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Collaborative learning in multi-user virtual environments

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Abstract: Multi-user virtual environments (MUVEs) have captured the attention and interest of educators as remote collaborative learning environments due to their immersion, interaction and communication capabilities. However, productive learning interactions cannot be considered a given and careful consideration of the design of learning activities and organizational support must be provided to foster collaboration. In this paper, a model to support collaborative learning in MUVEs is presented. This model enables the scaffolding of learning workflows and organizes collaborative learning activities by regulating interactions. Software architecture is developed to support the model, and to deploy and enact collaborative learning modules. A user-centered design has been followed to identify successful strategies for modeling collaborative learning activities in a case study. The results show how interactions with elements of 3D virtual worlds can enforce collaboration in MUVEs.

Keywords: 3D virtual worlds; Collaborative learning techniques and platforms; Collaborative workflows and applications Collaborative workspaces a nd applications

1. Introduction

There is a consensus among researchers that learning is most effective when learners work in groups, exchange ideas with their partners and collaborate to achieve solutions to problems (Johnson et al., 2002; Slavin, 1996). Consequently, researchers have attempted to define conceptual approaches that support collaboration (Kreijns et al., 2003; Slavin, 1996), deploy instructional methods to enforce collaborative group work (Lehtinen et al., 1999) and explore the best use of social technologies to improve collaboration (Harris and Rea, 2009).

In recent years, there has been growing interest in the use of multi-user virtual environments (MUVEs) as collaborative learning environments (Chittaro and Ranon, 2007, Dalgarno and Lee, 2010). MUVEs provide the illusion of a 3D space where people can interact, as avatars, with 3D objects populating the environment and also communicate with one other (Bainbridge, 2007; Davis et al., 2009). However, just as in face-to-face environments, productive learning interactions among participants are not guaranteed and some mechanisms must be provided to foster collaboration (Dillenbourg, 2002; Kreijns et al., 2003).

In collaborative learning environments mediated by technology "activities are performed by learners and are mediated by artifacts, while both learners and artifacts are contained in a place" (Prasolova-Førland, 2004). This characterization of collaborative learning environment in terms of learner, place and artifact encompasses four types of interactions occurring in distance education: learner–learner, learner–instructor, learner-object and learner-interface (Moore, 1989; Hillman et al., 1994). Designing these interactions to coordinate supportive interventions through-out a number of learning activities occurring at multiple social levels, in different contexts and media, would support the orches-tration of collaborative learning processes (Fischer and Dillenbourg, 2006). The design of these interactions can be directly or indirectly shaped by the computer-supported collaborative learning (CSCL) environment and is the focus of this study.

The spatial dimension and multimodal capabilities of MUVEs offer new possibilities for designing, deploying and enacting collaborative learning activities. The aim of this research is to exploit affordances of MUVEs to design and support collaborative learning activities. To this end, a model that enables scaffolding of learning workflows and organizes collaborative learning activities by regulating interactions in MUVEs is proposed. Software architecture that implements the model is used to evaluate collaboration in a case study scenario where users must practice communicative skills.

This paper is organized as follows: first, the related work is presented. Second, a 3D virtual collaborative learning model is proposed in Section 3 and the architecture that supported it is presented in Section 4. A case study designed by following the proposed model is described in Section 5 and its implementation is evaluated in Section 6. Finally, the paper concludes with a summary of the findings.

2. Related work

"Collaborative learning refers to instructional methods whereby students are encouraged or required to work together on learning tasks"(Lehtinen et al., 1999). Any attempt to enforce collaboration would improve learning outcomes (Johnson et al., 2002; Slavin, 1996). Kreijns et al. (2003) state that conceptual approaches to enforce collaboration include conditions such as:

- Positive interdependence. This refers to the degree to which the performance of a single member is dependent on the performance of all others Johnson et al. (2002) as cited by Strijbos et al. (2004).
- Promotive interaction. To meet personal goals, group members must encourage and help their peers to succeed (Kreijns, et al., 2003; Slavin, 1996).
- Individual accountability. It stands for the extent to which group members are held individually accountable for jobs, tasks or duties, central to group performance or group efficiency. It was introduced to avoid the "free-rider effect" (Slavin, 1996).
- Effective group dynamics. It refers to the affective social structure required to engage participants to act as a unit. It contributes to group cohesion, common understanding, an orientation towards cooperation and the desire to remain in the group (Kreijns, et al., 2003).

The emerging technology of MUVEs is becoming a promising media to enhance collaborative learning. Their basic capabilities, namely representational fidelity, immediacy of control and presence have been associated with learning benefits (Chittaro and Ranon, 2007; Dalgarno and Lee, 2010; Dickey, 2005; Dillenbourg, 2002; Lee et al., 2010; Witmer and Singer, 1998).

Representational fidelity. Three dimensional graphics allow for realistic and detailed representation of 3D landscapes populated with 3D objects and characters (Chittaro and Ranon, 2007). Realism also includes mimicking the physical properties of the real world and the possibility of including 3D sound for a more immersive sensation.
Immediacy of control. The rich interface provided by MUVEs allows participants to perceive the world from different viewpoints and provides them with real time interactive capabilities to modify the state of the world (Burdea and Coiffet, 2003).
Presence. The terms presence and immersion have been used interchangeably by some authors. However, a distinction can be made between a subjective sense of being in place and the technical capabilities to render sensory stimuli. The former is considered presence (Usoh et al., 2000), the latter, immersion (Dalgarno and Lee, 2010; Huang et al., 2010).

These capabilities are the basic in enabling natural collaboration and effective group dynamics by offering participants social awareness, and communication mechanisms.

Social awareness. Unlike what happens in web environments, MUVE participants know who is in their surroundings and what is being done (Benford et al., 1997; Greeberg et al., 1996). Social learning technologies can also be integrated into MUVEs to support learners, for instance, to aid them in finding appropriate content or connecting with the right people (Vassileva, 2008).
Communication. Besides the written and oral communication also found in web-based learning environments, MUVE learners can use, albeit to a limited degree, non-verbal communication through their avatar's body, facial expression, tone of voice, etc. Most learning experiences carried on initially in Second Life and those related to learning foreign languages exploit these MUVE communication features (Salt et al., 2008; Wang et al., 2009).

The enforcement of collaboration in computer-mediated learning environments requires both the support to manage learning workflows and also the coordination of interactions that lead to collaboration (Dillenbourg et al., 2009).

In web-based environments, coordination of learning workflows has been achieved through the use of modeling languages (IMS Global, 2003; Dalziel, 2003) or authoring tools to handle collaboration (Hernández-Leo et al., 2006; Belgiorno et al., 2008). Some attempts have also been made to integrate learning management systems into 3D virtual worlds (Livingstone and Kemp, 2008; Del Blanco et al., 2010; Fernández-Gallego et al., 2010). However, none of these approaches take advantage of MUVE capabilities.

Regarding interaction coordination, use of space has been highlighted for both its pedagogical significance and its impact in creating a sense of community and collaboration (Clark and Maher, 2001; Minocha and Reeves, 2010). A step forward was made by De Lucia et al. (2009) when they included areas to support educational activities and areas for socializing and meet-ing informally. These spaces were designed to promote the sense of belonging to a community as well as to enhance the perception of awareness, presence and communication (De Lucia et al., 2009). Initial attempts to regulate interaction of avatars with assets in MUVEs have been made using security capabilities provided by 3D virtual world platforms (Scheffler et al., 2008). However, these mechanisms have not yet been integrated into learning environments.

3. The 3D virtual collaborative learning model

The main objective of the proposed 3D virtual collaborative model is to guide learners to perform a set of collaborative activities in MUVEs that lead to meaningful learning outcomes. The model allows synchronization learning points to be specified in order to foster the progressive development of those individual or collective competencies required to achieve the final learning outcomes. The model also allows division of labor to be specified in order to promote positive interdependence through interactions with 3D assets.

The proposed model takes its inspiration from the IMS LD specification (Koper and Tattersall, 2005) which allows the teaching–learning process to be described as a set of activities to be performed by participants in accordance with their roles in environments that are filled with resources and services (Amorim et al., 2006; Paredes and Marins, 2012). IMS LD estab-lishes that these elements are to be organized following a theatrical metaphor. The metaphor views learning activities as plays, organized in a sequence of acts. An act consists of several role-parts; these role-parts are assigned to activities in order to accomplish specific learning objectives. Each activity is conducted within an environment consisting of learning objects, and services and role-parts are performed by actors (Hernández Leo et al., 2004). The IMS LD specification is maintained by the IMS Global Learning Consortium (IMS Global, 2003). The proposed model reshapes this theatrical metaphor to guide learners toward colla-borative learning experiences and deploys them in MUVEs as simulations. Indeed, each act is defined as the atomic unit of collaboration and it is associated with a 3D virtual social space; interactions with 3D objects are regulated according to avatar roles; and specific object interactions are recognized as synchro-nization points that guide learning workflows.

3.1. Regulating learning workflows

The teaching–learning specification of a course, module or lesson is described in a "Module of learning" (MOL) as a sequence of acts. Each act is performed in a 3D scenario and it comprises a set of interactions with 3D objects, which can be a 3D object in the scenery or an NPC (non-player character). Either may have programmed interactive behavior. The former are integrated into the 3D scenario, the latter look like avatars. Interactions are of two types, namely learning interactions and transition interactions (LI and TI, respectively). LIs describe the interactions that avatars must perform with one or more 3D objects (NO_AS_OBJ type). These interactions allow participants to acquire knowledge and practice skills in the current act. TIs represent synchronization learning points and specify the interactions that avatars must perform with 3D objects of assessment (AS_OBJ type) in order to advance to the next act. Avatars can only perform the interactions allowed by their role (see Fig. 1). Once an avatar progresses to the next act, it is placed in a new 3D scenario filled with new 3D interactive objects and invested with a new role. Therefore, interactions included in the model enable the scaffolding of learning workflows. Table 1 shows the grammar that specifies the 3D virtual collaborative learning model and the data associated with the non-terminals of the grammar.

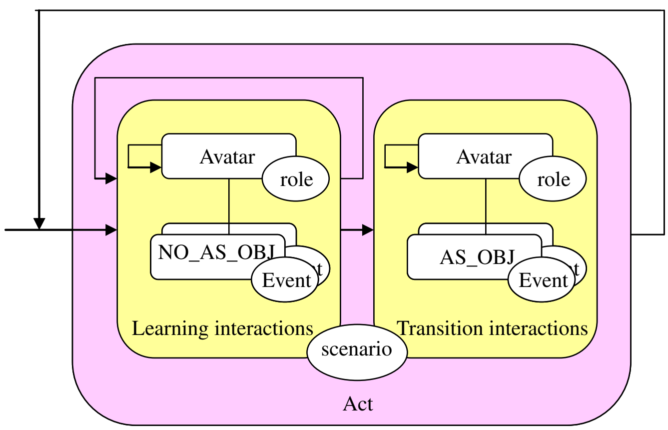

Fig. 1. State diagram of the module of learning.

For example, in a collaborative learning environment (CLE1) deployed in a MUVE representing “Gran Vía” boulevard” (Madrid), three acts are defined: introduction, interdependence and group assessment. First, in the introduction, students receive the necessary instructions to carry out the learning activities. Then, in the interdependence act students form groups that become experts in different knowledge areas and finally, students collaboratively solve a problem in the group assessment act. The first act takes place in the “Plaza de Cibeles” where all students receive the instructions for the course either from an NPC instructor or via an information panel. Receiving course instructions are the learning interactions that must be done before performing the transition interaction: going through the first portal. According to the formal definition, the CLE1's first act is defined by the following constructors:

```
cle1=mol_mk([introduction, interdependence,
        groupAssessment])
    introduction=act_mk(1,
                        plazaDeCibeles,
                        [studentRole],
                        [npcInstructor, infoPanel, firstPortal],
                        [<studentRole, [npcInstructor,
                        infoPanel]>],
                        [<studentRole, firstPortal>])
    studentRole=role_mk("student", 1, [john, mary, tom,
    david, alex, susan])
    john=participant_mk(...)
    npcInstructor=obj_mk("npcInstructor", NO_AS_OBJ,
    [initialTalk1])
    infoPanel=obj_mk(...)
    portalFirst=obj_mk(...)
```

Table 1
3D virtual collaborative learning model grammar.

Grammar rules		Data
S::=MOL		
MOL::=LI TI MOL	ModuleOfLearning= Act=	<acts: [Act]> <actId: Integer, scenario: 3dModel, roles: [Role], objects: [Object], learning_interactions: LI, transition_interaction: TI >
LI::=Participant Object Action <SCRIPT> LI::=ε	LI= Role=	[<Role, [Object]>] <roleId: String, actId: Integer, participants: [Participant] >
Participant::=<ACTOR>	Participant=	<partId: String, role_in_act: [Role], current_act: Integer, current_role: String, history: History >
Object::=<NPC> |<3D_MODEL>	Object=	<objId: String, type: AS_OBJ|NO_AS_OBJ, events: [Event] >
	Event=	<eventId: String, action: <Action, scritp()> >
Action::=<CLICK_ON> |<KEYSTROKE> |<PROXIMITY>	Action=	click_on|keystroke|proximity
TI::=Participant Object Action <SCRIPT>	TI=	[<Role, Object>]

```
initialTalk1=event_mk( "initialTalk1", <proximity,
  welcome_dialog1.wav>)
```

Transition to the interdependence act involves: (1) a change of 3D virtual scenario; (2) deployment of new 3D interactive objects; and (3) definition of new participant actor roles.

3.2. Regulating interactions

In online virtual environments in general, and in MUVEs in particular, learners must interact with instructors, partners and learning objects (Moore, 1989; Hillman et al., 1994). The proposed model specifies learner-object interactions directly through the regulation of access to 3D objects in each act. The model also provides a framework where learner–instructor and learner–learner interactions can be shaped to support collaborative learning activities.

Access to 3D objects is regulated through the interaction specifications in the acts of the play. In each act, LIs and TIs tie participants' roles to the scripting capabilities of the 3D objects they are allowed to manipulate. Roles are characterized by identification, scope and those participants entitled to perform each one. Object specification includes object identification, type (assessment or non- assessment) and the set of events describing the kind of actions participants playing a given role are allowed (see Table 1). Role-based restriction of object access acts to scaffold the learning activities within the acts. Careful access design will promote positive interdependence among learners.

For example, the interdependence act in CLE1 defines three roles associated with a subject of specialization: theatreExpert, cinemaExpert and musicExpert. In order to become an expert in a given subject, avatars must perform the interactions allowed on the subset of objects restricted to their role. Positive interdependence is established through the transition activity where all participants must answer "quiz1". Indeed, each group of experts must share their knowledge with the other groups and contribute to answering the quiz in order to advance to the next act.

```
interdependence=act_mk(2,
granViaStretch1,
[theatreExpert, cinemaExpert, musicExpert],
[npcCinema1, npcCinema2, infoCinema1,
npcTeatre, infoTeatre1, infoTeatre2,
npcMusic, infoMusic,
quiz1],
//Learning interactions
[<theatreExpert, [npcTeatre, infoTeatre1, infoTeatre2]>,
  <cinemaExpert, [npcCinema1, npcCinema2, infoCinema1]>,
  <musicExpert, [npcMusic, infoMusic]>],
  //Transition interactions
[<theatreExpert, quiz1>,<cinemaExpert, quiz1>,<musicExpert,
  quiz1>])

//John and Mary will become music experts
musicExpert=role_mk("musicExpert", 2, [john, mary])

//Objects to be manipulated by music experts
npcMusic=obj_mk("npcMusic", NO_AS_OBJ, [musicTalk])
infoMusic=obj_mk("infoMusic", NO_AS_OBJ, [musicRead])
quiz1=obj_mk("quiz1", AS_OBJ, [answerQuiz1])

//Events specification for music experts
musicTalk=event_mk("musicTalk", <proximity, music_dialog.
  wav>)
musicRead=event_mk("musicRead", <click_on, music.txt>)
answerQuiz1=event_mk("answerQuiz1", <keystroke,
  get_process_data()>)
```

Finally, the group assessment activity in CLE1 involves interactions among students to decide which play the group should attend. The decision must satisfy a set of restrictions provided by an NPC instructor. Students must collectively solve the problem posed and provide a single answer.

```
groupAssessment=act_mk(3,
  plazaDeEspaña,
  [studentRole],
  [npcInstructor, answerPanel],
  [<studentRole, [npcInstructor]>],
  [<studentRole, answerPanel>])
```

4. Software architecture to support the 3D virtual collaborative learning model

The proposed model represents a theoretical one to specify 3D virtual collaborative learning environments. In order to validate the model, software architecture was developed to create, deploy and enact 3D virtual collaborative learning environments. The proposed architecture is an extension of Open Wonderland (OWL) (Open Wonderland Foundation, n.d.), a client-server toolkit for building 3D virtual worlds. OWL is highly modular and designed with a focus on extensibility (Kaplan and Yankelovich, 2011). Besides its immersive and communication capabilities that enable the deployment of collaborative social spaces, it offers particular features useful in supporting the proposed theoretical model:

(1) The environment can be customized by designers' artwork and multimodal information can be included both statically and dynamically.
(2) The OWL scripting mechanism allows the interaction customization of 3D objects for learning purposes.
(3) OWL has capabilities to assign users to groups, along with a security mechanism that restricts interactions with assets according to group membership.

The software architecture proposed extends OWL to allow: (1) the creation of 3D virtual collaborative learning environments, (2) the management of learning workflows, and (3) the regulation of learning interactions. Creating the learning environment involves administrative course issues, deployment of social spaces that include the 3D model filled with interactive 3D objects and specification of the collaborative learning experience in accordance with the 3D virtual collaborative learning model. Learning management workflow implements mechanisms that assign participants to a new act once they have successfully completed the previous one. Management of learning workflows deals with the deployment of 3D assets and the assignment of roles to participants at the beginning of each act. Finally, the regulation of interactions uses participants' role specification in each act to control access to 3D objects.

4.1. Architectural overview

From a physical perspective (Fig. 2), the architecture to support the 3D virtual collaborative learning model is organized as a client-server platform and it is based on Open Wonderland. The OWL server is composed of a web service based on the Glassfish application server (http://glassfish.java.net) and three services for

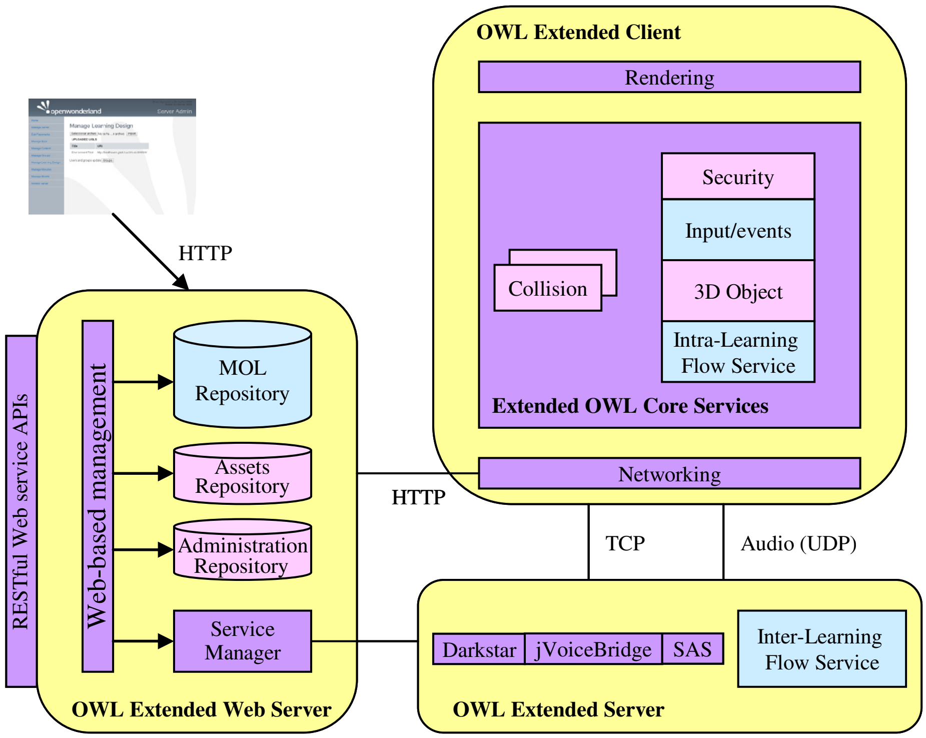

Fig. 2. Physical view of the architecture to support the 3D virtual collaborative learning model.

handling distributed platform for online games with the Darkstart server (http://reddwarfserver.org), providing immersive audio with the jVoiceBridge server (http://tinyurl.com/jvoicebridge), and allowing server-hosted application sharing with the shared application server (SAS) (Kaplan and Yankelovich, 2011).

The proposed architecture extends the OWL web server for authentication and world assets with mechanisms to enact each act according to MOL specification (see Table 1). A new service is included in the OWL server to manage the learning workflow: Inter-Learning Flow Service. This service is in charge of guaranteeing the transition between acts and it involves the deployment of a new act with assets, learning resources and role assignment to learners. The deployment of the new act requires all learners to have accomplished their learning activities from the previous act.

The OWL client acts as a browser for connecting the OWL servers and it is composed of a rendering layer; a communication layer; and a set of core services such as object movement, collision detection and security enforcement. A new core service has been added to regulate participant-object interactions: Intra-learning flow service. This service follows the MOL specification to add new functionalities to 3D objects through scripting and uses the security service to regulate interactions according to avatars' roles.

The combination of the inter-learning flow service and the intra-learning flow service makes it possible to use MUVEs as collaborative learning environments, with predefined learning goals that must be achieved according to instructional design specifications using the corresponding learning resources, and according to the role of each student within the group. Without these services, MUVEs are just meeting places where neither learning nor collaboration is guaranteed.

4.2. *Inter-learning flow service*

Inter-learning flow service is responsible for the organizational regulation of the play's lifecycle. This task involves receiving the necessary data from Service Management for instantiating each act, determining when to establish the transition to the next act, and deploying that next act. The transition between acts requires synchronizing student learning activities; all students must finalize one act before the system deploys the subsequent one. Table 2 shows the semantic rules followed by the inter-learning flow service.

The process of organizing work flow is cyclical. It starts when Service Management recovers data from the MOL Repository accord-ing to inter-learning flow service requirements ($1 in R1 and $1 in R2 on Table 2). Then, the Inter-Learning Flow Service deploys the scenario and enhanced assets with specified scripting and security capabilities are placed in the 3D model ($2 in R2 on Table 2). Participants perform learning and transition interactions and those who successfully pass the assessment advance to the next act ($1 in R3 on Table 2). Finally, transition to the next act is decided once all participants have interacted successfully with the assessment object ($4 in R2 on Table 2). The latter constitutes the synchronization point between acts.

4.3. *Intra-learning flow service*

In running time, intra-learning flow service regulates participant interactions with 3D objects following the MOL specification. Interaction regulation ensures that participants perform the learning and transition interactions: (1) in the right order, with the appropriate objects; and (2) in accordance with their role. This requires the scripting and security of the 3D objects' capabilities as well as taking participants' roles into account. This service is responsible for handling the collaborative learning activities within an act. Thus, it guarantees that students achieve the outcomes established by the instructional design specification.

The rules that regulate intra-flow interactions are presented in Tables 3 and 4. The flow of activities within an act involves, first, the interaction with non assessment objects ($1 in R3 on Table 3), followed by an interaction with an assessment object ($1 in R5 on Table 3) that will fire the transition to the next act ($1 in R2 on Table 3). Furthermore, these learning and transition interactions are tied to the acts and must be participants only interactions in a given act ($1 to $4 in R2 on Table 4). Likewise, participants can only perform those interactions allowed by their role ($1 in R3 and$1 in R3 on Table 4).

Table 2
Semantic rules for regulation of learning workflows.

	Grammar rules	Semantic rules
(R1)	S::=**$1** MOL	**$1**={MOL.current_act=1;MOL.mol=mol}
(R2)	MOL$_1$::=**$1** **$2** LI **$3** TI **$4** MOL$_2$	**$1**={TI.actId=MOL$_1$.current_act; act=(MOL$_1$.mol).get_act(MOL$_1$.current_act)} **$2**={deploy(act)} **$3**={mutex=get_n_participants(act)} **$4**={ wait(mutex); MOL$_2$.current_act ++, MOL$_2$.mol=MOL$_1$.mol }
(R3)	TI::=Participant Object Action<SCRIPT>**$1**	**$1**=if (<SCRIPT>.return_value==“success”) then {(Participant.id).current_act=TI.actId+1; (Participant.id).current_role =(Participant.id).get_role_in_act(TI.actId+1); signal(mutex)}

Table 3
Semantic rules to guarantee the correct use of 3D assets in learning and transition interactions.

Grammar rules	Semantic rules
(R1) S::=MOL	
(R2) MOL$_1$::=LI TI **$1** MOL$_2$	**$1**={if (NOT LI.interaction_value OR NOT TI.interaction_value) exit(illegal_interaction_error) }
(R3) LI$_1$::=Participant Object Action <SCRIPT>LI$_2$ **$1**	**$1**={LI$_1$.interaction_value= ((NO_AS_OBJ? true: false) AND LI$_2$.interaction_value) }
(R4)::=ε **$1**	**$1**={LI$_1$.interaction_value=true }
(R5) TI::=Participant Object Action<SCRIPT>**$1**	**$1**={TI.interaction_value= AS_OBJ? true: false) }

Table 4
Semantic rules to guarantee participant interactions with 3D assets in accordance with their roles.

Grammar rules	Semantic rules
(R1) S::=**$1** MOL	**$1**={MOL.current_act=1, MOL.mol=mol }
(R2) MOL$_1$::=**$1** LI **$2** TI **$3** **$4** MOL$_2$	**$1**={LI.actId=MOL$_1$.current_act, act=(MOL$_1$.mol).get(MOL$_1$.current_act } **$2**={if (!in(LI.interactions, act.learning_interactions)) exit(illegal_interaction_error) } **$3**={if (!in(TI.interactions,act.transition_interactions)) exit(illegal_interaction_error) } **$4**={MOL$_2$.current_act ++, MOL$_2$.mol=MOL$_1$.mol }
(R3) LI$_1$::=Participant Object Action <SCRIPT>LI$_2$ **$1**	**$1**={pcr=Participant.current_role, oid=Object.objId, LI$_1$.interactions=append(<pcr, oid>, LI$_2$.interactions)) }
(R4)::=ε **$1**	**$1**={LI.interactions=nil }
(R5) TI::=Participant Object Action<SCRIPT>**$1**	**$1**={pcr=Participant.current_role, oid=Object.objId, T I$_1$.interactions=<pcr, oid > }

5. Case study

The proposed collaborative learning experience takes place in a 3D multi-user virtual world that imitates the Madrid landmark, “Gran Vía Boulevard”, an emblematic area because of its architecture, commerce, and cultural offering (see Fig. 3). Students, by means of their avatars, will walk up and down the boulevard compiling information on the shows available in the different theaters with the final goal of purchasing a ticket for the show they prefer. Participants put communicative language skills into operation in order to carry out various activities, including language comprehension, expression and interaction.

Communicative language skills are promoted through activities with different degrees of structuring and mechanisms of collaboration. Participants perform their tasks using multi-modal information represented by virtual artifacts.

Reading activities. Participants explore the virtual world, reading information tagged to 3D objects included in the scenario (see Fig. 4). Information becomes visible when avatars approach the scripted 3D objects containing information about the plays.
Listening activities. Synthetic characters enact dialogues that provide participants with information about shows available in the theaters (see Fig. 4). Participants hear the dialogues as they approach the characters.
Writing (or individual assessment) activities. Participants are asked to write short sentences on post-it 3D objects in order to pass the final exam that gets them access to their tickets.
Speaking activities. Participants are encouraged to interact orally with each other to acquire a common understanding of the boulevard's cultural activity. The 3D platform offers 3D audio capabilities for performing these tasks.

Furthermore, collaborative activities were created by combining the previous activities in different ways.

Interdependence activities. These involve listening and speaking. Participants hear different but complementary information about the upcoming shows. They must share the information they receive in order to acquire a common understanding. The information is provided to participants selectively by synthetic characters playing the roles of tourists.
Group assessment activities. These involve speaking and consensus decision making. A collaborative test must be answered by the group of participants. Each group is scored on its performance.

Fig. 3. "Gran Via" Boulevard virtual world.

5.1. *Research questions*

The proposed learning situation offers several degrees of task structuring to lead reading, listening and writing skill development, as well as to promote communication among participants so they can acquire a common understanding of the problem to be solved. The aim of the study was to identify successful strategies for modeling collaborative learning activities in MUVEs using the proposed framework. The research questions were:

1. Is it possible to model conditions that enforce collaboration in MUVEs using the proposed 3D virtual collaborative model?
2. What factors have an impact on the automatic orchestration of collaborative learning activities in MUVEs?

5.2. *Methodology*

This study adopted a structured, iterative methodology for user-centered design. This methodology means user involvement in two steps of the collaborative learning environment develop-ment. User-centered design, typically used for designing web applications, becomes relevant for the design of 3D virtual worlds, not only as tri-dimensional interfaces, but also as collaborative environments. This kind of evaluation has proven to be an effective engineering method to support interactive systems development (Nielsen and Molich, 1990). According to Nielsen (1994), a relatively small sample of 5–10 users is sufficient to find the critical shortcomings in order to eliminate them for the next step. Following this approach, two pilot collaborative learning environments were designed and evaluated.

5.3. *Participants*

Following the criteria stated by Kujara and Kauppinen (2004), a relevant user group was identified and selected for this study. For this purpose, 24 foreign language students were recruited to work through the task scenarios. None of them had experience in the use of virtual worlds. Participants ranged in age from 20 to 40. They received payment for their collaboration in the study. DNX|Designit, a company specialized in usability studies, was in charge of the user recruitment process.

5.4. *Procedure*

The 3D virtual learning environment's early development was based on a first user task analysis, which drove the early design. This analysis was carried out by a team of two educators

Fig. 4. Reading and listening activities.

Table 5
Main results offered by the research carried out through the case study.

Findings	Results observed in CLE1	Results observed in CLE2
Focus 1. Positive interdependence		
Restriction on access to 3D assets was key in achieving interdependence. Interdependency was enforced by the assessment activity.	Participants explored the environment individually Positive interdependence emerged when participants were required to answer the test Each participant contributed individually to the assessment activity	Participants behaved as cohesive groups and tended to explore the world together Participants exchanged ideas and opinions throughout the learning experience When participants had to answer the test, all of them were able to answer all the questions correctly
Focus 2. Promotive interaction		
3D virtual world communication capabilities were useful when participants needed help Promotive interaction was possible thanks to social awareness in the 3D virtual world	Participants asked for help when they had technical problems or had forgotten what to do Participants preferred to ask peers for help via messaging Participants went to help their peers when they noticed delays. Participants were visibly happy to be supported by their partners	Participants helped each other constantly Participant preferred to share ideas by means of oral communication
Focus 3. Individual accountability		
Restriction in access to information forced participants to focus attention on their role.	Participants felt responsible for accomplishing their individual tasks.	Highly cohesive groups discovered information all at once. In these groups, the “free-rider effect” was observed.
Focus 4. Group dynamics		
Low granularity acts favored the emergence of group cohesion	The most successful activity in promoting mutual knowledge was the introductory activity There was a natural tendency to avoid collaboration	Although, groups were not forced to choose the same theater for the fourth activity, almost all the groups made their decision by consensus Participants shared personal preferences and their intention to attend the real shows on “Gran Via” after the learning experience
Focus 5. Limitations experienced by participants during the learning experience		
MUVEs as 3D interfaces have technical usability issues that should be addressed to achieve successful learning experiences Deployment of learning activities in MUVEs benefits from proper use of narrative clues	Participants had difficulties identifying the synthetic character playing the role of the instructor Participants had serious problems remembering all the instructions provided by the instructor character in the introductory activity Some participants experienced difficulties with navigation due to a lack of tools to support direction indicators and the use of third person camera Some technical problems caused participants to lose concentration	Participants did not experience problems with: identification of synthetic character roles; following instructions; navigation Although technical problems persisted, they were more minor
Focus 6. Successful aspects experienced by participants during the learning experience		
Basic capabilities of 3D virtual worlds were helpful in achieving physical and social immersion Simulation of a real situation in a mirror world is shown to be a good solution for fostering engagement	Participants particularly enjoyed the customization of their avatars No motion problems were observed. Participants insisted on walking on sidewalks and crossing streets at pedestrian crossings Most of the success of the participants’ experience lay in the environment's realism and natural design, and the actions that took place in it According to participants, the system's consistent response to their actions greatly contributed to their sense of being an active part of the world	Participants greatly appreciated performing the learning activities in a 3D virtual world that mimicked the real world. Participants found the correspondence between space and learning activities useful Participants were pleased to perform activities in the 3D virtual world with other avatars Concise instructions provided by synthetic characters were considered very useful by participants

specialized in teaching communication skills, two usability evaluators, two software engineers and the project manager. Developers implemented a first pilot including the set of tasks required for the application as defined in the previous user task analysis.

For each pilot, six sessions were carried out with two students participating in each session. Both of these students, located in different rooms, acted as participants in the learning environment. Members of the development team were in charge of resolving technical problems. Each participant was guided and observed by an evaluator and the sessions, designed to last 90 min, were video-recorded. 5-min interviews were held with the participants to gain information about their prior experience using virtual worlds and for them to state their expectations. That was followed by a 15-min tutorial to teach them how to behave in the 3D virtual world. The next hour was dedicated to carrying out the collaborative learning activities in the virtual world. During this process they were asked to use the “think out loud” protocol and evaluators observed participants’ behavior as they used the application. Finally, each participant had a follow-up interview with his/her evaluator.

The data collected was analyzed and a number of recommendations were made. Based on these recommendations, the second pilot was designed.

6. Results and discussion

The 3D virtual collaborative model presented in Section 3 was powerful enough to allow the collaborative activities in the case study to be specified with different degrees of structur-ing. Sections 6.1 and 6.2 present two pilots implemented using different granularity of tasks. Table 5 shows an overview of the main findings of this research.

6.1. First pilot collaborative learning environment (CLE1)

The main objectives of the first pilot were to understand how to use elements of 3D virtual worlds as effective narrative mechanisms to support the scaffolding of learning workflows as well as to determine whether participants could, with minimal automatic orchestration, carry out a collaborative task composed of simple activities in the 3D virtual world deployed with our architecture.

The learning activity flow was structured in three acts, namely, (1) welcome and introductory activity, (2) interdependence activity and (3) group assessment activity. The first activity took place in Plaza Cibeles (on Gran Via's east end) where a synthetic character explained the goal of the sequence of activities, and how and where to accomplish each of them. The interdependence activity took place between Plaza de Callao and Plaza de España (on Gran Via's west end). OWL's group capabilities were used to restrict participant interaction with information provided by synthetic characters. Participants were only allowed to hear a part of the characters' conversations so that they had to exchange information with their partner in order to acquire a common and complete understanding of it. Finally, participants had to collaboratively decide which play to attend in Plaza España while satisfying certain restrictions.

6.2. Factors that impacted interactive collaboration

In this pilot some problems related to using MUVEs as learning environments were detected, namely difficulties navigating in 3D virtual space, and problems involving synthetic characters as instructors.

Some participants experienced navigation difficulties in the 3D virtual world, mentioning the lack of tools to provide direction indicators, such as a map, street names or defined cardinal points. Also, the point of view used was that of a camera located behind the participant's avatar, i.e. a third person, and this sometimes led to a partially or completely obstructed view, which made it more difficult to navigate in the environment. However, this issue seemed to have no impact on the progress of the experience.

The evaluators also observed some problems, related to the use of the virtual world as an interface, which caused participants to lose concentration. Fortunately, mutual aid groups were established to overcome technical difficulties. In fact, these disadvantages promoted interaction among participants and contributed to generating a true sense of group.

Additionally, participants had difficulties identifying the synthetic character with the role of instructor. Some participants even believed that the character was an avatar and tried to speak to it. They felt disappointed when they realized that it was not possible to communicate with the character. For example, one of the participants said, "*…when I tried to ask it a question, I realized it was not human…*" and another suggested: "*… it could have something like a label explaining that he was the instructor…*" Moreover, some participants had serious problems remembering all the instructions provided by the npc-instructor in the introductory activity. One participant commented "*You are told about many tasks all at the same time. You catch the really easy ones, and forget the rest.*" This last issue had a negative impact on group dynamics. Indeed, participants who understood and remembered instructions tended to perform their activities with no concern for their peers. Fortunately, the group assessment activity, along with the interdependence relationship design, forced collaboration among participants. Finally, all groups completed the activities within the time allotted.

6.3. Second pilot collaborative learning environment (CLE2)

Due to the results of the evaluation of the CLE1, certain changes were made to overcome the problems that had been encountered. To this end, the world was populated with a greater number of decorative objects, location panels were incorporated as a navigation aid and synthetic characters acting as instructors were explicitly identified. In order to help participants focus on simpler tasks, the sequence of activities was spatially reorganized.

The main goal of this pilot was to determine whether reducing the orchestration granularity of CLE1 would have a positive impact on learning activities.

The learning environment was modified so that four activities comprised CLE2: (1) a welcome and an introductory activity, (2) an interdependence activity combined with a group assessment activity, (3) a reading activity, and (4) an individual assessment activity. The first activity took place in Plaza Cibeles where a synthetic character identified itself as an instructor, explained the goal to participants and invited them to start the next activity. The remaining activities were assigned to different stretches of the boulevard: from Plaza de Cibeles to Red de San Luis, from Red de San Luis to Plaza de Callao, and from Plaza de Callao to Plaza de España for activities (2), (3) and (4), respectively. Participants were informed about the tasks to complete in situ, both through information panels and by synthetic characters acting as instructors. At the beginning of each stretch, a character briefly but concisely explained the activities to be carried out there and what to do when the activity was completed. In the third activity, participants also had to pass a collaborative test in order to advance to the reading activity which gave them access to the synopsis of the shows. In the final activity, each participant had to decide which show to attend and write the reasons for this decision on a 3D post-it object. Once this activity was finished, a transportation portal appeared.

6.4. Collaborative interaction evaluation

Analysis of the results of the second pilot shows improvement in achieving those conditions that enable collaboration identified by Kreijns et al. (2003). Improved collaboration was more relevant in positive interdependence and effective group dynamics, was noticed to a lesser extent in promotive interaction, and was not relevant in terms of individual accountability.

The interdependence activity unfolded as planned in both pilots; participants, through oral conversations, exchanged information they had compiled and passed the collaborative test with no difficulty. In our framework, positive interdependence depended highly on the restriction in interactions with learning assets regulated by the intra-learning flow service.

Despite the limited amount of time available for the activities, affective social links emerged among participants. Informal conversations were more frequent than those established in CLE1, and oral communication prevailed over social messaging. Although groups had no obligation to choose the same theater for the fourth activity, almost all the groups made their decision by consensus. What's more, they exchanged personal preferences and their intention to attend the real shows on the real world Gran Via. The following dialogue illustrates the social climate of the learning environment.

> *I want to see 'Carmen' by Bizet, but I'm going to ask my partner. I would like to go with her*—participant_1
>
> *Well… I prefer '40 El Musical'*—participant_2
>
> *Ok, let's go to the musical, and… what about going out for dinner afterwards*?—participant_1.

Analysis of the teams' cohesiveness achieved in both pilots highlights the relevance of regulating interactions in 3D virtual learning environments. CLE1 and CLE2 pilots revealed that more synchronization learning points led to better group cohesion. Thus, effective group dynamics depend not only on the design of the module of learning, but also on the regulation of the inter-learning flow service.

In CLE2, participants behaved as cohesive groups and tended to explore the world together. Individuality was diminished in comparison with the previous pilot study, and it was more difficult to determine the contribution of each team member. Low granularity of interactions seemed to favor collaboration in the framework provided. However, further studies are necessary to evaluate whether a greater degree of intra activity interaction regulation would lead to similar levels of collaboration.

Finally, the physical continuity of the environment where activities took place, a boulevard, served to structure the narrative process, thus supporting the inter-workflow of activities. Participants were guided through the sequence of activities simply by walking along "Gran Via" boulevard. However, participants only recognized the virtual space as a facilitator for their interactions when navigation problems were overcome by including information panels. Research states that the effective development of spatial representation of large-scale environments first requires identifying distinctive environmental features that will function as reference points during navigation, then connecting these landmarks in sequence and finally, establishing relationships between locations (Siegel and White, 1975, as cited in Burigat and Chittaro (2007)). In our case, information panels served to inform about landmarks, after each activity a synthetic character informed about the next landmark to reach, the linearity of the street established the relationship between the landmarks, and finally, the inter-learning flow service regulated the transitions between acts. Further studies should be done to determine whether the location of the information panels, along with the physical continuity of the landmarks along the boulevard, facilitates the building of the cognitive map required for the navigation process.

7. Summary and conclusions

In this paper, we presented a model to specify collaborative learning environments in MUVEs. The model allows specification of learning workflows and regulation of collaborative interactions as theater play simulations in 3D virtual worlds. On a macro-level, the scaffolding of learning workflows is based on the distinction of certain interactions as synchronization points. On a micro-level, interaction regulation is based in the restriction of access to 3D assets which hinges on the role each learner must perform in successive steps of the teaching–learning process. We claimed that the application of these two techniques would lead to the design of collaborative learning environments. Thus, we presented supporting architecture to validate the model.

The architecture deployed a user-based case study that was carried out in two steps. The first step was key to understanding how to use elements of 3D virtual worlds as effective narrative mechanisms to support the scaffolding of learning workflows, as well as to identifying certain collaborative problems. The second pilot showed that collaborative learning activities based mainly on interdependence and effective group dynamics can be designed and implemented using the proposed framework. Users recruited for the study were learners of foreign languages with real needs for collaborative learning activities promoting communication skills. Their profile was extremely useful to study positive interdependence and group dynamics. Furthermore, the users' lack of experience in virtual worlds was useful to find the facilitators and barriers of the virtual world and the way the learning activities were deployed. Although the proposed architecture provides technological support for deployment of collaborative learning experiences in MUVEs, it is necessary to design low-granularity acts to maintain group cohesion. Also essential is a careful use of 3D spaces and interactive 3D objects within instructional design to promote collaborative activities.

This work is a contribution towards exploiting learning affordances of MUVEs within collaborative instructional design and not merely as environments where collaboration may emerge spontaneously. It is advisable to deploy further case studies in different contexts and over extended periods of time in order to continue the evaluation of the proposed framework.

Our collaborative learning model was validated over an architecture that uses a client-server toolkit for building 3D virtual worlds: Open Wonderland (OWL). Although OWL offers the required distributive and rendering capabilities for collaborative experiences, it is a toolkit in its initial steps of development According to our experience, OWL is not mature enough to support more than fifteen users at a time and it is advisable to use a simple scenario in order to achieve better performance.

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