration system evaluated through the aforementioned scenario.

3.1 Orchestration

Dillenbourg et al. defined orchestration as "the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels" [39]. The orchestration metaphor has been an important topic in the Technology Enhanced Learning (TEL) research community during the last years (see [40] and [41] as examples of this interest). The conceptualization and scope of orchestration have been profusely discussed: while Dillenbourg restricts orchestration to the enactment of learning

TABLE 1
Challenges for the Orchestration of ULEs

Orchestration aspects [13]	Challenges	Examples in Orientate! scenario
Design	Preparing the activities to be implemented with multiple technologies in multiple spaces	The scenario was challenging (even at a conceptual level) for a non-expert, non-technical teacher, due to the multiple technologies and spaces involved: what tool should be used to create the sketch, what device will students use. . .
Management	Regulating efficiently the across-spaces learning situation and its technological and social resources	There were several artifacts that had to be created and used by the teacher and the students in multiple spaces and with different devices and technologies (e.g., the questions placed along the orienteering race)
Adaptation	Providing efficient ways to modify the learning design and the access to its artifacts from different spaces, in runtime	Some artifacts did not have to be accessible from a certain space (e.g., answers to questions in the wiki) until the activity in another space was finished (e.g., in the park). Outdoor activities can be affected by extraneous events like the weather, the Internet connectivity, etc.
Awareness	Providing teachers with information about what is occurring and what has happened in different spaces	The teacher needed to know, during and after the end of the activities, what the students had accomplished in different spaces using multiple technologies (e.g., which questions had been created, which photos had been uploaded)
Roles of the teachers and other actors	Sharing the orchestration load with students, allowing a certain level of self-regulation	Students designed orienteering routes for another group of students, and created and uploaded several artifacts to be used in subsequent activities in multiple spaces (e.g., race questions)
Pragmatism	Complying with the participants' contextual and institutional constraints	The scenario followed the prescriptive curriculum (e.g. starting with nearby experiences and progressively expanding to more far away ones), the official schedule of the school, and was carried out by participants not expert in ICT
Alignment	Coordinating the resources in different spaces to attain the learning goals	In the scenario, several devices and technologies were coordinated in a continuous learning experience across different spaces, toward the educational goal of developing orienteering skills
Theories	Using the appropriate orchestration and pedagogical theories that correspond to the scenario and the teacher preferences	The pre-service teacher used his preferred pedagogical and organizational approaches. For example, he maintained typical orienteering activities based on the use of markers, and he selected existing AR and Web 2.0 tools to connect such activities with others in different spaces

situations [42], other authors extend the orchestration scope, covering the whole process from the creation of a learning situation (also known as learning design [43]) to its enactment [44], [45]. The role of the teacher in the orchestration process is also not unanimously established: while some authors consider the orchestration as strongly teacher-centered [12], others emphasize the importance of sharing the orchestration load with students, especially in complex scenarios such as ubiquitous ones [16], [46]. Indeed, a number of authors have proposed conceptual frameworks that describe the different aspects and characteristics of orchestration [12], [47]. Prieto et al., reviewing TEL literature related to orchestration, propose a framework which attempts to be more general and non-restrictive, encompassing the different aspects mentioned within the TEL community under the "orchestration" umbrella [13]. From this work emerges a definition of orchestration as "the process by which teachers and other actors design, manage, adapt and assess learning activities, aligning the scaffolding at their disposal to achieve the maximum learning effect, informed by theory while complying pragmatically with the contextual constraints of the setting" [48]. The framework defines eight aspects that characterize orchestration (hence its name, '5+3 Aspects' framework): design, management, adaptation, awareness, roles of the teachers and other actors, pragmatism, alignment and theories. The use of the framework as a research instrument was evaluated by Prieto [48], which concluded that the framework provides an integrated view of TEL practice in authentic settings. In spite of its broad conception (derived from its holistic nature) the framework also demonstrated its usefulness as an instrument for guiding research data gathering. This more general approach fits well with our purpose of evaluating the support to orchestration provided by GLUEPS-AR in a ULE, considering the multiple aspects that the different approaches in the TEL community encompass under the orchestration concept.

The '5+3 Aspects' framework can be also used to structure the analysis of the orchestration challenges that ULEs pose in settings like the Orientate! Scenario (see Table 1). Although some of the definitions and conceptualizations of this metaphor stem from work in ubiquitous learning environments [16], [39], [46], so far the detailed analysis of the orchestration challenges in authentic learning situations has been mostly focused on physical classrooms and web-based blended learning [12], [13], [30], [32], [33], [47], [49], [50]. An exception is the work reported by Looi and Toh [17], who explored how the use of students' mobile devices in science courses affects orchestration. However, their study focused mainly on the activities happening inside the classroom. Also, Sharples and Anastopoulou reflected about the orchestration challenges in inquiry based learning situations where the activities out of the classroom consisted in collecting data to be analyzed later on in the classroom [51].

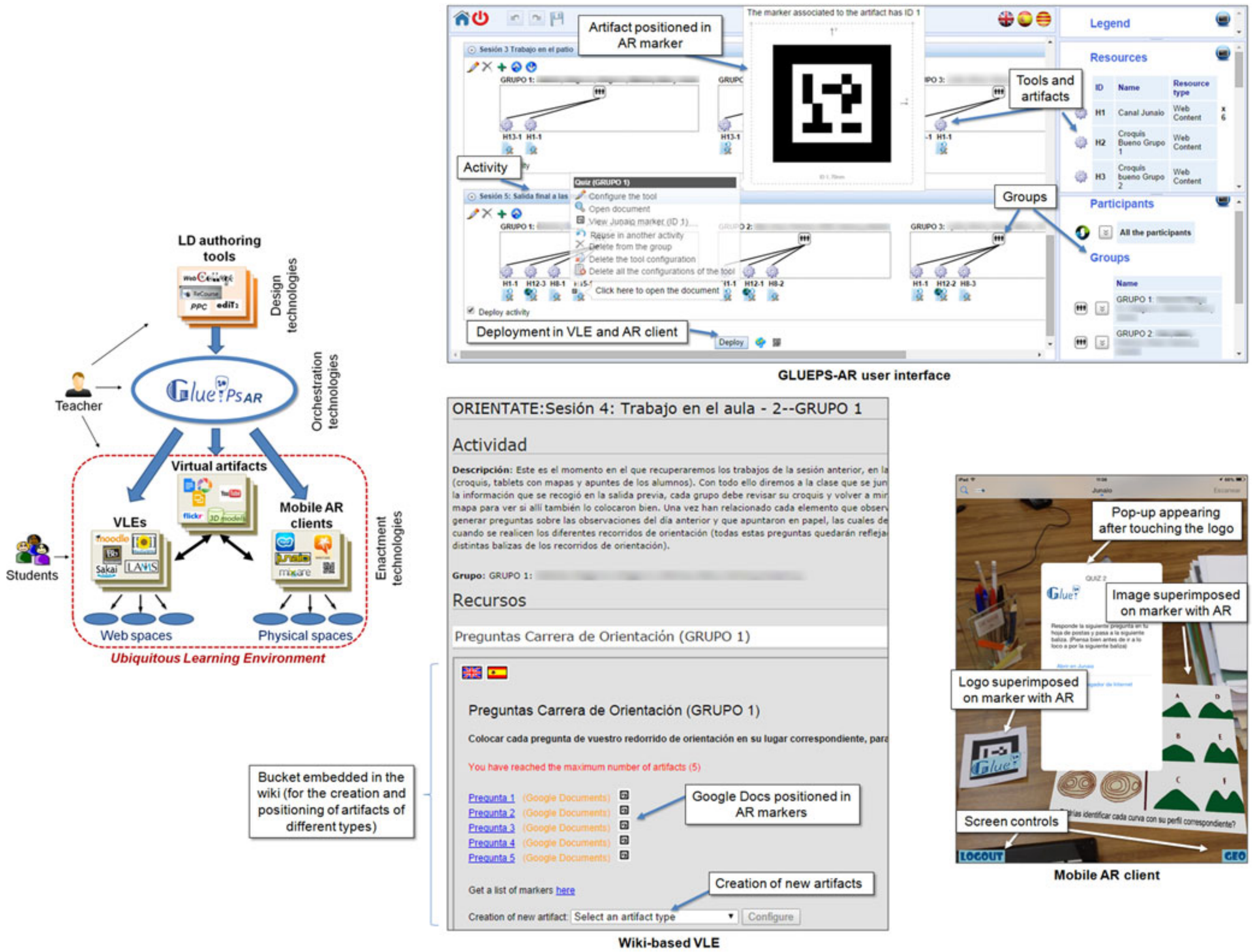

Fig. 2. GLUEPS-AR orchestration system (left), and user interfaces of GLUEPS-AR and enactment technologies (right).

Table 1 shows a number of orchestration challenges that ULEs may pose to teachers, categorized following the '5+3' orchestration framework and illustrated with examples of the Orientate! Scenario. Although similar to those of learning activities in classrooms and blended learning, in ULEs their complexity increases due to the involvement of new spaces and technologies. Also, students may play an important role in these settings since they may help reduce teacher orchestration load, e.g., by managing their own learning artifacts. The evaluation of the support provided by GLUEPS-AR to these orchestration challenges (which are illustrated with the Orientate! scenario) is the main contribution of this paper.

3.2 The GLUEPS-AR System

Multiple technological systems have been developed with the specific purpose of helping orchestrate learning situations [15], [16], [45]. GLUEPS-AR [18] does so for the case of across-spaces learning situations conducted in ULEs (see Fig. 2). GLUEPS-AR is able to deploy the teachers' pedagogical ideas (i.e., their learning designs [43]) expressed using multiple existing authoring tools [19], in different ULEs. Such ULEs may be composed of existing well-known VLEs (e.g., Moodle, wiki-based ones) and existing mobile AR clients (e.g., Junaio, Layar[6], or any common QR code reader). In addition, GLUEPS-AR enables the access to virtual artifacts (e.g., web pages, 3D models, or artifacts generated with Web 2.0 tools, like Google Drive documents) from both VLEs and AR clients. Fig. 2 includes screenshots of the user interfaces of GLUEPS-AR and the enactment tools employed in the Orientate! Scenario: a wiki-based VLE and the Junaio mobile AR client. As the figure illustrates, teachers have access to GLUEPS-AR user interface, as well as to authoring and enactment tools. Students do not have access to the GLUEPS-AR user interface (they only use the enactment tools). The figure also shows the main elements of the involved user interfaces. Fig. 3 lists the main orchestration support features of GLUEPS-AR, grouped by orchestration aspect.

Up to now, GLUEPS-AR has had a strong teacher-centered perspective, lacking any kind of runtime flexibility for students to self-regulate their learning artifacts [18]. This limitation can be especially severe in ULEs, since the complex learning artifact management may entail a great orchestration load for the teacher [16]. In order to allow a certain degree of flexibility and student self-regulation during enactment, while retaining pedagogical control by the teacher, we

6. http://www.layar.com. Last access October 2014.

✓ **Design**: Modification/completion and automatic deployment in ULEs of learning designs created in multiple authoring tools (not necessarily supporting multiple spaces)
✓ **Management**: Structuring of activities, groups and learning artifacts, as well as positioning in different spaces. Automatic creation of tool instances
✓ **Adaptation**: Changes in learning design during runtime, including properties such as accessibility or positioning in a certain space
✓ **Awareness**: Centralized control panel wherein all created artifacts can be monitored and accessed
✓ **Roles**: Students' self-regulation of learning artifacts positioned in different spaces during enactment by means of learning buckets embedded in ULEs
✓ **Pragmatism**: Possible use of several existing VLEs and AR clients
✓ **Alignment**: Integration of physical and web spaces by enabling the access to virtual artifacts from VLEs and AR clients
✓ **Theories**: Possible use of existing authoring and enactment tools compliant with the teacher preferred organizational and pedagogical approaches

Fig. 3. GLUEPS-AR orchestration features.

have extended GLUEPS-AR to implement the concept of *learning buckets* [46]. A learning bucket is a container of tools and artifacts that GLUEPS-AR embeds in the VLE or AR client (Fig. 2 depicts a bucket embedded in a wiki). The bucket is defined and configured by the teacher at design-time. At runtime, using the bucket, the teacher and the students are able to create artifacts of different kinds (e.g., a photo, a Google Drive document). These artifacts can be positioned in physical or web spaces (e.g., geolocated in a physical space to be accessed in a subsequent activity using AR).

In order to explore to what extent GLUEPS-AR provides orchestration support for teachers in across-spaces learning situations, we evaluated its use in the Orientate! scenario.

4 Evaluating the Orchestration Support for Teachers of GLUEPS-AR

This section describes the evaluation study performed to explore the research question driving our work: *How does GLUEPS-AR help teachers orchestrate their across-spaces learning situations conducted in ULEs?*

The evaluation relied on a qualitative research study [20] wherein the Orientate! learning situation described in Section 2 was designed, deployed and enacted using GLUEPS-AR. This study took place from February to May, 2013. As mentioned above, the teachers involved were a pre-service teacher (leading the whole design and enactment process), and the in-service teacher in charge of the class (who assessed the pre-service teacher in his *practicum*, and hence, participated in the enactment observing, suggesting and supporting him). The class was formed by 18 sixth-grade students (around 12 years old).

4.1 Evaluation Method

To conduct the evaluation, we have followed the Evaluand-oriented Responsive Evaluation Model (EREM) [52], using several data gathering techniques. The EREM is a framework conceived as an evaluation model for a wide range of ubiquitous collaborative learning scenarios. It relies on a responsive evaluation approach [53], strengthening the idea of conducting evaluations centered in the phenomena to be evaluated (evaluand) rather than in the field of expertise of the evaluators (e.g., human computer interaction, didactics, etc). This evaluation method follows an interpretive research perspective [21] that does not pursue statistically significant results or generalizations. Rather, it aims at a deeper understanding of the concrete phenomena under study [54], in our case, the orchestration support provided by GLUEPS-AR for teachers performing across-spaces learning situations in ULEs.

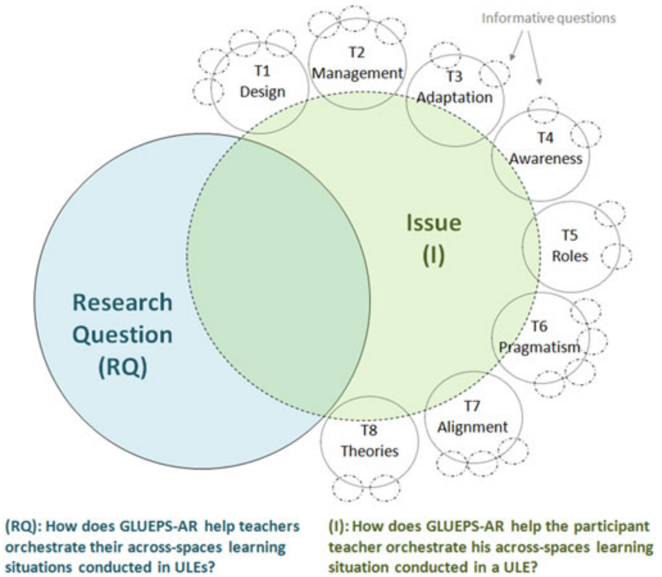

Fig. 4. Anticipatory data reduction showing research question (RQ), issue (I) and topics (T).

To explore the research question, the evaluation team conducted an anticipatory data reduction process [55] during the evaluation design (see Fig. 4), using the '5+3' orchestration framework as a basis to characterize orchestration. Thus, an *issue* was defined as the main conceptual organizer of the evaluation process: *How does GLUEPS-AR help the participant teacher orchestrate his across-spaces learning situation conducted in a ULE?* Such issue, centered in the study of orchestration, was divided into eight more concrete *topics* to help us understand the different dimensions within the issue. These topics match the eight aspects the '5+3' framework uses to model orchestration: *design*, *management*, *adaptation*, *awareness*, *roles of the teachers and other actors*, *pragmatism*, *alignment* and *theories*. In the same fashion, each topic is explored through various informative questions. The schema "research question—issue—topics—informative questions" (see Fig. 4) also guided the data collection during the evaluation, which was carried out using a profuse set of data sources. Table 2 describes the different data gathering techniques employed, and their purpose in the evaluation process. During the data analysis, a single member of the evaluation team coded the data sources using the same anticipatory data reduction schema as an initial category tree thus predetermining the initial set of codes to use *a-priori* [55]. Finally, the evaluation team jointly interpreted the data and identified the findings.

We have used different strategies to ensure the quality of the research process, attending to our qualitative perspective. To increase the credibility, transferability, dependability and confirmability of our research [20], [54], [55], several approaches were followed: prolonged engagement during four months of work with the pre-service teacher and persistent observation in the field; acknowledgement of participant opinions, by interviewing the teachers and by analyzing teachers' and students' reflections on the teacher diary and the students' notebooks; integration of the thorough collaborative observation reports in a single portfolio, thus enabling a thick description of the phenomenon under

TABLE 2
Data Gathering Techniques

Technique	Description	Purpose
Collection of participant-generated artifacts (Art)	Collection of a diverse set of electronic artifacts generated by the teacher and the students, and digitalization (e.g., pictures) of non-electronic ones. Types of data collected include emails, learning designs and products, students' notebooks, teacher reflections.	Registering the learning design process, as well as the use of GLUEPS-AR, the wiki and the mobile AR client by the participants. Being aware of the teacher's asynchronous activities. Gathering the opinions of the pre-service teacher and the students. Complementing the observation of the enactment with information of the learning artifacts generated.
Screen recording (Screen)	Recording, using specialized software, of the actions conducted in the computer by the teacher during the training and the deployment sessions, as well as the actions of the evaluation team during the deployment validation session.	Understanding the design and deployment processes, and measuring the amount of time that these processes require.
Observation (Obs)	Naturalistic, semi-structured observations during the training and deployment sessions, as well as during the enactment. The observations were guided by an anticipatory data reduction schema (see Fig. 4), and conducted by up to five different experienced observers (at least three in each enactment session). The data collected were audio/video recordings, pictures and observation notes.	Registering the actions, impressions and other emergent issues of the teacher during the training and the deployment sessions, and of the teacher and the students during the enactment. Recording the actions and impressions of the evaluators during the deployment validation.
Questionnaire (Quest)	Qualitative, web-based exploratory questionnaire, designed in an iterative review process by 5 evaluators and 1 external researcher. It was composed of open-ended and closed items (6-point scale [1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = somewhat agree, 5 = agree, 6 = strongly agree]).	Getting the initial opinions of the pre-service teacher over a wide range of matters before conducting the interview.
Interview (Int)	Qualitative, semi-structured, face-to-face, one-to-one conversation with the pre-service and the in-service teachers (recorded and transcribed).	Capturing the opinions of the teachers in depth, after an initial analysis of other data sources (e.g., observation data, questionnaire answers, etc).

scrutiny, reported in detail to the whole evaluation team; peer review within the evaluation team to avoid bias; triangulation of data sources, methods and researchers to cross-check data and interpretations. The triangulation of researchers was conducted by involving in the evaluation team experienced researchers with distinct perspectives (i.e., with pedagogical or technological background). Such researchers participated conducting independent observations, which were compiled and discussed in a joint collaborative multimedia report for each session. The triangulation of methods involved the usage of several data gathering techniques (questionnaire, interview, etc). The triangulation of data sources was carried out employing multiple data sources and informants, ensuring that each finding was corroborated by multiple pieces of evidence of different types. We have adopted a descriptive style to report the research and its results, with a detailed account of the context, participants and learning situation, as well as of the evaluation design and its implementation, including the data gathering techniques employed. Such detailed account is another strategy typically employed in qualitative research to achieve credibility and transferability of the results.

Fig. 5 shows the evaluation process, which has been divided into happenings (evaluation events), in which different data gathering techniques were used (along with the labels used to refer to them throughout the text). The overall evaluation process started in February (H1), when an initial two-hour training session of GLUEPS-AR was performed with the pre-service teacher. After the session, and during two weeks, the pre-service teacher accessed GLUEPS-AR by himself (with occasional support of one of the evaluators), performing tests and deploying learning designs in a Moodle VLE and Junaio AR client. Once he was aware of the affordances of the system, he designed a learning situation (H2) and decided to use a wiki-site as the VLE for the learning situation. Then, the evaluation team deployed the pre-service teacher's design across the wiki-site of the course and Junaio, in order to verify the deployment process, and for time-measurement purposes (H3). In a subsequent happening (H4), the pre-service teacher himself deployed the learning design using GLUEPS-AR. He did so in two steps: 1) he did a partial deployment of the design in a room prepared for data gathering, with the support of the evaluators (using Pedagogical Pattern Collector[7] [56], PPC, as the authoring tool); 2) he completed afterwards the design on his own (remotely), re-deploying it several times using GLUEPS-AR to fine-tune the resulting wiki, with sporadic support from one of the evaluators. Then, the enactment of the described learning situation was conducted during five different sessions spanning three weeks (H5) in April and May. Finally, feedback from the in-service and pre-service teachers, as well as from the students, was gathered through a web-based questionnaire, two interviews, a document with the pre-service teacher's reflections and the students' notebooks (H6).

7. http://web.lkldev.ioe.ac.uk/PPC/live/ODC.html. Last access October 2014.

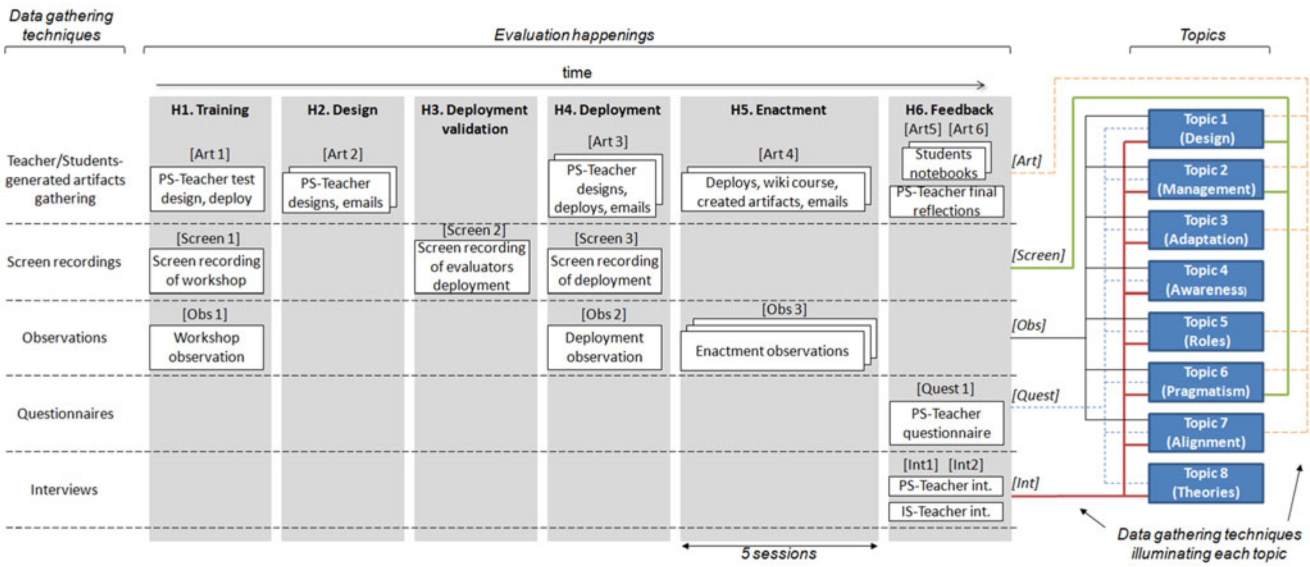

Fig. 5. Evaluation happenings, topics, and data gathering techniques (see Table 2) used during the evaluation.

4.2 Results

This section summarizes the main results obtained in the evaluation, following the topic structure of the anticipatory data reduction process (see Fig. 4). Since such topics correspond to the different aspects of the '5+3' orchestration framework, they enable us to explore how GLUEPS-AR provides orchestration support. In the next sections, each orchestration aspect is introduced paraphrasing its definition from the '5 + 3' framework [13], followed by a discussion of the main related findings and limitations. The main findings and limitations related to all topics are compiled and summarized in Table 3 and Table 4. Both tables include pointers to the data sources that support the findings (using the same labels as in Fig. 5), thus exemplifying the triangulation process followed throughout this study. Due to space restrictions, only a selection of excerpts of these data sources is presented in Section 4.

4.2.1 *T1. Design*

The design aspect of orchestration refers to the planning of the learning activities. It includes both the conceptualization and creation of learning designs (e.g., through authoring tools, or directly in the enactment platforms). The evaluation showed that *GLUEPS-AR enabled the non-ICT-expert pre-service teacher to deploy his across-spaces learning designs in different ULEs*. He deployed different across-spaces learning situations with GLUEPS-AR into ULEs using Moodle [Art 1, Screen 1, Obs 1] and a wiki [Art 3, Screen 3, Obs 2] as VLEs.

TABLE 3
Findings of the Evaluation Process

Topic	Findings	Supporting data
Design	GLUEPS-AR enabled a non-ICT-expert teacher to deploy his across-spaces learning designs in different ULEs	Art 1, Screen 1, Obs 1, Art 2, Screen 2, Obs 2, Art 3, Screen 3, Quest 1, Int 1
Management	GLUEPS-AR helped the pre-service teacher to manage the whole learning situation, from design to enactment	Screen 2, Art 3, Screen 3, Obs 2, Quest 1, Int 1
Adaptation	GLUEPS-AR supported the adaptation of the design before, during and after the enactment sessions	Art 4, Obs 3, Art 6, Quest 1, Int 1
Awareness	GLUEPS-AR allowed the pre-service teacher to be aware of the students' actions at the web space during and after the end of the activities, and of the students' performance at the physical space after the activities had finished	Obs 3, Quest 1, Int 1
Roles	GLUEPS-AR provided students with a certain degree of flexibility to self-regulate their learning artifacts, allowing the pre-service teacher to share the management load with them	Obs 3, Art 5, Art 6, Quest 1, Int 1
Pragmatism	GLUEPS-AR complied well with the constraints of the pre-service teacher, the institution, and the educational contexts involved	Art 1, Screen 1, Obs 1, Art 2, Art 3, Screen 3, Obs 2, Obs 3, Quest 1, Int 1
Alignment	GLUEPS-AR enabled the creation of a ULE combining the different physical and virtual spaces, helping achieve the learning objectives and the engagement of the students	Obs 3, Art 5, Quest 1, Int 1, Int 2
Theories	GLUEPS-AR allowed the pre-service teacher use the pedagogical and organizational approaches he wanted to use	Quest 1, Int 1

TABLE 4
Limitations Found in the Evaluation Process

Topic	Limitations	Supporting data
Adaptation	Difficult use of GLUEPS-AR's user interface in mobile devices	Obs 3, Art 6
Awareness	Limited awareness provided by GLUEPS-AR during the activities in physical spaces	Quest 1, Int 1
Pragmatism	Connection and performance problems in the outdoor uploading of artifacts	Obs 3
Pragmatism	User interface terminology not adequate for participants	Obs 3
Roles	Excessive additional lecture time required for increasing the students' flexibility in the management of learning artifacts	Int 1

He also reported in the questionnaire as well as in the interview that GLUEPS-AR allowed him to "make real" his conceptual design (e.g., he answered 6, "*Strongly agree*", in a 1-6 scale to the assertion "With the systems used I was able to deploy a learning design involving multiple virtual and physical spaces" [Quest 1]; in an interview, he answered "*[. . .] it [GLUEPS-AR] helped me a lot. Apart from the tools that I was able to use to put the activities into practice, it also supported me in creating a wiki [course], and have all the activities organized*" to a question regarding the support provided by GLUEPS-AR to the design and enactment of the activities [Int 1]). The pre-service teacher also reported, both in the questionnaire and the interview, that he would not have been able to deploy and conduct his learning design in the ULE without GLUEPS-AR (he answered 2, "*Disagree*", in a 1-6 scale to the assertion "I would have been able to perform the learning situation without GLUEPS-AR", explaining his response: "*I don't know another way of putting together all tools that were integrated, and in a same wiki*" [Quest 1]; in the interview, he explained "*I wouldn't have been able [without GLUEPS-AR]. I guess that there may be other methods for creating wikis, such as wikispaces [. . .], but with wikispaces [. . .] I think it wouldn't have provided so many possibilities like GLUEPS-AR does*" [Int 1]). Thus, the pre-service teacher did not have severe problems to transform, with the help of GLUEPS-AR, his conceptual design into a deployed course in the ULE. The creation of the course, however, required a certain previous effort to review other across-spaces designs and to test GLUEPS-AR so as to be aware of its possibilities. This conceptualization part was the most challenging for him.

4.2.1 T2. Management

This orchestration aspect refers to the regulation of the learning activities, which involves issues related to the management of the classroom, time, groups, tools or artifacts. The pre-service teacher indicated that *GLUEPS-AR helped him to manage the whole learning situation, from design to enactment*. Thus, for instance, he answered 5, "*Agree*", and 6, "*Strongly agree*", in a 1-6 scale, to the assertion "The systems used helped me to manage the learning situation from its design to its enactment", and to the same assertion regarding the management during enactment, respectively [Quest 1]; in the interview, he specified "*It allows to create various groups in every activity. Then, you can define a different artifact for every group. The setup of the resources is also very interesting, for instance, Google Docs, which could be reused in the next activity. You do not need to do it again. What you did in the first activity could be directly reused in the other. This helps you save a lot of time*" [Int 1].

An important aspect of management is the time a teacher spends in the implementation of a scenario. The pre-service teacher spent 3 h 42 min in the first phase of the design and deployment, and reported 24 hours in total devoted to the implementation of the learning situation [Art 3, Screen 3, Quest 1]. This included the time spent with PPC and GLUEPS-AR to design and deploy the initial idea, and the time dedicated to modifications and revisions using GLUEPS-AR and the wiki during the enactment sessions. These numbers contrast with the time dedicated by a member of the evaluation team to deploy the same learning design (53 min) [Screen 2]. The difference between these two time lengths is very large, and we sought to understand the reasons for this difference by analyzing the observations and the final interview with the pre-service teacher. It was found out that this extra time could be attributed in part to the initial learning curve of GLUEPS-AR, and mainly to the fact that the pre-service teacher worked out the conceptual design in parallel to the deployment and enactment of the activities (e.g., the first 1 h 4 min of the deployment session were devoted to reflect about the design and the options for its technological implementation [Screen 3]; in the deployment session it was observed that the pre-service teacher still needed to clarify his ideas: "*There is discussion about how does the teacher implement the routes (with geoposition, with markers, etc). It seems that the pre-service teacher is not sure about the concrete implementation yet*" [Obs 2]). In spite of this long time, the pre-service teacher reported that "*The time, in the end, is not much time. It is only that at the beginning it is difficult to learn how to manage everything. For instance, things related to the buckets. But when you learn, it doesn't take a lot of time. Actually, it is totally worth it*" [Int 1].

4.2.4 T3. Adaptation

Teachers should have support for adapting the design to different contexts, and in the face of emergent circumstances during the learning activities themselves. Evaluation showed that *GLUEPS-AR supported the adaptation of the design before, during and after the enactment sessions*. Throughout the five enactment sessions, several expected and unexpected events occurred, which required changes using GLUEPS-AR. For instance, the pre-service teacher positioned some artifacts in a physical space to be accessed using AR, making them not accessible from the wiki (sometimes on purpose, sometimes by mistake); however, students required access to such artifacts in the classroom. The pre-service teacher just modified the accessibility of the artifacts in GLUEPS-AR and re-deployed (e.g., "*The pre-service teacher accesses GLUEPS-AR to modify the learning design and deploy it again. He does it in less than four minutes*" [Obs 3—Session 3]; "*[. . .] again, we had to modify things in the platform, because there were hidden resources*" [Art 6—Session 5]). This runtime adaptability of the visibility of the design elements from different spaces was critical during the Orientate!

scenario. Aside from this kind of enactment-time changes, the pre-service teacher changed and adjusted several times the learning design before and between the enactment sessions [Art 2, Art 4]. This was acknowledged by the pre-service teacher in the questionnaire (he answered 5, "*Agree*", in a 1-6 scale to the assertion "I think GLUEPS-AR allows to perform unexpected changes during the learning activities", and he specified that "*Aside from making changes during the activities, there is a possibility of performing modifications before and after the end of the activities [...] In addition, making changes on-the-fly avoided setbacks and even the cancellation of part of the activities*" [Quest 1]).

Regarding adaptation support, the main limitation was found in *GLUEPS-AR's user interface (employed by the teacher for orchestrating), as it was not usable in mobile devices* (due to the version of the Javascript framework used). Thus, certain modifications regarding unexpected events during the fifth session in the park had to be performed remotely using a PC, instead of on site using a tablet (e.g., "*[...] the group that did not perform the task in the right way had confused places in the map of their zone, and some marker contents didn't match with points in the map. Thus, one of my colleagues-observers had to call one of his colleagues, to change everything from his computer*" [Art 6—Session 5]).

4.2.5 T4. Awareness

Teachers need to be aware of what is happening (or has happened) in a learning activity. This information may help intervene in case something goes wrong, to provide formative assessment, or to evaluate what is going on. Awareness can be provided *during* and *after* the end of the activities. The evaluation showed that *GLUEPS-AR allowed the pre-service teacher to be aware of the students' actions at the web space during and after the end of the activities, and of the students' performance in the physical space after the activities had finished*. The pre-service teacher answered 5, "*Agree*", in a 1-6 scale, to assertions regarding whether he considered that the system allowed him to be aware *during* the activities about what students were doing in virtual spaces, and *after* the end of the activities about what students were doing in physical and virtual spaces; also, in the interview, he explained that "*when activities are being performed in web sites, yes [I am aware], because, using the teacher's view, I manage directly all the groups, and [...] while everybody is creating question 2, I am able to enter in every group and see question 1 from the teacher view [...]*" [Int 1]. The wiki created with the help of GLUEPS-AR acted as a kind of control-panel, since it compiled the resources created in different spaces (e.g., he asserted "*[...] access the wiki again, and it allowed me to see if they had uploaded all the pictures [...], this even after finishing the activity, when the children were resting [...]. While they are working in the web space and after the end of the activities in physical spaces it is easier to control them*" [Int 1]; in addition, it was observed that "*The pre-service teacher is uploading the maps in the tablets' gallery and taking pictures of the paper sketch-maps, uploading them too. This way, everything is automatically integrated in the wiki*" [Obs 3—Session 2]). Nevertheless, although the wiki and GLUEPS-AR enabled the pre-service teacher to structure and access the different artifacts generated by students, he did not have much time during the sessions to monitor the activity of the students through these systems. The evaluation showed also that *GLUEPS-AR provided very limited awareness during the activities in physical spaces*. This limitation prevented the pre-service teacher, for instance, to be aware of the whereabouts of the different students or groups, or what artifacts were being accessed (e.g., the pre-service teacher said in the interview, when asked about the awareness in physical spaces, that "*in the physical spaces I think it [GLUEPS-AR] doesn't provide so many possibilities, because you have everything set up, [...]. Once started, in the physical spaces it is very difficult to follow them [students]*" [Int 1]). This lack of awareness may be a limitation for the assessment in cases where there is only one teacher, and groups of students are distributed over a large area.

4.2.6 T5. Roles

This aspect emphasizes the roles that teachers and other actors take in the orchestration. In the evaluation we gathered evidences pointing out that *GLUEPS-AR provided students with a certain degree of flexibility to self-regulate their learning artifacts, allowing the pre-service teacher to share the management load with them*. GLUEPS-AR's support for management load sharing was mainly due to the use of learning buckets (see Section 3) (the pre-service teacher answered 4, "*Somewhat agree*", in a 1-6 scale to the assertion "The systems used allow to transfer part of the management load to the students, e.g., taking decisions about the learning artifacts or performing operations over the artifacts, such as create or modify them" [Quest 1]; also, in the interview he specified that "*I shared with them part of the load, but in this case I have not shared much. [...] I created the bucket with five Google Docs and they just had to open and fill them [...]. The pictures were taken by them [...] I just explained how to handle the bucket, and they named and uploaded the pictures*" [Int 1]; the students' notebooks also illustrate this self-regulation: "*We were the first group that finished, so while the rest were completing their tasks, we uploaded the pictures to the [wiki] web*" [Art 5]). By using buckets, GLUEPS-AR allowed the teacher to give responsibility to students, and allowed the students to take their own decisions about artifacts. This seemed to favor student engagement and motivation (e.g., the pre-service teacher answered 4, "*Somewhat agree*", in a 1-6 scale to the assertion "I think that the system allows to give more responsibility to students, allowing them to take decisions about artifacts" [Quest 1]; in the interview he explained "*[...] enabling them to create a [orienteering] route is not only useful for putting into practice the theoretical knowledge, but also is motivating for them. Not just to give them existing maps, but also enable them to create the maps. [...] The fact of giving them the freedom of being responsible for the success of the activity is motivating for them. And it is also interesting because the entire group gets involved*" [Int 1]; in addition, it was observed that "*Group 2 is sharing out the writing of the questions and their inclusion in the web by means of the bucket. They are passing the laptops from one student to another around the table. They seem to be self-regulating well*" [Obs 3 – Session 4]; also, one of the observers asked the children about this: "*To confirm whether the children understand what they are doing, I ask them. All of them answer correctly that they are generating the questions that the other group will have to solve*" [Obs 3 – Session 4]). We also found that *due to time restrictions, the pre-service teacher limited*

the flexibility offered to the students (e.g., he created the Google Drive documents and positioned them in AR markers, for the last activity in the park, instead of asking the students to do it): "*It would have been possible to give them more [freedom], but I didn't do it because of their age and the additional lecture time it would have supposed*" [Int 1].

4.2.7 T6. Pragmatism

The pragmatism orchestration aspect highlights the importance of keeping in mind the constraints of authentic educational settings. Regarding this aspect, the evaluation showed that *GLUEPS-AR complied well with the constraints of the pre-service teacher, the institution, and the educational contexts involved*. The pre-service teacher, a non-ICT-expert, reported that GLUEPS-AR is easy to use and he would use it again in the future, although it has an initial learning curve (e.g., he answered 5, "*Agree*", in a 1-6 scale to the assertion "I think that the system is easy to use for non-ICT-expert teachers" and answered 6, "*Strongly agree*", to the assertion "I would use the systems again in my practice" [Quest 1]; in the interview, he answered "*The creation of artifacts and all that is very easy when you learn how to do it. [...] Maybe the first activity or the first session was difficult, but after that, the rest were very easy*" [Int 1]). He also acknowledged that GLUEPS-AR does not restrict the range of applicability to a single type of across-spaces learning situation, ULE, social level (e.g., individual or group) or pedagogical approach (e.g., the pre-service teacher answered 5, "*Agree*", or 6, "*Strongly agree*", in a 1-6 scale the questions regarding the range of applicability of the system [Quest 1]). This range of applicability allowed him to design a learning situation compliant with the official curriculum, the institution educational program, and the technologies and spaces he wanted to use.

During the study we detected also *connectivity and performance problems in the functionality related to the outdoor uploading of artifacts* (in uploading pictures to Picasa). Although they did not affect the enactment of the activities negatively, it is a limitation that could be detrimental to other contexts or learning situations. Another limitation was *the terminology used by the system user interface, which was sometimes not familiar for the participants*. An example is the term "artifact" (e.g., "*a child is joking with the word artifact*" [Obs 3—Session 5]). This limitation points to the need of adapting the tools and their user interfaces better to the educational contexts they are meant for.

4.2.8 T7. Alignment

Another orchestration aspect is how to align (or coordinate) the different elements to be orchestrated in order to achieve the learning goals. The analyzed data evidences that *GLUEPS-AR enabled the creation of a ULE combining the different physical and virtual spaces, helping to achieve the learning objectives and the engagement of the students*. GLUEPS-AR helped create a continuous learning experience in the multiple activities carried out in different spaces (e.g., the pre-service teacher answered 6, "*Strongly agree*", in a 1-6 scale to the assertion "The system allows a continuity between the activities performed in different physical and virtual spaces" [Quest 1]; he also said in the interview "*What was created in web spaces passed to the physical ones, and everything created in the physical space, like the pictures, could go directly to the web space. [...] the transition between classroom and outdoor was... everything complemented very well, and I think that the activity was like a whole, and it followed an order*" [Int 1]). In addition, both, the pre-service and the in-service teachers acknowledged that the engagement of the students was favored by the technology and the ULE [Quest 1, Int 1, Int 2] (e.g., the in-service teacher recognized that "*at the beginning it seemed that those things were not going to be appealing to the children: the orienteering, which was new to them, [...]. But with the technology they liked it much more*" [Int 2]), which was also noticed in the observations and the students' notebooks (e.g., it is illustrated with some of the students' comments: "*These have been the best sessions of physical education of the world [...]. It has been very funny and very cool*", "*We had a very good time conceiving clues and difficult challenges [...]. Above all and first of all, it was great. It was very funny [...]. The class: The best of the year*" [Art 5]; also, from observations: "*I ask a girl from group 3: What is the thing you liked or attracted your attention more in the session? She answers: to use the tablet for orienteering*" [Obs 3—Session 2]; "*The 3G connection of the tablets has not failed and so far the activity is being developed without a hitch. Students seem to be very motivated and they are running from one marker to another*" [Obs 3—Session 3]). Also, both the pre-service and the in-service teacher reported that GLUEPS-AR and the learning situation helped achieve the learning objectives (e.g., the pre-service teacher answered 5, "*Agree*", or 6, "*Strongly agree*", in a 1-6 scale to assertions related with the achievement of the objectives and if GLUEPS-AR and the learning situation facilitated it [Quest 1]; in the interview, asked about the achievement of the learning objectives, the in-service teacher answered "*Yes [the learning objectives were achieved]. I think that [they were achieved] more than enough*" [Int 2]).

4.2.9 T8. Theories

Finally, this aspect deals with the models and theories regarding how orchestration should be performed. Beyond theoretical considerations or measurements of the orchestration itself, we focus on exploring whether the teachers were able to use the pedagogical and organizational approaches they wanted to use or not, i.e., whether the orchestration technology altered the way they would orchestrate similar learning situations. Evaluating this aspect we can detect, for example, if a technology helps a teacher in all the rest of aspects, but it forces him to change his intended way of working, which might lead to the teacher not adopting the technology in his practice. In this sense, evidence shows that *GLUEPS-AR allowed the pre-service teacher to use the pedagogical and organizational approaches he wanted to use* (he answered 6, "*Strongly agree*", in a 1-6 scale to the assertion "The systems allowed me to put into practice the pedagogical approaches that I wanted to use", and he answered 2, "*Disagree*", to the assertion "The system forced me to organize student work in a different way than I'm used to" [Quest 1]). However, since the pre-service teacher was not very experienced in teaching, it would be interesting to explore this aspect with more veteran teachers, who may have more rigid organizational and pedagogical beliefs.

5 Discussion, Conclusions, and Future Work

Orientate! is an innovative learning scenario that took place in multiple physical and virtual spaces, involving a wide ecology of technological and social resources. It was created and enacted by a non-ICT-expert pre-service teacher within the official curriculum and classroom hours. This scenario poses several orchestration challenges, that we structured using the '5 + 3' orchestration framework, including: the preparation of activities to be implemented with multiple technologies in multiple spaces (*design*), the need to modify the learning design and the accessibility to its artifacts from different spaces (*adaptation*), the sharing of the orchestration load with students (*roles*), or the coordination of resources in different spaces toward scenario's learning goals (*alignment*).

The ubiquitous orchestration technology used in our study, GLUEPS-AR, provided the pre-service teacher with support for the multiple orchestration aspects highlighted in the '5+3' orchestration framework. The system made the across-spaces learning situation feasible for him, and aided him to take advantage of such heterogeneous resources. The pre-service teacher imported into GLUEPS-AR a learning design created with an (external) existing authoring tool, and completed it with spatial information. Also, GLUEPS-AR integrated the wiki-based VLE, the Web 2.0 tools and the AR client, following the instructions of the teacher's learning design, thus fostering a seamless learning experience. The learning buckets embedded in the resulting ULE allowed the students and the teacher to create learning artifacts in different spaces during the enactment, thus sharing the orchestration load. Besides, GLUEPS-AR helped the teacher in other orchestration aspects, such as in the runtime adaptation of the different design elements, as well as the structuring, management, and automatic deployment of the activities, groups and resources. Also, GLUEPS-AR allowed the teacher to choose between multiple existing authoring and enactment tools (e.g., PPC, a wiki, Junaio, Google Drive), facilitating the fulfillment of the theoretical (e.g. promotion of collaborative learning) and pragmatic (e.g. the involvement of non-ICT-expert teachers and students) requirements of the context, teachers and institutions.

The evaluation process presented in this paper illustrates certain lessons, which may be useful for other research efforts in the orchestration of ULEs. One such lesson is that *the design of the learning situation in a ULE was challenging* for the pre-service teacher in its very conceptualization, due to the new possibilities opened by GLUEPS-AR in across-spaces scenarios. We have also seen how *ULEs may be highly prone to unexpected events and technology failures*. In our case, the capability of changing the design and the accessibility of artifacts in different spaces during runtime was critical to avoid breakdowns. Teachers should also be able to make these changes from the different spaces (e.g., with a mobile device while being outdoors). We have also realized that *technology (e.g., AR) could help teachers avoid the current lack of awareness* when several spaces are used in an activity, or when a space has intrinsic difficulties for the teacher perception. Thus, for example, we could help teachers by providing them with runtime awareness during activities in physical spaces. In addition, the Orientate! scenario *required a degree of student self-regulation*, to create the orienteering routes and challenges, as well as to upload their pictures. It is worth noticing that the orchestration system enabled such self-regulation, allowing the pre-service teacher to decide the desired degree of self-regulation. Another lesson learned is that *an orchestration system* like GLUEPS-AR *may transform a set of independent spaces into a unique ULE*, with seamless transitions between the spaces, *enabling the participants to focus on their learning goals instead*, and helping achieve the benefits of a seamless learning across spaces [9]. It is also interesting to highlight the *intrinsic difficulties of evaluating an across-spaces learning situation* like the one described. The Orientate! learning situation required students to work in groups in different physical and virtual spaces using multiple technologies. Hence, a high number of evaluators were needed to be able to observe the different actors simultaneously (e.g., up to five observers in one of the sessions).

It is important to mention that researchers, occasionally, had to help teachers to solve certain technical problems. Thus, although the researchers had the main role of observers, we had to take part occasionally during enactment (e.g., modifying the resources' accessibility using the GLUEPS-AR user interface from a computer in an outdoor session, or reminding the pre-service teacher about how to perform a certain operation in GLUEPS-AR). These participatory observations helped move the learning situation onwards, avoiding breakdowns when facing an identified limitation or a prototype technological fault, which, once detected, was not relevant for evaluation purposes.

A major concern raised by the evaluation was the long time reported by the pre-service teacher for the conceptualization, implementation, changes and revisions of the learning situation. The evidence gathered points out that this excessive time was due to three main factors. In part it was due to the learning curve of all the new technologies used by the teacher (not only GLUEPS-AR as an orchestration system, but also Junaio, some Web 2.0 tools or wiki functionalities were novel for the teacher). The evaluation showed how well the teacher appropriated GLUEPS-AR, being finally independent in its use. A second factor was that he reflected severely and took critical decisions about the learning design while he was making it explicit and deploying it. This was especially important in this case, since he was not an experienced teacher and making certain decisions proved difficult for him. It is a well-known fact that learning design approaches impose an additional effort in the preparation of activities. However, as exemplified by the teacher's positive comments, this extra time can be acceptable if the teacher perceives that the results are worth it. A last factor, related also to the teacher relative lack of experience, was that GLUEPS-AR opened new possibilities, enabling him to connect the activities in different spaces, and to use innovative technologies such as AR (as the teacher mentioned in his final reflections). He had to internalize, embrace these new possibilities, which represented still more aspects to reflect about, before finally materializing the final learning situation. Nevertheless, these results point to a line of further research, focused on the analysis of whether more experienced teachers are able to appropriate these technologies more effortlessly.

We consider that an evaluation like the one performed here, exploring the support provided by a system to the

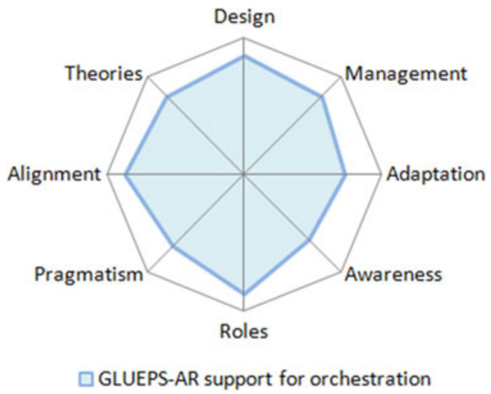

Fig. 6. Radial diagram of GLUEPS-AR's support for orchestration

different aspects that can be encompassed under the orchestration metaphor, may be extended to systems not explicitly designed to cover the whole spectrum of orchestration aspects. Hence, any orchestration technology could benefit from an exploration of how it affects the different aspects of orchestration, and especially those that technology is not designed for: a technology focused in supporting the awareness aspect could be detrimental for other aspects, such as management, and this fact could remain unnoticed if the evaluation is centered solely in the awareness support. A holistic evaluation like the one performed can be visualized with the radial diagram showed in Fig. 6. The diagram represents the authors' subjective understanding of the evaluation results, summarizing GLUEPS-AR's orchestration support. It was created by the evaluation team in a panel, after discussing the evaluation results. The figure shows that the orchestration aspects better supported by GLUEPS-AR are *design*, *alignment* and *roles*. On the other hand, the main aspect to improve is the *awareness* (due to the limited awareness during activities in physical spaces), as well as the prototype implementation limitations described in Section 4 about GLUEPS-AR's user interface in mobile devices (affecting the *adaptation* aspect), and the outdoor uploading of pictures (affecting *pragmatism*).

There is a tension between trying to cover the complete spectrum of orchestration (all its aspects) through a single feature-filled system, or by means of many simpler, different ones. On the one hand, a single system avoids the problem of learning how to use multiple orchestration technologies. On the other hand, trying to cover all the orchestration aspects in depth with a single proposal may produce extremely complex systems, with possible scalability and integration drawbacks. We plan to further explore this tension in the future.

We also plan to conduct, using GLUEPS-AR, other learning situations in different ULEs (e.g., ULEs involving also 3D virtual worlds) and educational contexts. We expect this will allow us to obtain a deeper knowledge about how technology may help teachers in the orchestration of ULEs. Another path for future research work has to do with the quantification of the support provided to different orchestration aspects, which could lead to a more precise radial diagram, similar to the subjective one in Fig. 6. This could aid, for instance, to identify what actions may help or be detrimental in a certain orchestration aspect, enabling comparisons among different orchestration technologies. Also, further research could lead to a classification of possible components of each aspect of the 5+3 orchestration framework, since in some cases we found difficulties in mapping a finding with an orchestration aspect. Moreover, we are already exploring how to provide evaluators with better tools for a more efficient evaluation process in across-spaces learning situations. The present study and the lessons learned from it, together with other past and future research in this emerging field, could lead to a set of design principles for creating orchestration systems for ULEs.

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Juan A. Muñoz-Cristóbal received the BS degree in telecommunications engineering and the MSc degree in ICT research from the University of Valladolid, Spain, in 1998 and 2010, respectively, and the MSc degree in free software from the Open University of Catalonia, Spain, in 2010. After 10 years working as an engineer in telecommunication service providers, he joined the GSIC-EMIC research group at the University of Valladolid, where he is carrying out a PhD Thesis in technology enhanced learning.

Iván M. Jorrín-Abellán received the PhD degree from the University of Valladolid, Spain, in 2006. He is an associate professor of Qualitative Research Methods at Kennesaw State University. He is the former director of the Center for Transdisciplinary Research in Education (CETIE-UVa) at the University of Valladolid (Spain). His current research is devoted to the study of the educational implications of Computer-Supported Collaborative Learning scenarios, with special attention to new ways of evaluating these particular settings.

Juan I. Asensio-Pérez received the MSc and PhD degrees in telecommunications engineering from the University of Valladolid, Spain, in 1995 and 2000, respectively. He is currently an associate professor of telematics engineering at the University of Valladolid. His research interests within the field of Technology-Enhanced Learning include: Computer-Supported Collaborative Learning (CSCL) scripting, the integration of external tools in Virtual Learning Environments, the technological support for the orchestration of CSCL situations, the semantic annotation of learning tools in the Web of Data, and the application of Augmented Reality technologies for the support of CSCL situations across multiple virtual and physical spaces.

Alejandra Martínez-Monés received the PhD degree from the University of Valladolid, Spain, in 2003. She is an associate professor of computer science at the University of Valladolid. Her research interests in the field of Technology-Enhanced Learning relate to how to use computers to support teachers and students in the application and evaluation of innovative teaching and learning strategies, especially CSCL situations. Her research contributions include the use of social network analysis to support the evaluation of CSCL environments; the integration of scripting and monitoring strategies to enhance classroom orchestration, the use of augmented reality to support seamless integration of learning spaces; and the application of mixed methods to evaluate CSCL and other complex learning situations.

Luis P. Prieto received the PhD degree in ICT from the University of Valladolid, Spain, in 2012. Before receiving the PhD degree, he worked as a research and development engineer for nine years. He is currently a Marie Curie postdoctoral fellow at the École Polytechnique Fédérale de Lausanne, Switzerland. His primary research interests include the orchestration of TEL and CSCL activities, professional development to support technological change, and the application of augmented reality, paper, and tangible interfaces to education.

Yannis A. Dimitriadis received the BS degree from the National Technical University of Athens, Greece, in 1981, the MS degree from the University of Virginia, in 1983, and the PhD degree from the University of Valladolid, Spain, in 1992, all in telecommunications engineering. He is currently a full professor of telematics engineering at the University of Valladolid. His research interests include technological support to the orchestration of computer-supported collaborative learning processes. He is a senior member of the IEEE.