Learning Buckets: Helping Teachers Introduce Flexibility in the Management of Learning Artifacts Across Spaces

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Abstract—Technology offers rich opportunities for learning across different physical and virtual spaces. However, most of current across-spaces proposals are either highly teacher-centered, inflexible in the students' self-management of learning artifacts during the enactment, or allow the teacher little/no control of such students' management of artifacts. Moreover, these proposals tend to be disconnected from the practices and tools that are usual in the classroom. How can we achieve a middle ground between keeping the teacher in control of across-spaces situations and, at the same time, providing students with a degree of flexibility to manage learning artifacts? Aiming to address such a challenge we propose the notion of learning bucket, and the Bucket-Server, a system implementing such a notion. A learning bucket is a container of learning artifacts which are generated and/or accessed across-spaces by the students during the enactment, according to constraints configured by teachers at design time. The responsive evaluation conducted, based on a feature analysis and a pilot study with experts, suggests that learning buckets can help evolve from teacher- to student-centered approaches, while maintaining the teacher in control of students' actions. The evaluation also indicates that the Bucket-Server surpasses the support provided by alternative proposals to across-spaces learning.

Index Terms—Artificial, augmented, and virtual realities, Computer uses in education, education, Ubiquitous computing, mobile environments

1 Introduction

Technologies like mobile devices, Virtual Learning Environments (VLEs) [1] and Augmented Reality (AR) [2] are blurring the walls of the traditional classroom and helping shape Ubiquitous Learning Environments (ULEs) [3] by combining seamlessly different physical and virtual learning spaces [4], [5]. Although ULEs have shown affordances for learning (e.g., regarding accessibility, immediacy, permanency, interactivity, and situation [6]), they are also complex environments that pose challenges for teachers to develop meaningful learning situations [5]. To help teachers create these across-spaces learning situations (i.e., learning situations that seamlessly integrate activities taking place in the different physical and virtual spaces that make up a ULE), many systems have been proposed that include authoring tools to translate the teachers' pedagogical ideas into a format interpretable by computers [7], [8], [9], [10]. These proposals usually force students to follow a learning design in which most details (e.g., the tools to be used, such as Google Docs[1], or the concrete learning artifacts to be used by specific students, such as a concrete Google Docs document) are specified a priori, thus limiting student autonomy during the enactment. This "agency issue" is defined by some authors [4] as a clear challenge for practitioners that try to enact across-spaces learning situations. Although a certain level of guidance, or scaffolding, may be desirable in some pedagogical approaches (such as in collaborative learning by using scripts [11]), too much coercion can prevent natural student interactions that are known to promote learning [12]. Therefore, a certain level of flexibility might be desirable in order to enable teachers and students to introduce modifications in the designed learning situation, without altering its pedagogical intention [13]. On the other hand, too much freedom could eventually end up with a situation in which students perform learning tasks (and even interact among them) in a way that does not reflect the pedagogical intentions and the learning goals of the teacher [13]. Therefore, there is a need for a compromise between flexibility and guidance, which should be defined by the teacher based on her pedagogical intentions. Such flexibility should involve only those elements of a learning situation that do not alter its pedagogical essence [13]. In this paper, we focus on the flexibility during the enactment regarding the use of *learning artifacts*: initial resources created by the teacher, as

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1. http://www.google.com/docs/about/. Last accessed December 2016.

well as intermediate products and final outcomes of the learning process that can be created by the students and shared across activities and spaces. Due to their role as mediators in the learning activities [14], [15], learning artifacts are important elements in different pedagogical approaches, such as Computer Supported Collaborative Learning and Inquiry Based Learning [16], [17].

Some of the proposals enabling teachers to create across-spaces learning situations implement also mechanisms to provide a certain degree of flexibility during the enactment in the students' use of *learning artifacts* [5], [18], [19]. However, these proposals usually have a limited support for teachers to regulate the degree of flexibility offered to the students [11], [13]. In addition, these approaches take usually the form of ad-hoc systems, isolated from other activities and systems used in teachers' current practice (e.g., the official VLE of their institution), which can negatively affect teachers' orchestration load [24]. In the present paper we address the research question of *how technology can help introduce flexibility in the management of learning artifacts during the enactment of across-spaces learning situations, guided by the teachers' pedagogical decisions, and in a way that is integrated within the teachers' current practice*.

In order to help address this issue we propose the notion of *learning bucket*, and the *Bucket-Server*, a system that implements the aforementioned notion. A *learning bucket* is a container of positioned learning artifacts (i.e., learning artifacts tagged with space coordinates) that is configured by teachers with *constraints* that limit what the students can do within it. Learning buckets are included by teachers at design time in the activities of their learning designs. During the enactment, the students generate and access across-spaces the buckets' artifacts. For example, an artifact like a Web 2.0 tool instance (e.g., a Google Docs document or a Flickr[2] picture) could be generated by students and tagged with geographical coordinates from within a web-based VLE, and be accessed afterwards by other students using AR at the physical location corresponding to the coordinates. The *Bucket-Server* -the system implementing the notion of learning buckets- enables the integration of learning buckets into different existing software applications created to be used in specific learning spaces (e.g., VLEs in web spaces, AR apps in physical spaces). We evaluated the Bucket-Server by means of a feature analysis (a systematic comparison of the proposal with alternatives in literature) and a pilot study in which experts in across-spaces learning used a Bucket-Server prototype and gave feedback.

The structure of the rest of the document is as follows. The next section presents related work and design requirements proposed for overcoming identified limitations of existing approaches. Section 3 describes the notion of learning bucket and the Bucket-Server system. The evaluation conducted is explained in Section 4, and finally, Section 5 summarizes the main conclusions obtained, as well as the main paths for future work.

2 Related Work and Limitations

2.1 Approaches Providing a Flexible Management of Learning Artifacts During the Enactment

Many approaches in the literature have proposed *solutions that enable the students a flexible management of learning artifacts during the enactment of learning situations*. Most of them have focused on web spaces, although there are a number of approaches supporting different physical and virtual spaces.

Among those proposals focused on web spaces and enabling the students a flexible management of learning artifacts during the enactment, there are approaches: i) based on learning design languages, that adapt the activities at runtime according to decisions taken at design time [16], [25], [26], [27], [28], [29]; ii) enabling students to "upload" to a VLE artifacts created with general purpose tools (such as Microsoft Office) or ad-hoc authoring tools [30], [31], [32], [33], [34], [35], [36]; iii) enabling students to select their learning tools, and sometimes also to define the sequence of activities (these are also known as Personal Learning Environments, PLEs) [37], [38], [39], [40], [41], [42], [43], [44]; iv) enabling students to make explicit the learning design they want to conduct [45].

Among those proposals supporting across-spaces and enabling the students a flexible management of learning artifacts during the enactment, we find mainly: i) approaches (mostly for inquiry-based learning) supporting the data collection during field trips and later access to artifacts gathered using a web VLE [6], [17], [20], [21], [46], [47], [48], [49], [50], [51], [52]; ii) authoring tools enabling students to create virtual artifacts, and access them from a physical space using AR [22], [23], [53]; iii) mobile location-based educational games enabling students the collection of virtual objects, clues, etc. [54]; iv) authoring tools enabling students to create mobile location-based educational games [55].

2.2. Limitations of the Reviewed Approaches and Design Requirements

All the approaches reviewed in Section 2.1 enable the students some flexibility in the management of learning artifacts during the enactment of learning situations. However, many of the described approaches provide limited support for their use in *across-spaces learning situations*, preventing seamless transitions between activities conducted in different virtual and physical learning spaces [5]. Seamless learning can be facilitated by means of *context* awareness and adaptivity -i.e., by systems that are aware of the learner's situation, and that adapt the learning contents to such situation [3], [5]. Nevertheless, many of the reviewed approaches *do not enable teachers and students to position learning artifacts in different kinds of spaces, e.g., web and physical spaces (limitation 1)*. Also, different kinds of learning spaces and activities may entail different technological constraints for such context awareness and adaptivity [56]. Due to these constraints, in across-spaces learning situations the capability of supporting different technological options for context-awareness in different spaces can be relevant in many cases. Despite this fact, many approaches *do not support different positioning types, such as geo-position, markers, etc., (limitation 2)* or *do not enable teachers and students to access contextually the same learning artifact from different kinds of spaces, e.g., web and physical spaces (limitation 3)*.

In addition to the problems for supporting across-spaces learning situations, several approaches do not allow the *integrated use of technologies already existing in teachers' daily practice*. This can create seams in the operation of the different systems [57] and can impact negatively in the teachers' orchestration load [24]. This general problem of integration with teacher practice can be reified in two specific

2. https://www.flickr.com. Last accessed December 2016.

TABLE 1
Design Requirements Proposed To Support Across-Spaces Learning Situations that Include Teacher-Controlled Flexibility and the Students' Management of Learning Artifacts During the Enactment

DR1. Enable teachers and students to position learning artifacts in different kinds of spaces (e.g., web and physical spaces)
DR2. Support different positioning types (geoposition, markers, etc.)
DR3. Enable teachers and students to access contextually the same learning artifact from different kinds of spaces (e.g., web and physical spaces)
DR4. Enable learning situations supported by different ICT-enabled learning environments commonly used in existing educational practice (e.g., multiple VLEs)
DR5. Enable the integrated use of multiple ICT artifacts and tools commonly used in existing educational practice, as is the case of those of the Web 2.0
DR6. Enable teachers to define multiple kinds of constraints (regarding technological choices, contextual factors, arbitrary decisions, etc.) in order to regulate what students are able to do with learning artifacts

limitations that affect most of the reviewed approaches: they *do not enable learning situations supported by different ICT-enabled learning environments commonly used in existing educational practice, e.g., multiple VLEs (limitation 4)*; and they *do not enable the integrated use of multiple ICT artifacts and tools commonly used in existing educational practice, as is the case of those of the Web 2.0 (limitation 5)*.

A final limitation has to do with the *capability for teachers to control the degree of flexibility offered to students*. An important aspect when giving flexibility to the students is enabling teachers to specify the type of flexibility they want to promote according to their pedagogical intentions without affecting the pedagogical essence of the learning design [11], [13]. This can be achieved by allowing teachers to configure "extrinsic constraints" (those not affecting the essence), such as those that refer to technological choices (e.g., tools to use), contextual factors (e.g., location) or arbitrary decisions (e.g., number of students per group) [13]. However, many of the approaches reviewed in Section 2.1 *do not enable teachers to define multiple kinds of constraints (regarding technological choices, contextual factors, arbitrary decisions, etc.) in order to regulate what students are able to do with learning artifacts (limitation 6)*.

From the six limitations identified in the previous paragraphs we can derive a list of Design Requirements (DR, see Table 1) that can provide an answer to the challenge of *supporting across-spaces learning situations that make an integrated use of technologies already existing in teacher practice, and include teacher-controlled flexibility in the students' management of learning artifacts during the enactment*. We conducted an initial screening of the support provided by the approaches reviewed in Section 2.1 to these design requirements (see Table A.1 in the Appendix, which can be found on the IEEE Xplore Digital Library at https://ieeexplore.ieee.org/document/7896594/), and we concluded that all the approaches lack support to many design requirements. Although this lack of support can be reasonable because the reviewed approaches might not have been created considering the challenge that we address in this paper, the screening highlights that the mentioned challenge exists. The following section describes the *learning bucket* notion and the system implementing it, which following the aforementioned design requirements, aims to address this challenge.

3 Learning Buckets

This section describes the proposed learning bucket notion and the Bucket-Server, a system implementing such notion.

3.1 What Is a Learning Bucket?

A *learning bucket* is a configurable container of learning artifacts that are positioned (i.e., tagged with space coordinates) in different physical and virtual spaces (compliant with **DR1**, see Table 1). A learning bucket is defined at design time. A teacher can include learning buckets (initially empty or with artifacts) in her design, assigning them, for instance, to different groups in different activities. At design time, the teacher can also configure the bucket with *constraints*, limiting what students can do within the bucket, for example, what types of artifacts can be included, how the artifacts can be positioned, the number of artifacts that might be generated, etc. The constraints, which can also be modified afterwards by the teacher, limit the flexibility offered to students, in order to promote the coherence of the students' actions with the pedagogical intention stated by the teacher at design time (**DR6**).

A learning bucket is an element that can be embedded in different third party applications. More specifically, it can be integrated into multiple types of applications for their educational use in different spaces (**DR4**): typical web-based VLEs (e.g., Moodle[3], Blackboard[4]), mobile AR clients (e.g., Layar[5], Argon[6]), etc. The teacher could decide at design time that a learning bucket will be reused in the same or different environment and space and by the same or different actors. In addition, a learning bucket supports the management -creation, deletion, positioning, etc.- of the multiple types of artifacts that can be included in a bucket -e.g., an implementation of the learning bucket notion could integrate artifacts of multiple widespread Web 2.0 tools (**DR5**). During the enactment of learning situations, teacher or students can add new learning artifacts, and position them in physical and virtual spaces (**DR1**).

Learning buckets allow students to take decisions with respect to the artifacts to use, always under the constraints imposed by the teacher. For instance, they could add new artifacts within predefined limits, they could position such artifacts with different methods (e.g., with geographical coordinates, with fiducial markers, etc.) (**DR2**), and in different physical and virtual spaces (e.g., in a physical space using AR, in a web VLE), or they could select the type of artifact to use. The learning bucket itself could also be positioned in a space. As an example of the applicability of the learning buckets, a group of students could access a bucket in a specific physical space (e.g., a park) using an AR app, and they could create, using the bucket, different artifacts (e.g., documents and pictures), which could be automatically positioned where they are created, or manually

3. https://moodle.org. Last accessed December 2016.
4. http://blackboard.com. Last accessed December 2016.
5. https://www.layar.com. Last accessed December 2016.
6. http://argonjs.io. Last accessed December 2016.

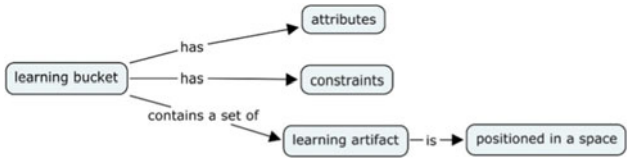

Fig. 1. Learning bucket conceptual model.

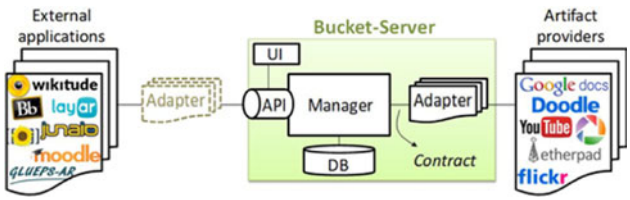

Fig. 2. Bucket-Server architecture.

positioned in another location and/or another space (e.g., a web-based VLE) (**DR3**) to be accessed subsequently.

Fig. 1 shows the conceptual model of a learning bucket. A bucket is characterized by a number of attributes (general properties of the bucket) and constraints (properties of the bucket that define what is possible to do in it). A bucket may contain a set of learning artifacts, which are positioned in virtual or physical spaces. A learning artifact can be any virtual resource: a document, a web page, a 3D model, a tool instance, or even another learning bucket.

3.2 Bucket-Server: A Learning Buckets Implementation

The *Bucket-Server* is a system implementing the proposed concept of learning buckets. It allows the management (create, modify, remove, retrieve) of both learning buckets and learning artifacts contained in the buckets, from within other software applications (e.g., VLEs, mobile AR clients, etc.). As aforementioned, such artifacts can be, for example, instances of Web 2.0 tools (e.g., Google Docs, Picasa[7] or Flickr), web resources (web pages, online documents), or other artifacts accessible through an URI (e.g., a 3D model in an online repository).

3.2.1 Bucket-Server Architecture and Data Model

Fig. 2 shows the architecture of the Bucket-Server. The *manager* is the controller of the system, responsible for managing learning buckets and their artifacts, and storing the information (buckets and logs) in the persistent *data base* (DB). It is the central element, with interfaces with *external applications* and *artifact providers*. The manager provides an *API* for the communication (directly or through *adapters*) with external applications (e.g., VLEs such as Moodle, mobile AR clients such as Layar, Wikitude[8], Argon, etc.) (**DR4**). The manager communicates also with artifact providers through another layer of adapters. These adapters standardize the operations of the manager over the different artifact providers, so that the manager can always use the same set of operations defined in a contract[9], independently of the API of each artifact provider. An artifact provider could be, for instance, a commonly used

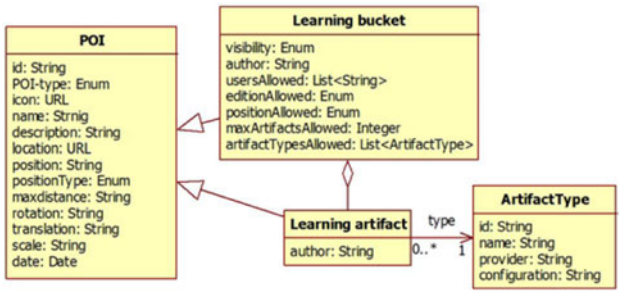

Fig. 3. Bucket-Server data model.

Web 2.0 tool (e.g., Google Docs) (**DR5**). The Bucket-Server has also a *user interface* (UI), which acts as a client of the manager, using the API to interact with it. The UI allows the graphical operation of buckets and their artifacts independently of the learning environment in which they are embedded.

Fig. 3 shows the data model implemented in the Bucket-Server. In order to enable the positioning and access of artifacts and buckets in different physical and virtual spaces (**DR1, DR3**), we have used the Point of Interest (POI) model [7]. Such POI model is comprised of the more common attributes present in different systems, data models and specifications[10] describing resources positioned in physical spaces. In the Bucket-Server data model, both learning artifacts and learning buckets are POIs, inheriting the POI's attributes (e.g., the attribute *positionType* which allows different positioning modes, such as geographical coordinates, QR codes, or fiducial markers, **DR2**). Additionally, as shown by Fig. 3, the learning bucket can contain learning artifacts. A learning artifact can be of different types, corresponding to the artifact providers integrated with the Bucket-Server (see Fig. 2). The information element *ArtifactType* identifies the type of artifact, its provider, and the configuration fields (which will be displayed in the UI) necessary to configure its artifacts. Besides the attributes inherited from the POI model, a learning bucket defines its own ones: *visibility* to enable the teacher to hide the bucket and its artifacts (e.g., in the sequence of activities of a VLE like Moodle); *author* (the user that created the bucket); and a set of attributes that define the constraints, restricting what is possible to be done in the bucket.

The data model is extensible and new attributes can be included in the data model. However, in order to facilitate the configuration of learning buckets by the teachers we have prioritized simplicity over completeness. Thus, the current implementation of the data model supports a set of constraints which can be complemented in the future with new ones, in case they are needed. The constraints that are included are listed below, classified according to the conceptualization of extrinsic constraints stated by Dillenbourg & Tchounikine [13] (see Section 2) (**DR6**):

- Regarding technological choices: *artifactTypesAllowed* - restrictions over the possible types of artifacts that can be used, among the set supported by the Bucket-Server installation.

7. https://en.wikipedia.org/wiki/Picasa. Last accessed December 2016.
8. http://www.wikitude.com. Last accessed December 2016.
9. Therefore, the contract is the set of expected behaviors and APIs that the adapters needs to implement to communicate with the Bucket-Server manager [58], [59].

10. It is interesting that a new IEEE Working Group is working in a model for AR Learning Experiences and in current drafts of the model they are also considering a notion of "Point of Interest" (see https://standards.ieee.org/develop/wg/AR-LEM.html and https://arlem.cct.brookes.ac.uk/, last accessed December 2016).

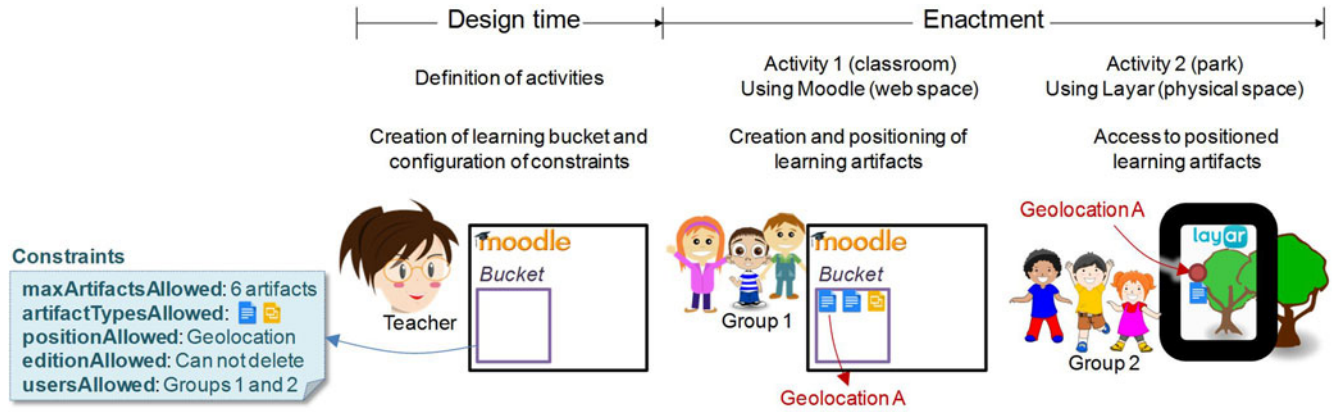

Fig. 4. Example of the use of a learning bucket.

- Regarding contextual factors: *positionAllowed* - restrictions over the *positionType* POI attribute.
- Regarding arbitrary decisions: i) *usersAllowed* - restrictions over the students allowed to access the bucket; ii) *editionAllowed* - possible operations that the students can conduct with artifacts, e.g., create, remove, etc.; iii) *maxArtifactsAllowed* - maximum number of artifacts that can be created in a bucket.

A learning bucket can be reused by the same or different applications, across multiple physical and virtual spaces, to achieve continuity in the different activities of a learning situation. Fig. 4 shows an example of the use of a learning bucket in a learning situation about botany. In the figure, the teacher defines at design time two activities in which a learning bucket will be used, the first one to be conducted in the classroom using Moodle, and the second one in a park using an AR app such as Layar [60]. She also creates a learning bucket from within a VLE such as Moodle (web space), and configures the bucket with constraints to limit what the students will be able to do. The teacher allows the students of *Groups 1* and *2* to create up to 6 artifacts in the bucket, of the types Google Docs and Google Slides. She also enables the students to geolocate the artifacts they create, and she does not allow students to delete artifacts. During the enactment, Group 1, using Moodle (Activity 1, web space) creates Google Docs and Google Slides with information related to a type of tree present in a nearby park. They also position such artifacts in the location of the trees using geographical coordinates. In Activity 2, Group 2, using Layar in the park (physical space), accesses at the location of the aforementioned trees the artifacts created by Group 1 in the previous activity.

3.2.2 Bucket-Server Prototype

We have developed a prototype of the Bucket-Server aiming to explore the learning bucket notion and its use in across-spaces learning situations. The technologies used in the prototype are Java for the manager and the adapters, HTML and Javascript for the user interface, and MySQL for the buckets database. We have created an artifact provider adapter for the GLUE! [61] Tool Mediator[11], enabling with a single adapter to include in the buckets all the artifact types supported by GLUE! (multiple Web 2.0 tools, widgets, etc.). Also, we have created an application adapter for the GLUEPS-AR system [7]. GLUEPS-AR is an across-spaces orchestration system that enables the deployment[12] of learning designs -which could have been defined in a variety of authoring tools- in ULEs composed of web VLEs and/or mobile AR clients. With the Bucket-Server prototype, learning buckets are used as any other learning artifact in GLUEPS-AR, and they can be included at any point of the design, being reused in different activities, etc. Since GLUEPS-AR supports across-spaces learning situations, once the buckets are created, they can be deployed into the learning environments supported by GLUEPS-AR (VLEs and mobile AR clients). For example, in the case of a VLE such as Moodle, the bucket would be embedded in the corresponding course deployed by GLUEPS-AR. As GLUEPS-AR integrates multiple VLEs (Moodle, Mediawiki) and multiple mobile AR clients (Junaio[13], Layar, Mixare[14], QR code readers) [60], learning buckets can be included in learning designs making use of any combination of all these applications. Thus, buckets and their artifacts can be positioned in different spaces (web and physical), and can be accessed (buckets and artifacts) from different spaces and positioning types (e.g., fiducial markers, QR codes, geoposition).

4 Evaluation

We have carried out an evaluation to explore the research question that guides our work:

How can technology help introduce flexibility in the management of learning artifacts during the enactment of across-spaces learning situations, guided by the teachers' pedagogical decisions, and in a way that is integrated within the teachers' current practice?

We formed an evaluation team composed of five researchers with different background (technological or pedagogical). The evaluation consisted of (1) a *pilot study with experts*, where the evaluation team performed an across-spaces learning situation in a workshop with a group of experts in the across-spaces learning field; and (2) a *feature analysis* in which

11. A Tool Mediator is an intermediary system that enables the integration of multiple tools with a single adapter [62]. We used GLUE! in the prototype in order to benefit from the existing GLUE! adapters, but any other Tool Mediator could be used.

12. I.e., the setting up of the technological implementation in which the enactment will be carried out.

13. https://en.wikipedia.org/wiki/Junaio. Last accessed December 2016.

14. http://www.mixare.org. Last accessed December 2016.

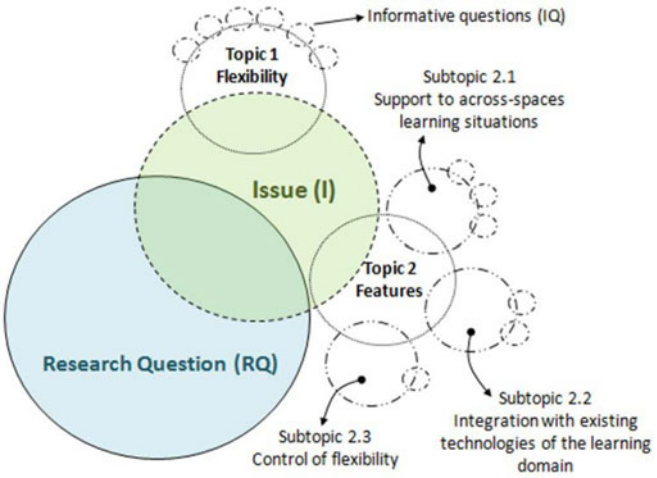

Fig. 5. Anticipatory data reduction showing research question (RQ), issue (I), topics, subtopics, and informative questions (IQ).

the evaluation team scored the support provided to the design requirements posed in Section 2, both by the Bucket-Server and by alternative approaches in the literature.

4.1 Method

For the evaluation, we have followed the Evaluand-oriented Responsive Evaluation Model (EREM) [63]. The EREM is a framework based on a Responsive Evaluation approach [64], and it is conceived to guide evaluators of innovations in a wide range of ubiquitous and collaborative learning situations. This kind of evaluation is framed within an interpretive research paradigm [65], [66], aiming to a deep understanding of the particularity and the richness of the concrete phenomena under study, instead of pursuing statistically significant results or generalizations. Due to this fact, it is usual in interpretive research to use small and purposive samples of people, and study them in depth [67].

To explore the research question we have carried out an anticipatory data reduction process [67] during the evaluation design (see Fig. 5). We defined an evaluative issue as the main conceptual organizer of the evaluation: *Do learning buckets help teachers introduce a controlled but flexible management of learning artifacts during the enactment of across-spaces learning situations that may involve technologies existing in current practice? If so, how?* We divided such issue into two manageable topics to help us better illuminate the complexity of the proposed issue, and we used the Bucket-Server prototype to investigate the topics. The first topic focused on exploring if the Bucket-Server provides *flexibility in the management of learning artifacts during the enactment of across-spaces learning situations*. Such topic was aimed to understand the general support of the Bucket-Server to the flexible management of learning artifacts during the enactment. The second topic was centered on exploring the support provided by the Bucket-Server to the design requirements defined in Section 2, and therefore, on how its *features overcome the limitations of current approaches that provide flexibility during the enactment of learning situations*. We also divided the second topic in three subtopics (see Fig. 5), again to help us reduce the complexity of the topic. All these topics were studied through a set of informative questions. The schema "research question–issue–topics–(subtopics)–informative questions" (see Fig. 5) also guided the data collection during the evaluation, which was carried out using multiple data sources, thus ensuring the trustworthiness of the evaluation. Table 2 describes the different data gathering techniques employed, and their purpose in the evaluation process.

Fig. 6 illustrates the evaluation process followed, divided into happenings (evaluation events). The process involved a pilot study [68] with experts, as well as a feature analysis (i.e., a systematic comparison of the features of different approaches or systems). The involvement of experts in this pilot study allows us to confirm if the problem tackled by the learning buckets is considered as significant in the field, and that the solution provided by the learning buckets is original. The feature analysis also helps us confirm the originality of the learning buckets. Through the pilot study we explored both topics (*flexibility during the enactment* and *features*), and the feature analysis focused on topic 2 (*features*). During the pilot study, different data gathering techniques and sources were used: naturalistic observations, web-based questionnaires, and collection of artifacts generated by the participants. Data analysis was carried out using NVivo[15] software, and with the anticipatory data reduction schema (see Fig. 5) acting as an initial category tree [67]. With the feature analysis we explored whether the support of learning buckets to the defined design requirements improves the support provided by other approaches in the literature. We followed the feature analysis screening method of the DESMET evaluation methodology [69]. The screening method is a qualitative feature-based evaluation that can be performed by an evaluation team (in our case five researchers), who determines the features to be assessed, the rating scale, and does the assessment. Questionnaires (*score sheets*, see Fig. 6) are used to assess the features, and the scores are summarized in a final report called *evaluation profile*.

During the evaluation, triangulation of methods, techniques and sources were used, to cross-check data as well as to ensure the quality, credibility and rigor of the responsive evaluation and its results [70]. The different data gathering techniques used in each happening are shown in Fig. 6 with the labels used all along the text to refer to them.

4.2 Pilot Study with Experts

4.2.1 Context

The pilot study took place around a workshop (Madrid, May 2013) of a Spanish R&D project called *Educational Reflected Spaces*[16], related to learning across physical and virtual spaces. Thirty researchers from three Spanish universities (University of Valladolid, Pompeu Fabra University of Barcelona and Carlos III University of Madrid) attended the workshop.

4.2.2 Intervention

In order to explain and demonstrate the notion of learning buckets and the Bucket-Server system, two members of the evaluation team created, deployed (using GLUEPS-AR integrated with the Bucket-Server prototype) and enacted an across-spaces learning situation consisting of activities *before*,

15. http://www.qsrinternational.com/products.aspx. Last accessed December 2016.

16. http://eee.gast.it.uc3m.es. Last accessed December 2016.

TABLE 2
Data Gathering Techniques and Labels Used to Quote Them Along the Text

Technique	Type of data	Label
Collection of participants' generated artifacts	Collection of a diverse set of artifacts generated by the trainers (learning design, wiki pages/course, learning buckets, learning artifacts, pictures, emails) and the experts (learning artifacts, emails). Used to register the use of learning buckets, and to complement the observation with information of the learning artifacts generated.	[Art]
Observation	Audio/video recordings and observation notes taken during the workshop with the experts, to register their actions, impressions, and other emergent issues.	[Obs]
Questionnaires	Feedback questionnaires composed of open-ended and closed items regarding the use of buckets; and score sheets of the support provided by systems to a set of features. Used to collect the opinions of the experts and the evaluation team about the Bucket-Server.	[Quest] [Score]

during and *after* the workshop. The learning situation was aimed at the collaborative creation of a "virtual Madrid" inside the classroom, using learning buckets, in order to help understand the notion of learning buckets and the Bucket-Server system, as well as their affordances. Fig. 7 describes the learning situation conducted. The pedagogical objective of the learning situation was that the researchers attending the workshop could learn about some representative monuments and buildings of Madrid, the city wherein the workshop was developed. Eight of the researchers attending the workshop completed at least three of the four activities of the learning situation, while the rest of the participating researchers only completed the activities conducted during the workshop. We will refer throughout the paper to these eight researchers as the "experts" (who assessed the learning buckets), in order to distinguish them from the rest of the workshop attendants. The experts split into three groups (one per university), and in a first activity, remotely and previously to the workshop, they used learning buckets embedded in a wiki-based VLE to create learning artifacts (using Web 2.0 tools, images and web contents) with information about some monuments and historical buildings of Madrid. They also associated the artifacts with AR markers. Such artifacts were accessed in a subsequent face-to-face activity by the experts during the workshop, using the Junaio mobile AR client. AR enabled the small-scale virtual recreation of a nearby outdoor space in the classroom, facilitating the group discussion and collaborative work about such space [71]. Finally, there were a face-to-face lecture about learning buckets and a remote activity after the workshop in the wiki-based VLE, in which the experts watched a video explaining how the used learning buckets had been created.

4.2.3 Happenings

During the first happening (H1 in Fig. 6), the trainers (two members of the evaluation team) designed and deployed the learning situation described in Fig. 7 using the WebCollage authoring tool [72] and GLUEPS-AR integrated with the Bucket-Server. They created learning buckets using the GLUEPS-AR user interface, which were embedded in the wiki-based VLE to be used during the study. Then, five experts conducted the remote activity prior to the workshop using the wiki-based VLE (H2). In the remote activity, the five experts used learning buckets to create and position learning artifacts. The trainers monitored the artifacts created by the five experts in the wiki, scaffolding them when needed. In the next happening during the workshop (H3), all eight experts (together with the rest of the researchers attending the workshop) conducted the aforementioned face-to-face activities of the learning situation (a virtual Madrid and a lecture) (see Fig. 7). In a new happening (H4), seven experts finished remotely the last learning activity. Finally (H5), we gathered feedback about the learning buckets through a web-based questionnaire. Seven experts from the three universities answered the questionnaire, including experts in AR, blended learning, across-spaces learning and orchestration of learning

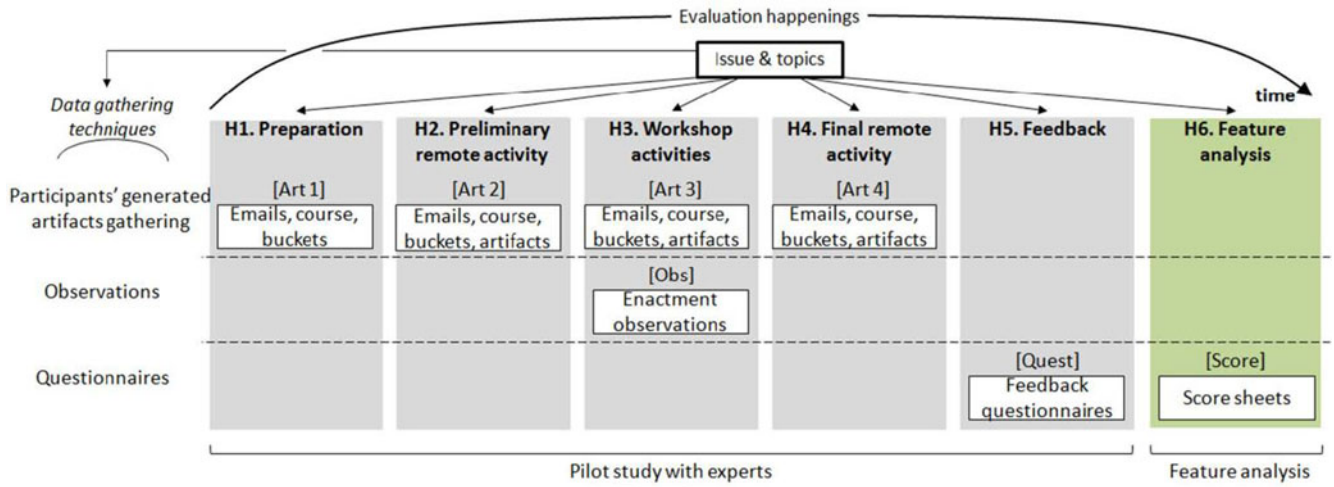

Fig. 6. Evaluation happenings (H) and data gathering techniques used during the evaluation.

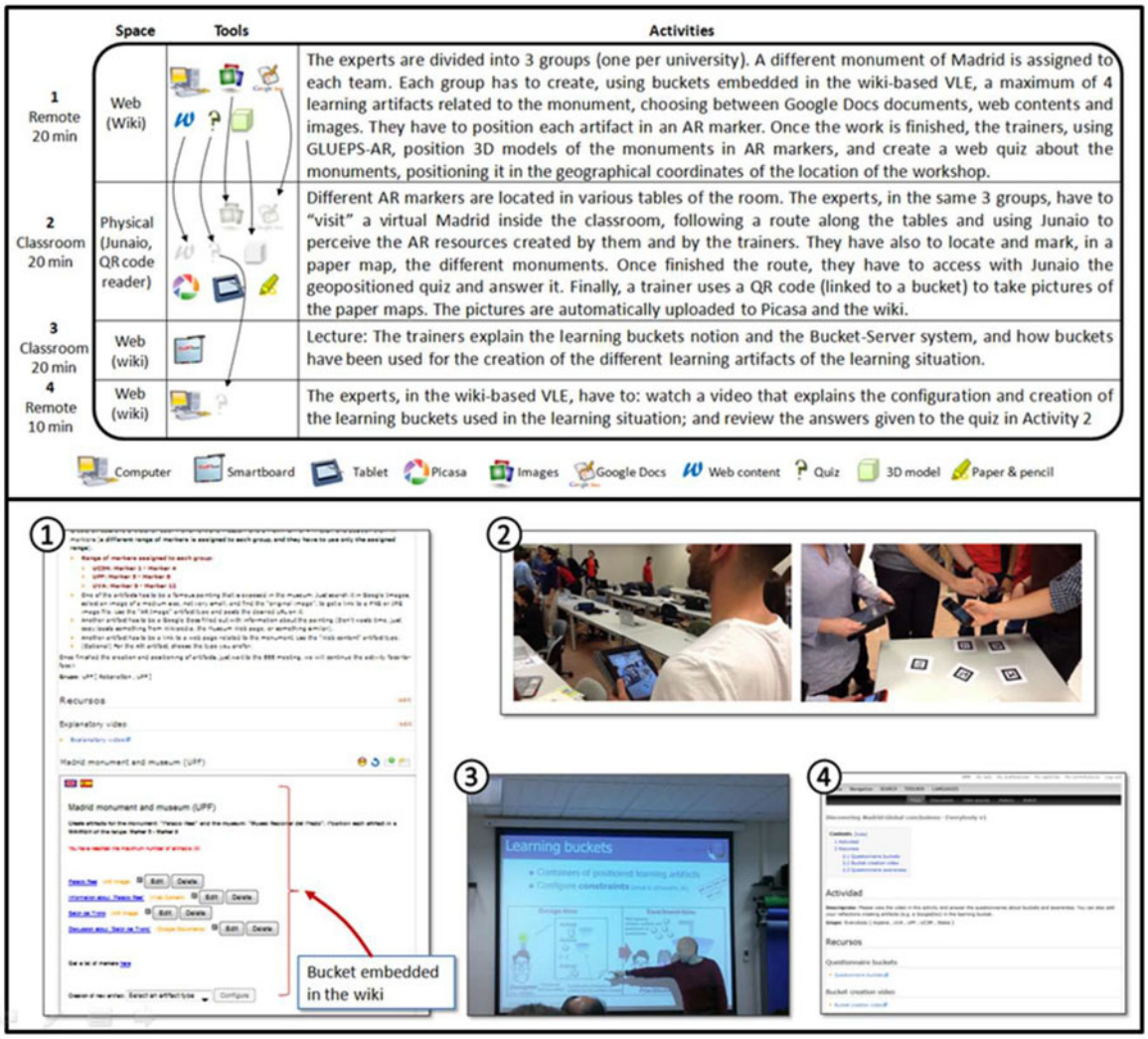

Fig. 7. Virtual Madrid in the classroom using learning buckets. Description of the learning situation (top) and snapshots of the four activities (bottom).

situations (see Table A.2 in Appendix, available in the online supplemental material).

4.2.4 Findings

This section describes the main findings obtained during the pilot study, organized following the anticipatory data reduction diagram (see Fig. 5). Throughout the text, the data sources that support the different assertions are indicated with labels (see Fig. 6) between square brackets. Due to space restrictions, only a selection of excerpts of the data sources is included in the text. It is important to emphasize that, in accordance with the responsive evaluation approach followed, we do not aim at obtaining statistically significant results or generalizations, but to explore in depth, and understand, the experts' perspective and impressions regarding the learning buckets.

4.2.4.1) Topic 1 (Flexibility During the Enactment). This topic focuses on exploring the support provided by the Bucket-Server to the flexible management of learning artifacts during the enactment of the across-spaces learning situation conducted. Table 3 shows the type, positioning type and number of the buckets and buckets' artifacts created by the trainers and the participants during the different activities [Art 1-3]. The results of the evaluation were positive regarding the flexibility provided by the Bucket-Server in the management of learning artifacts during the enactment of across-spaces learning situations [Art 1-3, Quest]. In the exploratory questionnaire, the experts recognized as positive such flexibility provided by the learning buckets (see questions 1, 2 and 3 in Table A.3 in Appendix [Quest], available in the online supplemental material). They also acknowledged that the Bucket-Server can enable teachers to share their management load with the students. In the questionnaire, the participants agreed with the assertion regarding the management load (see question 4 in Table A.3 [Quest], available in the online supplemental material), and some other comments of the experts in relation to the benefits of the learning buckets confirm such view ("*[It is interesting that] the students themselves participate in the instantiation [i.e., the implementation] of a learning situation*", "*[bucket benefits include] the implication of the students in the activity, a meta-cognitive learning [. . .] and lightening the work of the teacher*" [Quest]). The experts acknowledged also that the Bucket-Server can aid in the adaptation when facing emerging events during the enactment of across-spaces learning situations (see question 5 in Table A.3 [Quest], available in the online supplemental material).

In addition, the experts' feedback was very positive in the questionnaire regarding how the Bucket-Server would be able to facilitate students' own decisions about learning

TABLE 3
Buckets and Buckets' Artifacts Created by Trainers and Participants [Art1-3]

Trainers			Participants		
Artifact type	Positioning type	No. artifacts	Artifact type	Positioning type	No. artifacts
Bucket	Web	3	Google Docs	Fiducial marker	2
Bucket	QR code	1	AR image	Fiducial marker	6
Picasa picture	Web	1	Web content	Fiducial marker	3

artifacts, being responsible for their learning process in across-spaces learning situations (see questions 6 and 7 in Table A.3, available in the online supplemental material; it was also supported by several of the open-ended answers, such as "*[A benefit of learning buckets is that] they allow to pass from teacher-centered approaches to student centered ones*" [Quest]. Such capabilities of the Bucket-Server to promote decision making and responsibility were also observed during the enactment of the learning situation, in which the experts decided the artifacts they wanted to create, choosing between different artifact types (Google Docs documents, web content and images) [Art1-2].

An interesting finding was that although the experts considered the Bucket-Server easy to use by both teachers and students (see questions 8 and 9 in Table A.3 [Quest], available in the online supplemental material), the experts' response regarding the ease of use by teachers was the lowest rated item in the questionnaire (question 9 in Table A.3 [Quest], available in the online supplemental material). One of the experts recommended the improvement of the Bucket-Server user interface: "*The interface to manipulate buckets is not very intuitive. For instance, to create an artifact, you have to go to the bottom, and the creation-button is not identified with any typical icon for creating something new*" [Quest].

The Bucket-Server was also considered useful by the experts. They considered the teacher-configurable constraints useful to restrict what students can be able to do (see question 10 in Table A.3 [Quest], available in the online supplemental material). Experts agreed also with assertions regarding that buckets' constraints allow teachers to keep control of what students can do with buckets (see question 11 in Table A.3 [Quest], available in the online supplemental material), and about the importance of such constraints to the subsequent management of student-created artifacts by the teacher (see question 12 in Table A.3 [Quest], available in the online supplemental material). Some experts suggested the inclusion of additional constraints, such as temporal restrictions or related to social organization ("*aspects of social organization in the access to the bucket: hierarchical, democratic, etc*" [Quest]). Some of the benefits of learning buckets highlighted by the experts (in addition to those already mentioned) were: the support for students to participate in the creation of learning artifacts with information for different spaces (which participants recognized that could be also applicable to learning environments such as PLEs and Massive Open Online Courses, MOOCs); being a generic container allowing the grouping of artifacts in both design and enactment time; or the fact that they enable collaboration of participants *in-situ* and participants in virtual environments; and the runtime awareness of what is happening during the enactment [Quest].

4.2.4.2) Topic 2 (Features). All the features corresponding with the design requirements posed in Section 2 were supported during the learning situation. Thus, the Bucket-Server enabled trainers and experts to position learning artifacts in different spaces using different positioning types (see, e.g., Table 3 [Art1-3], and question 13 in Table A.3 [Quest], available in the online supplemental material). The trainers positioned a bucket in a QR code to upload pictures to Picasa, and such pictures were positioned only in the wiki. The experts positioned the learning artifacts they created in fiducial markers. An email from the trainer to one of the groups illustrates the positioning affordance: "*I see that you have created a couple of artifacts in the wiki [...], but they are not positioned correctly: One is positioned in a QR code and the other one is not positioned [in the physical space]. You should position them using markers (option 'Position in a marker') from the range you are assigned (Marker 5 to Marker 8)*" [Art 2]. Also, an expert stated in the questionnaire that "*I see clearly how to position resources in the physical world, but I don't see how to position them in the [3D] virtual world. In that case, it would be Virtual Reality instead of AR, but it would be very useful*" [Quest]. The learning artifacts created by trainers and experts were accessed subsequently from the wiki as well as from the physical classroom using AR (some observation notes and video annotations illustrate this: "*the group of the Pompeu Fabra University starts to see the artifacts*", "*the group of the Carlos III University is using Junaio and viewing with AR the artifacts: images, Google Docs documents, etc.*" [Obs]). Finally, evidence gathered showed that the Bucket-Server allowed a continuity of the learning experience in activities performed in different physical and virtual spaces. During the learning situation, the experts created artifacts remotely in a web-based VLE (the wiki), which were afterwards accessed from the physical classroom using AR. In addition, artifacts created from the physical classroom were subsequently accessed from the wiki (pictures from the paper-based maps taken by the trainer) [Art 2-4]. Results in the questionnaire valued very positively that the Bucket-Server enables such continuity (see question 14 in Table A.3 [Quest], available in the online supplemental material), and leveraging multiple physical and virtual spaces (see question 15 in Table A.3 [Quest], available in the online supplemental material). Also, one of the experts suggested a modification of the user interface to include positioning types enabling the use of artifacts in 3D virtual world spaces [Quest].

Moreover, the Bucket-Server enabled the trainers and the experts the integrated use of multiple systems already existing in the educational domain [Art 1-4, Obs, Quest]: commonly used artifacts and tools, such as Web 2.0 tools (Google Docs, Picasa), different web contents and images; and different kind of learning environments such as a wiki-based VLE

TABLE 4
Evaluation Profile of the Different Approaches

Features	Conformance score obtained											
	Cah10 [46]	Cas10 [37]	Con14 [38]	DJ10 [17]	Gie10 [48]	Gri12 [39]	Mik13 [50]	Mul12 [20]	Sim13 [35]	Vog10 [21]	Zha10 [36]	Bucket-Server
DR1. Enable teachers and students to position learning artifacts in different kinds of spaces (e.g., web and physical spaces)	1	0	0	3	4	0	1	4	2	4	0	5
DR2. Support different positioning types (geoposition, markers, etc.)	0	0	0	0	0	0	0	0	0	3	0	5
DR3. Enable teachers and students to access contextually the same learning artifact from different kinds of spaces (e.g., web and physical spaces)	0	0	0	1	4	0	1	4	1	2	1	5
DR4. Enable learning situations supported by different ICT-enabled learning environments commonly used in existing educational practice (e.g., multiple VLEs)	0	5	5	0	0	5	0	0	3	0	0	5
DR5. Enable the integrated use of multiple ICT artifacts and tools commonly used in existing educational practice, as is the case of those of the Web 2.0	0	4	4	1	0	4	4	0	4	3	4	4
DR6. Enable teachers to define multiple kinds of constraints (regarding technological choices, contextual factors, arbitrary decisions, etc.) in order to regulate what students are able to do with learning artifacts	2	2	3	4	4	2	4	4	2	0	4	4
Total	3	11	12	9	12	11	10	12	12	12	9	28
% over the total possible	10	36,67	40	30	40	36,67	33,33	40	40	40	30	93,33

and the Junaio mobile AR client ("*the group of the Pompeu Fabra University is accessing with Junaio a Google Docs document [...] created by some of the groups and positioned in a marker*" [Obs]).

In addition, the Bucket-Server enabled the trainers to configure constraints for limiting what experts were able to do within buckets [Art 1-4, Quest]. These constraints were the maximum number of artifacts that could be created in the buckets; the permissions to create, update or delete artifacts; the available artifact types that the participants could use; and allowing the experts to position artifacts.

4.3 Feature Analysis

A feature analysis was carried out by the evaluation team (composed of 5 researchers) in order to compare systematically the support provided by the Bucket-Server and by current approaches to the design requirements indicated in Table 1 (topic 2, see Fig. 5). It is important to note that the feature analysis does not outline the general characteristics or quality of the approaches. It is specifically focused on the systematic comparison of the indicated features, which were defined to help introduce flexibility in the management of learning artifacts during the enactment of across-spaces learning situations. Since most of the approaches were not designed with this specific purpose, it is reasonable that they do not support the indicated design requirements as the Bucket-Server.

The feature analysis was carried out in three stages: initial screening, assessment, and discussion panel. In the first stage, a member of the evaluation team screened the support provided by alternative approaches to the design requirements (Table A.1, available in the online supplemental material) in order to select the approaches to be compared with the Bucket-Server. We selected the approaches that provide some support, according to the screening carried out, in at least two of the three aspects of the explored challenge, namely: across-spaces support, integration with teaching practice, and teacher control of students' flexibility (see Section 2, Fig. 5 and Table A.1, available in the online supplemental material). Based on this criterion, eleven approaches were selected to be assessed by the evaluation team (see Table 4).

During the second stage, each member of the evaluation team scored (in a 0-5 scale), using score sheets [Score] as recommended by DESMET [69], the support of different approaches to the design requirements. Each evaluator rated at least two approaches in addition to the Bucket-Server. In order to score an approach, the evaluators studied the related publications and manuals, and tested the tools if they were accessible.

Finally, the evaluation team, jointly in a 3-hour panel, shared the score sheets, discussed conflicting criteria, and generated an evaluation profile agreeing a final score for each approach. Table 4 shows such evaluation profile.

The Bucket-Server was the system with the highest score, and the only one supporting all the features. The next scored systems were iTEC Composer [35], nQuire [20], the service-based framework for interoperability between VLEs and PLEs [38], Lemonade [48], and the LESTS GO project prototype [21]. Lemonade and nQuire showed to be limited in the integration of existing technologies in the educational practice, and the service-based framework [38] showed a restricted support to across-spaces learning situations. iTEC Composer presented limitations in the support of across-spaces learning situations and in the regulation of the flexibility offered to the students. The LETS GO project prototype showed some limitations in the integration of existing technologies in the educational practice, and in the teacher regulation of the student flexibility during the enactment. It is interesting to observe that the Bucket-Server's across-spaces support (features DR1 to DR3) stands out from the across-spaces support provided by the rest of approaches. It is especially prominent in the

possible use of different positioning types (DR2), which does not restrict a limited use of a specific kind of space (e.g., to outdoors using GPS). Another aspect that emerged from the analysis was that almost all the systems implement some mechanism for allowing teachers to regulate what the students can do with learning artifacts. However, only six systems (including the Bucket-Server) propose different types of configurable constraints regarding, e.g., technological choices, contextual factors or arbitrary decisions.

5 Conclusion

The evidence gathered in the evaluation suggests that the Bucket-Server, and therefore the learning bucket notion, can provide teacher-controlled flexibility in the management of learning artifacts during the enactment of across-spaces learning situations that are not isolated from the teachers current practice. Thus, the learning buckets can enable teachers to configure different types of constraints regarding technological choices, contextual factors and arbitrary decisions to control the freedom of the students during the enactment. Also, the learning buckets showed a better support to across-spaces learning situations than the support provided by alternative approaches. In addition, the learning buckets enable the integrated across-spaces use of widespread tools, such as a wiki, Google Docs or Picasa. Moreover, evaluation evidence suggests that learning buckets can enable students to participate in the technological implementation of the learning situations, and can be an interesting instrument to support the evolution from teacher-centered approaches toward more student-centered ones in across-spaces learning.

Such flexibility can be especially important in approaches which are inherently rigid in what students are able to do during the enactment, as is the case of those proposals, such as GLUEPS-AR, based on the use of learning design authoring tools. In such proposals it is usual that tools to use or artifacts to produce during the enactment are completely specified a priori. Learning buckets, as illustrated during the evaluation, can provide teacher-controlled flexibility to enable teachers and students to manage their learning artifacts across-spaces.

As an alternative to the use of authoring tools and a deployment system such as GLUEPS-AR, we plan to explore in the future the direct integration of the Bucket-Server with learning environments such as widespread VLEs. Such integration could convert a learning environment not natively supporting across-spaces learning situations (e.g., Moodle), into a system where teachers and students create across-spaces contents (e.g., resources to be used in subsequent activities in other spaces different to the web one of Moodle). Also, some of the possible enhancements detected during the evaluation should be explored in the future, such as the possible integration of 3D virtual worlds and the improvement of the user interface.

Regarding the learning buckets configurable constraints, although the initial set of configurable constraints in the data model of the Bucket-Server is rather simple, it could be extended for enabling more complex regulation of the degree of flexibility. In particular, the current implementation of constraints is limited in its capability for mapping the pedagogical intentions of the teachers. The current constraints demand an effort for teachers to "translate" their pedagogical intention to constraints, and not all pedagogical intentions can be supported. Similarly, the current constraints implement a simple access control based on the W3C Basic ACL ontology[17], although other more complex access controls could be implemented (e.g., a context-aware role-based access control [73]). We considered that a simple set of constraints was the best way to start exploring the concept, but future research could focus specifically on the possible constraints that could be configured and their effect on usability and cognitive demand, as pointed by some of the participants in the evaluation.

This paper presents a first step in our research of learning buckets. In this first step we have obtained evaluation evidence suggesting that the proposal is relevant (by the pilot study with experts) and original (by the feature analysis) to help introduce flexibility in the management of learning artifacts during the enactment of across-spaces learning situations. Nevertheless, in order to explore in depth the help provided by the learning buckets to teachers in their real practice, we plan to continue our research by using the Bucket-Server in other educational situations with teachers and students, including different pedagogical approaches and technologies. We also plan to explore how the Bucket-Server could provide support for reusing learning artifacts in different buckets and in different positions and spaces. This reuse would extend the possible range of across-spaces learning situations that teachers could create with learning buckets. It could also enable the reuse of learning buckets and their artifacts out of the scope of the learning situations in which they are created, e.g., following a similar approach than the learning object repositories [74].

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