# Web3D Technologies in Learning, Education and Training: Motivations, Issues, Opportunities

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**Abstract**

Web3D open standards allow the delivery of interactive 3D virtual learning environments through the Internet, reaching potentially large numbers of learners worldwide, at any time. This paper introduces the educational use of Virtual Reality based on Web3D technologies. After briefly presenting the main Web3D technologies, we summarize the pedagogical basis that motivate their exploitation in the context of education and highlight their interesting features. We outline the main positive and negative results obtained so far, and point out some of the current research directions.

*Keywords*: human-computer interface; interactive learning environments; multimedia/hypermedia systems; programming and programming languages; virtual reality.

## 1. Introduction

The use of Virtual Reality (VR) as an educational tool has been proposed and discussed by several authors (e.g., Wickens, 1992; Winn, 1993; Helsel, 1992). Virtual Environments (hereinafter, VEs) offer the possibility to recreate the real world as it is or to create completely new worlds, providing experiences that can help people in understanding concepts as well as learning to perform specific tasks, where the task can be repeated as often as required and in a safe environment. A considerable problem is that developing and delivering Educational Virtual Environments (hereinafter, EVEs) with traditional and/or proprietary VR technologies

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can be very expensive (e.g. due to the cost of special VR hardware), and the developed solutions are not accessible to many learners. An emerging solution is provided by Web3D open standards that allow the delivery of interactive VEs through the Internet, reaching potentially large numbers of learners worldwide, at any time. Moreover, unlike typical VR solutions, Web3D VEs can be independent from the platform and require only a standard PC and a plug-in for a Web browser.

The paper is structured as follows: Section 2 introduces the main Web3D technologies for the novice reader; Section 3 motivates their exploitation from a pedagogical point of view, while Section 4 outlines the educational contexts in which they can be used; Section 5 and 6 respectively discuss the present advantages and limitations of using Web3D technologies in education; Section 7 illustrates issues and results in the evaluation of educational applications of Web3D technologies; Section 8 concludes the paper with a final discussion.

## 2.  Web3D Technologies

Traditionally, VR systems are associated with high costs (e.g., due to the special hardware that is needed, such as head-mounted displays or multiple projectors, and 3D input devices), complexity in development, and, thus, scarce availability. In the latest years, an emerging trend concerns the possibility of building 3D VEs that can be experienced through the Web using the hardware that can be found in common, low-cost personal computers. The term "Web3D technologies" denotes the languages, protocols and software tools that make this possible. Web3D technologies are based on the same general ideas behind other Web

technologies: content (represented in a proper format) is stored on a server and is requested by the client (e.g., through HTTP), where it is displayed by a browser (or, more typically, by a special plug-in for the Web browser).

Nowadays, thanks to the increase in network bandwidth and processing power (especially in 3D graphics capabilities) available to the average user, Web3D technologies allow one to build VEs as complex as those provided by VR systems only a few years ago. With respect to VR systems, Web3D solutions tend to be lacking in supporting immersive hardware, but can be built at a much lower cost, and can be experienced by a much larger number of people (even in multi-user mode, i.e. navigating together the same VE). Another important aspect of Web3D solutions is the strong integration with existing Web resources, from files to applications: Web3D VEs can both augment Web sites with 3D interactive content (e.g., a VE can appear into a Web page together with HTML content) and display other contents available in the Web (for example, images and video).

As of today, the most known and used Web3D technology is VRML (Virtual Reality Modeling Language), an open ISO standard (VRML, 1997) which originated in 1995. Recently, a new ISO standard, called eXtensible 3D Graphics (X3D, 2004), has been proposed as a successor of the VRML language. Both VRML and X3D development are managed by the Web3D Consortium[1], and result from the effort of several organizations, researchers and developers worldwide.

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[1] www.web3d.org

Web3D open standards have also strong relations with other standards for multimedia. For example, the MPEG-4 standard (2002) integrates several concepts from the VRML (and, more recently, X3D) language to describe interactive scenes that include 3D objects and environments.

Besides open standards, there are other technologies for 3D on the Web, the best known examples being probably Java3D (2005), an extension of the Java language for building 3D applications and applets, and Shockwave 3D (2005) from Macromedia. Although some of them have similar capabilities with respect to their open counterparts, and can be thus effectively used to build Web3D educational applications, in this paper we will focus on open Web3D standards. Our motivation is that open standards allow, in most situations, for lower costs, easier reusability of content, and easier integration with existing and future educational content and applications.

In the following, we briefly introduce the main Web3D open standards: VRML and X3D.

### 1.1    The Virtual Reality Modeling Language (VRML)

The idea of a language for building 3D content for the Web originated back in 1994, when Mark Pesce and Tony Parisi built an early prototype of a 3D browser for the Web, called Labyrinth. As a result of a community effort, in October 1994, at the Second International Conference on the World Wide Web, the first specification of VRML was published. In the following years, version 1.0 of the language underwent a series of improvements, leading to version 2.0, which was released in August 1996 at SIGGRAPH. This version was later

submitted to ISO, and was published as an ISO standard in mid 1997 with the name VRML97 (VRML, 1997).

As pointed out by Carey and Bell (1997), VRML provides a language that integrates 3D graphics, 2D graphics, text, and multimedia into a coherent model, and combines them with scripting languages and network capabilities. The language includes most of the common primitives used in 3D applications, such as light sources, viewpoints, geometry, animation, fog, material properties, and texture mapping. While VR typically focuses on immersive 3D experiences (e.g., using head-mounted displays) and 3D input devices (e.g., data gloves), one of the design goals for VRML was to neither require nor preclude immersion. As a result, VEs implemented in VRML can also be experienced with the input/output devices of today's common personal computers (i.e., CRT or LCD monitor, keyboard and mouse).

From a more technical point of view, VRML files describe 3D objects and worlds using a *hierarchical scene graph* (i.e., a directed acyclic graph). Entities in the scene graph are called *nodes*. VRML defines 54 different node types, including geometry primitives, appearance properties, sound and video properties, and various types of nodes for animation and interactivity. Nodes store their properties in *fields*; the language defines 20 different types of fields that can be used to store different types of data, from single integers to arrays of 3D rotations. This scene graph structure makes it easy to create large worlds or complicated objects starting from simple objects. It is also possible for the VE creator to define new nodes (i.e., extend the language) that may be useful in specific situations using a mechanism called *prototyping* (and the corresponding instruction called *Proto*). For example, this mechanism

has been used to extend VRML with nodes to represent and animate 3D human figures (H-Anim, 2001) and to implement distributed simulations in shared, networked VEs (Brutzman, 1998).

VRML97 defines a *message-passing mechanism* by which nodes in the scene graph can communicate with each other by sending events. This mechanism, together with special types of nodes, called *sensors* and *interpolators*, enable user interaction and animation capabilities. For example, the *TimeSensor* node generates temporal events as time passes and is the basis for all animated behaviors. A set of nodes, called *Interpolators*, are then able to continuously translate temporal events into data needed for animation. For example, the *PositionInterpolator* node is able to translate temporal events into coordinates in 3D space. By properly connecting these nodes with 3D objects, one can animate (e.g., move) objects. Other sensors are useful in managing user interaction, generating events as the user moves through the world or when the user interacts with some input device (e.g. mouse pointing or clicking).

More complex behaviors (such as realistic physics simulation) can be implemented by using *Script* nodes, that allow the VE creator to define arbitrary behaviors, defined in any supported scripting language (the VRML97 specification defines Script node bindings for the Java and JavaScript languages). When needed, one can also control the VE from an external program (e.g., a Java applet on a Web page) through an External Authoring Interface (EAI) that enables external programs to control the VRML browser.

*1.2    EXtensible 3D Graphics (X3D)*

The EXtensible 3D (X3D) language for defining interactive Web-based 3D content was recently released as the successor of VRML, and was approved in 2004 as an ISO standard (X3D, 2004).

X3D inherits most of the design choices and technical features of VRML (such as those described in the previous Section); as a result, it is largely backward-compatible (i.e., many VRML files require only minimal changes for translation to X3D).

X3D improves upon VRML mainly in three areas. First, it adds new nodes and capabilities, mostly to support the latest advances in 3D graphics algorithms and hardware, such as programmable shaders and multi-texturing. Second, it introduces additional data encoding formats; more specifically, it is possible to represent, store and transmit X3D content using a VRML-like (textual) encoding, an XML-based (textual) encoding, and a binary encoding, that enables better data compression and thus faster downloads. Third, it divides the language into functional areas called components, which can be combined to form different profiles (i.e., subsets of the entire language) that are suited to specific classes of applications or devices (e.g., one could create a specific profile to take into account the limited capabilities of mobile devices).

The possibility of encoding X3D content using a XML-based syntax is probably the most important feature of the language with respect to the integration of interactive 3D content into educational applications. Many Web-based educational applications already store data (e.g. concepts, explanations, examples) using a XML representation, and later transform them (e.g. using XSL transformations) into formats that are more suitable for visualization (e.g., HTML

documents). The same approach  can then be used to obtain 3D interactive representations of educational content; an example in the field of chemistry has been proposed by Polys (2003).

## 3.  Pedagogical Motivations

Constructivism is the fundamental theory that motivates educational uses of VEs. Constructivists claim that individuals learn through a direct experience of the world, through a process of knowledge construction that takes place when learners are intellectually engaged in "personally meaningful tasks" (Conceição-Runlee & Daley, 1998). Following this theory, interaction with the world is relevant for the learning process. The possibility of providing highly interactive experiences is thus one of the best-valued features of VEs. As pointed out by Harper, Hedber and Wright (2000), apart from reality, the most appropriate way to generate a context based on authentic learner activity may be through the use of VEs.

When we interact with an environment, be this real or virtual, our type of experience is a first-person one (Winn, 1993), that is a direct, non-reflective and, possibly, even unconscious type of experience. On the contrary, third-person experiences, that result from the interaction through an intermediate interface (e.g., someone else's description of the world, a symbolic representation, a computer interface that stands between the environment and the user,…) require deliberate reflection and cannot provide the same depth of experience as the first-person ones[2] (Winn, 1993). In many cases, interaction in a VE can be a valuable substitute for

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[2] The terms first-person and third-person are often used in VR to indicate different points of view from which the user observes the VE, i.e., respectively through an egocentric viewpoint, as if the user were immersed in the environment (considering the current user's position, it shows the part of environment which should be in front

a real experience, providing a first-person experience and allowing for a spontaneous knowledge acquisition that requires less cognitive effort than traditional educational practices. For example, Antonietti and Cantoia (2000) experimentally evaluated how students make sense of an unfamiliar painting by taking a guided tour inside a VE representing the painting versus simply looking at a two-dimensional reproduction of the painting, and concluded that VR prompted students to conceptualize experience at an abstract level and stimulated spontaneous and imaginative elaboration.

Traditional educational methods rely on knowledge, acquired from books and teachers, that must be then applied to real situations. On the contrary, the situated learning approach (i.e., knowledge and skills are learned in the contexts reflecting how knowledge is obtained and applied in everyday situations) suggests that it is easier for students to learn concepts in the same context where these will be applied. Indeed, "a situated learning environment provides an authentic context that reflects the way knowledge will be used in real-life" (Herrington & Oliver, 1995). VEs can provide a good level of realism and interactivity and provide life-like situated learning experiences that link experience to theory.

Research in human learning processes demonstrates that individuals acquire more information if more senses are involved in the acquisition process (Barraclough & Guymer, 1998), i.e. we are more receptive when we see, listen, hear and act at the same time. In VEs, one can exploit this human capability by providing multisensory stimuli, such as three-dimensional spatialized sound or haptic stimuli (e.g., vibration, force).

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of her own eyes) and from an exocentric viewpoint, where the user can see her current position explicitly marked in the environment. In the paper, we use instead the meaning introduced by Winn (1993).

Constructivist theory also points out that learning is an activity that is enhanced by shared inquiry. Each individual creates her own interpretation of knowledge-building experiences, but it is necessary to develop a shared meaning to obtain reliable communication among people. Collaborative learning is a solution, and indeed groupwork activity improves personal cognitive development together with social and management skills. Collaborative learning is a learner-centred approach: each learner is expected to participate actively in discussions, decisions, common understanding and goal achievement (Brna & Aspin, 1997). Web3D technologies can provide new tools and scenarios for collaborative learning, connecting people that are physically located in distant places. An example of a Collaborative Virtual Environment (CVE) based on Web3D technologies is CVE-VM (see Figure 1), that is aimed at supporting teaching and learning in Brazilian schools (Kirner G., Kirner C., Kawamoto, Cantão, Pinto & Wazlawick, 2001). Children collaborate over the Internet to create their virtual world, thus actively constructing knowledge on the subjects of the world. Following the taxonomy of EVEs proposed by Youngblut (1998), CVE-VM is not a pre-developed application, where students can only interact with the VE, but a multi-user distributed application, where students work together not only to solve problems but also to extend the virtual world. The goal of this type of applications is indeed construction and deepening of knowledge, with a focus on collaboration among students.

## 4.  Educational Contexts

The flexibility and portability of Web3D technologies allow one to use them in building educational VEs (EVEs) for several contexts:

- *Formal education*. This comprises every type of scholar instruction, from kindergarten to college. In this context, EVEs are meant to be used by students supervised by teachers, often during classroom or laboratory lessons. For example, Mzoughi, Davis Herring, Foley, Morris and Gilbert (2005) have developed a Web3D interactive system that helps instructors teach and students learn about waves and optics;

- *Informal education*. This is the context of museums, cultural sites, zoos and similar institutions. In this context, the intended users are visitors, possibly helped by a guide. For example, Wojciechowski, Walczak, White and Cellary (2004) have proposed a system that allows museums to build and manage Virtual and Augmented Reality exhibitions based on Web3D models of artifacts;

- *distance or electronic learning*. This comprises both self-instruction through the Web and computer-mediated learning that involves a human teacher interacting with the user through the Internet. For example, Ong and Manaan (2004) have developed a Web3D-based interactive teaching package that provides a dynamic and interactive environment for a course on automated machine tools at the Manufacturing Division of the National University of Singapore.

- *Vocational training*. This refers to training in skills required for one's job. Industry, medicine and the military are only some of the many domains where training is an everyday practice. Virtual training is meant to be a substitute of on-the-field experiences at least in the first training phase; for example, in the domain of medical training, Li, Brodlie, and Philips (2000) have developed a Web3D training simulator for percutaneous rhizotomy (discussed in more detail in Section 5).

- *Special needs education*. People with physical or cognitive disabilities require special educational techniques. In general, VEs allow them a wider range of experiences with respect to traditional lessons, even experiences they will not have the chance to try in the real world. An example of special needs education using Web3D technologies is provided by Karpouzis, Caridakis, Fotinea, and Efthimiou (2005), who developed an educational platform for learning sign language.

## 5. Advantages of Web3D Technologies in Education

Educational uses of Web3D technologies present a number of advantages with respect to traditional learning practices. In general, EVEs can provide a wide range of experiences, some of which are impossible to try in the real world because of distance, cost, danger or impracticability. For example, it is possible to reconstruct ancient buildings and cities to show how they might originally have been and how life was in ancient times, or it is possible to train astronauts on correct procedures before they leave Earth. Thanks to Web3D technologies, these EVEs can be made accessible anywhere there is a computer connected to

the Internet. For example, Ramasundaram, Grunwald, Mangeot and Comerford (2005) developed a Web3D-based virtual field laboratory that provides students with a simulation environment to study environmental processes in space and time that cannot be experienced on a few real field trips.

An important advantage is related with using three dimensional graphics, which allows for more realistic and detailed representations of topics, offering more viewpoints and more inspection possibilities compared to 2D representations. In many educational contexts (e.g., medicine) this can be crucial to better understand topics (e.g., anatomy). John (2005) provides several examples of how Web3D technologies can be employed for medical education and training.

Another advantage is the possibility of analyzing the same subject or phenomenon from different point of views. This way, users can gain a deeper understanding of the subject and create more complete and correct mental models to represent it. As an example, Li et al. (2000) developed a Web3D training simulator for the treatment of trigeminal neuralgia, a neurosurgical procedure that requires the insertion of a needle under the skin of the patient to puncture the foramen ovale. The interface (shown in Figure 2) provides the trainee with two different viewpoints: the external one, which is the surgeon's usual viewpoint (center of Figure 2), and the internal one (top left of Figure 2), which is the needle's viewpoint. The latter will not be experienced by the trainee in real world, but helps her to locate the foramen ovale and create a correct mental model of its position.

A different example of multiple viewpoints is provided by the Virtual Big Beef Creek project (Campbell, Collins, Hadaway, Hedley & Stoermer, 2002), where a real estuary has been reconstructed to allow users to navigate, get data and information to learn about ocean science (see Figure 3). Users can explore the environment using different avatars (i.e., embodiments of the user in the VE) whose viewpoints and navigation constraints are different. For example, if the user chooses to be a scientist, she can move as a human being and acquire data such as water temperature, while if she chooses to be a fish, she can swim deeply in the ocean and cannot surface.

More generally, Web3D technologies allow one to develop Web-based EVEs that provide the knowledge-building experiences discussed by Winn (1993) and related to the concepts of *size*, *transduction* and *reification*. In a VE, users can change their size to gain a better point of view on the explored subject. For example, they can grow until they can see interplanetary spaces or they can shrink until they become able to see atoms and molecules. The concepts of transduction and reification are somewhat deeper and more complex. A transducer is a device that converts information into forms available to our senses. A VE can convert every type of data into shapes, colors, movements, sounds, or vibrations, i.e. into something that we can see, hear or feel as a haptic sensation. VEs can therefore be considered as transducers that widen the range of information accessible through a first-person experience. For example, the WebTOP system (Mzoughi et al., 2005) helps in learning about waves and optics by visually presenting various kind of physical phenomena, such as reflection and refraction. Reification refers to the process of creating, through transduction, perceptible representations of abstract

concepts, such as algebraic equations (Winn, 1993). Through transduction, reification, and changes in size, users can perceive even what in the real world has no physical form. As Winn (1993) points out, the above mentioned three kinds of knowledge-building experience "are not available in the real world, but have invaluable potential for education".

Interacting with another human being can be easier and more appealing than interacting with a book or a computer. As a consequence, the possibility of interacting with virtual humans inside EVEs can be considered as an advantage whose usefulness in the educational context is manifold. First, virtual humans can be an embodiment or representation of the user in the VE. This is important in collaborative EVEs, where users must be aware of where others are and what they are doing. Second, virtual humans can represent the subject of study, as in training simulations for clinicians and first-aid operators, e.g. see John (2005) for Web3D surgical simulators. The value added by a virtual patient compared to a dummy is also the possibility of physical and, where appropriate, emotional responses, that increase the realism of the experience and the involvement of trainees.

Emotions are also important when dealing with virtual teachers, in distance and electronic learning contexts. The mere presence of a lifelike character has proved to have a positive impact on student's perception of the learning experience, called the "persona effect" (Lester, Converse, Kahler, Barlow, Stone & Bhoga, 1997). An even stronger impact on motivation can be obtained through a virtual learning companion or a virtual teacher, that shows interest and sensitivity to the student's progress, displaying enthusiasm when the student achieves good results and disappointment when the student is wrong (Johnson, Rickel & Lester, 2000).

Developing a virtual human with such sophisticated capabilities may require a lot of design and programming efforts. A possible solution can be provided by software architectures that provide Web3D content creators with the ability to integrate virtual humans (with non-trivial behaviors capabilities) into VEs with little programming effort. Such an architecture has been proposed by Chittaro and Ieronutti (2005).

Collaborative VEs give every user the opportunity of working with one or more virtual companions. These companions are usually avatars of other users, that can be co-located or distributed over different geographical locations. In both cases, virtual humans' behaviour is controlled by real people, and depends on what the interface allows them to do and on their ability in using the VE. A more complex approach allows users to interact with simulated companions and their computer-generated behaviors. There are several reasons to create virtual companions; for example, they can substitute missing teammates necessary to perform a task, they can ask questions if the user is too passive, they can try to perform tasks if the user does not feel ready to do it, they can make errors to show the user the consequences or they can simply make the user feel more at ease in a lesson setting. Economou, Mitchell and Boyle (2000) provide a series of requirements for the implementation of real and virtual learning companions in collaborative EVEs.

Virtual teachers, or animated pedagogical agents, present other important advantages. First, they introduce the social dimension into distance and electronic learning, which are often perceived as cold, impersonal and thus demotivating. Second, they can show how to perform a task instead of simply explaining how to do, with the effect of decreasing the learning time

in contexts where learning by example is more effective than learning by explanation. For example, Karpouzis et al. (2005) employ a virtual human to show how text entered by the student translates into sign language for the deaf. Third, pedagogical agents can use nonverbal communication both to enrich explanations and to give feedback to users. For example, they can drive users' attention towards an object with a deictic gesture or with their gaze, or they can react positively or negatively to users' answers through facial expressions. This type of communication is preferable to the verbal one, because it does not interrupt or distract the user (Johnson, Rickel & Lester, 2000). An example of how virtual humans can be used in educational contexts is the foreign language training and cultural familiarization application proposed by Sims (2005), i.e., a virtual course to teach elements of Iraqi dialect, nonverbal language, culture and customs. In this course, virtual humans serve both as actors, playing interactive sketches concerning common situations, and as instructors, explaining and asking verification questions about language expressions and proper behaviors in the considered context (Figure 4).

## 6. Limitations Of Web3D Technologies In Education

The use of Web3D technologies in educational practice presents some open issues. Some of them are common to all VEs, such as difficulties in navigation (Youngblut, 1998) and in using 3D interfaces. Users are often unable to move as they want, they get easily lost or do not know how to reach a particular location or point of view. Since educational environments often target non-expert users, both movement and spatial cognition should be made very

simple for the user. Although VEs are potentially able to provide a first-person experience as defined by Winn (1993), several EVEs provide users with a set of options through an interface that is not always easy to understand and simple to use.

Other problems affecting all EVEs concern the educational context, e.g. teachers' lack of experience or difficulties in classroom use. While VEs in vocational training are used to learn and practice how to perform a task before doing it in the real world (and thus teaching methodologies are not very different from traditional ones), the traditional approach in formal education involves a knowledge-bearing teacher that explains concepts to students. EVEs are mainly aimed at fostering active knowledge discovery and construction and the teachers' role changes from being the one with all the answers to a companion or guide (Youngblut, 1998). Lesson structure also needs to be changed in a consistent way. As a consequence, integrating EVEs and traditional lessons in an effective way is a very difficult task that is still under investigation.

Users' disappointment can negatively influence learning: the expectation of learners can often be too high if they think that the VE will mimic reality, and the lack of realism then detracts from the learning process. It can sometimes be effective to abstract the task to something simpler, that does not aim at faithfully reproducing the real task, but simply at acquiring the skills that are necessary to perform it. An example of task abstraction is provided by the MIST (Minimally Invasive Surgical Trainer) system (McCloy & Stone, 2001), a surgical simulator for acquiring laparoscopic psychomotor skills. The VE does not faithfully represent organs, but abstracts them using approximate geometric shapes.

A particular category of problems is related to the use of immersive VR hardware (when it can be financially afforded). Although an  immersive experience can be more effective than a desktop one, but a user placed inside a CAVE or wearing a Head Mounted Display (HMD) may not able to follow explanations (oral, written or gesture) provided by the teacher, and she may not be able to take notes or to complete written questionnaires (Dede, Salzman, Bowen Loftin & Sprague, 1998). Moreover, textual instructions and information can be problematic, because text in a 3D environment can be more difficult to read and HMDs often have low resolutions.

It must be added that Web3D technologies do not currently offer an easy and flexible support to the adoption of immersive hardware and special peripherals. However, Web3D researchers are working at overcoming this limitation. For example, Behr, Dähne and Roth (2004) are developing solutions to use VRML/X3D with immersive and augmented reality hardware, while Soares and Zuffo (2004) are developing an X3D browser that runs on commodity computer clusters and immersive hardware. An example of commercial product that deals with special peripherals is the Reachin Laparoscopic Simulator (Reachin, 2004) for the training of surgeons: the Reachin API uses an extended version of VRML 97 to provide additional nodes to describe haptic properties of objects. Haptic force feedback is provided to the trainee, improving both the realism and the usefulness of virtual practice. Recently, the Web3D community has promoted the creation of a working group whose aim is the extension and standardization of Web3D technologies with respect to different user interface hardware (X3D User Interface, 2004).

## 7. Evaluating Results

When evaluating an EVE, three main aspects should be taken into account, i.e. understanding, transfer of training and retention. Understanding is usually evaluated, and there is a considerable number of positive results reported in the literature. Unfortunately, no standard adequate evaluation method has been developed yet and thus results might not be reliable.

The transfer of training from the virtual to the real world can be mainly applied to vocational training or, in general, to sensory motor tasks. It seems reasonable to think that a simulation can be a valuable substitute for the real world at least in the first phase of training. In fact, few systematic empirical studies have been carried out to show this and have not led to clear conclusions about "what sort of training shows transfer, in what conditions, to what extent and how robust the transferred training has proved to be" (Rose, Attree, Brooks, Parslow & Penn, 1998). This lack of evaluations may be partially due to the lack of cheap, easily delivered EVEs. Web3D technologies could thus give the opportunity to carry out more tests, also through Internet delivery, of EVEs. A number of Web3D training simulators has been developed for surgical procedures, such as the treatment of abdominal aortic aneurysm (Brodlie, Khalili & Li, 2003) or ventricular catheterisation (John, Riding, Philips, Mackay, Steineke, Fontaine et al., 2001). The evaluation of a simulator for lumbar puncture, for example, has shown positive results on the training of clinicians, who agreed this tool improved their practical skills (Moorthy, Jiwanji, Shah, Bello, Munza & Darzi, 2003).

People remember positive experiences with more pleasure and more than negative ones. Since educational virtual experiences are generally considered more appealing and entertaining than traditional ones, their use should increase the retention of acquired knowledge. In fact, there are no long term studies to prove or disprove this thesis, because almost all carried out evaluations cover very short time periods of use of EVEs (Youngblut, 1998).

A positive result reported by the available evaluations is that users enjoy EVEs. They are more curious, more interested and have more fun with respect to learning with traditional methods. As a consequence, they get more involved in their education process and apply more willingly to it (leading some to use the words "edutainment" and "entertainment education").

## 8. Discussion and Conclusions

During the '90s, several projects have been carried out with the aim of bringing EVEs into educational practice. Despite this effort and reported positive results, EVEs are not yet part of typical educational practices. While vocational training and informal education contexts have seen a growth of EVEs, the formal education context seems to progress much more slowly.

A first reason is related to insufficient funds of educational institutions. In this case, Web3D technologies can play an important role both in reducing costs and in making EVEs more easily accessible to institutions through the Internet or Intranets.

A second issue concerns the justification of the approach. Unfortunately, there is a lack of validated results: evaluations of EVEs have been generally carried out on small groups of

individuals over a short time. Studies involving more users and carried out over long term periods are thus needed to thoroughly assess the benefits and limitations of these solutions. EVEs should be tested as integral parts of curricula, so as to give students and teachers the time to get used to them and to integrate them into everyday practice.

The attitude of teachers towards EVEs and their adoption into classroom activity is another factor. Some teachers may not be interested in new technologies, perceiving them as a waste of time or as a too radical change to their traditional methodology, or simply they may not be familiar with computers and they may not like the fact that their students often have more expertise than them. This issue can be partially tackled by involving teachers in the design of EVEs, by offering them computer training and by developing learning environments that do not require them to demonstrate any expertise.

Another issue concerns proper design of EVEs, e.g. taking into account both the constructivist theories that have been mentioned in this paper and the usability issues, such as simple navigation abilities.

Finally, the proper integration of EVEs into curricula is an issue in itself. At a minimal level, EVEs can deal only with the examples and exercises proposed by a traditional textbook. At a more ambitious level, the 3D environment, from a constructivist point of view, could come before the textbook as the main way to familiarize with the topics. The first approach is easier to implement and introduce in a classroom, but limits the potential of using EVEs in education. The second approach would require to significantly rethink educational practice. Finding the best trade-off between them is thus an important aspect.

## References

Antonietti, A. & Cantoia, M. (2000) To see a painting versus to walk in a painting: an experiment on sense-making through virtual reality. *Computers and Education 34*(3-4), 213-223.

Barraclough, A. & Guymer, I. (1998). Virtual Reality - A Role In Environmental Engineering Education? *Water Science & Technology*, *38*(11), 303-310.

Behr, J., Dähne, P. & Roth, M. (2004). Utilizing X3D for Immersive Environments. *Proceedings of the 9th International Conference on 3D Web Technology*, 71-78.

Brenton, H., Hernandez, J., Bello, F. Strutton, P., Firth, T. & Darzi, A. (2005). Using multimedia and Web3D to enhance anatomy teaching. *Computers and Education,* this issue.

Brna, P., Aspin, R. (1997). Collaboration in a Virtual World: Support for Conceptual Learning*? Proceedings of the IFIP WG 3.3 Working Conference "Human-Computer Interaction and Educational Tools"*, 113-123.

Brodlie, K., El-Khalili, N. & Li, Y. (2003). Key Issues in Developing Web-based Surgical Simulators. *Proceedings of the workshop on Web3D for Medical Education and Training at the 8th International Conference on 3D Web Technology*.

Brutzman, D. (1998). The virtual reality modeling language and Java. *Communications of the ACM*, 41(6), 57-64.

Campbell, B., Collins, P., Hadaway, H., Hedley, N. & Stoermer, M. (2002). Web3D in Ocean Science Learning Environments: Virtual Big Beef Creek. *Proceedings of the 7th International Conference on 3D Web Technology*, 85-91.

Carey, R. & Bell, G. (1997). *The annotated VRML97 Reference Manual*. Addison Wesley.

Conceição-Runlee, S. & Daley, B.J (1998). Constructivist Learning Theory to Web-based Course Design: An Instructional Design Approach. *Proceedings of the 17th Annual Midwest Research-to-Practice Conference in Adult, Continuing and Community Education***.**

Dede, C., Salzman, M.C., Bowen Loftin, R. & Sprague, D. (1999). Multisensory Immersion as a Modeling Environment for Learning Complex Scientific Concepts. In N. Roberts, W. Feurzeig, & B. Hunter, *Modeling and Simulation in Science and Mathematics Education*, Berlin: Springer-Verlag.

Economou, D., Mitchell, L. W. & Boyle, T. (2000). Requirement elicitation for virtual actors in collaborative learning environments. *Computers and Education 34*, 225-239.

Harper, H., Hedberg, J. & Wright, R. (2000). Who benefits from virtuality? *Computers and Education 34*, 163-176.

Helsel, S. (1992). Virtual reality and education. *Educational Technology 13* (5), 38 – 42**.**

Herrington, J. & Oliver, R. (1995). Critical Characteristics of Situated Learning: Implications for the Instructional Design of Multimedia. Learning with Technology. *Proceedings of ASCILITE'95 Conference*, 253-262.

Ieronutti, L. & Chittaro, L. (2005) Employing virtual humans for education and training in X3D/VRML worlds. *Computers and Education,* this issue.

ISO/IEC FCD 19774 (2004). Humanoid animation (H-Anim) Available: http://www.web3d.org/x3d/specifications/ISO-IEC-19774/index.html (last access on August 2004)

Java 3D (2005). The Java3D API. http://java.sun.com/products/java-media/3D (last access on April 2005)

John, N. W. (2005). The Impact of Web3D Technologies on Medical Education and Training. *Computers and Education*, this issue.

John, N.W., Riding, M., Phillips, N.I., Mackay, S., Steineke, L., Fontaine, B., Reitmayr, G., Valencic, V., Zimic, N., Emmen, A., Manolakaki, E. & Theodoros, D. (2001). Web-based Surgical Educational Tools. *Proceedings of Medicine Meets Virtual Reality 2001,* 212-217.

Johnson, W.L., Rickel, J.W. & Lester, J.C. (2000). Animated Pedagogical Agents: Face-to-Face Interaction in Interactive Learning Environments. *International Journal of Artificial Intelligence in Education*, 11, 47-78.

Karpouzis, K., Caridakis, G., Fotinea, S. E. & Efthimiou, E. (2005). Educational Resources and Implementation of a Greek Sign Language Synthesis Architecture. *Computers and Education,* this issue.

Kirner, G., Kirner, C., Kawamoto, A. L. S., Cantão, J., Pinto, A. & Wazlawick, R. S. (2001). Development of a Collaborative Virtual Environment for Educational Applications. *Proceedings of the 6th International Conference on 3D Web Technology*, 61-68.

Lester, J.C., Converse, S.A., Kahler, S.E., Barlow, S.T., Stone, B.A. & Bhoga, R.S. (1997). The Persona Effect: Affective Impact of Animated Pedagogical Agents. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 359-366.

Li, Y., Brodlie, K. & Philips, N. (2000). Web-based VR Training Simulator for Percutaneous Rhizotomy. *Proceedings of Medicine Meets Virtual Reality 2001*, 175-181.

McCloy, R. & Stone, R. (2001). Science, medicine, and the future. Virtual reality in surgery. *British Medical Journal*, *323*(7318), 912-915.

Moorthy K., Jiwanji, M., Shah, J., Bello, F., Munz, Y. & Darzi, A. (2003). Validation of a Web-Based Training Tool for Lumbar Puncture. *Proceedings of Medicine Meets Virtual Reality 2003*, 219-25.

MPEG-4 International Standard (2002). MPEG-4 Specification. International Standard ISO/IEC JTC1/SC29/WG11 N4668.

Mzoughi, T., Davis Herring, S., Foley, J. T., Morris, M. J. & Gilbert, P. J. (2005). WebTOP: A 3D Interactive System for Teaching and Learning Optics. *Computers and Education,* this issue.

Ong, S. K. & Mannan, M. A. (2004). Virtual reality simulations and animations in a web-based interactive manufacturing engineering module. *Computers and Education 43*, 361-382.

Polys, N. (2002). Stylesheet transformations for interactive visualization: towards a Web3D chemistry curricula. *Proceedings of the 8th ACM International Conference on 3D Web Technology*, 85-90.

Reachin (2003). Reachin Laparoscopic Trainer 2.0. 2003. Available at http://www.reachin.se/products/reachinlaparoscopictrainer/ (last accessed on August 2004)

Ramasundaram, V., Grunwald, S., Mangeot, A., Comerford, N. B. & Bliss, C. M. (2005). Development of an environmental virtual field laboratory. *Computers and Education, 45*(1), 21-34.

Rose, F.D., Attree, E.A., Brooks, B.M., Parslow, D.M., Penn, P.R., Ambihaipahan, N. (1998). Transfer of training from virtual to real environments. *Proceedings of the 2nd European Conference on Disability, Virtual Reality and Associated Techniques*.

Shockwave (2005). Macromedia Shockwave. http://www.macromedia.com/software/shockwaveplayer/ (last accessed on April 2005).

Sims, E.M. & Pike, W.Y. (2004). Reusable, Lifelike Virtual Humans for Mentoring and Role-Playing. *Computers and Education,* this issue.

Soares, L. P. & Zuffo, M. K. (2004). Jinx: An X3D Browser for VR Immersive Simulation Based on Clusters of Commodity Computers. *Proceedings of the 9th International Conference on 3D Web Technology*, 79-86.

VRML International Standard (1997). VRML97 Functional Specification. International Standard ISO/IEC 14772-1:1997. Available at http://www.web3d.org/x3d/specifications/vrml/ISO_IEC_14772-All/index.html (last access on January 2005).

Wickens, C.D. (1992). Virtual reality and education. *Proceedings of the 1992 IEEE International Conference on Systems, Man and Cybernetics,* vol. 1, 842-847.

Winn, W. (1993). A Conceptual Basis for Educational Applications of Virtual Reality. HITL Report No. R-93-9.

X3D International Standard (2004). X3D framework & SAI. ISO/IEC FDIS (Final Draft International Standard) 19775:200x. Available at http://www.web3d.org/x3d/specifications/ISO-IEC-19775-IS-X3DAbstractSpecification/ (last access on January 2005).

Wojciechowski, R., Walczak, K., White, M. & Cellary, W. (2004). Building Virtual and Augmented Reality museum exhibitions. *Proceedings of the 9th International Conference on 3D Web Technology*, 135-144.

X3D User Interface. Panel at the 9th International Conference on 3D Web Technology, Monterey (California), 2004.

Youngblut, C. (1998). Educational Uses of Virtual Reality Technology. Technical Report No. IDA Document D-2128, Institute for Defence Analyses.

Figure 1. The CVE-VM application (Kirner et al., 2001). Image courtesy Tereza G. Kirner, Universidade Metodista de Piracicaba, Brazil.

Figure 2. Web3D training simulator for the treatment of trigeminal neuralgia (Li et al., 2000).
Image courtesy Li, Y., Brodlie, K. and Philips, N., University of Leeds, UK.
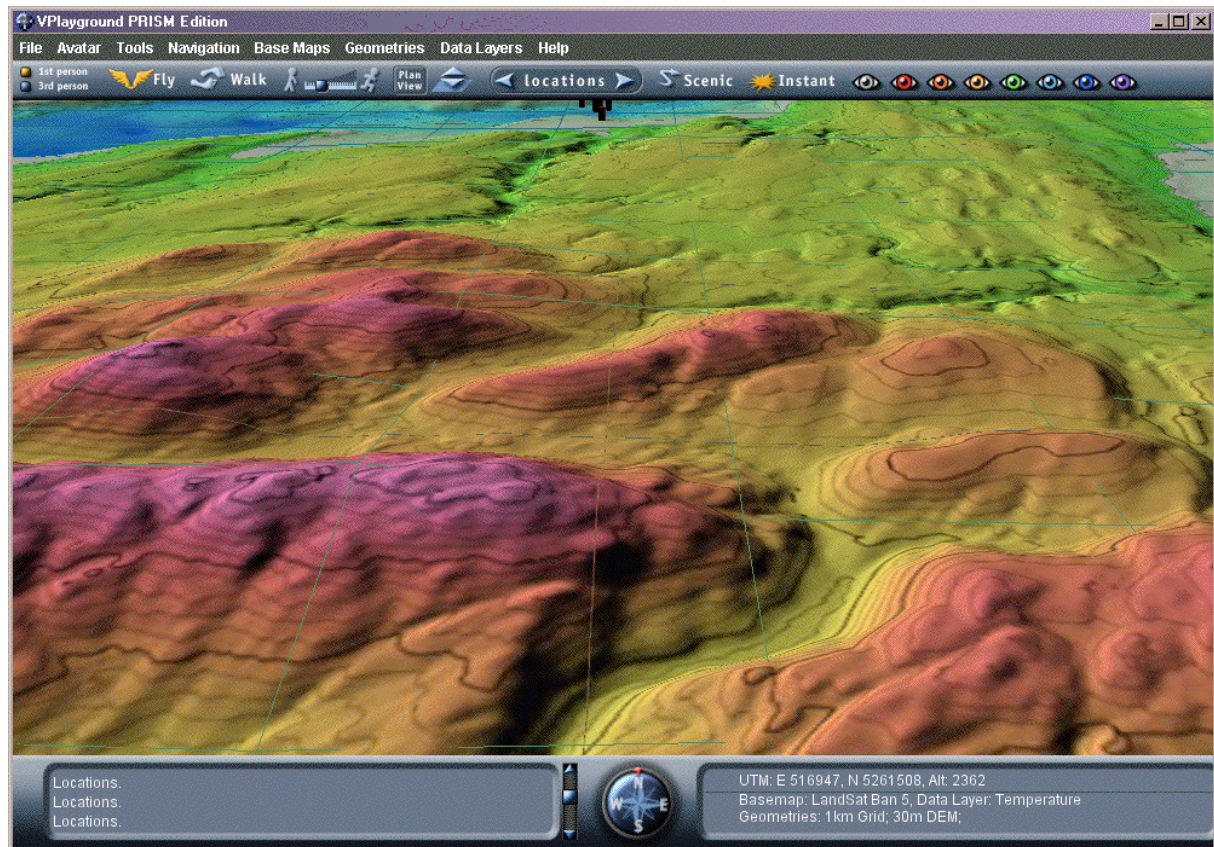
Figure 3. The Virtual Big Beef Creek (Campbell, Collins, Hadaway, Hedley & Stoermer, 2002). Image courtesy Bruce Campbell, University of Washington, USA

Figure 4. Online Mentors for Foreign Language Training and Cultural Familiarization (Sims & Pike, 2004). Image courtesy Edward Sims, VCom3D, USA.