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Building Virtual Reality Environments for Distance Education on the Web: A Case Study in Medical Education

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***Abstract*—**The paper presents an investigation into the role of virtual reality and web technologies in the field of distance education. Within this frame, special emphasis is given on the building of web-based virtual learning environments so as to successfully fulfill their educational objectives. In particular, basic pedagogical methods are studied, focusing mainly on the efficient preparation, approach and presentation of learning content, and specific designing rules are presented considering the hypermedia, virtual and educational nature of this kind of applications. The paper also aims to highlight the educational benefits arising from the use of virtual reality technology in medicine and study the emerging area of web-based medical simulations. Finally, an innovative virtual reality environment for distance education in medicine is demonstrated. The proposed environment reproduces conditions of the real learning process and enhances learning through a real-time interactive simulator.

***Keywords*—**Distance education, medicine, virtual reality, web.

I. Introduction

The potential of virtual reality technology has introduced a new dimension in the field of distance education. In contrast with the conventional two-dimensional presentation of educational material, virtual reality technology allows the visualization of data in three dimensions and provides interactive functionalities that reinforce the feeling of immersion into a computer-generated virtual world. According to many researchers and educational practitioners this alternative form of education facilitates learning due to the ability of human brain to perceive better and assimilate easier a 3D computer-graphics representation than a simple text [1]. It is also widely recognized that VR technology engages students' attention and turns education into an entertaining procedure contributing thereby to the active participation of students in learning process.

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One of the most beneficial uses of VR technology is the development of virtual reality environments on the Web. This capability provides a novel framework for distance learning and life-long education shifting the centre of education from physical classroom to network [2]. Hence, students can approach knowledge from any place, even from their own home, having as much time as they really need to study the educational material adapting so the learning process to their personal needs [3]. However, in order to support and enhance learning through Web-based virtual environments, specific pedagogical methods should be applied and well-defined rules should be followed. The paper investigates this area and aims to clarify these issues providing some basic rules that should be considered in the stage of designing and building of these applications. Basic pedagogical methods such as behaviourism, cognitivism, constructivism and collaborative learning are studied focusing mainly on the efficient preparation, approach and presentation of learning content to fulfill its educational objectives. The designing rules presented in this paper are classified in three categories according to the triple nature of these applications: hypermedia, virtual and educational nature. Each of these categories contains a number of requirements that should be taken into account by a designer to ensure the usability and effectiveness of the final application.

In medicine, VR technology has already affected various areas. 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 are some of the areas virtual reality has been successfully applied to [4]. Especially in the field of medical education, virtual reality has already shown great potential. Students can better understand physiological principals, study basic anatomy or perceive the interrelationship of different anatomical structures. This fact is of great importance in medical education especially in cases that teaching of anatomy is not feasible by any other means. Nevertheless, the majority of medical simulations used for the training of new doctors require dedicated, powerful and sometimes expensive graphical workstations [5]. Therefore, these applications still constitute a privilege of a limited number of universities, research institutes and hospitals. Recent advances, however, in VR and Web technologies can change this situation allowing the development of web-based medical simulations, which are

cost-effective and characterized by free-accessibility. One of the primary objectives of this paper is to study the emerging area of Web-based medical simulations and highlight their main advantages.

Finally, the paper demonstrates a novel virtual reality environment developed for distance education in medicine through Web. The proposed application reproduces conditions of the real learning process in a physical educational environment (e.g. classroom, laboratory, etc) and enhances learning through a real-time interactive simulator for the study of a specific pathological condition (the simulation represents the cellular structure of human liver and simulates a pathological condition resulting in a disease known as Jaundice). Considering the pedagogical methods and the rules described at the beginning of the paper the proposed distance learning system presents the educational material either in three dimensions (VRML models) or traditionally in two dimensions (texts, pictures, videos etc). The user-student can navigate into virtual worlds and interact with virtual objects (e.g. boards) in order to discover new knowledge. 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, while the incorporation of the medical simulation in the proposed system provides to students an alternative way of learning beyond the traditional teaching methods.

II. Pedagogical Approach

Web-based virtual learning environments play a multilateral educational role providing not only a platform for the presentation of educational material, but also a communication means among the members of a learning community. These capabilities allow the creation of a *virtual classroom*, i.e. a virtual learning environment in which educators and learners are able to perform classroom-like tasks [6]. To ensure the educational effectiveness of the learning environment, appropriate pedagogical methods should be considered, especially in the designing phase of the system. The mostly applied pedagogical methods used for this purpose are outlined below.

A. Behaviourism

Behaviourism theory faces human mind as a black box and considers that a response to a stimulus can be quantitatively observed, ignoring totally the effect of thought processes occurring in mind [7]. In essence, the behaviourism school focuses on measurable and observable facts excluding ideas, emotions and processes performed in mind. Atkins has studied the effect of behaviourism theory on web-based distance education defining basic rules regarding the structure of educational content. Specifically, course designer should divide learning content into small conceptual units and instructional steps, define sequences of instructions using either conditional or unconditional branches and enhance learning providing repetition loops in critical points so as to route students back in certain sections depending on their performance on diagnostic tests [8]. In general, a designing approach with respect to behaviourism theory considers a student as a passive recipient and thus a well-structured learning material is required to facilitate the acquisition of a new behaviour through rehearsal and correction [9].

B. Cognitivism

In contrast with behaviourism, cognitivism theory focuses on human mind processes, such as thought, memory etc. The primary objective of cognitivism is to discover, identify and model the mental process performed in student's mind during the learning process [10]. Hence, in a cognitive approach, student's mind is not considered as a passive black box, but as a complex device, which receives information from the environment, processes this information and stores the outcome to a short-term or a long-term memory. A permanent storage requires careful organization of data and correlation of new information with existing knowledge so that information to be shifted from short-term to long-term memory.

The designer of an online learning environment should focus on the stimulation of students' senses. This can be achieved by following a designing approach, which engage students' attention on important information and encourage searching of knowledge. Designers should also organize information in such a way that students are able to connect new information with existing conceptual models in some meaningful way [11]. Hence, information should be connected with experiences from real life so that students can easily understand and assimilate the provided knowledge. In any case, however, flood of information should be avoided, since it inevitably leads to a conceptual saturation, which implies that information is not stored into the long-term memory.

The effectiveness of cognitivism theory in online learning process is widely recognized. A cognitive design of a web-based virtual learning environment should be based on the previous knowledge of learner, while the acquisition of new knowledge requires an active mental process from the part of the learner.

C. Constructivism

Constructivism theory moves one step further than cognitivism considering that knowledge is constructed by learners themselves based on their personal experiences. Thus, learners acquire an active role within the learning process, since they not only absorb information, but also connect it with previously assimilated knowledge, constructing so their own interpretation [12]. Therefore, in constructivism learners are not just passive recipients of external stimulus, but they are also able to search, choose, adapt and finally interpret information according to their conceptual background.

To this end, the designing of an online learning environment according to constructivist school focuses on the active participation of students in learning process. Prerequisite for the fulfillment of this objective is the

interaction of learners with the educational material in order to discover or create new knowledge. Web-based simulations constitute a typical case of such interactive learning applications, in which each action of learner within virtual environment is interpreted in new knowledge. On the other hand, the communication among members of a learning process is of great importance in constructivism, since it allows the exchange of experiences and ideas resulting in a better interpretation of the available information.

One of the main benefits of constructivism theory is that it considers learners as the centre of learning process. Consequently, the constructivist approach implies that learners will learn more with a teacher than from a teacher [10], [13] and that they will learn more with a virtual learning environment than from a virtual learning environment.

D. Collaborative Learning

Collaboration between learners and teachers is a common request of various pedagogical methods (e.g. constructivism). In online education, the concept of collaborative learning is considered essential for the performance of classroom-like tasks and a prerequisite for the creation of a virtual classroom. The term collaborative learning refers to an instruction method, in which students at various performance levels work together in small groups towards a common educational goal [14]. In contrast with previous pedagogical approaches, in which learners are considered to be isolated, collaborative learning introduces the concept of 'group'. In groups, learners are able to cooperate, exchange ideas and share experiences in order to acquire knowledge on specific thematic areas.

Current Web technologies are considered suitable for the development of collaborative learning environments due to their interactive functionalities. Collaboration can be achieved in two ways, either synchronously or asynchronously. Synchronous communication involves the participation of both students and teacher at the same time e.g. teleconference, while in asynchronous communication, which is more common, there is a complete time flexibility. That is, teachers and students do not need to participate in learning process at the same time (e-mail is the most common type of asynchronous communication).

The key benefit of collaborative learning is that increases interest among learners and promotes critical thinking. Its role in distance education on the Web is essential allowing students to work together in groups searching for solutions in common problems. Its application in web-based virtual environments opens up new possibilities in distance education, creating conditions, which approach these of learning process in a real classroom.

III. Designing Requirements Analysis

A web-based virtual learning environment (the term hypermedia virtual learning environment can be alternatively used) is not just a conventional website used for disseminating educational content or a web page containing 3D graphics. It is a combination of virtual reality and web technologies centralized on the fulfillment of specific educational objectives. For the effectiveness of the final application, specific designing rules should be followed to ensure its usability, i.e. an efficient, understandable and pleasant communication between user and system [15]. In this paper the designing rules presented are classified in three categories according to the triple nature of these applications: hypermedia, virtual and educational nature (Fig. 1).

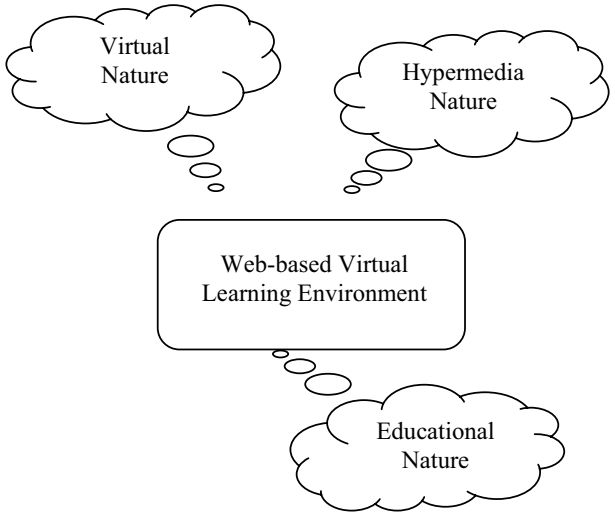

Fig. 1 The triple nature of Web-based virtual learning environments

A. Hypermedia Requirements

Web constitutes both a presentation platform for a learning content and a communication means among the members of a virtual classroom. Therefore, the hypermedia nature of a learning environment should be considered, first and foremost, by the designer of the application. In [16] a comprehensive study is presented regarding the designing of a hypermedia application. Based on this study, the usability of a hypermedia learning application can be achieved by applying the following requirements:

- *Webpage loading speed*: The loading speed is considered as one of the most critical usability factors of a web application and it heavily depends on the network and the total size of a webpage.
- *Local search engines*: Search engines are considered necessary in websites containing a large number of web pages.
- *Navigation support*: A web application should be designed in such a way, so that users have a complete view of the overall structure of the application i.e. users should always know their accurate location in the site as well as their possible transition options. This kind of problems can be effectively addressed by the use of site maps, which provide the required navigation information to the users of a web application.

- *Simple User Interface*: The user interface should be simple emphasizing on the educational material rather than containing features aiming to impress users.
- *Small size of pages*: All significant information and possible options are preferable to be visible in just one screen.
- *Simple address and title*: The website address and title should be simple, brief, comprehensive and fully represents the educational content.
- *Uniform designing*: A uniform design should be followed in all pages of a hypermedia application.
- *Content update*: The maintenance of a hypermedia application is of great importance for the fulfillment of its educational objectives. Thus, the educational content should be periodically updated by the administrator of the application according to the requirements of the educational process.
- *Appropriate terminology*: The instructional designer should use appropriate terminology, which is familiar and fully understandable by the learners.

Finally, apart from the aforementioned requirements, a virtual learning environment with regards to its hypermedia nature is a designed information space, which integrates heterogeneous technologies and provides interactive functionalities allowing the communication (synchronous or asynchronous) among the learners and teachers of a learning community [17].

B. Virtual Reality Requirements

Virtual reality technology has been recently introduced in the field of education and thus there are no explicit rules for the designing of a learning environment containing 3D computer graphics. Nevertheless, the designing of these applications should fulfill some basic usability criteria characterizing common virtual reality environments. In a simplified methodology the designing of a virtual world can be divided in four basic steps [18]: the geometry and appearance of virtual models, their import to the virtual reality toolkit, the modeling of their behaviour and finally the virtual environment visualization in a virtual reality facility. Another approach is presented by Kaur [19], which proposes a methodology of five steps: i) requirements specification, ii) gathering of reference material from real world objects, iii) structuring the graphical model and dividing it between designers, iv) building objects and positioning them in the virtual environment, v) enhancing the environment with texture, lighting, sound and interaction and optimizing the environment. Extensive researches on the usability of a virtual reality environment have shown that the efficiency of the final application heavily depends on three main features [20]:

- *Navigation*: Navigation is one of the most important usability factors of a virtual environment. This feature allows users to move within the virtual world and explore it in order to find out new knowledge. In the designing phase of an application, special care is needed to the elimination of users' disorientation problems. To this end, the use of signs, marks or maps is required for the correct guidance of users within the virtual world, ensuring so an easy approach to the educational material. Moreover, the designing of the navigation system should be user-friendly so that non-familiar users to be able to manipulate it easily.
- *Interaction*: Beyond a simple observation of the visualized learning content, virtual reality technology, due to its interactive functionalities, moves one step further allowing the manipulation of the educational data. Therefore, a virtual learning environment should support a natural way of interaction, which mimics as close as possible the real world, contributing so to the easy and fast familiarization and adaptation of users to the virtual environment. Finally, the interactive points should be clear and supported by suitable signs inciting users to interact with the virtual environment.
- *Presence*: The third factor, concerning the concept of presence in a virtual world, deals in essence with the realism level. The realism can be enhanced by the use of textures, sounds, lights and complex models providing users with a feeling of presence in a virtual world.

In any case, however, the main objective of a virtual learning environment is the active participation of students in the learning process. The interactive features supported by a virtual environment allow the modification of the virtual world and thus the creation of new knowledge. This principle is also applied to simulation applications, whose contribution in medical education is studied in section IV.

C. Educational Requirements

An educational software is not an electronic book aiming to substitute the teaching in a real classroom, but a complementary educational tool whose goal is to help and enrich the real learning process. Coordinated actions have been recently performed by institution and organizations aiming to set designing specifications for educational software. Approaching web-based virtual learning environments as an educational software for distance education, a series of specifications should be considered by the designer of the application [21]:

- The educational application should be usable both as a complementary tool in a school/university classroom and as a stand-alone distance learning application.
- It should also encourage the active participation of students in the learning process.
- Emphasis should be given to the exploratory nature of the proposed educational activities.
- The learning environment should engage student's attention and promote a deep study of the learning content.
- The educational material should be as diachronic as possible.
- The application should focus on issues relating to learning disabilities.

- Apart from the acquisition of knowledge, the learning environment should allow the development of specific skills.
- Processing, modeling and simulation are major features of an educational system.
- The application should combine instructive goals from different disciplines.
- Taking advantage of the recent advances in computer technologies, the system should promote the communication among learners.
- The designer should ensure the extendibility and reusability of the application. This will facilitate the update of the application and reduce the cost of a future extension.

As it is clear from the above, the designing of a web-based virtual learning environment is a challenging task, which requires the use of various technologies (web, virtual reality, multimedia etc) centralized on the fulfillment of high educational requirements. The aforementioned specifications aim to facilitate the designer to ensure the usability and efficiency of the final application. However, an efficient designing requires also a comprehensive analysis of both the user requirements and the technological possibilities with regards to the available network bandwidth and the required computational power. In the following sections, the role of virtual reality and web technologies in distance education in medicine is investigated and an innovative web-based virtual learning environment is presented.

IV. VR in Medicine

Recent advances in computer and virtual reality technologies offer great potential to the development of advanced medical simulations, which provide a visually realistic modeling of organs' anatomy and behaviour as well as means of interaction with the user in real time. One of their beneficial uses is the training of new doctors allowing practice without danger to patient and without limits on the number of times that each student can practice. Medical simulations provide also a training environment for study and practice on a variety of pathologies even on rare or unusual cases without the need of a patient with a specific disease. Furthermore, they allow actions that are not possible in real life e.g. navigation through the anatomy or use of unreal tools etc and they can be used as effective and reliable tools for the evaluation of students' performance.

To this end, medical simulations are considered nowadays as an integral part of the education and training of medical students. Especially in the training of new surgeons, a large number of simulations are used as valuable educational tools. The existing surgical simulations can be broadly classified in three categories [22]: needle-based simulations, minimally invasive surgery simulations and open surgery simulations. The first category concerns the manipulation of small medical instruments such as needles, guide-wires and catheters e.g. the Immersion CathSim Vascular Access Simulator [23]. The second category, Minimally Invasive Surgeries (MIS), involves the insertion of instruments into the human body from small incisions as in cases of laparoscopic and endoscopic operations e.g. the LASSO project [24]. Finally, the third category comprises of open surgery simulations [25][26], in which large incisions in the human body are required.

Nevertheless, the development of a medical simulation is a challenging task involving realistic modeling of human organs, interaction in real time and modeling of the physical behaviour of medical models e.g. deformable modeling. Therefore, the majority of medical simulations used for the training of medical students require dedicated, powerful and sometimes expensive graphical workstations. Thus, the knowledge extracted by the use of medical simulations constitutes a privilege of a limited number of universities, research institutes and hospitals. This fact, however, raises questions about the dissemination of this knowledge, especially to universities that are not equipped with medical simulations, as well as the possibility of an educational institution to obtain an adequate number of simulators in order to cover its educational needs.

The advent of the World Wide Web and its broad use opens new possibilities to the training of medical students providing a solution to the aforementioned problems. Its combination with virtual reality technology allows the development of Web-based medical simulations, which are cost-effective and provide free accessibility to all students. This means that medical students are able to use the simulations from any place, even from their own home, needing just a conventional PC. These virtual learning environments are considered suitable for distance learning in medicine providing significant advantages [5]:

- Free accessibility and low-cost
- A large number of users can use the simulator at the same time.
- Limited software requirements (only a simple VRML browser is required without any other special software)
- Web-based simulations can run from any place in the world.
- Students can safely practice many times on specific procedures before performing them on a real patient.
- In case of powerful computations, users can share the power of a remote server

However, there is still a question whether the development of web-based simulations with sufficient realism and speed to enable real time interactions is possible. Within WebSET (Web-based Standard Educational Tools) project [27], medical simulations were developed for neurosurgery, lumbar puncture and laparoscopy procedures showing that World Wide Web can provide an effective virtual environment within which training can be enhanced by 3D simulation and interaction.

In this paper, a novel virtual reality environment developed for distance education in medicine through Web is

demonstrated. The proposed application is not just a Web-based medical simulation for the training of medical students, but an integrated virtual learning environment aiming to fulfill multiple educational objectives. The prototype application is presented in the following section.

V. The Prototype System

As it is clear from the previous section, the use of virtual reality in medicine is mainly focused on the development of medical simulations aiming to help students to perceive physiological principals or anatomical structures, acquire skills and study specific pathological conditions. However, medical education constitutes a multilateral process, which requires, apart from the use of simulations, the communication among students and professors, the use of appropriate notes and medical images as well as the attendance at lectures or even at surgical operations performed by experienced surgeons. Therefore, distance education in medicine needs complex learning applications ensuring the fulfillment of the aforementioned requirements. In this paper, we propose an integrated virtual learning environment for distance education in medicine through web, which reproduces conditions of a real learning process and enhances learning through a real-time interactive simulator.

Specifically, the objectives of the proposed learning environment are the following:

- *Provision of learning content*: Medical education requires medical images of high resolution as well as the use of microscopes from the learners themselves. To fulfill this requirement the system provides a wide range of medical images taken with a microscope. Furthermore, it contains relative educational content from the real learning process at the university.
- *Attendance at virtual lectures*: The role of a professor in a real learning process as well as the teaching of courses through lectures at the university can not be substituted by notes. Advices or experiences transferred from professors to students are considered a critical part of a learning process. Virtual reality and multimedia technologies can reproduce a real lecture transferring students to a virtual classroom, where videos are projected on virtual screens. This technology can also be used for the reproduction of documentaries, conference talks, lectures from other universities and so on.
- *Cooperation among the members of the application*: The communication among the members of a learning process is a prerequisite for the creation of conditions developed in a real classroom. Collaborative learning is achieved through asynchronous communication (e-mails), which provide a complete space and time independence among professors and students.
- *Support of simulations*: One of the main objectives of the application is to provide a support platform for web-based medical simulations accompanied by relative educational content. The medical simulation that is currently supported by the application is the simulation of Hepatic Cells.
- *Connection to external data sources*: A critical issue in education is the easy access of students to a wide range of scientific sources. The proposed application takes advantage of the benefits arising from the use of web to connect students to external e-libraries allowing so the searching of further information related with the educational content of the application.

The designing of a web-based virtual learning environment requires a combination of heterogeneous technologies considering various pedagogical methods and designing requirements as presented in Sections II and III respectively. The proposed system is essentially a hypermedia application and thus it is a collection of HTML pages, which constitute the base of the application. Due to its hypermedia nature, the application is approachable via web and allows asynchronous communication and connections to external e-libraries. A common prototype was followed for the designing of all HTML pages, as shown in Fig. 2, while the VRML worlds are embedded and presented always at the centre of the HTML pages.

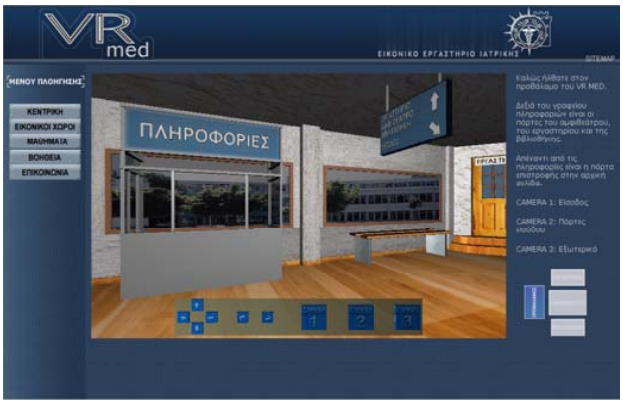

Fig. 2 For the designing of HTML pages a common prototype was used. VRML worlds are always presented at the centre of pages.

The virtual environment consists of a set of virtual worlds, each of which performs a different educational role. The use of 3D graphics in the learning application aims to create an attractive environment, in which students can perceive and assimilate easier the educational material. Hence, the fundamental goal is to engage students' attention to critical information, which is transferred from the short term to the long term memory according to the cognitivism theory. Moreover, all virtual worlds have been designed and developed in such a way in order to encourage searching of knowledge and incorporate constructivist features, which contribute to the active participation of students and the acquisition of knowledge through their interaction with the virtual worlds.

(a) (b)

Fig. 3 (a) The virtual classroom and (b) the interactive board.

(a) (b)

Fig. 4 (a)The virtual laboratory and (b) the interactive screen.

The architectural structure of the virtual environment is divided in two parts: the physical learning environment and the simulation of the application. The physical learning environment consists of a number of virtual worlds that reproduce conditions of the real learning process in a physical educational environment, while the primary goal of the medical simulation is to enhance learning. Students visit each virtual world searching for knowledge and they participate in different learning processes. The designing of the virtual worlds is focused on three main features: navigation, interaction and presence. In particular, special care was given to the development of a user friendly navigation system, which allows even non-familiar users to easily navigate within the virtual worlds (the navigation system is always visible at the bottom of each virtual world). On the other hand, for the easy access of students to the educational material and the avoidance of users' disorientation problems, special signs, voice messages, navigation maps, as well as functions allowing the direct transition of users to predefined positions were used. Furthermore, multiple interactive functionalities are supported both by the physical learning environment (e.g. interactive boards) and the simulation of the application (e.g. deformation of hepatic cells, change of the cell's transparency etc). Finally, the feeling of presence in the virtual worlds was supported by the use of textures, lights, sounds and detailed 3D modeling in order to enhance the realism of the virtual environment.

Specifically, the virtual environment consists of the following virtual worlds:

- *Entrance*: The role of the entrance (Fig. 2) is mainly to enhance the feeling of presence within the virtual environment and transfer students to a familiar place, which is a part of previous knowledge and makes them able to perceive easier the interface of the system. The entrance is the first virtual world of the application and it leads students to the three other educational rooms: classroom, lab and library.
- *Classroom*: The virtual classroom plays a significant role in the learning process reproducing conditions developed in a real university classroom. Students participate in the learning process, in which they have direct access to the educational material (images and text) through their interaction with a virtual board. Specifically, as shown in Fig. 3, the virtual board is divided in five parts. The bottom of the board allows students to choose the course (e.g. Histology-Embryology I) and its left part contains the chapters of each course. The educational material is presented at the centre (images) and the right part (text) of the board, while special buttons on the upper part allows the browsing of the educational content.
- *Laboratory*: The lab of the application plays a dual role. Primarily, its role is to allow students to attend virtual lectures. This can be achieved through a virtual

screen (Fig. 4), which reproduces videos from real lectures. The video is assigned as a texture on the virtual screen, while students can handle it (start, stop) using buttons located on the upper part of the screen. The second role of the virtual lab is to connect the physical learning environment with the simulation of the application. Specifically, students interact with the virtual microscopes, which are active objects of the virtual world and transfer students to the simulation of hepatic cells.

- *Library*: The virtual library provides connections with external data sources. Specifically, students are able to navigate within the virtual world of the library searching for knowledge and interact with virtual objects (books, signs etc), which connects to external information sources (e.g. e-libraries) containing relative educational content (Fig.5).

Fig. 5 The virtual library.

- *Simulation*: The simulator is a real-time interactive application, which allows the study of a specific pathological condition and the cellular structure of human liver (Fig.6). 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. The modeling of all models was performed under the guidance and supervision of expert doctors. The simulation provides multiple interactive functionalities, such as navigation in 3D space, deformation of cells or change of their transparency. Thus, students actively participate in the learning process acquiring knowledge through their interaction with the virtual models.

The proposed application has been designed and developed for the distance education of medical students, however, it can be also used as a valuable complementary tool in a real university classroom. Especially, the use of the Web-based simulation in a real learning process can assist students to perceive easier the cellular structure of human liver as well as to study the development of a pathological condition resulting in jaundice.

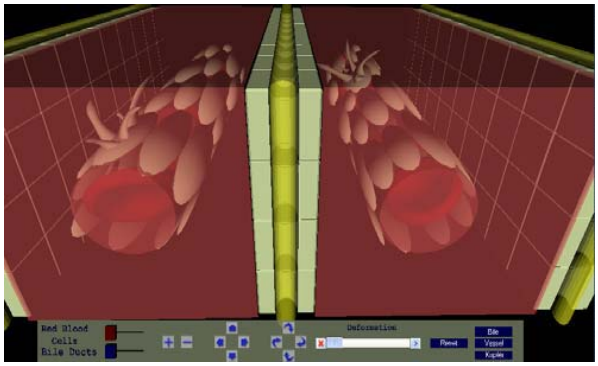

Fig. 6 The simulation of hepatic cells

VI. Conclusion

In this paper we presented a study on the designing and building of virtual reality environments for distance education on the Web. The mostly applied pedagogical methods such as behaviourism, cognitivism, constructivism and collaborative learning were studied and specific designing requirements were analysed based on the triple nature of web-base virtual learning environments. Finally, a study on virtual reality and web technologies in medical education as well as an innovative virtual learning environment for medical students were presented. The proposed application takes advantage of the recent advances on Web and virtual reality technologies in order to reproduce conditions of a real learning process and enhance learning through a real-time interactive simulator providing significant advantages to the distance education of medical students. In the future, the application can be extended to support a wide range of medical simulations and relative educational material providing so a more integrated educational role.

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