Journal of Information Technology Impact
Vol. 6, No. 2, pp. 61-72, 2006

A Hypermedia Virtual Environment for Education in Medicine

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Abstract

In the field of distance learning, hypermedia virtual environments have introduced a new era, changing radically the traditional educational methods and offering new learning experiences to students. Hypermedia virtual environments take advantage of the capability of World Wide Web to provide easy access to information and in conjunction with virtual reality technologies enable the visualization of the educational material in a novel and realistic manner. The objective of this paper is to demonstrate a hypermedia virtual environment focusing on the medical education. The paper also studies the emerging area of Web-based medical simulators and the impact of their use on the education of medical students. The primary goal of the proposed environment is to reproduce conditions of the real learning process in a physical educational environment (e.g. classroom, laboratory, etc) and to enhance learning through a real-time interactive simulator for the study of a specific pathological condition in the four dimensions of 3D space and time.

Keywords: Web-based Simulation, Virtual Reality, Distance Learning, Collaborative Environment.

Introduction

Hypermedia virtual environments seem to be very promising tools in the area of distance learning and their increased use by educational institutions reveals more and more benefits. In general, an educational virtual environment can be defined as one or more virtual worlds that offer multiple educational functionalities to each user-student (Bouras & Tsiatsos, 2002).

One of the key benefits of hypermedia virtual environments is easy access to the educational material. As Federico noted "*we are in the midst of a paradigm shift in education and training from classroom centric to network centric*" (Federico, 1999). As a consequence, students are able to participate in the educational procedure from any place (even from home) and for as much time as really needed to study the educational material and thus to adapt the learning process to their personal needs. Especially the use of multimedia and virtual reality technology in the education constitutes the base for the implementation of interactive systems offering to students the ability to extend their knowledge without any help from their teachers (Manitsaris, 2001). Such interaction enforces the active participation of students in the educational procedure. Hence, students participate in a virtual environment not as passive observers, but as active members that can either discover knowledge or even produce information during the educational procedure.

However, in order to support and enhance learning through virtual environments, sufficient pedagogical methods should be applied (Christie & Fedros, 2004; Valasidou et al, 2005). A mostly applied pedagogical method is collaborative learning. The concept of collaboration is closely related to the active participation of more than one persons in the learning process. This leads to the development of environments that support collaboration and interaction among learners and teachers for educational purposes (Bouras & Tsiatsos, 2002). World Wide Web constitutes an appropriate platform for the development of collaborative educational environments that provide direct connection between students, teachers and educational material resources. Such communication can be either synchronous or asynchronous. A synchronous communication indicates that students and teachers communicate in real-time e.g. a video conference. On the other hand, an asynchronous communication provides time flexibility i.e. the simultaneous presence of students and teacher is not a prerequisite. In this case, communication can be performed via e-mails, discussion forums etc.

A challenging area for educational virtual environments is medical education and training. The high demands of medical education require, apart from the aforementioned features, enhanced realism and real time simulations. Recent advances in computer and virtual reality technologies permit the development of interactive medical simulations, which can be distributed via Web to all Internet users that are equipped with a conventional PC. Such development enables students and young doctors to acquire, within a virtual environment, the required experience and skills on a variety of pathologies. This paper aims to demonstrate a hypermedia educational system for medical students, which reproduce conditions of the real learning process in a physical educational environment (e.g. classroom, laboratory, etc) and enhance learning through a real-time interactive simulator for the study of a pathological condition in the four dimensions of 3D space and time. Specifically, the simulation represents the cellular structure of human liver and simulates a pathological condition resulting in a disease known as Jaundice.

The remainder of this paper is structured as follows. In the next section a study on the area of medical virtual environments on World Wide Web is presented. Following this, the structure of the proposed hypermedia virtual environment is described and the simulation of the cellular structure of human liver is presented. Finally, the last section outlines the conclusions of this study and presents the impact of the proposed hypermedia virtual environment system on the education of medical students.

Medical Virtual Learning Environments on World Wide Web

Virtual reality has affected a wide range of applications in medicine such as: surgical procedures, medical therapy, preventive medicine, patient education, medical education and training, skill enhancement and rehabilitation, visualization of massive medical databases and architectural design for health care facilities (National Institute of Standards and Technology, 1995). In the field of medical education, traditional teaching methods mainly involve the use of animals, cadavers or real patients to help new doctors acquire the required experience and skills. However, virtual reality technologies have changed the traditional learning process in medicine by enabling the development of advanced medical simulators i.e. virtual learning environments to help students understand important physiological principles or basic anatomy (Riva, 2002). The numerous advantages of virtual learning environments in medical education are already known and recognized by the scientific community. Specifically, medical simulations provide:

- a cost effective training system,
- a safe environment where students can practice without danger to patient and without limits on the number of times that each student can practice,
- practice on a variety of pathologies even on rare or unusual cases without waiting for a patient with a specific disease,
- an effective tool for the evaluation of students' performance and
- actions that are not possible in practice (e.g. navigation through the anatomy or use of unreal tools, etc).

Nowadays, a large number of simulators are used as valuable educational tools in medicine. The existing simulators can be broadly classified in three categories (Liu et al, 2003). The first category includes needle-based simulations, which concern the manipulation of small medical instruments such as needles, guide-wires and catheters (e.g. the Immersion CathSim Vascular Access Simulator (Ursino et al, 1999)). The second category is called Minimally Invasive Surgeries (MIS), which involves the insertion of instruments into the human body from small incisions. Simulations of laparoscopic and endoscopic operations belong mainly to this category (e.g. the LASSO project (Szekely et al, 2000)). Finally, the last category includes the open surgery simulations (O'Toole et al, 1999), where large incisions in the human body are required.

However, the majority of medical simulations used for the training of new doctors require dedicated, powerful and sometimes expensive graphical workstations (Brodlie et al, 1999). The advent of the World Wide Web and its broad use open new possibilities for improving the training of doctors through distance learning virtual environments. As Brodlie et al (Brodlie et al, 1999) refer, the use of medical simulations via World Wide Web provides significant advantages. First of all, Web provides free accessibility and enables simulations to run from any place in the world. Furthermore, the only requirement of the virtual environment is a simple VRML browser without any other special software. In addition, in case of powerful computations, users can share the power of a remote server, while a large number of users can use the simulator at the same time. Finally, a family of applications with a consistent methodology can be used for different medical procedures.

Nevertheless, the question raised is whether the development of Web-based simulations for distance learning with sufficient realism and speed, in order to enable real time interactions, is possible. In the context of WebSET (Web-based Standard Educational Tools) project (El-Khalili et al, 2000), medical simulations were developed for neurosurgery, lumbar puncture and laparoscopy procedures. Such developments show that World Wide Web can provide an effective virtual environment for enhanced training through 3D simulation and interaction (Dodd et al 2002). Specifically, a neurosurgery procedure developed within WebSET project concerns the simulation of ventricular catheterization, giving students the possibility to acquire an appreciation of the ventricular system in the brain and learn how to cannulate it in an emergency. On the other hand, the lumbar puncture simulation involves the insertion of a needle between vertebrae in the lower back directly into the spinal cord to take a sample of spinal fluid for various tests. Finally, in the laparoscopic operation a verres needle inserts into the abdominal cavity to inflate the cavity by pumping carbon dioxide into it.

Another application of a medical virtual learning environment is the simulation used by the Department of Neurosurgery in the Leeds General Infirmary to train surgeons in the treatment of trigeminal neuralgia (Li et al, 2000). A well-recognized treatment for trigeminal neuralgia is percutaneous rhizotomy procedure. This procedure involves the insertion of a needle into the patient's face and guiding it towards the foramen ovale, which is punctured to allow access to the nerve causing the pain. The simulation provides an alternative exercise for trainees to practice before performing the operation on real patients.

In the next section we present a novel virtual environment for the education of students in medicine. The proposed system adopts common practices and pedagogical methods used in distance learning virtual environments and incorporates techniques of real-time Web-based simulations to provide an integrated Web-based educational system for medical students.

The Structure of the Proposed Hypermedia Virtual Environment

The objective of the proposed hypermedia virtual environment is to provide students of medical school and specifically students of department of histology embryology and anthropology with a useful educational tool for distance learning via Internet. The proposed environment constitutes a complementary system to the educational procedure, is cost effective and designed to facilitate the learning process with an attractive, efficient and pleasant manner.

An effective virtual environment should be user-oriented. A user-oriented system is focused on the users' requirements and takes into account their capabilities and previous knowledge or experience to similar systems and their familiarity with virtual reality worlds and Internet technologies. Hence, the final system should be properly designed in order to provide easy use, without the need for preliminary training of the user. Specifically, the following guidelines have been proposed (Barbatsis, 2002) for designing a virtual system:

- Avoidance of redundant information (e.g. unnecessary graphical information)
- Use of specific terminology, understandable to target-users.
- User friendly interface that provides sufficient information and guidance to the user especially when he/she moves within the virtual world e.g. use of signs for the guidance of the user, sound messages, easy exits from the virtual worlds etc.
- Consistency in the designing of each part of the system.
- Sufficient help support and providence of clear error messages.

Considering the above guidelines the proposed distance learning system has been designed to take advantage of the Internet and virtual reality capabilities in order to present the educational material either in three dimensions (VRML models) or traditionally in two dimensions (texts, pictures, videos etc). Moreover, the system provides free access to students via Internet, regardless of place or time and collaboration among students and teachers with various forms of asynchronous communication. Specifically, collaborative learning is supported either by e-mail communication, whereby students can set questions to the teacher regarding the course, or via the forum area, where students can work in groups sending text messages concerning possible questions or problems. Alternatively, the system adopts the technique of "bulletin board" for issuing any announcements regarding the course (e.g. examination dates).

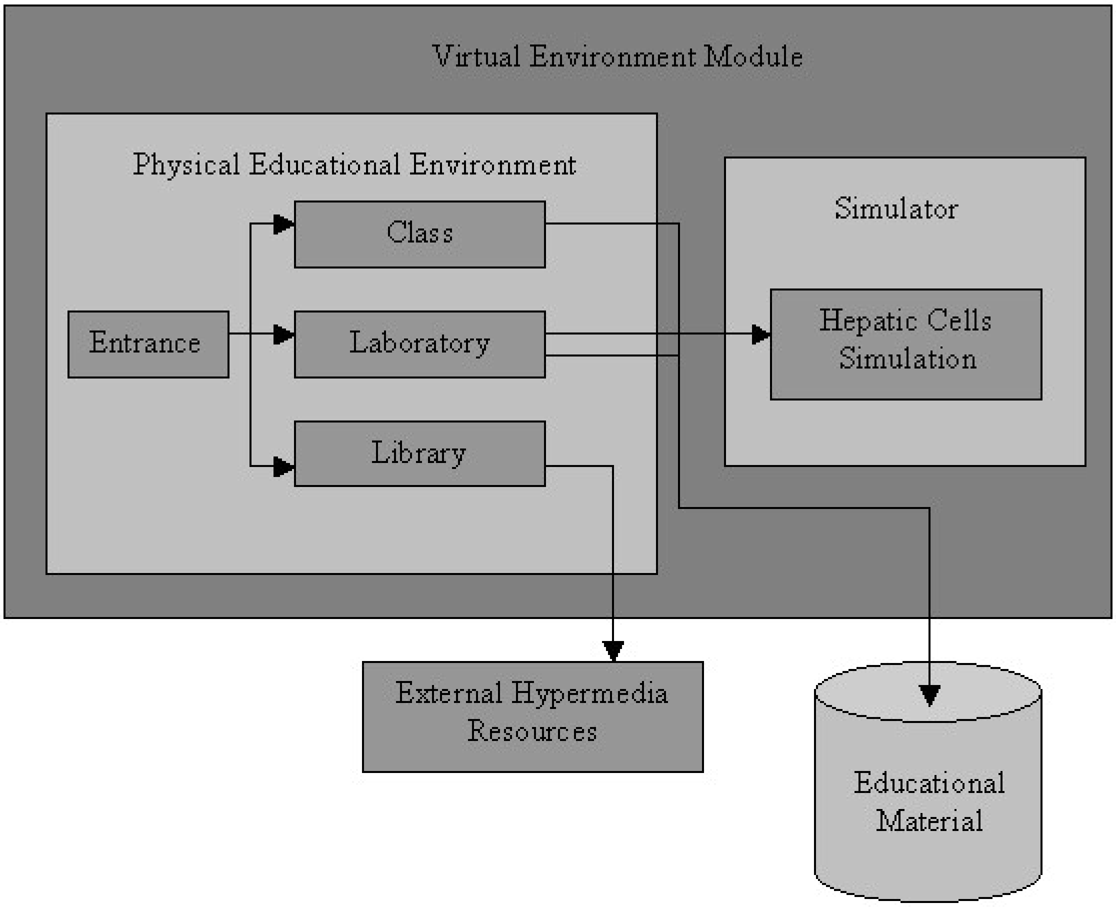

*Figure 1***.** The Structure of the Virtual Environment

The core of the proposed system is the Virtual Environment Module (VEM), whose structure is depicted in Figure 1. The VEM is a collection of virtual worlds aiming to provide multiple educational functionalities to students. As it is shown in Figure 1, VEM is divided in two subsystems. The first subsystem consists of virtual worlds that reproduce conditions of the real learning process in a physical educational environment, while the second subsystem is a medical simulation, whose primary goal is to enhance learning.

(a)

(b)

Figure 2. Representation of the physical educational environment. (a) The virtual laboratory and (b) the virtual library.

The modeled physical educational environment consists of four virtual worlds: the entrance, the class, the laboratory and the library. Two of the virtual worlds (the laboratory and the library) are indicatively presented in Figure 2. The modeling of the physical educational environment aims to transfer students to a familiar place, which is a part of previous knowledge and makes them able to perceive easier the interface with the system. The system provides the user with navigation support within the virtual environment and without placing any limitations or constraints regarding the virtual worlds that should be visited or the order that should be followed. Since some medical students are not familiar with VRML browsers and 3D technologies in general, a user-friendly navigation system was developed to enable user to navigate easier within the virtual environment. Working on this direction, we aim to address a general problem of virtual environments, which is the fact that many non-familiar users are not able to handle 3D environments and thus they stop using them.

The interaction with the virtual environment is performed via a mouse or keyboards that are commonly used in a conventional PC. The user interacts with objects of the virtual world, e.g. boards to display the multimedia educational material or doors to move from one room to other. Within the class or the laboratory, the user can attend lectures (e.g. videos) and find multimedia content (e.g. slides, images from microscopes, etc) from the real educational procedure. Moreover, the library provides links to external relevant resources. Through the virtual laboratory the user can be transferred to the second subsystem of the virtual environment, which is the simulation application.

The Simulation Application

The simulator is a real-time interactive application, which allows the study of a specific pathological condition and the cellular structure of human liver in four dimensions (x, y, z, t). The 3D representation provides perception of the cellular structure of liver in space and the fourth dimension of time allows students to study the progress of the pathological condition. Specifically, the bile in the human liver flows within long tube-like structures that are called bile ducts. Blockage of bile ducts due to pathological reasons (e.g. cancer) prevents bile from being transported to the intestine and bile accumulates in blood. In such a condition, which is called Jaundice, human skin and eyes become yellow from the accumulated bile in blood.

The simulation represents in 3D space a characteristic portion of the cellular structure of liver and the deformation of hepatic cells resulting in the flow of bile in the blood. Cells are represented as surfaces in order to decrease the computational requirements. The modeling of cells was performed under the guidance and supervision of expert doctors. Hepatic cells were modeled as cubic structures with a cavity along their four successive faces. Joining hepatic cells to form blocks (like walls) these cavities on their surface create long tube structures that are called bile ducts. Within these ducts, human bile flows i.e. the bile flows around each hepatic cell. In our simulation the bile is modeled as a yellow cylindrical-like structure.

The simulation aims to present just a characteristic portion of the cellular structure of the liver and therefore three blocks of hepatic cells have been modeled as it is shown in Figure 3. Among these blocks there are two blood vessels. The cellular structure of these blood vessels is presented as well in this simulation. Blood vessels consist of ellipsoid cells of various sizes and some special cells, which are called Kupfer cells. Kupfer cell is one of the most important types of cells since it is highly phagocytic. Kupfer cells perform a number of functions. However, the most important is their ability to endocytose and remove from the blood potentially harmful materials and particulate matter such as bacterial endotoxins, micro-organisms, immune-complexes and tumor cells. Their modeling requires smooth curvatures due to their complex structure and thus a large number of polygons is needed. In Web-based applications, memory requirements and fast access via Web should be seriously considered. Therefore, a compromise between realism and speed is required. To keep the number of polygons low in order to increase the speed of the simulation only two Kupfer cells (one in each vessel) were indicatively modeled (in fact there are many Kupfer cells in each vessel). The blood flows within the blood vessels and it is a mixture of red blood cells and plasma. A number of red blood cells were modeled as discs with their centers pushed inwards.

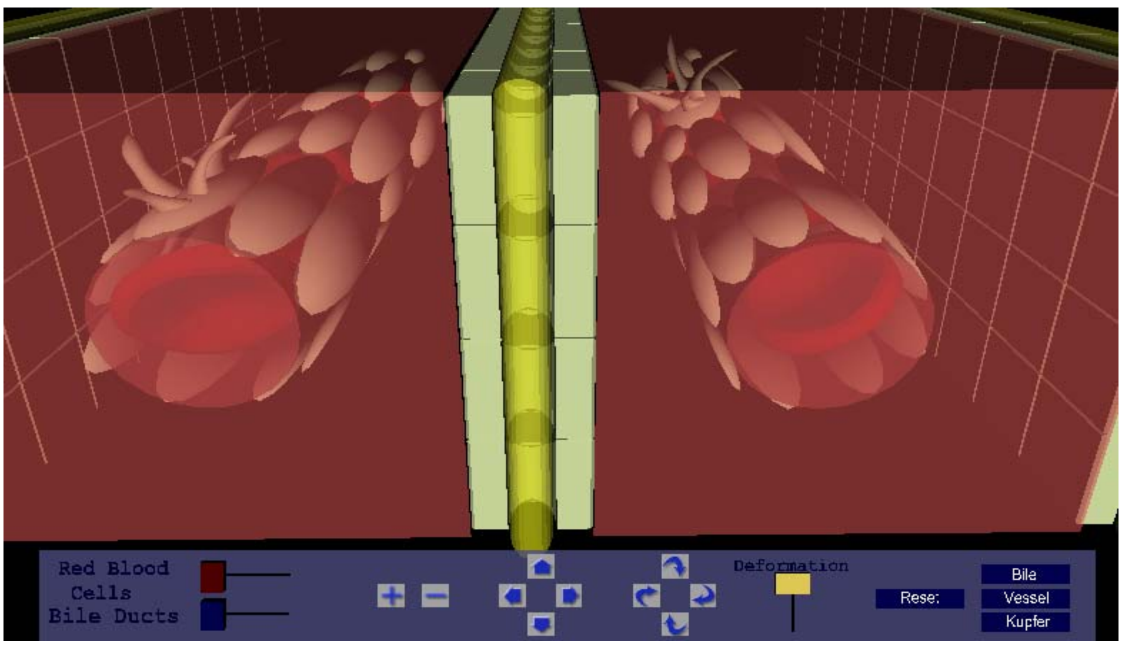

Figure 3. An indicative screenshot of the simulator.

The simulation supports multiple functions in order to enable medical students to explore the 3D model. Following a consistency in the designing of all virtual worlds of VEM, a user-friendly navigation system was developed to facilitate the exploring of the model to those students that are not familiar with VRML browsers and 3D technologies in general. The navigation system of the simulator enables the viewer to zoom in or out as well as to move in any direction he wishes (up, down, left, right). Moreover, it enables the rotation of the model around any arbitrary axis enabling thus the viewer to examine the model from different views. In order to facilitate the navigation, the simulator provides special options with which the user can be directly moved to specific positions in the 3D virtual world in order to study the model from close. Specifically, the simulator enables close views of bile ducts, red blood cells and Kupfer cells, as well as it enables direct return to the initial position.

Another advantage of the simulation is that it enables actions that are not possible in real life. These actions concern the adjustment of objects' transparency. The simulator is equipped with two special components, which enable the user to:

- Change the transparency of hepatic cells: This action enables the study of the bile ducts' network.
- Change the transparency of blood vessels' cells: This action enables the user to study how red blood cells move through blood vessels.

Finally one of the most important parts of this application is the simulation of the deformation of hepatic cells i.e. the simulation of the pathological condition in forth dimension. The deformation of hepatic cells is caused due to the increased pressure of bile on the cells' walls. The student can use a special controller to increase the pressure and consequently increase the degree of deformation of cells. As the cells are being deformed a hole is gradually created between hepatic cells and the bile flows in the blood. The flow of bile into the blood is simulated by changing gradually the color of blood from deep red to yellow. For modeling the deformation, a Java Applet containing a new algorithm called Dynamic ChainMail (Dimitropoulos & Manitsaris, 2005; Manitsaris et al, 2005), which have been developed especially for Web-based simulations, was used. The algorithm enables fast and realistic deformations of surfaces using simple geometrical calculations. For the simulation presented in this paper the deformation of only a part of hepatic cells was required. When deformation has finished the blood has a yellow color, which means that the patient suffers from Jaundice. Hence, the progress of the pathological condition in the simulation is determined by the student themselves. This is especially important as students are not any more simple passive observers of the educational process but they actively participate acquiring knowledge through the interaction with the virtual model.

Conclusions

World Wide Web along with virtual reality technologies has drastically affected traditional distance learning methods. In this paper, we presented an integrated hypermedia virtual reality application for the education of medical students. The system is based on an innovative designing that combines technologies used in common virtual learning environments and new techniques applied in Web-based medical simulations. The developed system permits students to study knowledge derived from the real learning process and to gain experiences that are difficult to be obtained through a real educational procedure.

The proposed application is a complementary system to the education of medical students and provides collaborative distance learning, with time and place independence. The use of virtual reality enables the visualization of the educational material with a unique and innovative manner, which is attractive, efficient and pleasant to students. Moreover, the implementation of a medical simulation in the proposed hypermedia virtual environment demonstrates to students an alternative way of learning beyond the traditional teaching methods. More specifically, the simulation provides the following advantages:

- Students can repeatedly study a specific pathological condition, even from home, in a virtual environment.

- The application is cost effective i.e. only a conventional PC and a VRML browser are required.
- Students can perceive better the cellular structure of human liver while navigating among cells.
- Actions that are not possible in practice are supported e.g. students can change the transparency of cells to study interior parts.
- The application enhances learning by enabling simulation in four dimensions i.e. students can study the development of the pathological condition.
- Students are active members within learning process and can discover knowledge interacting in real time with the 3D model (i.e. causing the gradual deformation of cells).

Considering the above, the use of hypermedia virtual environments provides a new base to distance learning in medicine. Future advances on computer and communication technologies are expected to allow the development of more complex medical simulations that will combine real time interaction and high levels of realism. Hypermedia virtual environments can be used as platforms for distance learning in medicine, where a family of simulations with a consistent methodology can be incorporated for different medical procedures.

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