

Coming Down to Earth: Helping Teachers Use 3D Virtual Worlds in Across-Spaces Learning Situations

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ABSTRACT

Different approaches have explored how to provide seamless learning across multiple ICT-enabled physical and virtual spaces, including three-dimensional virtual worlds (3DVW). However, these approaches present limitations that may reduce their acceptance in authentic educational practice: The difficulties of authoring and sharing teacher-created designs across different 3DVW platforms, or the lack of integration of 3DVWs with existing technologies in the classroom ecosystem (e.g., widespread web-based learning platforms such as Moodle, or mobile augmented reality applications). Focusing on a specific kind of 3DVW (virtual globes, such as Google Earth, used like 3DVWs), we propose a system that enables teachers to deploy across-spaces learning situations, which can be authored with a plethora of existing learning design tools, that involve different common web-based learning platforms, mobile AR applications and multiple kinds of virtual globes. A prototype of the architecture has been developed to evaluate this novel approach. The mixed-methods evaluation performed comprised both a feature analysis and a study where a teacher deployed an authentic across-spaces learning situation including Google Earth used as a 3DVW. Such evaluation shows that the system enables teachers deploy learning situations over different technological ecosystems composed by physical and web spaces, as well as by 3DVWs.

Keywords

3D virtual worlds, Virtual globes, Google Earth, Augmented reality, Across-spaces learning

Introduction

Advances in Information and Communication Technologies (ICT) are bringing about new possibilities for learning, such as those involving different virtual and physical spaces. For example, activities related to botany using a web platform in the classroom can be complemented with activities in a nearby forest (Kurti, Spikol, & Milrad, 2008). Different approaches have explored how to provide a continuous learning experience in these across-spaces learning situations (Kurti et al., 2008; Muñoz-Cristóbal et al., 2014), thus moving toward “seamless learning” (Chan et al., 2006). Mobile devices and Augmented Reality (AR) are among the technical scaffolds that have been explored to connect these physical and virtual spaces (Billinghurst & Duenser, 2012; Muñoz-Cristóbal et al., 2014; Sharples, Sanchez, Milrad, & Vavoula, 2009).

Three-dimensional virtual worlds (3DVW) such as Second Life (<http://secondlife.com>) or Open Wonderland (<http://openwonderland.org>) constitute an additional type of learning space that can be found in currently proposed across-spaces learning scenarios. 3DVWs are three-dimensional virtual environments with similarities to the real world that provide the illusion of being there. 3DVW users are represented using avatars that can interact with other users and objects of the 3DVW in a synchronous or asynchronous fashion (Dickey, 2003; Warburton, 2009). The use of 3DVWs in education has been explored during the last decades, and has shown to provide different learning benefits. More specifically, 3DVWs increase student motivation and also enable the perception of objects from multiple perspectives, the simulation of experiences impossible in the real world, or help knowledge transfer to the real world through the contextualization of learning (Dalgarno & Lee, 2010; Dede, 2009; Dede, Salzman, & Loftin, 1996; Dickey, 2003; Warburton, 2009). Existing examples of across-spaces learning situations involving 3DVW include the combination of activities in Moodle (<https://moodle.org>) and Second Life (Livingstone & Kemp, 2008), or the synchronous interaction among students visiting a replica of a city in Open Wonderland and students physically located in the “real” city, using AR in mobile devices (Ibáñez, Maroto, García Rueda, Leony, & Delgado Kloos, 2012).

However, most of the approaches considering across-spaces learning situations that include 3DVWs show limitations that may contribute to the current lack of acceptance of their proposals in real educational practice (Gregory et al., 2013; Hendaoui, Limayem, & Thompson, 2008; Warburton, 2009). One limitation is the lack of support for teachers to create their own across-spaces learning situations. Also, the available range of technologies for the enactment of the authored scenarios is very limited (e.g., the specific combination of Moodle and Second Life in Livingstone & Kemp, 2008, or Open Wonderland and an ad-hoc mobile client in Ibáñez, et al., 2012). Additionally, existing proposals tend to consider 3DVW-supported activities in a rather isolated way with respect to activities in other 3DVWs, or supported by already existing technologies in the classroom (VLEs, Web 2.0 tools, AR tools).

To overcome these limitations, this paper proposes the architecture and prototype of a system capable of supporting teachers in creating, with a number of existing authoring tools, and deploying their own across-spaces learning situations in a variety of technological ecosystems comprising multiple learning spaces. These ecosystems may be composed of different mainstream VLEs and Web 2.0 tools (web learning space), multiple mobile AR applications (augmented physical learning space), as well as distinct 3DVWs (3DVW learning space). Thus, the system enables activities taking place in multiple physical, 3DVW and web spaces, at the same time or sequentially. Additionally, learning designs can be shared and reused in different technological ecosystems (e.g., those including different 3DVWs).

The system proposed is an extension of the one reported in (Muñoz-Cristóbal et al., 2014), which did not support 3DVWs as learning spaces. Our new proposal integrates Virtual Globes (VGs) such as Google Earth (<http://www.google.com/earth/>), used as a 3DVW. VGs are virtual 3D representations of the surface of the Earth, which are widely known and recurrently used with educational purposes (Chen & Choi, 2010; Lund & Macklin, 2007; Rakshit & Ogneva-Himmelberger, 2008; Schultz, Kerski, & Patterson, 2008; Ternier, Klemke, Kalz, van Ulzen, & Specht, 2012; Wells, Frischer, Ross, & Keller, 2009). Although VGs lack certain presence and interaction features of 3DVW, there exist proposals for their conversion into 3DVWs (see, e.g., Dordevic & Wild, 2012, or <http://youbeq.com>, which include user interaction and avatars in Google Earth). Technical reasons also make it recommendable to integrate VGs in across-spaces learning platforms, since both VGs and physical spaces use the same type of (geographical) coordinates, thus simplifying the flow of learning artifacts and participants among spaces. Furthermore, the growing availability of 3D content for mainstream VGs (see, e.g., Xiao & Furukawa, 2012) opens new opportunities for setting up innovative learning scenarios in VGs, and may promote the adoption of VGs used like 3DVWs by teachers.

The next section describes limitations of current approaches to across-spaces learning situations that include 3DVWs, and distills design requirements that a system should fulfill in order to enable teachers to devise and perform such situations. Then, the paper proposes the architecture and prototype of a system implementing those design requirements. The paper also reports on the evaluation of the proposed system, which involved a feature analysis and a study where a teacher designed and deployed an across-spaces learning situation. Finally, some reflections and conclusions are mentioned.

Limitations of current approaches and design requirements

Several proposals for supporting across-spaces learning situations include activities in 3DVWs. In order to connect *3DVW with web spaces*, some approaches (Dickey, 2003) simply embed a web browser in the 3DVW user interface, triggering different web pages upon the occurrence of certain events in the virtual world. Some approaches can display web pages inside the 3DVW. This is also the case of OPENET4VE (Fernández-Gallego, Lama, Vidal, Sánchez, & Bugarín, 2010) which is able to deploy learning situations in different 3DVWs. Other interesting proposals are Sloodle (<http://www.sloodle.org>; Livingstone & Kemp, 2008), for linking Moodle with Second Life and OpenSim, and the system presented by Pourmirza & Gardner (2013), which links Facebook (<https://www.facebook.com>) with Open Wonderland.

Other approaches study the connection of *3DVWs with physical spaces*. In the Citywide project (Izadi et al., 2002), students explore a physical space (e.g., an archaeological site). At specific locations, students are asked to connect to a 3DVW where they can access objects related to the physical locations. Similarly, Ibáñez, et al. (2012) present a hybrid learning environment where activities may occur both in a physical street using mobile AR, and in a 3DVW

mirroring that same street using desktop computers. Participants in any of the two spaces can see avatars of the other participants and interact with them.

Table 1. Limitations of existing approaches for adoption in educational practice, and design requirements proposed to overcome such limitations

Limitations	Design requirements
Limited range of supported spaces (physical, web, 3DVW).	DR1. Virtual learning resources should be accessible from all three kinds of spaces: physical, web, 3DVW.
Lack of authoring tools usable by teachers.	DR2. Allow teachers to create across-spaces learning situations without requiring high level of technical knowledge.
Activities designed for a specific 3DVW cannot be reused in other virtual worlds.	DR3. Enable teacher designs to be deployed in multiple 3DVWs.
Isolation of 3DVWs from other virtual worlds and technologies in use by teachers.	DR4. Compatibility with multiple platforms/systems within each supported space (physical, web, 3DVW).
	DR5. Users in a 3DVW and users accessing other 3DVWs or platforms/systems on other spaces, have to be aware of the presence of each other.
	DR6. Allow the use of different enactment technologies already in use by teachers and institutions.

Other proposals explore across-spaces learning situations involving *three types of spaces: physical, web and 3DVWs*. DigitalEE (Okada, Tarumi, Yoshimura, & Moriya, 2001) is a system for collaborative environmental education wherein a 3DVW replicates a forest. The participants in the 3DVW can interact with others moving through the real forest, equipped with laptops and GPS. Participants in the physical forest can generate and interact with information (e.g., pictures, videos) which is uploaded to the 3DVW as HTML pages.

However, these proposals are affected by some generic limitations of the 3DVWs (Gregory et al., 2013; Hendaoui et al., 2008; Warburton, 2009), which may prevent the adoption of such approaches in educational practice. In the following paragraphs, we identify limitations that can affect especially across-spaces learning situations involving 3DVWs. From these limitations, we derive a list of design requirements (DR) that may help to overcome such limitations (Table 1).

Typically, across-spaces approaches limit their range of applicability to a *specific combination of physical, 3DVW or web spaces* (see **DR1** in Table 1). Of the aforementioned proposals, only DigitalEE supports learning activities in a 3DVW as well as in physical and web spaces. Thus, e.g., if a teacher using Sloodle wants to include an activity in a physical space, she would need to use another system, probably not integrated so seamlessly with the rest of the technological support.

In addition, there are few cases in which the design of learning scenarios is supported by *authoring tools usable by teachers* without a high level of technical expertise (see **DR2** in Table 1). Such authoring tools have been studied in the field of learning design (Koper, 2005), as a way of explicitly represent pedagogical ideas using computer-interpretable languages, sometimes independently from the targeted enactment platform. OPENET4VE and the system described by Ibáñez, et al. (2012), for example, enable the use of IMS-LD (IMS Global Learning Consortium, 2003) learning designs, thus allowing the use of different authoring tools based in that specification to create activities. In a different way, teachers may design learning situations with Sloodle by using Moodle's user interface.

Another common limitation is that *activities designed for a specific 3DVW cannot be reused in other virtual worlds* (see **DR3** in Table 1). Of the aforementioned approaches, only OPENET4VE and Sloodle enable the use of more than one 3DVW (Second Life and OpenSim), and DigitalEE provides limited support to other VRML-compliant 3DVWs.

Finally, in existing proposals, *virtual worlds normally are isolated, disconnected from other 3DVWs and technologies already in use by teachers and institutions* (e.g., VLEs, Web 2.0 tools or AR applications), thus

hampering the adoption of such proposals in existing educational practice (see *DR4*, *DR5* and *DR6* in Table 1). Among the aforementioned approaches, only Sloodle integrates a widespread VLE (Moodle), and the system presented by Pourmirza & Gardner (2013) integrates Facebook. The rest of approaches integrate mostly ad-hoc, not widely adopted platforms.

Proposal

Following these design requirements, we propose an architecture that enables teachers to define their across-spaces learning situations with different existing authoring tools, and deploy them in complex technological settings which include multiple VLEs, mobile AR clients and VGs used like 3DVWs.

Architecture

Previous work by the authors (Muñoz-Cristóbal et al., 2014) has tackled similar problems of connecting isolated spaces using existing platforms, enabling teachers to deploy their learning situations in different web and AR-enabled physical environments, but not in 3DVWs. Following the design requirements in the previous section, we now extend the previous proposal to consider also VGs used like 3DVWs. The architecture (Figure 1) is based on *adapters* which allow the integration of multiple elements of the same type (i.e., authoring tools, external web tools, VLEs, mobile AR clients and VGs). Once an element is integrated in the architecture, it is connected with the rest of the elements, enabling a multi-to-multi approach comprising already-existing authoring tools (compliant with *DR2*) (e.g., those described in The Learning Design Grid, 2013), VLEs (e.g., Moodle or Blackboard [<http://www.blackboard.com>]), mobile AR clients (e.g., Junaio [<http://www.junaio.com>] or Layar [<https://www.layar.com>]) and VGs (e.g., Google Earth or SkylineGlobe [<http://www.skylinesoft.com>]) (*DR3*, *DR4*, *DR6*). Thus, a teacher could use multiple learning design authoring tools to define her across-spaces activities, and complete them (e.g., with positioning information for the learning artifacts in physical spaces and VGs) in the graphical user interface (*GUI*) of the system (*DR2*).

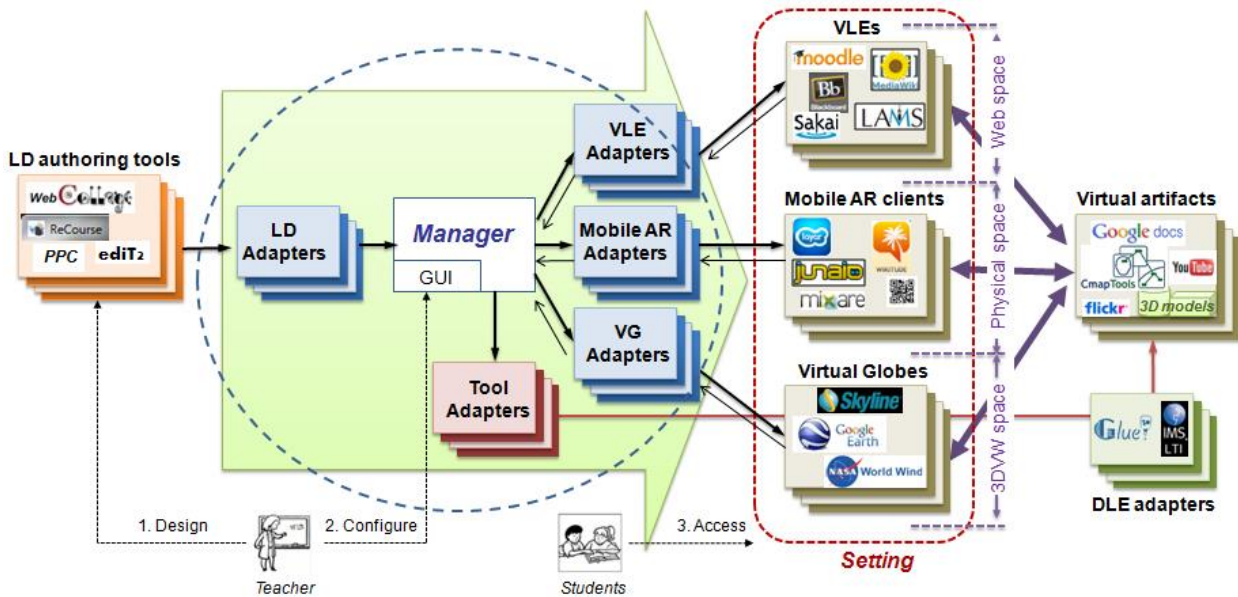


Figure 1. Proposed architecture

The architecture integrates also multiple tools and resources by means of *Tool adapters*. These Tool adapters may integrate, for instance, different Distributed Learning Environment (DLE) (MacNeill & Kraan, 2010) proposals such as Glue! (Alario-Hoyos et al., 2013) or IMS-LTI (IMS Global Learning Consortium, 2012). Thus, a single *DLE adapter* allows the use of multiple tools and resources in a learning scenario (e.g., in the case of Glue!, different Web

2.0 tools, widgets, 3D models or web resources) (**DR4, DR6**). These tools and resources can be accessed from any of the VLEs, mobile AR clients and VGs integrated in the system (**DR1**).

Since VGs are not by themselves 3DVWs (they do not provide avatars or interaction between users), the architecture, by means of the adapters and the *Manager*, enables the use of VGs as if they were 3DVWs, by adding avatars for the users and allowing interaction with any virtual resources and tools supported by the architecture (**DR1, DR5**). Students can interact with resources and tools or create new ones (e.g., opening a Google Docs document located in a VG, or uploading and positioning in the VG a picture taken in the physical space with their mobile device). Also, different communication tools (e.g., a chat) can be included in the teacher’s design and be deployed to this VG-based 3DVW, thus enabling students in a VG to chat with students using mobile AR in a physical location, or with students using a VLE in the classroom. The Manager element acts as a central hub for synchronizing user information in all spaces. Thus, e.g., users in a physical location can see the avatars of users in a VG using AR, and vice-versa (**DR5**).

Integration of multiple Virtual Globes

The integration of an existing VG in the architecture depends on a single requirement: the target VG should have an API or SDK for allowing third parties to position data elements (e.g., learning artifacts or avatars), typically known as “points of interests” (POI). Our proposal uses a POI model for learning artifacts and avatars, which is based on the model described in (Muñoz-Cristóbal et al., 2014). *VG adapters* are in charge of transforming POI representations following this common model, to the different native representations used by each of the VGs.

In order to assess the feasibility of such transformation for existing VGs, we have studied the API or SDK of some of the most widespread VGs (Rakshit & Ogneva-Himmelberger, 2008; Schultz et al., 2008): Nasa World Wind (<http://worldwind.arc.nasa.gov>), Bing Maps (<http://www.bing.com/maps/>), SkylineGlobe, Google Earth, Google Maps/Street View (<https://maps.google.com>) and ArcGIS 3D Analyst (<http://www.esri.com/software/arcgis/extensions/3danalyst>). We consider Google Maps/Street View also a VG because, although it does not support 3D views, its 360° realistic pictures provide an experience very close to that of 3D interfaces. We have also included Bing Maps for the sake of completeness, although its current support for 3D views is quite limited. *Figure 2* shows the POI model used by the proposed system, and the elements of such model that are supported in each VG. The figure also shows how transforming POIs between the proposed system and the different VGs would not imply a significant loss of information. Therefore, all VGs reported in *Figure 2* seem susceptible of being integrated into our proposal (**DR3, DR6**).

POI	Nasa World Wind	Bing maps	Skyline Globe	Google Earth	Google Maps / Street View	ArcGIS 3D Analyst
ID		+				?
POI-type	●	+	●	●		●
icon	●	+	●	+	+	?
name	●	+	●	●	+	+
description	●	+	●	●	●	●
location	+	●	+	●	●	?
position	+	+	+	+	+	+
position-type						
max-distance	●	●	+	●	●	●
rotation	+		+	+		+
translation						+
scale	+		+	+		+
date						

Figure 2. Elements of the POI model employed by the proposed system and their correspondence with the POI model employed by different VGs. (Position-type attribute is not supported, since VGs use only geographical coordinates)

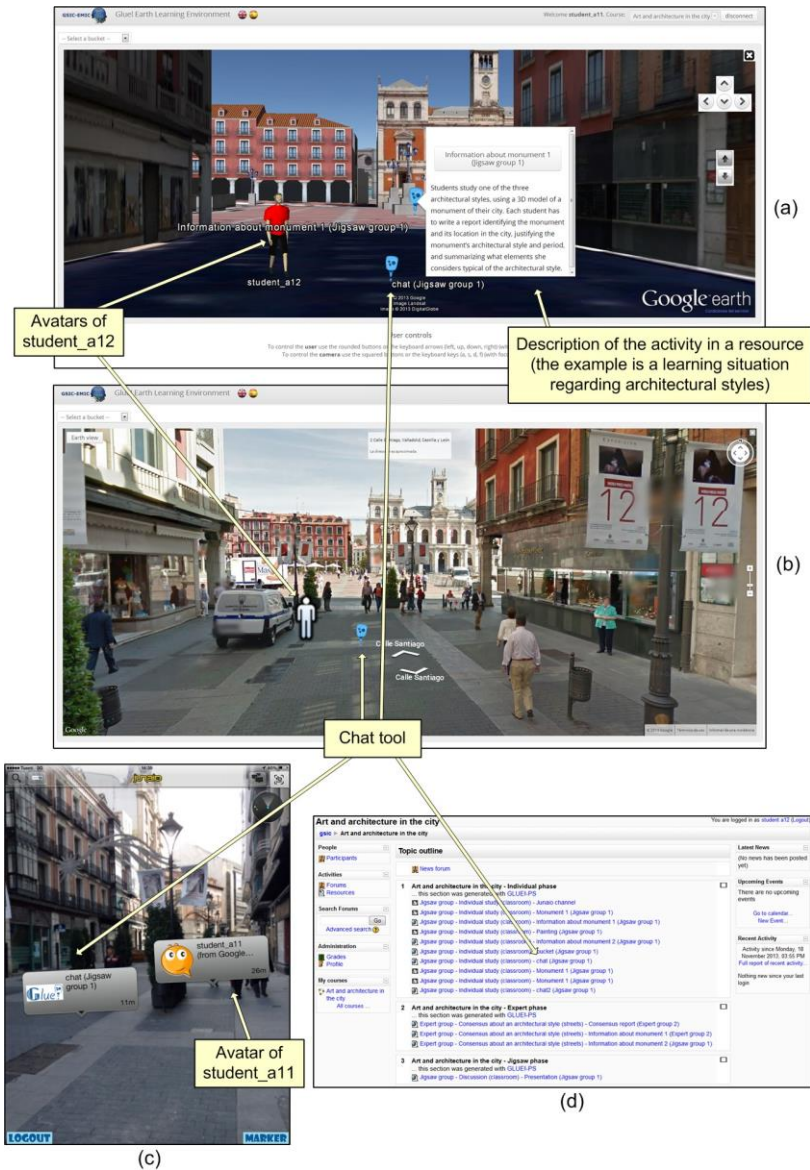


Figure 3. Example of a learning situation illustrating the user interfaces of different learning environments: Google Earth (a) and Google Maps/Street View (b) used like 3DVWs, the Junaio AR client (c) and Moodle (d)

Prototype

We have developed a prototype of the architecture, extending the predecessor architecture's prototype (Muñoz-Cristóbal et al., 2014), which already integrated three existing authoring tools (as well as other authoring tools compliant with IMS LD level A), two VLEs, four mobile AR clients and the Glue! DLE adapter. Furthermore, we have now integrated two VGs: Google Earth and Google Maps/Street View, used as 3DVWs, modifying the Manager to synchronize user information (and therefore, their avatars) in mobile AR clients and VGs. Figure 3 illustrates the user interfaces of different learning environments in an example learning situation involving Google Earth (a) and Google Maps/Street View (b) used like 3DVWs, the Junaio AR client (c) and Moodle (d). In the figure, a student (student_a11) may access the same activity in virtual downtown Valladolid (Spain) from two VGs: Google Earth (a) and Google Maps/Street View (b). From both VGs, she can see the avatar of another student (student_a12) and some geopositioned tools (in this case, a chat and a Google Docs document). Student_a12 is physically in the street in downtown Valladolid, and he is also watching the avatar of student_a11 and the geopositioned tools (c), using a mobile device with Junaio AR client. The chat shared by these students is also accessible from within Moodle (d).

Evaluation

An evaluation has been conducted to explore the research question driving our work:

Does the proposed system enable teachers to deploy their across-spaces learning situations including web spaces, AR-enabled physical spaces, and VGs (used like 3DVWs)?

The evaluation consisted of (1) a study wherein a university teacher used the system to deploy an across-spaces learning situation that included Google Earth used like a 3DVW; and (2) a feature analysis, where the evaluation team scored the support of existing approaches and the proposed system to the design requirements defined in Table 1. The next subsections describe the methodological considerations, the evaluation process and its results.

Method

We have followed the Computer Supported Collaborative Learning - Evaluand-oriented Responsive Evaluation Model (CSCL-EREM) (Jorrín-Abellán, Stake, & Martínez-Monés, 2009), using a variety of data gathering techniques in a mixed-method approach (Creswell, Plano Clark, Gutmann, & Hanson, 2003). CSCL-EREM is a framework, focused on the phenomena under evaluation, that provides evaluators with concepts and tools to guide the evaluation of CSCL phenomena (in this case, a technological innovation) in ubiquitous collaborative learning settings. CSCL-EREM is based on the responsive evaluation approach (Stake, 2004) and, therefore, aims at responding to the participants in the evaluation (instead of just describing, measuring or judging them), to get a deep understanding of the setting that may facilitate the adoption of the innovation in practice. This evaluation method is framed within the interpretive research perspective (Orlikowski & Baroudi, 1991), that does not pursue statistically significant results or generalizations, rather aiming a deeper understanding of the concrete phenomena under study (Guba, 1981), in our case, the use of the proposed system by a teacher.

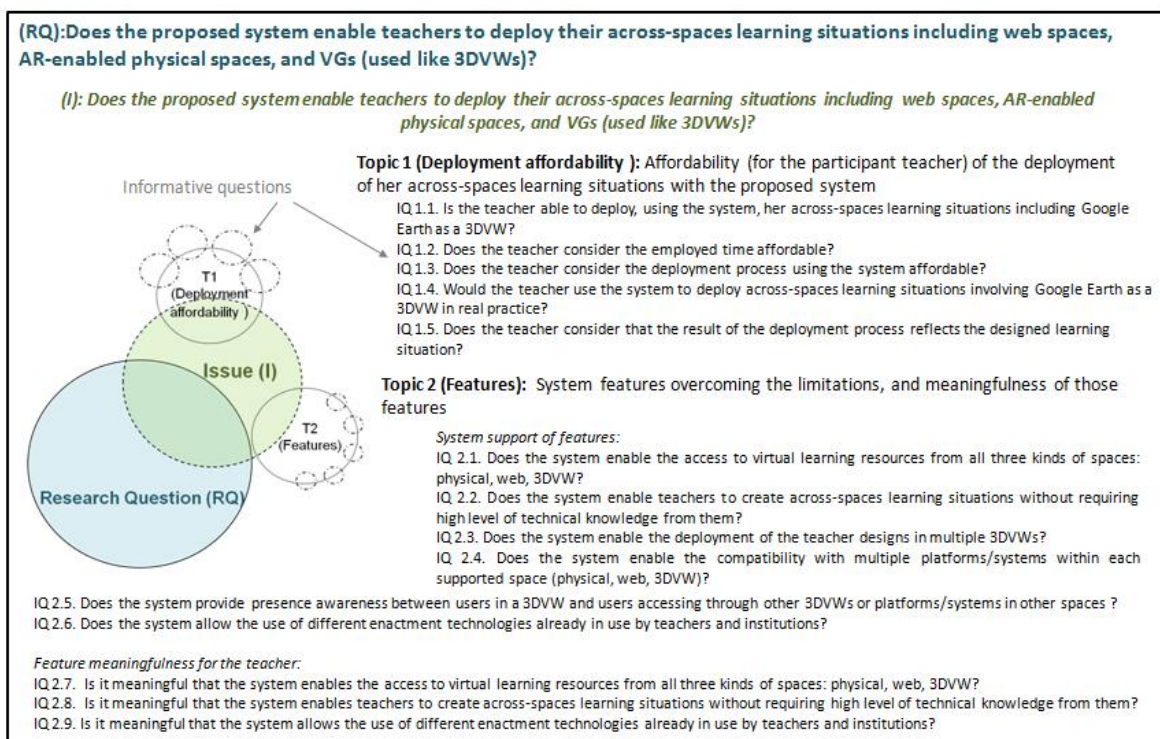


Figure 4. Anticipatory data reduction analysis. (RQ) Research question. (I) Issue. (IQ) Informative question.

To help illuminate our research question, we performed an anticipatory data reduction process (Miles & Huberman, 1994) during the evaluation design (see Figure 4). We defined an issue as the main conceptual organizer of the evaluation process. This issue was split into two more concrete topics, to help us understand different relevant dimensions within the issue: *The deployment affordability for the teacher of her across-spaces learning situations*

(topic 1), and *the support offered by the proposed system to overcome weaknesses of existing approaches and the meaningfulness of such features* (topic 2). Each topic is investigated through various informative questions, which finally are mapped to data gathering techniques.

As mentioned, the evaluation consisted of a study and a feature analysis. Along the study, a profuse set of data gathering techniques and data sources has been used: teacher-generated artifacts (e.g., emails or learning designs), time recordings, screen recordings (with software that recorded operations in the screen as well as audio and video out of the screen), naturalistic observations (audio, video, pictures and observation notes), web-based questionnaires and interviews (see Figure 5). In parallel with the study, we performed a feature analysis: a systematic comparison of the proposed architecture with alternative approaches, in order to explore if the support of the proposed system to the design requirements defined improves the existing approaches' support. For the feature analysis, we followed the screening method of the DESMET evaluation methodology (Kitchenham, Linkman, & Law, 1997). The screening method is a qualitative feature-based evaluation performed by a single individual or an evaluation group, who not only determines the features to be assessed and their rating scale but also does the assessment. Questionnaires (*Score Sheets* in Figure 5) are used to assess the features, and the scores are compiled in a final report (*Evaluation Profile*).

During our evaluation, triangulation of methods, data sources and evaluators was used, to cross-check data and interpretations as well as to assure the quality and credibility of the research (Guba, 1981). Figure 5 shows the evaluation process, which is divided in different *happenings* (evaluation events), as the CSCL-EREM model recommends, as well as the different data gathering techniques used in each happening, indicating the labels used to refer to them throughout the text.

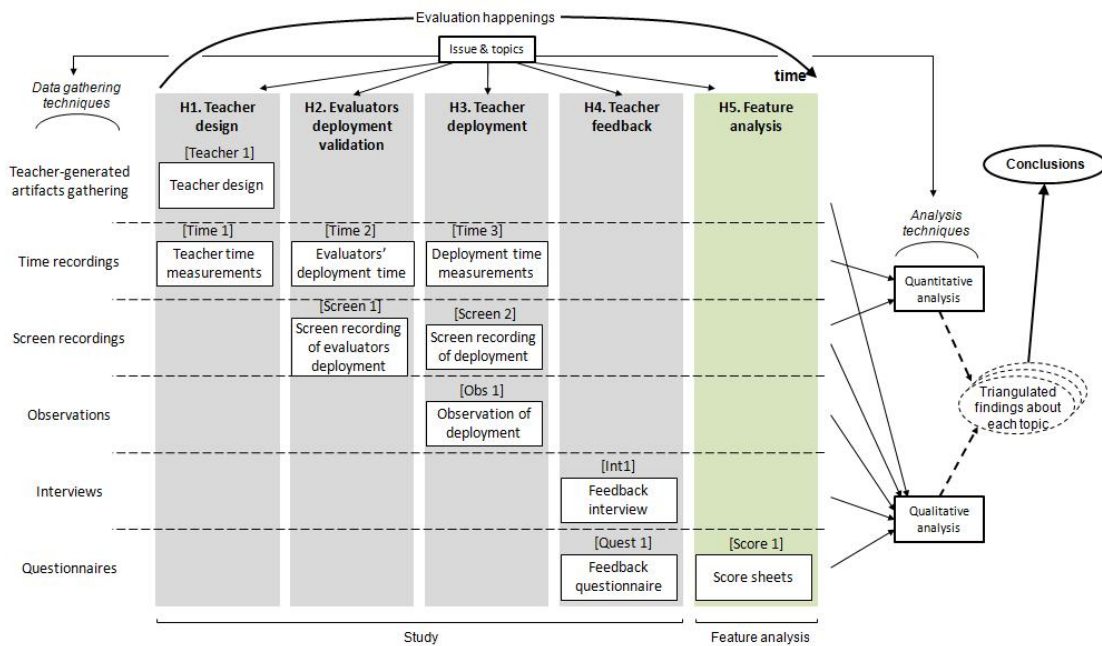


Figure 5. Evaluation happenings and data gathering techniques

Study

Context

The study was performed in the College of Education and Social Work, University of Valladolid (Spain). In the first year (out of four) in the *Degree in Primary Education*, within a mandatory course on ICT for pre-service teachers, four university teachers, usually perform an across-spaces learning situation related to the learning effects of advertising in everyday life. Usually, the situation involves the wiki of the course (used as a VLE), activities in the streets using mobile devices, and activities using Google Maps. Students are instructed to capture pictures of advertisement panels in their way home, writing down their location. Later on, they have to upload the pictures

manually to the wiki and, in groups, they create a map in Google Maps, marking the routes followed by the group's members, and create a marker in the map for each picture, associated to the URL of the picture in the wiki. Finally, students have to elaborate a reflective critique about the advertisements.

Intervention

One of the course teachers, a pedagogue relatively new to teaching (four years of teaching experience), who is familiar with ICT tools, showed interest in enhancing their usual across-spaces learning situation using Google Earth as a 3DVW (instead of the simple 2D Google Map described above). The proposed system may also help improve the connection of activities across the different spaces, automating several manual operations. In a first happening (H1, Figure 5), the teacher conceptualized a learning design without the support of an authoring tool. Then (H2), an ICT-expert from the evaluation team used the WebCollage (Villasclaras-Fernández, Hernández-Leo, Asensio-Pérez, & Dimitriadis, 2013) authoring tool to represent the teacher's learning design, and used the system prototype to deploy the design across the technological enactment platforms (wiki, QR codes and Google Earth). In a subsequent happening (H3), the participant teacher (with the support of an ICT-expert evaluator) performed the authoring of the design with WebCollage and the actual deployment using the system prototype. The teacher also assessed the resulting technological infrastructure, using it in the role of a student. During this deployment session, three observers were present (taking notes, pictures, videos and audio) who, later on, created a multimedia collaborative triangulated observation report, including also an annotated analysis of the complete video of the session. Finally (H4), the teacher gave feedback by means of a web-based questionnaire and a semi-structured interview (to provide further details about the deployment process and her perception of it).

Findings

Figure 6 illustrates the learning situation designed by the teacher, as a variation of the original across-spaces activities usually performed. It is composed of four collaborative activities spanning four hours of face-to-face work and two hours of remote work, performed in the classroom (using a wiki and Google Earth), in the streets (using QR codes and mobile devices for reading them), and online (using Google Earth). In order to use some of the time saved (due to the system's automation of the enactment), a new "counter-ad" activity was included at the end of the design. Also, a simple analysis of advertisement in general was replaced by a detailed analysis of the student-contributed advertisements.

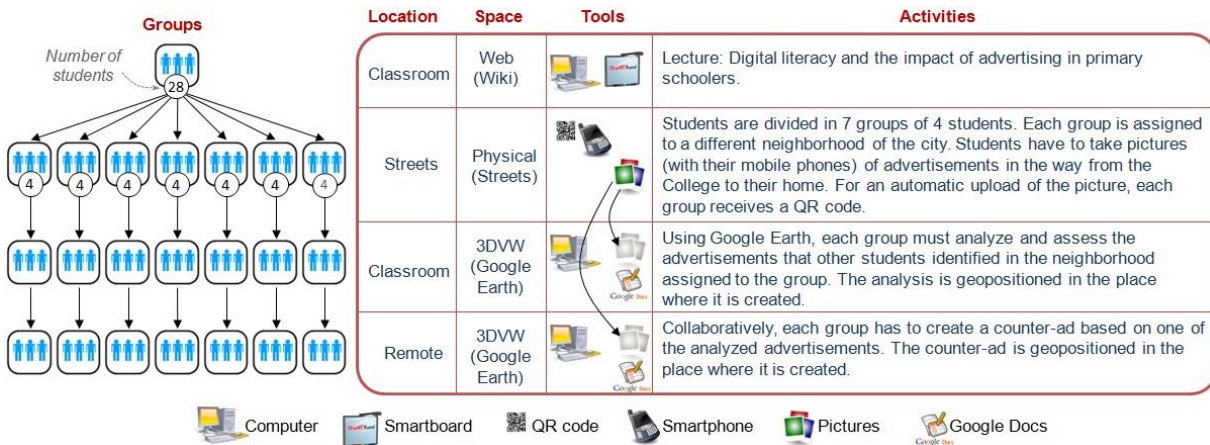


Figure 6. Description of the learning situation created by the teacher

The teacher deployed her learning situation using the prototype (IQ 1.1, see Figure 4), taking 54 minutes to author the design in WebCollage, and 37 minutes to configure that design using the prototype user interface (positioning learning artifacts, reusing tools between activities, etc.) [Time 3, Screen 2, Obs 1] (see Figure 5). As expected, the evaluator spent considerably less time than the teacher in this process, especially regarding WebCollage (7 minutes in WebCollage and 12 in the prototype [Time 2, Screen 1]). This difference was not only due to the evaluator's higher expertise with the systems, but also due to the mechanical nature of copying already-designed activities rather

than reflecting on them (as the teacher did) [Screen 1]. Indeed, even if the conceptual design had already been done on paper, the teacher included last-minute changes in activities during her use of WebCollage (e.g., a questionnaire was replaced by the counter-ad activity in Google Earth [Teacher 1, Screen 2]), and she queried the ICT-expert evaluator about the modeling of some activities using the provided tools (“[...] *The teacher explains a new activity for the last part of the design where she wants students to generate a counter-ad based on one of the previously analyzed ones. ‘How can I make it happen? Which is the best way for my students to upload the image with the counter-ad to Google earth?’ [...] [Obs 1].*”). The teacher considered the total time dedicated to the process was “long” (about 90 minutes) (IQ 1.2) ([when asked to assess the time dedicated in the deployment session:] “*Well, I think it was a long time [...] because in the end it took an hour and a half*” [Int 1]). Nevertheless, she considered such time as acceptable since she felt that the system was intuitive, and subsequent deployments would take less time (“*I think that with another go of practice, it would take me a lot less time*” [Int 1]; “*I think [the time dedicated] is acceptable, since the design can be reused in upcoming years, and in other courses performing minor adaptations [...] anyway, I’m sure that, with practice, the time [it takes] would be greatly reduced, since it is quite intuitive once you know some of the terms that are confusing at the beginning*” [Quest 1]). The teacher also considered the deployment process affordable (IQ 1.3), both in a questionnaire ([to the assertion “I think that the deployment of the scenario with the system has been easy”] she answered “*Agree*”, 5 in a 1-6 scale [Quest 1]) and in the interview [Int 1]. She also showed interest in using the system in her real practice (IQ 1.5). This idea was confirmed during the deployment session (“*I want to use it*” [Screen 1]) as well as in a questionnaire (“*I have the idea of putting [the scenario] in practice the next semester in my courses*” [Quest 1]) and on the interview (“[...] *and probably, if we put this [learning situation] into practice, since I’m convinced that I want to put it into practice, we will change things again [...]*” [Int 1]). After the deployment, she reviewed the resulting learning environment in the wiki and in Google Earth (see Figure 7), and simulated the tasks of a student [Obs 1, Screen 2]. She confirmed that it corresponded well to her initial design (IQ 1.6) [Int 1, Quest 1] (e.g., [to the assertion “do you consider that the result of the deployment process reflects your designed learning situation?”] she answered “*Strongly agree*”, 6 in a 1-6 scale). Finally, she valued as important the three features that she had used (IQ. 2.7, IQ 2.8, IQ 2.9), both in the questionnaire (she answered “*Strongly agree*”, maximum in the 1-6 scale, to the three questions asking about those features’ importance [Quest 1]), and in the interview (e.g., “[...] *a teacher has to be trained to be able to design contextualized activities [...], and that implies going beyond things or recipes that already exist. She has to be able to design these materials with the things that she can reach. On the other hand, a teacher also has to reuse things that are known to work, and which are free, [Web] 2.0 tools available to everybody*” [Int 1]).

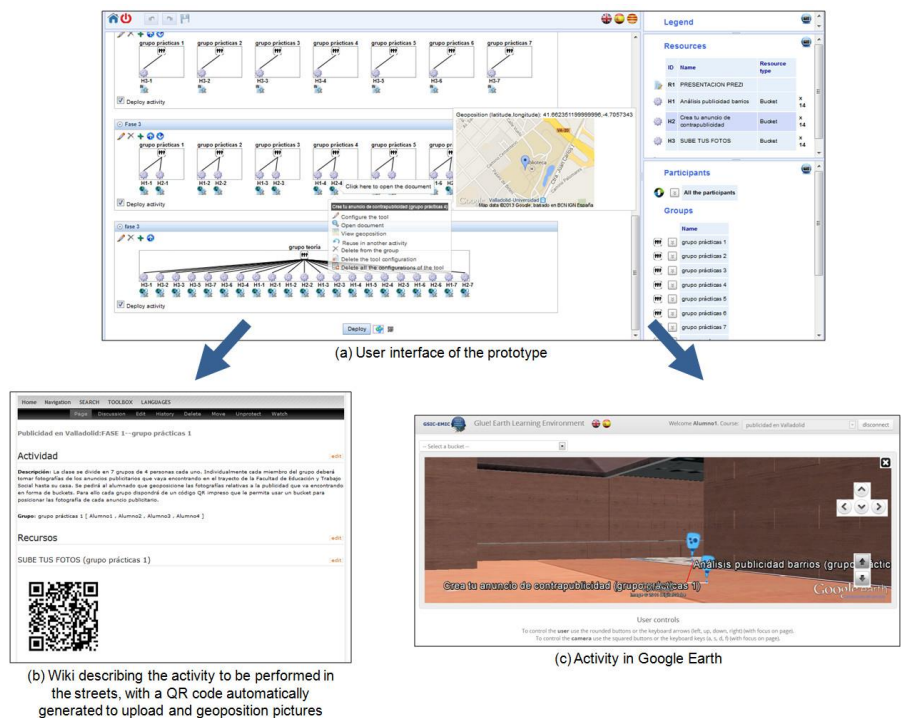


Figure 7. Deployment session: Learning situation configured in the system prototype by the teacher (a), the final result in the wiki (b), and in Google Earth (c)

Feature analysis

Simultaneously to the study, a feature analysis was performed by the evaluation team (H5, see Figure 5). Table 2 shows the Evaluation Profile summarizing the scores obtained (in a 0-5 scale) by the different existing approaches reported in the literature, assessing their support to the design requirements mentioned in Table 1. The publications on each existing approach were studied by the evaluation team. Then, evaluators provided an individual score [Score 1], which was then shared in a two hours panel to discuss conflicting criteria and agree on a final score for each of the approaches.

As Table 2 shows, the proposed system supports all the defined design requirements (IQ 2.1 – IQ 2.6). The feature with the lowest degree of support by the proposed system is DR2, since the authoring tool and user interfaces of the different systems (both the prototype and the authoring tools it supports) could be improved to reduce the learning curve for teachers without high technical knowledge. The existing proposal that was scored nearest second was DigitalEE, since it supports all three spaces (web, physical and 3DVW), and has potential to integrate more than one 3DVW (since it used a standard for the 3D scene's models).

Table 2. Evaluation profile of the different approaches: (Dickey, 2003) (Di), (Fernández-Gallego et al., 2010) (OP), (Livingstone & Kemp, 2008) (SI), (Pourmirza & Gardner, 2013) (PG), (Izadi et al., 2002) (Cw), (Ibáñez et al., 2012) (Ib), (Okada et al., 2001) (DEE) and the proposed system (PS)

Feature	Conformance score obtained							
	Di	OP	SI	PG	Cw	Ib	DEE	PS
DR1. Accessibility of learning resources from all three kinds of spaces.	0	0	0	0	0	0	5	5
DR2. Allow teachers to create across-spaces learning situations.	1	3	3	3	3	3	3	3
DR3. Enable teacher designs to be deployed in multiple 3DVWs.	0	4	3	0	0	0	3	4
DR4. Compatibility with multiple platforms/systems within each supported space.	0	3	0	0	0	0	0	5
DR5. Presence awareness between users in a 3DVW and users accessing other 3DVWs or platforms/systems on other spaces.	0	0	4	0	4	4	4	4
DR6. Allow the use of different enactment technologies already in use by teachers and institutions.	1	3	3	3	0	1	1	4
Total	2	13	13	6	7	8	16	25
% over the total possible	7	43	43	20	23	27	53	83

Discussion, conclusions and future work

The data gathered in our evaluation highlight that the deployment using the system is affordable for a teacher (topic 1). In addition, the feature analysis shows how the proposed system supports the design requirements defined to ease the adoption of across-spaces learning situations including 3DVWs. To the best of our knowledge, the rest of systems analyzed do not support all such design requirements. Indeed, none of the existing approaches supports all three features that were actually used by the teacher in the design and deployment of her learning situation (topic 2). Thus, the learning scenario devised by the teacher would not be deployable by her without the support of the proposed system (or at least, not in 90 minutes). The findings across these two topics help illuminate our initial research question, providing evidence that *the proposed system enables teachers to deploy their across-spaces learning situations including web spaces, AR-enabled physical spaces, and VGs used like 3DVWs*. We expect that the system and the design requirements proposed here may help to promote the adoption of 3DVWs in across-spaces learning situations, moving 3DVWs closer to everyday practice of teachers and their institutions. We claim that using currently-widespread VGs (e.g., Google Earth) as 3DVWs, and achieving seamless integration with other existing educational technologies (authoring tools, VLEs, Web 2.0 tools, 3D models or AR applications), could significantly help adoption in real practice.

It is worth noting that our feature analysis does not attempt to compare or evaluate across-spaces approaches in general. Rather, it is only valid to compare how different approaches support the specific design requirements we have defined as interesting for teacher adoption. Additionally, the feature analysis was performed using the cited publications as its main base. The evaluation team could not actually test all the approaches or study more detailed documentation. The feature analysis could also be improved by using other methods described by Kitchenham, et al. (1997).

We intend to delve further into this line of research, enacting the learning situation designed by the teacher, as well as exploring other learning situations that make use of the aforementioned set of features, with different teachers, in different educational contexts, and using a variety of existing technologies (e.g., other VLEs, mobile AR clients and VGs). We also plan further research to improve the prototype's usability (DR2), and its current limitations regarding identity and immersion of the users in the 3DVW (Dalgarno & Lee, 2010) (e.g., improving avatar features). Further investigation is also needed to propose a more general architecture, that is able to integrate other types of 3DVWs (e.g., Second Life), or to explore other known limitations of the 3DVWs (e.g., technological, social or psychological) not studied in the present article.

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