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The Virtual Radiopharmacy Laboratory: A 3D Simulation for Distance Learning

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This article presents Virtual Radiopharmacy Laboratory (VR LAB), a virtual laboratory accessible through the Internet. VR LAB is designed and implemented in the framework of the VirRAD European project. This laboratory represents a 3D simulation of a radio-pharmacy laboratory, where learners, represented by 3D avatars, can experiment on radio-pharmacy equipment by carrying out specific learning scenarios. This article describes the functionality provided by this laboratory, the motivation factors which led to its formation, the technological decisions that were made for the optimization of the system, as well as the envisioned steps to be carried out.

The wide expansion of the World Wide Web (WWW or Web) and the Internet has formed all the necessary preconditions for adopting this powerful means for purposes such as delivery of e-learning content, collaboration, and distance learning both in the industrial and the educational field. This trend has been proven beneficial for small communities of people, working in highly specialized areas and facing communication and collaboration difficulties due to spatial limitations (Laister & Koubek, 2001). The community of Radiopharmacy stands as an example for this kind of specialized communities.

In the technological field, Virtual Reality (VR) technology has been widely proposed and recognized as a major technological advance for supporting life-long education to individuals along with a flexible workforce. One of the unique capabilities of the VR technology is the successful translation of abstract concepts into visualized events and the interaction of students with them, that in real life could be limited due to distance, time, and safety factors (Youngblut, 1998). Furthermore, by exploiting 3D multi-user virtual environments, the user can interact with other users of the virtual environment, thus achieving a great sense of realism. Therefore, VR technology could have a high potential for supporting not only Resource-Based Learning (RBL) but also collaborative e-learning processes. However, current user interfaces fail to enable the user to be fully creative. In most cases the emphasis is given on the technology rather than on the fact that these interfaces should be designed for the content to be easily accessed. For example, in general, voice or gestures from the user are not used (Earnshaw, 2001).

In recent years, communities and educational collaborative virtual environments, in general, drew academic and research attention and a great number of educational institutions and organizations focused on the development of virtual collaboration environments. Among these efforts, a distributed virtual reality environment for simulation-based learning is C-VISions (Chee & Hooi, 2002). C-VISions is a research project, which focuses on the implementation of a multi-user 3D environment for educational purposes. For the learning process to be realized, users are represented by avatars in a 3D environment. Furthermore, the system provides collaboration and communication tools such as enhanced text chat and a global audio chat system. Another example of a virtual environment for educational purposes is The Virtual Labs Series—http://www.hhmi.org/biointeractive/vlabs/ produced by the Howard Hughes Medical Institute. This work is a collection of virtual laboratory exercises, fully interactive, created for the diffusion of biomedical know-how, with 3D modeled laboratory equipment covering different modern biological topics. The Virtual Lab Series begins to address the need to educate the public at large about the rapidly emerging fields of bioinformatics, genomics, and applied Internet-based research.

It must be mentioned that these environments focus either on the technical implementation and representation of the 3D world as C-VISions, or on the standard operation process as the Virtual Lab Series. Consequently, research has not yet presented an integrated educational 3D environment, which could provide a powerful 3D world with enhanced communication tools (avatars' gestures, voice, and text chat) and intelligent learner modeling functionality along with the ability to focus on the training procedure. This notation led to the implementation of the VR Laboratory, which will be described in detail in the remainder of this article.

On the whole, this article presents a 3D Virtual Radiopharmacy Laboratory that exploits the benefits of VR technology, and tries to overcome the previously mentioned problems to provide a simulation of a radio-pharmacy laboratory, where learners can experiment on radio-pharmacy equipment by carrying out specific learning scenarios as well as interact with other learners and mentors. This laboratory has been implemented in the framework of the VirRAD European project, which has as its main goal to support the Radiopharmacists' community worldwide.

The remainder of this article is structured as follows. In the next section the VirRAD Project is briefly described; while in the section, "Motivation and Design" the motivation factors and main design issues are presented. The section, "System Implementation and Architecture" is dedicated to the system implementation and architecture. Following this, the functionality provided by the VR Laboratory is presented. Finally, some concluding remarks and planned next steps are briefly described.

THE VIRRAD PROJECT

The VirRAD (Virtual Radiopharmacy—http://www.virrad.eu.org/) project is concerned with section III.2 of the IST 2001 work program "Education and Training." It started on February 2002, and it will run for almost three years.

The aim of the VirRAD environment, in general, is to provide a sustainable, user-driven, web-based interface, which supports communication between all members of the worldwide Radiopharmaceutical community. It will help them expand their horizons, share their ideas, disseminate best practices, and develop innovative solutions to universal radiopharmaceutical problems to promote the ongoing contribution of the specialty to science and health-care. VirRAD aims to integrate current RBL concepts with collaborative e-learning strategies (Laister & Koubek, 2001). Part of this environment will address the particular needs of trainee radiopharmacists by providing distance-learning material for supporting RBL (Ryan, Scott, Freeman, & Patel, 2000). The development of multimedia learning material will be closely coupled with the pedagogical theory of Mindful Learning

(Langer, 1997). Furthermore, as group-learning processes have been proven highly efficient, especially in problem solving, the virtual environment will support collaborative processes enabling the communication and collaboration among individuals both in a synchronous and an asynchronous manner.

To meet the aforementioned objectives, VirRAD system has been divided into the following main areas: (a) Community, (b) 3D VR Laboratory, and (c) Courseware (Bouras, Giannaka, Kapoulas, Nani, & Tsiatsos, 2003). The Community site provides a series of tools for the communication, collaboration, and information exchange among the radio-pharmacist's community members. These tools offer functionality such as personal cards, library, text chat rooms, virtual conference rooms, forum, news, links, events, an adverse reactions reporting system, and a glossary of terms. The Courseware aims to support and facilitate the access to non-VR learning material. Regarding the 3D VR Laboratory, it simulates a radiopharmacy laboratory to make radiopharmacy learners familiar with the execution of standard operation processes as well as to encourage and facilitate interactions among learners and mentors. Both Courseware and 3D VR Laboratory are supported by an intelligent learner modeling system for creating an integrated Instructional Component of the VirRAD system. The first prototype of the VirRAD system is available at http://community.virrad.eu.org.

The remainder of this article is dedicated to the description of the 3D VR Laboratory.

MOTIVATION AND DESIGN

This section presents the main motivation factors that inspired the design and the implementation of the VR Laboratory. The goal that should be achieved by this work is threefold:

1. To provide an e-learning environment for radiopharmacists students as well as to overcome communication difficulties among them.
2. To overcome limitations of current e-learning applications.
3. To avoid limitations met in most VR applications so far.

These goals are described in more detail in the following paragraphs.

At a first level we plan to support the community of Radiopharmacists as follows:

- To overcome the problem of interaction and communication among them.

- To support the radiopharmacy students to construct their knowledge in radiopharmacy in a “learning by doing” situation.
- To provide remote support to radiopharmacy students by radiopharmacy mentors.

According to Guimaraes, Maffeis, Pereire, Russo, Cardoso, Bergerman, and Magalhaes (2003), virtual laboratories are an important educational tool that deal with the lack of practical experience in education. With the aid of virtual laboratories, resource sharing becomes a reality and students and professionals have easier access to educational and research material that leads to productivity enhancement.

To achieve these goals, the VR Laboratory simulates a set of standard operation processes that take place in a real radiopharmacy laboratory. Furthermore, it offers various communication channels such as avatars’ gestures, voice, and text chat, for achieving a greater sense of realism.

At a second level, having in mind that the VR Laboratory is targeted to provide e-learning services to the users, the limitations of current e-learning applications should be overcome. Currently, the need for a paradigm change in e-learning has been noticed, which has not yet taken place (Laister & Koubek, 2001). In the past, Information and Communication Technologies (ICT) have been developed in a technology-centered way, but we are currently undergoing a change towards more human-centered concepts of using information technology for business, learning, and communicating with each other. However, RBL, which focuses on the interaction between human and computer, still prevails. Although, this approach has several advantages for supporting individual learning by providing interactive, media-rich resources for learning, several disadvantages have been identified. Some of these disadvantages involve the lack of peer contact and interaction of students working alone and the need for flexible, available tutorial support.

Moreover, according to Khilifa and Lam (2002), interactive distributed learning facilitates the acquisition of a higher level of understanding by the learners than the passive distributed learning, thus enabling the learning process to be more active and more explorative. To exploit the advantages of RBL and interactive distributed learning and, in parallel, overcome their disadvantages, the VR Laboratory offers the ability to be accessed in two ways: the study mode, which supports RBL through a fully interactive environment and multi-user mode, which supports collaboration and interaction among learners and mentors.

At a third level the main effort is focused on designing an environment that could be characterized as a “place” of interaction and not a simple, plain space. As mentioned before, current user interfaces have been proven insufficient for enabling the user to be fully creative. Furthermore, the theoretical advantages of multi-user VR technology are not exploited in an extended manner, as they mainly offer text chat communication and users' representation through avatars. For example, advanced communication features, such as voice or user gestures are not commonly used. To overcome these limitations, the design of the VR Laboratory is based on the concepts introduced by Dourish and Harrison (1996) about space and place: "A space is always what it is, but a place is how it's used." In addition, according to Dourish and Harrison, we have to deal with some aspects of the "real world," which can be exploited as part of a VR spatial model for collaboration and learning. The real-world value of the features listed next is that they provide critical cues, which allow individuals to organize their behavior accordingly (i.e., moving towards people to talk to them, or referring to objects so others can find them). VR Laboratory, presented in this article, exploits aspects of space and spatial mechanisms, such as providing identity, orientation, a locus for activity, and a mode of control, which can be considered as powerful tools for the design. These aspects are:

- *Relational orientation and reciprocity*: The spatial organization of the VR Laboratory should be the same for all participants. Since people know that the world is physically structured for others in just the same way as it is for them, they can use this understanding to orient their own behavior for other people's use.
- *Proximity and activity*: People act, more or less, where they are. They pick up objects that are near, not at a distance; they carry things with them; and they get closer to things to view them clearly. Understandings of proximity help relating people to activities and to each other. Similar properties are exploited in the VR Laboratory.
- *Partitioning*: Following on from the notion of proximity and activity is a notion of partitioning. Since actions and interactions fall off with distance, this distance can be used to partition activities and the extent of interaction. VR Laboratory uses rooms or locations to partition activity. For that reason it provides different rooms for high radioactive areas and for clean, sterilized areas.
- *Presence and awareness*: The sense of other people's presence and the ongoing awareness of activity allows them to structure their own activity, integrating communication and collaboration seamlessly, progressively, and easily. Similarly, the VR Laboratory presents views of other people through 3D humans like avatars, their role and their actions within the same environment.

The VR Laboratory is based on these aspects, tries to simulate not only the spatial model of a real Radiopharmacy laboratory but also the actions that take place in such an environment. Implementing and simulating the usage of equipment located in a radiopharmacy laboratory and the execution of standard operations, enable the processes to take place in a real radiopharmacy laboratory.

Furthermore, special attention in the design of the VR Laboratory is given to the direction of designing an easy and friendly interface. Simplicity of use is essential to establish an interface that can be used by everyone, and the user can focus his/her efforts on interacting with the environment without wasting time in trying to understand how to proceed through the environment.

The users can catch, carry, use, destroy objects, and so forth. Furthermore, by exploiting avatars and avatar's gestures, we try to satisfy crucial functions such as perception, localization, identification, and visualization of the others' actions (Thalmann, 2001).

SYSTEM IMPLEMENTATION AND ARCHITECTURE

This section is dedicated to describing the structure of the system that supports the VR Laboratory. The term structure is used for referring to the logical view of the static structure of the architecture in terms of its components, their interconnections, and the interfaces and operations offered by these components.

The step that follows the definition of the main design principles of the VR Laboratory is the assessment of the technologies that will facilitate the implementation of the system. VirRAD system should be an easily accessible web-based system, used by a worldwide community, taking into account bandwidth, and client-side system constraints. Therefore one of the major targets apart from implementing the VR Laboratory with the appropriate functionality is to satisfy the following prerequisites.

First, there is a need to minimize the client-side system requirements and the cost of client-side system set-up. This means that the end-user should be able to access the laboratory using a typical personal computer (PC) without excessive requirements either in hardware or in software. Second, the system should have the ability to support a maximum number of simultaneous users. This requirement should in particular be considered in the multi-user applications. Finally, using technologies, which do not require excessive hardware requirements, should also minimize the cost of the server side set-up.

According to these criteria, the system architecture is defined by some basic principles: The system should be based on a variety of communication protocols, should be scalable, as much as possible, platform independent, and based on well-known standards.

The system architecture (Figure 1) is based on several components that provide the needed functionality as follows: the database, the multi-user (MU) server, the web server, and the client. These components are described in detail. The database of the system stores the majority of the information about users such as profiles, roles, and avatars. VirRAD exploits the MySQL database management system.

The multi-user server offers the users a consistent and shared view of the Virtual Laboratory along with the support of the collaboration and communication among them. VirRAD exploits the Macromedia Flash Communication Server MX as a multi-user server due to the fact that this server could support not only multi-user 3D environments (i.e., VR Laboratory) but also the necessary communication channels such as text and voice chat. However the text and voice chat functionality have been implemented by using Macromedia Flash MX, and by exploiting specific communication components offered by Macromedia Flash Communication Server MX. Flash movies have small size, can be accessible over the WWW by a free plug-in (Flash player), and their quality of service is satisfactory over the Internet. The communication between the multi-user server and the respective clients (Shockwave and Flash player) is achieved using the Macromedia Real-Time Messaging Protocol (RTMP). The 3D functionality of the VR Laboratory has been implemented by using Macromedia Director MX, due to the fact that Director movies could be accessible over the WWW by a free plug-in (Shockwave player), they can include a variety of media such as sound, text, animation, and digital video. Furthermore, Director movies are compact and relatively small for web delivery.

As far as it concerns the web server, it is used for storing the client-side files of the VR Laboratory, voice chat and text chat. Furthermore, the web server stores and executes the PHP scripts to obtain the users' data from the database. The web server that satisfies these prerequisites is the Apache web server, which is free of charge, runs on almost all operating systems; supports PHP scripts; can host Director and Flash movies; and can interoperate with MySQL and Macromedia Flash Communication Server MX.

The client is the end-user's personal computer, with an Internet connection, the Flash Player, the Shockwave Player, and a web browser (that can embed Flash Player and Shockwave Player) as described in Figure 1.

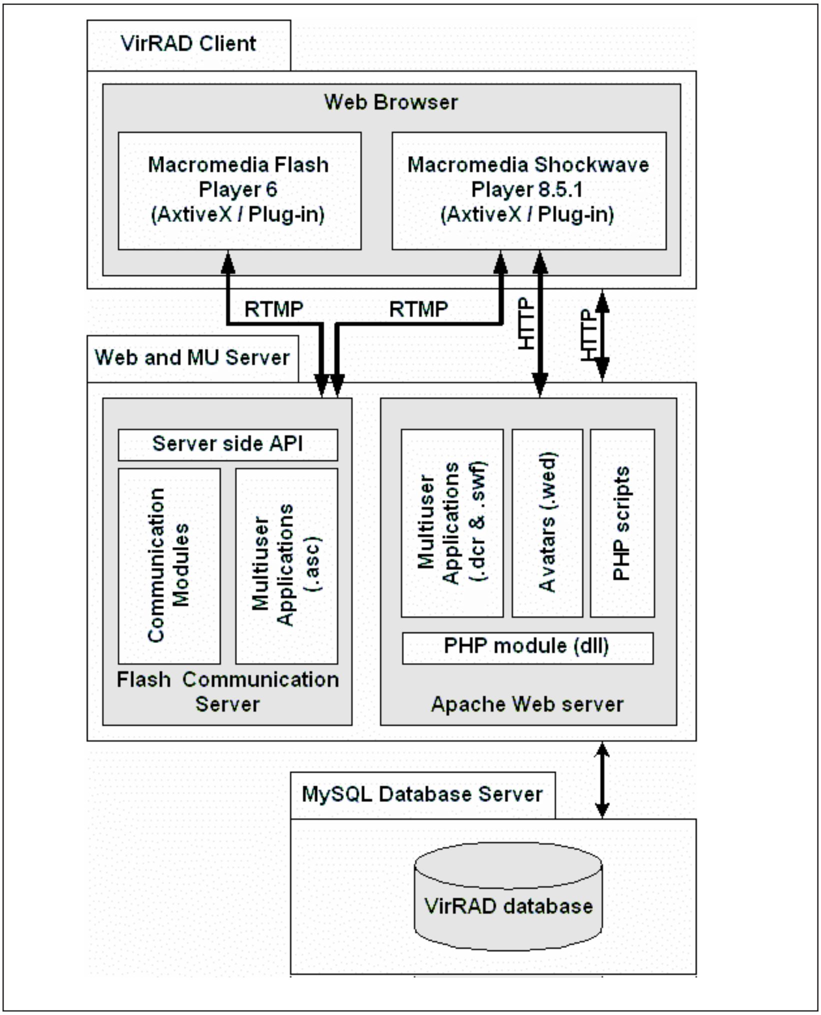


Figure 1. VR Laboratory architecture

VR LABORATORY FUNCTIONALITY

As previously mentioned, the VR Laboratory is a 3D simulation of a radio-pharmacy laboratory, where learners, represented by 3D avatars, can experiment on radio-pharmacy equipment by carrying out specific learning scenarios.

The learning scenario consists of some general steps that the learner should follow during the learning process. To enter the High Activity area the learner must be protected from any kind of radiation. Therefore, he/she should first get dressed with the necessary equipment. The next step is to prepare the equipment for the elution process. Elution is a process where Technetium99m, a radioactive material, is extracted from Molybdenum, another radioactive material using a device called generator. In some cases the eluted solution contains higher than normal Molybdenum quantity, which could be fatal for the patient. Therefore, there should be a validation check to the eluted solution. The process that follows the elution is the preparation of the actual radioactive medicine. This medicine must be first checked for its propriety through a procedure called "Quality Control." The following process prepares the actual radioactive medicine. Some ml from the eluted solution (Technetium99m) along with some ml from the sterile vial are put in another vial. The mixture leads to a new solution, which will be used for patient treatment if found proper. The quality control is to have a chromo graphic analysis of the prepared solution to verify that the process has been completed successfully.

VR Laboratory supports this scenario in two modes: (a) the study mode, and (b) the multi-user mode. In the study mode the user can interact with the environment without the presence of other users. His/her help is an intelligent learner modeling that in conjunction with warning messages guide him/her during the learning process. Regarding the multi-user mode, the user can see other users that have also visited the VR Laboratory and interact with them, by gestures, text chat, audio chat, and with the virtual environment. Ever though the learner modeling does not support this mode of the VR Laboratory, the participants have the ability to collaborate and communicate with each other to achieve a higher level of knowledge. The functionality provided by the VR Laboratory in these two modes is described in the following paragraphs.

Study Mode

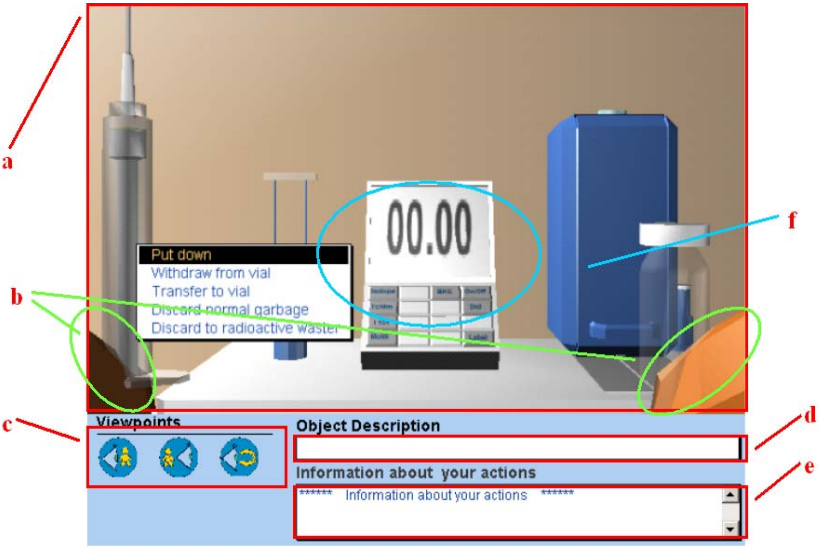
The interface of the VR Laboratory in the study mode includes the following areas/functionality (Figure 2).

- 3D area (Figure 2a):
- Viewpoints area (Figure 2c)
- Object description area (Figure 2d):

- Area where the system feedback about user actions is displayed (Figure 2e):

Using the buttons of the “viewpoints area” the user can change his/her viewpoint to have a different view of the laboratory. The user can choose between four viewpoints: “View behind the avatar,” “View in front of the avatar,” “View avatar hands,” (default viewpoint), and “Stand Up” (this viewpoint takes effect only when the avatar is sitting on a seat).

In the “object description area” the user can see the name of the object, in which his/her mouse is up.



****** Information about your actions ******

Figure 2. Study mode of VR Laboratory

In the “information about user actions” area the user can see information and get system feedback after some specific functions. An example of such information is the result of an elution process.

In the “3D area” the user can navigate his/her avatar (the avatar’s hands are displayed in Figure 2b) and manipulate active objects. The avatar navigation is achieved by using the arrow buttons of the keyboard. It is important to notice that the avatar has “collision detection” so as to recognize solid objects such as walls, other avatars, and so forth. For the user to carry out specific radiopharmacy scenarios, active objects that can be manipulated by the user are located in the 3D area. Examples of active objects are displayed in Figure 2f. The way that the user manipulates the equipment differs from object to object. The right mouse click on an object creates a menu that contains a list with the possible actions that the user can realize with the object. This list is generated dynamically and depends on the object itself, the location of the object and other objects that it may contain and/or may be attached to it (Figure 2) or in his/her other hand. In addition, some equipment devices in the VR Laboratory, which are static, such as the Calibrator Display and Laminar Airflow, operate with a left mouse click on the device’ s buttons.

During the process of a specific radiopharmacy scenario, when the user realizes an action that is not in accordance with the specific scenario, a warning message appears in the screen. The learner’s modeling assist to this point, could be proven beneficial for learners by providing them additional information about their mistakes and by indicating to them guidelines to successfully continue the learning process. This functionality indicates that the VR Laboratory environment could be characterized as a place of user-system interaction and not a native learning environment.

Multi-user Mode

The multi-user mode (Figure 3) of the VR Laboratory offers similar functionality with the study mode. The main difference is that in this mode the user can meet other learners and mentors who are also represented by an avatar and they can support him/her on the handling of the simulated equipment of the VR Laboratory as well as on the execution of the radiopharmacy scenarios, by using text and voice chat.

An important feature of the multiuser mode of VR Laboratory is the “Follow Member” functionality. During the learning process, every participant in the laboratory has the ability to choose between two options. He can interact with laboratory equipment and support other participants on execution of a radiopharmacy scenario or can ask permission from another participant to watch him/her while executing a radiopharmacy operation in the laboratory.

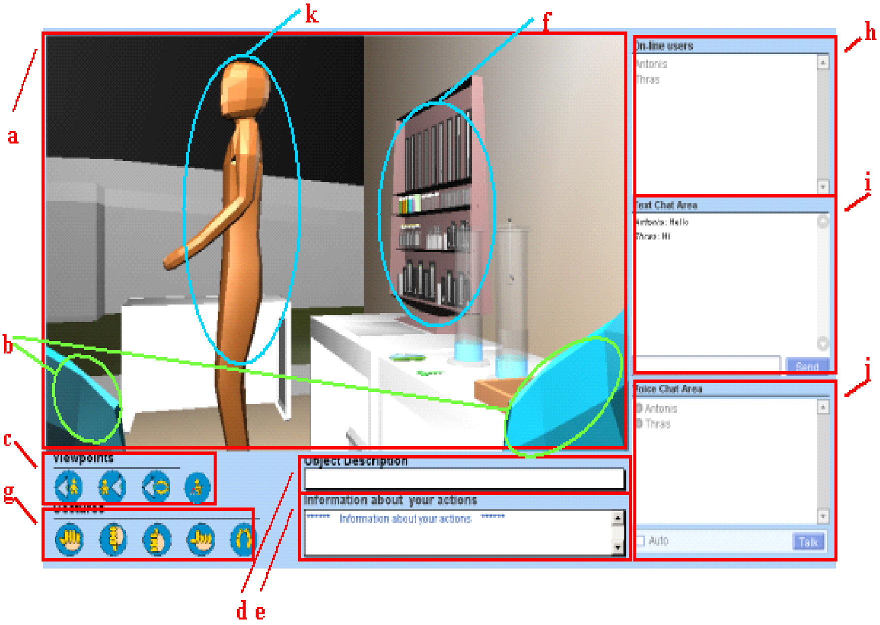
The interface of the multi-user mode of the VR Laboratory includes the following areas:

- 3D area (Figure 3a), which offers similar functionality to that of the study mode. Moreover the user can see the avatars of the other users who are online in the VR Laboratory at the same time (Figure 3k).

- Viewpoints (Figure 3c), which offers similar functionality to the viewpoints of the study mode.
- Object description area (Figure 3d), which offers similar functionality to study mode.
- Area where the system feedback about user actions is displayed (Figure 3e).
- Gestures area (Figure 3g), Online users area (Figure 3h), Text Chat area (Figure 3i), and Voice chat area (Figure 3j).

Using the buttons of the “gestures area” the user makes an avatar gesture, which is viewable by the other online users. This functionality is essential in a multi-user 3D environment because indicates the interactivity and friendliness of the environment. There are several ways that the user can communicate with other on line users by the use of gestures. These are: “I want to say something,” “No,” “Yes,” “Good bye,” and “View my hands.” In the “online users” area the user can see the names of the other users that are currently online in the VR Laboratory.

The functionality provided in the “text chat” area enables users to send text messages to other participants. Similarly the functionality provided in the “voice chat” area enables the users to discuss using voice.



ntonis: Hello
Thras: Hi

Figure 3. Multiuser mode of VR Laboratory

The main advantage of the multi-user mode of the VR Laboratory is that it provides a virtual environment that allows learners to interact with other learners or with the equipment of the laboratory, exactly as it would happen in a real radiopharmacy laboratory. Thus, through his/her 3D representation, every participant has the ability to communicate, discuss, and cooperate with other participants and together they have the ability to perform actions in the laboratory, having in mind that these actions must be in accordance with the specific learning scenario. Surely, it must be mentioned that as exactly it would happen in a real laboratory, the environment does not prevent a participant from doing an action that could possible cause the failure of the specific learning scenario. The latter, is another critical point that characterizes the VR Laboratory as a "place" of interaction and cooperation and not a simple, plain space.

FUTURE WORK

In this article we presented a first prototype of a 3D VR Laboratory. The step that follows this first prototype is to conduct a user evaluation to fine-tune, and enhance the functionality integrated. Furthermore, we plan to integrate more simulations in the current prototype to enable the users to conduct more standard operation processes that could take place in a real radiopharmacy laboratory.

Moreover, we plan to enhance the study mode by integrating a learners' modeling system. Within the VR Laboratory, learners will be learning on their own. Although peer group and mentor help are available through the communication channels of VR Laboratory, this help cannot be guaranteed, and hence some form of pedagogical assistance is likely to be required by the computer system itself. This need is emphasized by the requirement of the learner to be able to continue learning at home and this potentially means needing assistance from mentors or peers at unsociable hours. This pedagogical assistance will be given on an individual level, based on the system's understanding of the learner's strengths and weaknesses both in his/her comprehension of radiopharmacy and of his/her ability to organize effective self-learning strategies.

Finally among the envisioned steps is to improve the user's representation by developing better avatars. The representation of a user is a delicate issue, because realism helps to understand processes, but graphics of avatars can take the view on what is happening at an apparatus. Therefore, there must be a lot of work in the direction of improvement avatar's representation to be more functional and more attractive to the user.

CONCLUSIONS

As the Internet is turning into a truly multiservice network with a steady increase in bandwidth and decrease in response time, the environment becomes more suitable for implementations such as VR Laboratory.

The VR Laboratory tries to support both RBL and collaborative e-learning, by being accessed in two different modes, the study and multi-user mode, to enable radiopharmacy students to execute standard operation processes that take place in a real radiopharmacy laboratory as well as to support their communication and collaboration. Furthermore, it offers various communication channels such as gestures, voice, and text chat that help learners to interact and cooperate with each other.

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