

# Educational virtual environments: design rationale and architecture

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**Abstract** The use of collaborative virtual environments in e-learning is one of the most promising uses of virtual reality technology. While much research has been done in the area of networked virtual environments corresponding to the sharing of events, very little research has been done on specific services and functionality. However both the requirements and the kind of the offered services affect significantly the design of a system. In this paper we present the design and implementation of a platform suitable for educational virtual environments, which are collaborative virtual environments aiming at offering collaborative e-learning services to the users. Apart from the platform itself, we present the technological choices, and a new method for sharing virtual environments. Furthermore, we present an e-learning environment to support e-learning services using collaborative virtual environments from both the technical and functional point of view, along with the end-user evaluation results.

**Keywords** Multimedia application enabling software · Virtual environments · Distance and interactive training · E-learning · Educational community

## 1 Introduction

In the past few years a number of interactive Virtual Reality (VR) systems have been developed. An Educational Virtual Environment (EVE) [1] is a special case of a VR system where the emphasis is more on the education and collaboration rather than on simulation. EVEs are actually Collaborative Virtual Environments (CVEs) [16] that can be used for educational applications such as collaborative e-learning. As described in [8], CVEs are powerful and engaging collaborative environments for e-learning, because they are capable of supporting several important learning

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objectives. These objectives include experiential learning, simulation-based learning, inquiry-based learning, guided exploratory learning, community-based learning and collaborative learning.

This paper addresses the theoretical potential of CVEs for e-learning, with a particular focus on collaborative e-learning. Although there has been an increasing number of published papers describing 3D learning environments, we focus on the theoretical potential of CVEs because there have been few evaluations of their educational effectiveness. As described in [9], by drawing on educational theory and linking this to the capabilities of 3D environments, it is hoped that educational designers and developers will have a better basis for making decisions about whether or not to incorporate 3D environments into the resources they develop. Based on these results, a prototype for collaborative e-learning has been implemented and evaluated.

For the purposes of this paper, we define collaborative e-learning to be any kind of learning process performed by more than one person that takes place mainly in a Virtual Environment (VE). According to this definition we could implement collaborative learning if and when there is a need for several people to learn together [11]. A realistic visualization of the classroom can be accomplished by a 3D model of a virtual learning environment [10]. Furthermore, to encourage more learners' participation, their better representation, more learner-to-learner interaction, more contribution by the learners, less hierarchy and more empowerment, it seems to be efficient to use CVEs. Most of the commercial web-based training solutions lack sufficient realisation of real-time communication features, meaning a shared sense of space and presence. In general, third party applications refer to features such as application sharing and video conferencing. This issue is discussed in the next section of this paper. Motivated by the advantages of CVEs for supporting collaborative e-learning, that are discussed later in this paper, we have designed and implemented a prototype for collaborative e-learning using CVEs [3]. In this paper, we also focus on the implementation and design issues of a platform that supports this prototype.

We initially discuss the role of CVEs in e-learning and make a brief review of both general-purpose commercial platforms and research platforms for CVEs. Following this, we describe a virtual environment for collaborative e-learning, its basic functionality and usage scenario. We then describe the architecture, and the main components of the platform, called EVE, that has been designed in order to support the above environment, as well as the main implementation issues raised during the implementation of this platform. We then present the results of a usability evaluation of the prototype that it is conducted in order to validate the design of the EVE prototype. Finally, we present some concluding remarks and our vision for the next steps.

## 2 How CVEs can support collaborative e-learning

Many tools and technologies have been created and/or used in order to provide e-learning services to the users. The current components, tools and systems available can be divided into three different basic concepts as described in [14] and [22]: a) document-focused web-based training tools, b) meeting-focused tools, and c) 3D-centred tools.

The document-focused web-based training tools (e.g., Hyperwave eKnowledge Suite,<sup>1</sup> and WebCT<sup>2</sup>) focus on the management of documents and objects, respectively. Their main characteristic is tutor centeredness and their focus on individual learning. They are very suitable for distributing content and also partly for editing content. They offer good support in asynchronous communication, however, communication between teacher and learner is mostly in the foreground and not communication among learners. Thus, this tool type offers only little support for collaborative e-learning.

The meeting-focused tools concentrate on the support of synchronous communication of a user group independent of place. These tools, that can be separated into video conferencing tools (e.g., Microsoft's NetMeeting and Conference Server<sup>3</sup>) and synchronous training tools (e.g., Centra Symposium<sup>4</sup>), offer web-based communication support, where participants are represented with their name and live video picture. Some of the video conferencing tools were designed especially for the purpose of training situations. The approach of these tools is to virtually represent the concept of frontal learning. Thus, they are quite improper for collaborative e-learning. A general problem of these tools, regarding collaborative e-learning, is the reduced social presence of the participants that are represented in windows by means of live pictures. Thus, participants are rather given a feeling of distance than a feeling of proximity and group awareness. Videoconferencing is also weak in terms of shared activity awareness and it is not suitable for highly distributed deployment [12], [21]. The 3D-centred tools focus on letting each participant experience the existence and interaction with other participants. In 3D-centred tools the participants of a virtual session are represented as avatars, which can be chosen either from avatar libraries or they can be created individually by means of special features. Avatars can navigate through 3D environments, and all other participants can see events of single participants as well.

Using CVEs as communication media, we can offer the advantage of creating proximity and social presence, thereby making participants aware of the communication and interaction processes with others. Besides audio, written chat or using a shared application system they can additionally communicate by gestures, mimics and their positioning within this virtual space. Learners can act intuitively in such an environment. Avatars are a unique solution that CVEs offer to group communication and learning. It is a fact that persons participating in the virtual learning experience with human like full-body avatars feel more comfortable than in chat or audio-communication [14]. Specifically, high value is attributed to having all learning participants represented at the same time, even if there are up to ten participants, a feature not realisable in video-conferencing environments. The main benefit of the avatars is the psychological feeling of a sense of 'presence.' The sense of 'presence' results in a suspension of disbelief and an increase in motivation and productivity [14]. There are a number of important attributes to this experience. The ability to make basic gestures along with a voice or text message strengthens the understanding of the communication context [21]. A user's awareness of the spatial

<sup>1</sup> Hyperwave eKnowledge Suite, <http://www.hyperwave.de>

<sup>2</sup> WebCT, <http://www.webct.com/>

<sup>3</sup> Microsoft, <http://www.microsoft.com>

<sup>4</sup> Centra Symposium, <http://www.centra.com>

proximity and orientation of others has a strong impact on the dynamics of group communication [21]. Furthermore, these features can characterise a simple virtual space as a communication space [14]. In such an environment users feel as though they are working together as a group and tend to forget they are working independently. The technical realisation allows communication over lower bandwidths and no special equipment or connections are needed. However, the current CVE applications do not really take advantage of these (theoretical) potentials. This issue, which is discussed in the next section, guide us to design and develop a new platform for collaborative virtual environments.

### 3 Related technologies and research work on CVEs

Currently, there are many commercial platforms that support CVEs. The most significant are the Active Worlds,<sup>5</sup> Sense8,<sup>6</sup> ParallelGraphics' solution,<sup>7</sup> Moove's: Rose,<sup>8</sup> SmartVR's SmartVerse,<sup>9</sup> and Worlds.<sup>10</sup> In general, commercial products target to large groups of users: "the more people, the better" [13]. This leads commercial platforms to be reliable, attractive and easy to use as well as to work on available networks, mainly aiming at leisure or 3D chat. The generality that characterises commercial systems makes their use for educational purposes premature, as most of them do not support audio/video and multi-modal user communication. Furthermore, an attempt to modify them by integrating additional components may not be cost effective, because most of them are not based on open standards, and aside from that, their development toolkits are very expensive.

In the area of networked virtual environments much research work has been done. This resulted in systems, tools, protocols or even more platforms for networked virtual environments. The most significant prototypes and research work on the area of networked virtual environments are: DIVE (Distributed Interactive Virtual Environments)<sup>11</sup> [7], SPLINE (Scalable Platform for Large Interactive Environments),<sup>12</sup> VLNET (Virtual Life Network) [18, 20], and SmallTool [5]. Research platforms emphasize on specific research issues such as facial communication, support of heterogeneous networks [4, 19] or reliability, and tend to be limited in breadth [13]. Furthermore, they focus on particular applications and their re-usability is limited [17]. This gives rise to a proliferation of independent, often partial systems, making them inappropriate for educational purposes. The solution of integrating or combining work from different groups may be very difficult because of different philosophies and assumptions.

To summarize, there are several platforms to support on-line virtual communities. However, current platforms rarely support both educational communities and

<sup>5</sup> Active Worlds, <http://www.activeworlds.com/>

<sup>6</sup> The Sense 8 Product Line, <http://www.sense8.com>

<sup>7</sup> ParallelGraphics, <http://www.parallelgraphics.com/>

<sup>8</sup> Moove's Rose, <http://www.moove.com>

<sup>9</sup> SmartVR, <http://www.smartvr.com/>

<sup>10</sup> Worlds, <http://www.worlds.com/>

<sup>11</sup> The Dive Home Page, <http://www.sics.se/dive/>

<sup>12</sup> SPLINE, <http://www.merl.com/projects/spline/>

the above goals. The current 3D multi-user communication platforms do not really take advantage of their (theoretical) potentials for supporting collaborative e-learning. They are mainly dedicated to avatars' movement and text chat collaboration. Features, which aim on transporting content or supporting collaborative work, are not integrated neither are represented over extra windows or in separate frames. Thus, the increase of social presence is not accomplished. These reasons guide us to design and implement both an architecture and a protocol for the interaction between the components of this architecture, in order to support educational virtual environments.

#### 4 A collaborative virtual environment for e-learning

In order to implement a functional and effective e-learning virtual environment, our first step is to investigate its main functional features. These functional features should differentiate an e-learning environment from other virtual environments (3D or not), which are designed and implemented for general use.

As it is mentioned in the introductory part, this paper is focused on the theoretical potential of the 3D environments in order to support collaborative e-learning. Therefore, in this paper we are drawing on educational theory and linking this to the capabilities of CVEs. Our goal is to facilitate the educational designers and developers by having a better basis for making decisions about whether or not to incorporate 3D environments into the resources they develop as well as for extending their capabilities by integrating more functionalities.

According to Dillenbourg [11], every virtual environment that integrates the following features can be characterised as a collaborative e-learning environment:

- Users who have different roles and rights can visit the environment.
- The educational interactions in the environment should change the simple virtual space to communication space. This means that we should provide the users with multiple communication channels, which enable them to interact with each other, into the virtual space.
- The environment should be represented by various representation forms, which can range from simple text to 3D worlds.
- The learners in the environment should not be passive, but should be able to interact.
- The system that supports the e-learning environment should be able to integrate various technologies.
- The environment should support various e-learning scenarios.
- The environment should have common features with a physical space.

As it is described earlier, for purposes of this paper, we define collaborative e-learning to be any kind of learning process performed by more than one person that takes place mainly in a Virtual Environment (VE). This definition is consistent with the definition of the dialectical constructivism. According to [15], the dialectical constructivism is the view that learning occurs through realistic experience, but that learners require scaffolding provided by teachers or experts as well as collaboration with peers. Furthermore, according to [9], the use of computer-supported collaborative learning environments (and especially multi-user 3D environments with embedded communication tools) to allow learners to communicate and work together

on tasks is very consistent with dialectical constructivism, and very important for distance education students, who otherwise may not get the opportunity to work with other students.

The main design elements of a 3D CVE which is focused on collaborative e-learning are presented in Table 1. These design elements have been gathered after an analysis of Dillenbourg's interpretation of collaborative learning [11], and Moshman's interpretation of dialectical constructivism [15]. In order to present these elements the approach of [9] is followed.

According to Table 1, even if the use of a VR technology is not a required feature by the users a priori, it seems that the use of CVEs, and avatars along with supportive communication channels fit well as a solution. We call Educational Virtual Environment a CVE that is targeted to collaborative e-learning. This environment integrates (or it is supported) by design elements that are described in Table 1.

We propose and we have designed a prototype virtual environment for collaborative e-learning as an integrated environment, which is based on a set of virtual worlds. This set of virtual worlds aims to offer to the users the ability to navigate and interact in 3D shared space. We call this environment EVE prototype.

**Table 1** Constructivist CVE design elements for collaborative e-learning

Design element	Explanation
Situated remote communication	<p>Realisation of a multi-user 3D environment where interaction and representation is as close as possible to real learning situations to provide a sense of place that is shared among the users.</p> <p>Support of users representation: the environment could be populated by concurrent users, who could be represented in the environment. As discussed in a previous section the use of 3D human like avatars for user representation in virtual environment is a key feature for supporting collaborative e-learning. Therefore, it might be useful to represent the users by 3D human like avatars that can support mimics and gestures, in order to support virtual and social presence as well as to enhance the ways of communication among the users with non-verbal communication.</p> <p>Support of multiple communication channels such as avatar gestures, voice chat, and text chat.</p>
Remote task collaboration	<p>Distributed environments allowing the users to collaborate on tasks. This design element could be realised by: shared objects, application sharing, brainstorming board tool, locking /unlocking shared objects, and user handling.</p>
Remote task support	<p>Remote support by other learners, teachers, moderators. This design element could be realised by:            Uploading of e-learning material in the 3D environments            Application and data sharing</p>
Scaffolding tools	<p>Tools that can support collaborative e-learning techniques as well as to support the learners to undertake tasks in the virtual environment. This design element could be realised by both whiteboard, and brainstorming tools. For example the whiteboard tool could support the learner make a presentation of a task that s/he has been undertaken. Similarly the brainstorming tool could support the learners to exchange and collect ideas for a task that has been allocated to them by the tutor.</p>

Based on the above theoretical analysis, it seems that an Educational Virtual Environment comprises a media over which educational procedures and interpersonal communication could be performed in a manner closer to the end users' need. EVE prototype aims at presenting sophisticated services to the inexperienced user. We have designed such an environment by simulating well-known everyday life procedures and actions. Moreover, this environment could serve as a meeting point among the members of a learning community (e.g., university teachers and students). They provide the means for exchanging ideas, accessing of information and collaborating on learning activities.

In the next paragraphs the functional characteristics of EVE that we have designed and implemented is presented, as well as its usage scenarios.

#### 4.1 Functional description

We have implemented an educational virtual environment prototype that will satisfy the learning needs of a group with common learning needs.<sup>13</sup> The general user interface of the prototype is depicted in figure 1. The interface is divided into two main areas: (a) the 3D training room, and (b) the communication channel and tools.

The functionality of this prototype is described in detail in the following paragraphs.

##### 4.1.1 Space sharing

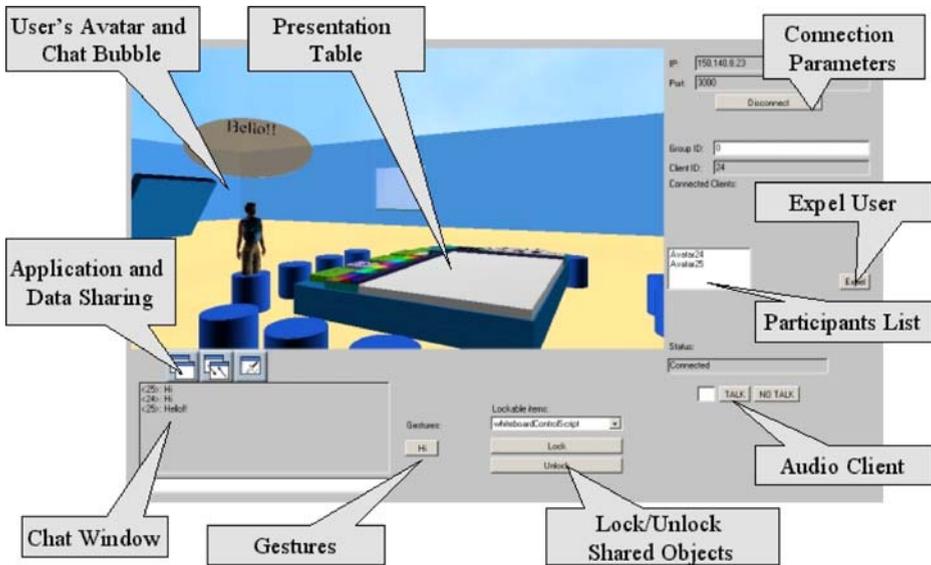
An Educational Virtual Environment aims at providing a place where different users can communicate with each other and with the environment as if they were in a real classroom. We satisfy the need to create the illusion that all users share the same space by transmitting all the events that occur, in the order they occur, to all of them. Furthermore, the existence of objects in the world that can be altered by the users, the shared objects, coupled with the feature of importing a new object into the world, give to our prototype a dynamic character, fulfilling the non-static nature of an EVE. This feature enhances the other participants' awareness and the virtual presence of the users.

##### 4.1.2 Communication channels

The easy and effective users' interaction is one of the main goals in the educational virtual environments. The EVE prototype supports the following types of interaction between the users:

- *Audio communication:* The main interaction channel is the audio communication channel. The users that participate in the same virtual environment, also participate in an audio session. The users can speak one at a time. The tutor/moderator has the full rights of the audio channel and s/he can manage audio communication by giving and taking the control of the audio channel.
- *Text chat:* The users that participate in the same virtual environment, also participate in a chat session for exchanging text messages. The text chat commu-

<sup>13</sup> EVE prototype is available at <http://ouranos.ceid.upatras.gr/vr>



**Fig. 1** User interface

nication is enhanced using bubble chat functionality, in order to help the user to see who is chatting. The text chat functionality can be used when the audio functionality is not usable for a client (e.g., not enough bandwidth, no audio equipment available). The bubble chat feature has been implemented in order to keep the focus of the users in the virtual classroom. Furthermore, we believe that this feature strengthens the activity awareness in the 3D space.

- Non-verbal communication:* Except for the text and audio communication channels, the interaction between the users is supported by non-verbal communication using avatars' gestures. The avatars' gestures provide a more realistic interaction among users, expressing when needed the emotion of each one to the others [6]. Furthermore, both shared actions on documents (using application sharing) and on shared 3D objects support non-verbal communication. The non-verbal communication is an innovative feature of Educational Virtual Environments and contributes in e-learning procedures in scenarios that demand silent user participation (such as on-line lecture scenario). Furthermore it simulates real situations and feelings of the users that enhances the social presence of the users.

The above-described types of communication contribute to the transformation of a simple VE to a communication place.

#### 4.1.3 User's representation

The users are represented by human like articulated avatars. The avatars can support animations (such as walking and sitting down) and gestures in order to support non-verbal interaction between the users. We not only focus on functions

for representing oneself but also visualizing his/her actions to other participants in the lesson. Available functions in our prototype are:

- Perception: the ability of a participant to see if anyone is around.
- Localization: the ability of a participant to see where the other persons are.
- Gestures: representation and visualization of others' actions and feeling. Examples are: "Hi," "Bye," "Agree," "Disagree," and "Applause."
- Bubble chat: when a user sends a text message, a bubble containing the message appears over his/her avatar.
- Who is talking: when a user speaks using the audio channel, a specific icon appears on his/her avatar.

#### 4.1.4 Presentation table

Though both space sharing and user representation are surely necessary in an Educational Virtual Environment, they are not enough to characterise a virtual environment as a learning environment. As discussed in Table 1, one of the most important features of an Educational Virtual Environment is the provision of tools for remote task collaboration. In the prototype of our collaborative e-learning environment we have implemented a presentation table, which is the central point in the training room. Using the functionality of this table the users can present their slides and ideas, comment on slides, upload and view learning material, as well as view streaming video. The avatars of all participants in the lesson can have a seat near the table, viewing not only what is presented on the table but also the other participants. Furthermore, the users can change their viewpoints in order to zoom in and out of the presented material. The presentation table provides the main tools for collaboration among the participants in EVE. These tools facilitate the performing of collaborative actions, and support users to undertake tasks, exchange e-learning material, etc. The presentation table has the following functionality:

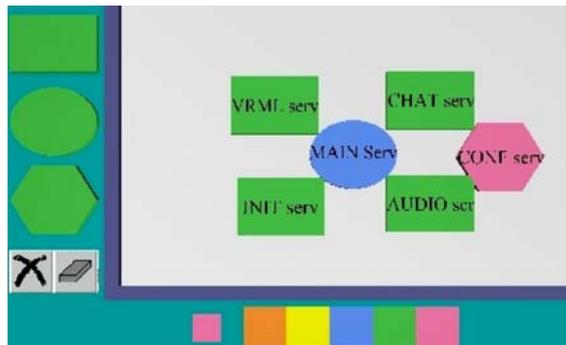
- *Library*: The library tool can be used in order to facilitate the remote task support. Its functionality contributes to the exchanging of e-learning material among the users. The user can click on the library button in order to turn the table and drag & drop learning material on the table. This material is represented as a small icon on the back side of the table. Actually, the user uploads URL's on the table. When the user clicks on the icon, the corresponding file is opened either on the whiteboard (if the corresponding file is picture or VRML object) or on a new window.
- *3D whiteboard*: This tool simulates the whiteboard, which is located in a real classroom. Furthermore, it supports slides projection and can also be used for on-line lectures. In figure 2, the 3D whiteboard is depicted. The 3D whiteboard supports slide projection, line, circle and ellipsis drawing in a wide range of colors and text input in many sizes and colors. It also offers undo last action capability as well as the cancellation of all previous actions on the whiteboard. In addition, the users can attach and demonstrate 3D (VRML) objects (which are previously uploaded on the library) on the whiteboard. This tool can also support the learner to undertake tasks in the virtual environment, such as to make a presentation, to attach comments on a slide that is presented by other learners, etc.

**Fig. 2** 3D whiteboard

- *Brainstorming board*: the brainstorming board can be used in a range of collaborative learning techniques (such as roundtable, brainstorming and card moderation) in order for learners to present their ideas in a structured way. The users can create cards in three shapes (rectangle, circle and hexagon) and five colours attaching text on them. They also can move and delete a card. Using this tool the users can brainstorm and generate a large number of ideas for solving a problem in a short period of time. Supposing that the tutor/moderator asks a question that has a large number of possible answers, each user can attach his/her idea to the brainstorming board using a card. This process continues until the learners run out of possible solutions. After the brainstorming, the tutor can prioritise the solutions and ideas using different colors and cards (shapes). This tool can also support the learners to execute tasks in the virtual environment. For example the group of learners can collect and exchange ideas using the brainstorming board in order to execute a task assigned by the tutor to them.

The brainstorming board is shown in figure 3.

- *Video presenter*: video presenter is used in order for the user to attend streaming video inside the 3D environment. The users have the capability to start and stop the movie. The video presenter tool is used in order to present pre-recorded streaming video. This tool contributes to the remote task support by presenting experiments, recorded lectures, etc.

**Fig. 3** Brainstorming board

#### 4.1.5 Application sharing

Except for the use of the presentation table, the users in a lesson can also present material, which is located in their local desktops using application and data sharing. Furthermore they can collaborate on documents and use 2D Whiteboard. This whiteboard is based on the Microsoft's NetMeeting whiteboard. It has similar functionality with the 3D whiteboard and it is also shared between the participants of the lesson. This functionality is very useful for conducting synchronous reading/editing on a document. This tool can be used as a scaffolding tool. It can also be used for supporting the remote task collaboration.

#### 4.1.6 User categorization

In order to enhance the remote task collaboration EVE supports users with different roles and rights. These roles are the tutor (moderator) and the student (learner). A tutor has more rights than a student in the e-learning environment. We accomplish this by providing each user with an access level that is set by the administrator during the creation of a new user's account. Furthermore, each shared object contains a variable that controls the access rights of that object. Thus, if a shared object has its access level equal to "STUDENT," then only users that have their access level equal or greater than "STUDENT" can access this object. The user categorization contributes to the performing of various e-learning scenarios. This functionality allows the participation of students, tutors/and or moderator in the virtual environment as described later in this paper.

#### 4.1.7 Locking/unlocking objects

There are cases where we need a certain object to be accessed only by one user at a time. For example, when a user writes on the whiteboard nobody else should be able to write or delete something on it. For this reason, we offer the capability to lock/unlock a shared object. When a user, who locked one or more objects in a world, leaves the scene without releasing the lock, the objects are automatically unlocked. Moreover, a user with higher access level (e.g., the tutor) than the one that possesses the lock of an object can obtain the lock of that object from the other user. Using this functionality the tutor can have explicit control on the shared objects. This functionality has been implemented in order to support various e-learning scenarios, as well as, to facilitate the moderation of the e-learning process. Furthermore, it supports the remote task collaboration.

#### 4.1.8 Expelling learner/participant

Sometimes, a learner/participant can become annoying, preventing the smooth completion of a lecture. In these cases, the tutor (in the on-line lecture scenario) and the moderator of the class (in the collaborative e-learning scenario) has the ability to expel this user. The only action he/she has to take is to select the user from a list of all users participating in the class and to press the "expel" button of the user interface. By clicking this button, the user is disconnected from the system.

#### 4.1.9 Usage scenario

The EVE prototype can support a collaborative e-learning scenario. In this scenario, the participating entities are the learners, the moderator, the shared objects and the educational material. All the learners are equivalent and they have the same access rights and authorities. The only additional capability that the moderator has in this scenario is that s/he can expel an annoying student from the virtual world and moderate the audio channel. The participants in a collaborative e-learning session can take a seat near the presentation table and start collaborating on a specific theme. Usually, the moderator asks a question using audio communication functionality (or substitutionally he can use text chat). Furthermore, the moderator can write the question or introduce an issue and upload it to the presentation table as a document. The learners can answer the questions using the audio collaboration functionality (or alternatively text chat). Also, the learners can use the brainstorming tool in order to write and attach their ideas to it. During the collaboration process the users can upload supportive e-learning material, into the library and show it to the presentation table or to the video presenter. If this learning material is a document the users can collaborate on it using the application sharing functionality. Furthermore, a user can lock a tool in order to work alone and the rest of the users attend what s/he is doing. When s/he finishes the other learners can continue their work.

### 5 Architecture

The design of the architecture aims to satisfy the following requirements in order to offer the above described functionality: (a) Scalability: the ability to support a maximum number of simultaneous users, which could vary according to the specific settings of each virtual world; (b) Consistency: consistency is realised by distributing and synchronizing users' input as well as the user's independent behavior in order to achieve the impression of a single shared world; (c) Openness: it should be possible to interface a VE with external applications. We have designed the EVE as a system based on international accepted standards and technologies. More specifically EVE is a web-based application that supports and integrates several forms of data. Furthermore, it exploits widely accepted conference standards (such as T.120) for the users' communication as well as H-anim<sup>14</sup> compatible avatars, which support animation and gestures, for the users' representation. In addition, EVE's implementation is based on open standards and technologies (HTTP, VRML,<sup>15</sup> and JAVA).

The basic idea of our architecture is to divide the processing load of necessary services of an Educational Virtual Environment (such as application sharing, chat and audio communication, e-learning content, etc.) into a set of servers [2] aside from communication of users or management of the virtual worlds as described in other models [4]. In order to divide the processing load of specific services we use

<sup>14</sup> Web 3D Consortium—Humanoid Animation Working Group H-Anim 1.1 specification. 1999, <http://www.h-anim.org/Specifications/H-Anim1.1/>

<sup>15</sup> Web 3D Consortium. The Virtual Reality Modeling Language (VRML)—Part 1: Functional specification and UTF-8 encoding”, 1997, <http://www.web3d.org/technicalinfo/specifications/vrml97/index.htm>

different application servers such as the Conference Server, and Chat Server. In addition, a separate Message Server (which consists of a ConnectionServer, an InitServer, and a VrmlServer) is used to serve a set of 3D worlds of the community. The separate sub-servers are used to carry out each of the specific operations of a Message Server. Following this approach, we achieve our initial goal of shattering the processing work into pieces and increasing the scalability of our system. These components are described as follows:

- **Message server:** The message server has three main tasks: (a) to transmit virtual world content, (b) to offer scalability and stability to the system and (c) to keep the 3D world consistent by reflecting every shared event to all participants in the virtual world. The structure of an educational environment implies a VE that can be separated into smaller parts, which are VEs dedicated to a specific e-learning course. This provides a “segmentation” of the virtual community that enables us to design a communication model, which consists of a set of message servers. The lessons in the e-learning community are conducted in multi-user 3D rooms (which called course rooms). The message servers host these 3D rooms. Each message server is responsible for a part of the course rooms, and in parallel it can act as back-up server for the rest of them (figure 4). In figure 4 each small square  $C_i$  represents a course room. The shady course rooms in each message server refer to the course rooms for which each message server is responsible. For example, Message server 1 is responsible for rooms C1, C2, and C3 and back-up server for the rest of them (C4 through C9). Similarly, Message server 2 is responsible for rooms C4, C5, and C6 and back-up server for the rest of them (C1 through C3 and C7 through C9). The same applies for Message server. Therefore, if a client  $P_i$  wants to visit course room C1, it is connected to Message server 1. The set of message servers constitutes a locus of control of the whole system.

As mentioned before the message server consists of the ConnectionServer, the InitServer and the VrmlServer. The ConnectionServer handles the connection requests of the participants. The InitServer holds the current state of the virtual community. Once a new participant (client) arrives in the VE, the InitServer transmits the entire list of shared nodes that maintains, to the newly added client. The VrmlServer is responsible for sending update messages to the participants.

- **Application servers:** Dedicated application servers are used in order to provide specific functionality. According to previous described requirements, the most useful applications, in order to support the educational process and to present educational material, are chat and audio communication, as well as application sharing. For these reasons we use three types of application servers: (a) conference server, which is responsible for providing application sharing functionality. (b) Chat server, which is responsible for chat capability and (c) Audio server, which supports audio communication.
- **Client:** System clients, which interact mainly with message server.

The interaction among the components of the architecture is presented in figure 5. This model is well suited for educational purposes because of the following reasons:

- It offers scalability, in order to support a large number of simultaneous users and/or provided services, because the processing load is split, and more application servers for additional services can be integrated, without affecting the end user. It should be noted that the achievement of scalability is very crucial

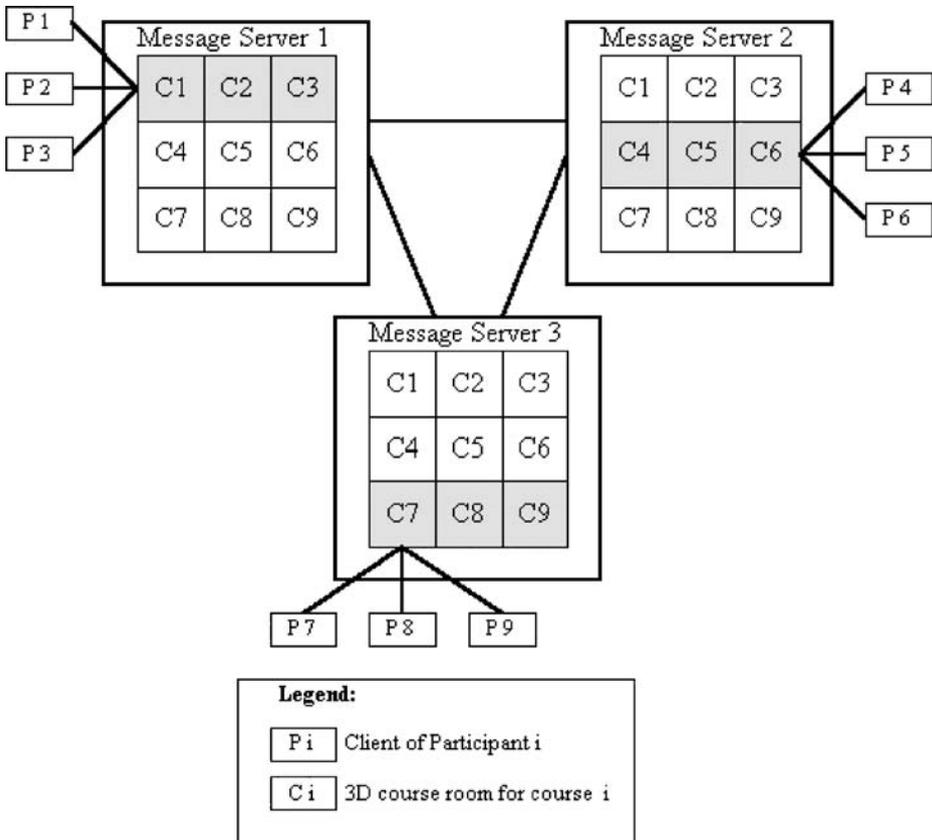


Fig. 4 Segmentation of 3D course rooms

for our prototype, which is designed for educational use, and it should be suitable for widespread use.

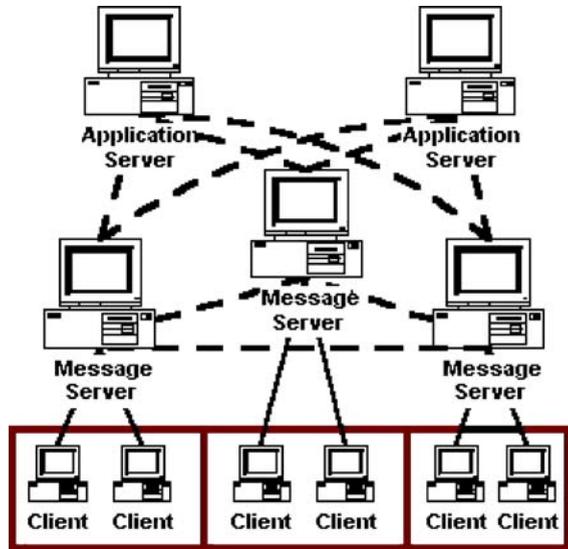
- It offers central management and authentication mechanism.
- It is not required excessive system or network characteristics by the end users.
- There is no central point of failure.
- It is flexible, because in case the number of users is small, some of the servers dedicated to one service can be consolidated in a message server.

A more detailed architectural view of EVE is presented in (figure 6).

Apart from the above described set of servers, EVE prototype exploits an HTTP server which contains all the necessary, HTML pages, VRML files, 3D object and other e-learning material.

In order to communicate with the above described set of servers, The client of EVE prototype consists of six components: the web browser, the VRML browser, the MainClient, the VRMLClient, the ChatClient, the AudioClient, and the ConferenceClient. The VRML browser is a plug-in, used to navigate user in the VRML world. Any VRML97, EAI compliant browser could be used for this reason. Parallel Graphics' Cortona is a tested and recommended solution. The MainClient

Fig. 5 Reference architecture



is a java applet that establishes and terminates the initial connection to Message Server. It notifies the user about the current connection status and it presents a list of the participants populating the same 3D world. The VrmlClient is a java applet responsible for the interaction between the user and the 3D scene. It works in two phases. In the first phase, it receives all shared nodes from InitServer and initializes the VRML world. In the second phase, the VrmlClient sends (and receives) events to (and from) VrmlServer and updates the VRML scene accordingly. In addition, this module gives the participants the capability to make predefined gestures and to lock/unlock shared objects. The ChatClient is a java applet that implements the

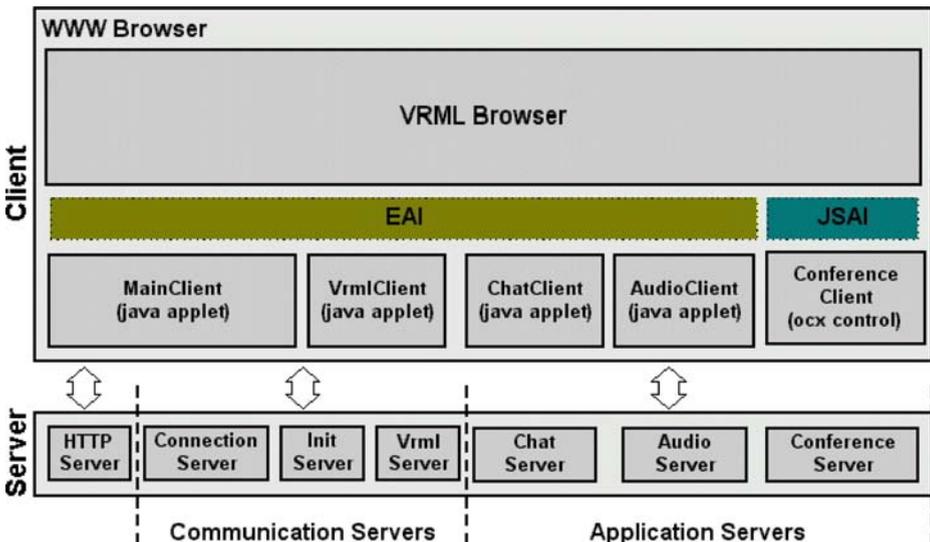


Fig. 6 Architecture and components

exchange of chat messages among users in the same VRML world and it offers text conference functionality to the prototype. The ConferenceClient acts as an application sharing client. It allows participants to enter in an application sharing (T.120) conference that is established in the Conference Server. This module is an ActiveX control and is based on the Microsoft NetMeeting SDK [2]. It offers the participants the functionality of document/application sharing, 2D shared whiteboard, and collaboration on documents. The audio client is a java applet that records the audio input of the client and sends the audio stream to the audio server. It can also receive and play the audio streams from the audio server.

## 6 Evaluation of the prototype

A usability evaluation of the prototype is conducted in order to validate the design of the EVE prototype. The goals of the usability evaluation were to (a) assess usability problems with the EVE interface, and (b) investigate more requirements of the end-users in order to improve the functionality of the EVE prototype.

Our aim was to evaluate the current functionality as well as the interface usability, in order to obtain results for future enhancements of the prototype. Furthermore, the general acceptance of the system by the end-users, and their estimations concerning the suitability of the system to support their learning situation were recorded. In the following paragraphs we describe briefly the evaluation process that has been followed and a summary of the evaluation results.

### 6.1 Evaluation process

The target group of the evaluation was teachers and students of Greek schools (lyceums). More specifically five (5) schools were recruited. Five (5) learners and one (1) teacher have participated in the evaluation process from each school. Also a technical expert and an observer were present in order to help the evaluation process.

The usability evaluation has been conducted in two phases in order to meet our goals: (a) an introductory phase, with guidance by a technical expert, and (b) an e-learning session without guidance.

The first phase was conducted to explore the basic functionalities of the EVE prototype. Main interests for this test were the basic avatar navigation in the 3D space, controllability of avatar gestures, the chat tool, the audio tool, the application sharing tool, and the usage of the presentation table. A technical expert has guided the users explaining them the functionality of the prototype. In that phase the think-aloud method was used: an observer of the session has asked the users about the functionality that they have used in order to get a deep understanding of the user's problems with the interface.

The second phase was an end-user learning session, where the end-users work within an authentic situation following the collaborative e-learning scenario. The aims were to observe how they would get along without a strong guidance, how they would use the gestures and how they would communicate (e.g., for which purposes they use the audio channel and the text chat). In order to get information about the advantages and disadvantages of the prototype and the appropriateness of different kinds of learning situations questionnaire and interview data are collected.

## 6.2 Summary of evaluation results

In this paragraph, a summary of the results of the usability evaluation is presented. Furthermore, suggested enhancements and functionality by the end users are presented.

### 6.2.1 *General impression and acceptance*

The concept of EVE prototype has been rated, by most of the end users, as interesting and promising solution for collaborative e-learning. They stated that the 3D-metaphor of a virtual classroom is a useful approach to support synchronous e-learning, especially for small groups of learners. Furthermore they have found that the simplification of the user interface using 3D metaphors, the support of different files formats and the use of the audio communication channel are the main factors for the general acceptance.

The usability of the user interface usability of the prototype has been rated positive. They all thought that they got along well with the system. However, they stated that the interface of the 2D tools needs improvement (e.g., the buttons for the avatar gestures should be replaced by icons). Furthermore they stated that the error tolerance of the system should also be improved.

### 6.2.2 *Advantages of the prototype*

During the evaluation of the prototype the end users have mentioned various advantages. The main are the social presence, intuitive VE, the combination of 3D, audio communication, text chat, and visualization on the presentation table. Furthermore, users believe that EVE prototype is best suited for presenting and discussing a topic. Collaboration while working on a theoretical task as well as informal exchange of information and collaboration while solving a practical task were also rated positively.

Other features that has been rated as very helpful are the following:

- Support of shared navigation within documents of various formats (such as pdf, word, excel, etc.) through application sharing and library functionality.
- Uploading of e-learning material in the 3D world using the drag and drop functionality in the library feature.
- “Who is talking,” which helps users recognize who speaks (meaning who uses the audio communication).
- Both brainstorming and whiteboard tools, which have been rated as very necessary for collaborative learning.
- The use of semi-transparent colors in the whiteboard tool, which is very useful for highlighting areas.
- Bubble chat feature, which helps users recognize who is chatting.

### 6.2.3 *Suggested enhancements*

One of the main results of the evaluation was the suggestion of new features that could be integrated in the current prototype. The main suggestions by the end-users were the following:

- Real-time video presentation, in order to present hard copy documents using a document camera.

- Freehand drawing on the whiteboard tool.
- Automatic assignment of a free seat near to the presentation table.
- E-mail support.
- Tooltips should be added in every clickable area.
- The avatars should have a context menu in order to manipulate them.
- The avatars should support facial expressions, at the same time with a gesture, in order to express feelings in a better way.
- A different seat near the presentation table should be added. This seat should be assigned to the moderator (tutor) and should provide him/her with special rights (such as locking/unlocking shared objects).
- Smaller 3D course rooms for 4–6 learners could be useful in order to support learning tasks for sub-groups of users.

## 7 Future work

This paper has discussed the theoretical potential of CVEs in order to support collaborative e-learning. The derivation of our approach in order to extract the basic design elements was based on a theoretical analysis, rather than on the results of empirical studies. In order to validate them we have conducted a usability evaluation, which has resulted in very promising results. This evaluation has also resulted in suggestions for additional features and functionality that could be integrated to EVE prototype. According to these results our next step is to improve the avatars' representation including functions such as visualization of the interest focus, and communication with facial expressions. Another goal is to implement a web based interface as a top level of our prototype platform for manipulating the users, the e-learning courses and the educational content. Furthermore, new types of 3D course rooms will be designed in order to support sub-groups of learners in a course room. These rooms will be called "break-out" rooms and will be used in order to realise specific collaborative learning techniques such as "think pair share" and "jigsaw." In addition, the integration of tools for content manipulation as well as interfaces for integrating standardised learning content is a feature that is planned to be integrated.

Furthermore, from the technical point of view, we would like to improve the scalability and networking characteristics of our prototype. In more detail we would like to improve the scalability of the system supporting multicast communication between the Message Servers and offering multicast groups for each world of the community. Moreover, we would like to improve the stability of the system making each message server back-up server of the rest of message servers. We also plan to simulate the proposed architecture in order to measure its effectiveness and scalability.

In addition we plan to extend the method of sharing the multi-user events, by implementing a VRML parser on the server side. This parser will be an extension of the SVE parser and will help the server to recognize the shared events without the usage of an SVE file.

As described in [8], the empirical evaluation of learning using desktop VR is still in its infancy. It should be evident, therefore, that the field of desktop VR in education and learning remains open and requires focused and systematic research. Therefore, after finalising the above described steps our next goal is to make experimental evaluations about how a user can learn in a virtual environment, as well

as to compare these results with the process of learning using a comparable platform without VR-technology.

## 8 Conclusion

The use of CVE in order to offer e-learning services and especially in collaborative e-learning is very promising. Even if the derivation of our approach in order to extract the design elements was based on a theoretical analysis, the results of this analysis could be very helpful to educational developers considering the use of 3D learning environments.

Main reasons are that CVEs offer many communication and collaboration features as well as better participants' awareness than other technologies, such as videoconference. CVE's that offer e-learning services can be characterised as Educational Virtual Environments. As any CVE requires an infrastructure, the Educational Virtual Environment needs a supporting platform for making the 3D worlds multi-user and offering basic functionalities such as audio communication, text chat as well as application and document sharing. As discussed in this paper the use of current commercial platforms and/or research platforms for CVEs is not efficient. Commercial platforms are characterised by generality and they need a lot of modifications in order to support Educational Virtual Environment. Research platforms emphasize on specific applications or they try to resolve specific issues and they are characterised by limited re-usability. For these reasons we have decided to design and implement a platform to support EVEs.

In this paper, we have presented the basic features of the Educational Virtual Environments as well as the functionality of the EVE prototype that we have implemented. Our second step was the design of the system architecture and the system implementation. Finally a usability evaluation of the prototype is conducted in order to validate the design the EVE prototype. The evaluation results were very promising and motivate us to continue our work on enhancing the EVE prototype with more features.

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