7 Virtual and Augmented Reality

D. Fabri, C. Falsetti, A. Iezzi, S. Ramazzotti, S. Rita Viola, and T. Leo

7.1 Introduction

Virtual and augmented reality are deemed powerful learning tools because they allow, in principle, experiential learning without displacing the learner when real-experience environments are available. In order to attain satisfactory experiential learning, technology should have extremely challenging features and performances. These requirements become more and more compelling in the field of E-Learning, where the ideal of having rich individual teaching assistance for each learner is pursued (ADLNET 2004) through the exploitation of ICT.

In this contribution, we will refer to E-Learning as having a learning experience on the web. Therefore no a priori distinction between education and training will be done. Learning experiences involve a number of pedagogical, psychological and contextual aspects (see, for example, Mantovani and Castelnuovo 2003), for which the role of technology has to be suitably calibrated. Learning experiences develop according to learning process models that evolve from individual learning to social and situated learning up to knowledge creation and management. Accordingly, the requirements of technological features and performances are varied. Moreover, it is not easy to give a common definition of virtual and augmented reality, since they involve several different and heterogeneous technologies.

However, we will focus on the technical possibility of providing the user with a plausible sense of presence. Therefore this chapter will survey:

1. The evolution of the definitions of virtual reality (VR) and augmented reality (AR) in time together with the evolution of pedagogical approaches followed in both traditional learning and E-Learning

2. The evolution of the available technologies together with the improvements of the Internet
3. Examples of the applications available at present for E-Learning

Finally, a few possible research and application developments on VR and AR technology related to the enhancement of the sense of presence in E-Learning will be discussed.

7.2 Virtual Reality and Augmented Reality Versus Pedagogical Models

As far as epistemology is concerned, the meaning of “reality” should be discussed before reflecting on the “virtual” attribute. Here we will refer to the current common sense feelings about reality.

In general terms, virtual reality (VR) is a technology that allows a user to interact with a computer-synthesized environment, be it a real or an imaginary one.

According to Fitzgerald and Riva (2001), “the basis for the VR idea is that a computer can synthesize a three-dimensional (3D) graphical environment from numerical data. Using visual and auditory output devices, the human operator can experience the environment as if it were part of the world. This computer generated world may be either a model of a real-world object, such as a house; or an abstract world that doesn’t exist in a real sense but is understood by humans, such as a chemical molecule or a representation of a set of data; or it might be in a completely imaginary science fiction world”.

Augmented reality (AR) can be considered a particular extension of VR. The user’s sensation of the world is augmented by virtual objects that provide additional data/information on the real environment. Although in the literature, different definitions of AR have been given, the following ones can be considered representative:

- Vallino (1998) states that “AR is an area of virtual reality research that concentrates on the technology to merge synthetic sensory information, usually visual information, into a user’s perception of their environment. Unlike VR, which seeks to immerse the user in a completely computer-generated world, augmented reality wants to keep the user immersed in the real world and add information to their perception of it”.

- Liarokapis (Liarokapis et al. 2002) states, “The main objective of AR technology is to superimpose computer-generated information directly into a user’s sensory perception, rather than replacing it with a completely synthetic environment. Users within AR systems must be able to interact with the 3D information in a natural way, like they do in the real environment”.
- Kauffmann and Papp (2006) state, “AR is a variation of VR. VR technology completely immerses a user inside a synthetic environment. While immersed, the user cannot see the surrounding real world. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composed with the real world. Therefore, AR supplements reality, rather than completely replacing it. AR can be said to require the following three characteristics: (1) combines real and virtual (2) interactive in real time (3) registered in 3D”.

Looking at these definitions, we see three points worthy of attention:

1. The enhancement of perception through augmented sensations (AR)
2. The aim to a natural way of interaction between user and synthetic environment (AR and VR)
3. The presumption that the user is completely immersed in the VR synthetic environment

These points are in some way permanently present in the history of VR and AR. The names “virtual reality” and “augmented reality” were proposed, respectively, in 1987 by J. Lanier and in 1990 by Boeing’s researchers. The origins date back to the ’50s and ’60s (Brooks 1999), in the field of vehicle and flight simulators for military applications.

In the ’60s, research mainly focussed on 3D interactive computer graphics. Ivan Sutherland pioneered these studies at MIT’s Lincoln Laboratory. In 1963, Sutherland completed Sketchpad, a system for drawing interactively on a CRT display with a light pen and a control board. The system was useful for the interactive manipulation of images. In a few years, these studies gave rise to the head-mounted 3D computer display (HMD). In 1967, Bell Helicopters carried out tests in which a pilot wore a HMD that showed videos from a servo-controlled infrared camera mounted beneath the helicopter. The camera moved with the pilot’s head, both augmenting his night vision and providing a level of immersion sufficient for the pilot to equate his field of vision with the images from the camera. This kind of system would be later named AR. In the same year, at the University of North Carolina, the first force feedback system was developed for the GROPE project (Brooks et al. 1990). The system supported the scientific visualization of molecular docking by giving graphic representation of molecules and their inter-atomic forces. Through a special hand-grip device, the user was able to change relative position and orientation of molecules to search the minimum binding energy configuration. The system evolved from 2D to full 6D (GROPE-III). During '90s, Brooks's laboratory extended the use of VR to radiology and ultrasound imaging.

Advances in flight simulators, human-computer interfaces and augmented reality systems pointed to the possibility of immersive, real-time control systems for research, training and to improve performance. VR was extended to surgery in a context of telesurgery, that is, the use of robotic devices remotely controlled with computer-mediated sensory feedback. Use of telesurgery and robot-assisted surgery is at present widespread, in particular for minimally invasive surgery and in tele-neosurgery (Wusheng et al. 2004). The first telesurgery equipment was developed at SRI International in 1993 and the first robotic surgical intervention was performed in 1998 at the Broussais Hospital in Paris.

Virtual worlds had and have elective applications in the domains of entertainment, aesthetic inspiration and socialization, where they are increasingly realistic and immersive. By 1969, Myron Krueger (University of Wisconsin) created a series of projects on the nature of human creativity in virtual environments. His VIDEOPLACE system was based on sensing floors, graphic tables, and video cameras and processed interactions between a participant's image and computer-generated graphical objects. It is worthwhile to underline that the system focused on the representation of the user's actions by the computer.

Data Glove is probably the most used device to interact with virtual worlds. The first one was developed in 1977 (University of Illinois). In 1982, Thomas Zimmerman invented the optical glove. It was meant as an interface device for musicians and was based on the common practice of playing "air guitar". This was able to track hand and finger movements to control instruments like electronic synthesizers. In 1983, the Digital Data Entry Glove was built; its features included sufficient flexibility, as well as tactile and inertial sensors to monitor hand positions for a variety of applications to comprehend data entry. In 1985, the first commercial VPL Data-Glove was produced and brought to market in 1987 by VPL Co. (California).

The time was then right to speak about immersivity, that is, a modality of human computer-interaction that is bi-directional, real-time and allows mutual reactive feedback among the two interaction actors.

The first immersive VR system – Virtual Visual Environment Display (VIVED) – was developed at NASA labs in 1985. It evolved in a virtual interface environment workstation (VIEW) in 1989. VIVED defined a de facto standard suite of VR technology, including a stereoscopic HMD, head tracker, speech recognizer, computer-generated imagery, data glove and 3D audio.

Military and medical requirements continued to drive these technologies through the 1990s, frequently by partnerships with academia or entertainment companies. With the diffusion of Internet (by the ’90s), virtual worlds, AR and telepresence were successfully launched as platforms for creative work, games, training environments, research and social spaces.

VR and AR developments are strictly related to the increase of computational power. The corresponding reduction of costs brings affordability to VR and AR systems in learning and training. Edutainment and entertainment have a widespread commercial market.

The aims of creating an artificial world as realistic as possible and of providing user interaction through modalities as similar as possible to everyday experiences, are explicit. The attention is on sensations, perceptions and cognition. Sensation here refers to the elementary physiological process through which the human body receives physical energy from the external environment. It is a process that involves the organs of sense and doesn’t imply a conscious involvement. Perception here refers to the process through which the sensation is organized. It is an active process happening in the brain relating the sensation to the external object and involving the experience as well. Cognition here refers to the process of the mind involving memory, imagination and representation of the world. See (Metzger 1975) for examples. In the case of AR, the human-sensitive capability is enhanced. Sensitive capability is related to the specific role that presence plays in training, in relation to the process of learning and transfer of skills. The sense of presence (Mantovani and Castelnuovo 2003) makes the learning experience engaging, and trainees will experience thoughts, emotions and behaviours similar to the ones experienced in a real-life situation, thus allowing the creation of a recallable experience.

Therefore, the potential of AR and VR with respect to learning technologies, namely in the direction of experiential learning, in light of pedagogical policies based on active, constructivist approaches and involving technology mediated/enabled learning is, in principle, universally agreed upon. The characters of technology have to be carefully tuned in to the pedagogical models and the individual learning styles involved in a specific learning experience.

Pedagogical models underlying the introduction of ICT technologies in learning refer to:

- Active learning theories, according to which learning is seen as the outcome of a process involving the direct and experiential manipulation of the field the learner is dealing with (Kolb 1984; Felder and Brent 2003)

- Constructivist learning theories, according to which learning is seen as the personal and subjective construction of the learner, according both to the experiences he/she is doing and to the ones he/she had done (Bruner 1990; Kolb 1984)
- Social and situated learning theories that generalize constructivist viewpoints to social construction shared by groups of people, depending on the particular context in which they happen (Engeström 1987; Wenger 1998)

In this latter context, an important role can be attributed to knowledge creation and management. Without entering into the discussion of the knowledge cycle (Leo 2005) it can be said that in many knowledge domains, the creation of communities of practice working on suitable virtual environments is able to promote the definition of new, relevant and exploitable knowledge.

It appears that VR is particularly suited for training in the case of emulation of real-world objects, while representation of symbolic knowledge shows better results in the implementation of constructivist approaches and for social and situated learning (involving emotional interactions too), while AR could provide its best in material knowledge sharing aimed at performance enhancement (for example, in the case of maintenance of particularly complex appliances such as air traffic control radar systems, or cabling the shell of aircrafts).

It can be argued that the more plausible they are, the stronger learning may become. To satisfy such a requirement, the main functional components of the technological suite allowing effective VR and/or AR can be classified as follows:

1. Appropriate model of phenomenon to be emulated, reaching a sufficient approximation. Sufficient approximation here refers to sensorial and perceptual human capabilities. Imagination, if properly activated, can supplement poor models but in the present context we intend to focus on enabling technologies.
2. Sufficiently powerful computational resources, in terms of processors and memory; moreover, specific languages, algorithms and architectures are needed. They can be globally named virtual engines (VE). We will consider the VE as embedded in a client–server architecture because of the assumption that the learning experience happens through the web or a private network.
3. Input/output devices. Input devices are directed towards the electronic system. Output devices are directed to the users.

4. Systems for effective interaction and reactive feedback between a user and a synthetic environment. In our view, such a class of appliances is particularly important for a simple and ecological interaction.

Regarding the forth aspect, let us underline that VR applications generate sensations that the human brain and mind are able to, and are habituated to, reconnect and reconstruct perceptual experiences and related representations according to the phylogenetic personal evolution. If this natural modality of learning is disrupted, the user may experience difficulties and fatigue.

A last point is that class 4 components are in principle able to allow virtual experiences involving non-verbal communication and interaction among persons. Examples of such technologies are virtual worlds (Virtual Worlds Review 2006) and avatar-based applications (Activeworlds 2006).

7.3 Review of the Main Enabling Technologies

We will follow the classification of technologies just proposed and point out that most review papers available in the literature about VR- and AR-enabling technologies consider only class 2 and 3 components.

Models, in particular mathematical models of physical phenomena, will not be surveyed because of their endless coverage. Every knowledge domain has elective modelling methods. In general, suitably detailed models give rise to algorithms whose implementation requires extensive computational power, and some key problems. Multiple time scales, for instance, still exist.

Our attention will be mainly focused on technologies enabling the "natural" modality of human-synthetic world interaction. We think about all sensory-motor activities a person performs to interact with and to explore the real world (walking from one place to another, speaking, watching an object modifying the peripheral field due to the movement of the head, touching an object to evaluate its consistency, hearing a sound and trying to detect its source and so on). To mimic such activities in a satisfactory manner, great computational power is required. The needed information has to be made available with the best precision and the minimum latency time to allow the user to interact in real time with the virtual world (Mäki-Patola et al. 2005). For many years, supercomputers with parallel architectures and, more recently, distributed computing, have been able to provide the needed computational power, even if at costs that are generally unaffordable in the context of learning systems. Parallel computing is the simultaneous execution of the same task, split up and specially adapted on multiple processors in order to process it faster (Atty et al. 2006; Allard et al. 2004). Computational grids (Forster and Kesselman 2003; DAME 2003) allow the sharing, selection and aggregation of a wide variety of geographically distributed computational resources (such as supercomputers, computer clusters, storage systems, data sources, instruments, people) and introduce them as a single, unified resource to solve large-scale computer and data-intensive computing applications.

7.3.1 Virtual Engine

The VE is a key component of the VR system that reads its input devices, accesses task-dependent databases, updates the state of the virtual world and feeds the results to the output displays. It is an abstraction. It can be one computer, several co-located ones, or many remote computers collaborating in a distributed simulation (Burdea and Coiffet 2003).

In our view, the VE is embedded in a client–server architecture. Therefore, it comprehends computational resources and communication services. With regard to computational resources, the following can be said:

Frequently VR/AR technologies are considered coincident with computer visualization. At the highest levels of quality (fiction movies, military applications, high tech industrial applications), this requires specific hardware and software architectures for the rendering processes, such as the creation of 2D scenes from 3D models. These processes ask for pipeline architectures.

The pipeline architecture uses parallelism and buffers, and works on three levels: application, geometry and rasterizer. The application level software reads input devices (such as gloves, trackers), changes the coordinate reference systems, performs collision detection and collision response and reduces model complexity.

The geometry level computes the geometric model based on coordinates and transforms and reconstructs the scene based on lighting models such as wire-framed (the simplest one shows polygon-visible edges); the flat-shaded model (which assigns the same color to all pixels in a polygon [or side] of the object); Gouraud or smooth shading (which interpolates colors inside the polygons based on the color of the edges); Phong shading (which interpolates the vertex perpendicular to the object surface before computing light intensity based on the most realistic shading model (Burdea and Coiffet 2003)). The geometry stage receives the primitives from the application stage and uses a series of geometric operations such as transformations, projections, and clippings in order to pass the new coordinates and the color to the rasterizer stage. This stage can be implemented by software modules, by hardware devices or by both. At the end of this stage the scene is ready to be represented. The Rasterizer hardware converts information about 2D vertices from the geometry stage (x, y, z, colour, texture) into pixel information on the screen and provides an efficient buffering system to reduce the flicker phenomenon.

The VR engine manages the objects' model too. The VR object modelling cycle is composed of I/O mapping, geometric modelling, kinematics modelling, physical modeling and object behaviours for intelligent agents.

All these duties are fulfilled by high level programming languages that exploit, for implementation, HW and SW resources available in the computers they run on (either client or server). The more used and most promising languages can be classified in two main commercial categories: open source (OS) and proprietary. In this paper we will deal with OS languages. They are listed and briefly described as follows. They are XML based. XML (Extensible Markup Language) is used for data representation and is a powerful language that describes data structures. It is a simple and very flexible text format derived from SGML (ISO 8879) and developed by W3C Consortium:

- The xVRML and VRML97 (virtual reality modelling language) specifications (VRML 2006) were created to put 3D worlds onto the Internet using an idiosyncratic notational system. The xVRML Project is focused on evolving this into a more modern approach based on using an XML-based notation and an XML schema-based definition. The xVRML Specifications (Walczak and Cellary 2002), xVRML (2003), are based on the xVRML schema, which in turn provides a model of the data in a virtual reality instance document (called a world). The xVRML schema and specifications will also form the basis for the development of "view" and "controller" software technologies to express xVRML-instance documents.
- X3D is a royalty-free OS file format and run-time architecture that represents and communicates 3D scenes and objects using XML. It is an ISO-ratified standard that provides a system for the storage, retrieval and playback of real-time graphics content embedded in applications, all within an open architecture that supports a wide array of domains and user scenarios. It has features that can be tailored for use in engineering and scientific visualization, CAD and architecture, medical visualization, training and simulation, multimedia, entertainment, education and more. The development of real-time communication of 3D data across all applications and network applications has evolved from its beginnings as the virtual reality modelling language (VRML) to the considerably more mature and refined X3D standard.

- JAVA3D (2006) introduces a new view model that takes Java's vision of "write once, run anywhere" and expands it to include display devices and six-degrees-of-freedom input peripherals such as head trackers. This "write once, view everywhere" nature means that an application (applet) written using the Java 3D view model can render images to a broad range of display devices, including standard computer displays, multiple-projection display rooms, and head-mounted displays, without modification of the scene graph. It also means that the same application, without modification, can render stereoscopic views and take advantage of the input from a head tracker to control the rendered view.[1] The quality of attainable visualization depends on the HW/Firmware available on the computer running the Java applets; at present no comparison can be made to the visualization of the computer visualization systems.

In the current implementation, Java 3D mixes a lot of Java code with OpenGL calls:

- The OpenGL® (2006) application programming interface (API) began as an initiative to create a single, vendor-independent API for the development of 2D and 3D graphics applications, to allow effective porting of applications from one hardware platform to another.
- Toolkits have to be mentioned too. They are extensible libraries of object-oriented functions designed to help the VR developer. They support various common input/output devices used in VR (so drivers need not to be written by the developer) and allow importing of CAD models, editing of shapes, specifying of object hierarchies and collision detection as well as multi-level detail, shading and texturing and run-time management. Toolkits have built-in networking functions for multi-user interactions, etc., and can be classified in various ways: text-based or graphical-programming; type of language used and library size; type of input/output devices supported; type of rendering supported; general purpose or application specific; proprietary (more functionality, better documented) or public domain (free, but less documentation and functionality).

Moreover, it should be stressed that the use of VR in E-Learning applications could require some sort of knowledge management system to allow the capture of the knowledge developed during the learning process, its

[1] Java 3D API Specification, Chap. 8, "View Model".

organization and its presentation back to users, for instance in the form of a richer virtual environment.

As far as communication services are concerned, let us stress that effective use of VR on the Internet requires the adoption of specific communication protocols and the ability to dynamically modify the information present in the network according to the bandwidth available. Examples of such protocols include Distributed Interactive Simulation Protocol (DIS), Transmission Control Protocol (TCP), User Datagram Protocol (UDP), Protocol Data Unit (PDU), and Network Time Protocol (NTP).

Therefore, at either the client or server side, predictive systems can be required to reduce latency (Jung et al. 2000; Furht 1998).

7.3.2 Input/Output Devices

Output devices allow the user to sense the virtual environment. Human senses need specialized interfaces, for example:

- Vision requires graphics displays, which are the physical means for visualization. In the case of individual viewing, these displays are personal displays. The image may be monoscopic or stereoscopic, monocular (for a single eye) or binocular (for both eyes).
- Sound requires interfaces that provide synthetic sound from the virtual world. The sound can be monaural (both ears hear the same sound) or binaural (each ear hears a different sound).
- Force and touch demand haptic interfaces (Kim et al. 2006; Brau et al. 2005).

At present, smell and taste interfaces are mainly rather rough prototypes (Nakaizumi et al. 2006).

A number of input devices are needed. They are available in a rich variety. We discuss in greater detail those deemed significant for natural interaction:

- *3D pointer*. A 3D pointer is a three-dimensional mouse with six degrees of freedom. The Wanda (AT 2006) was the first of the wands/3D pointers. Until now it was the most common input device for CAVE-style (2002) VR interfaces. CAVE is a multi-person, room-sized, high-resolution 3D video and audio environment invented at EVL in 1991. Graphics are projected onto three walls and the floor, and viewed through active 3D glasses.

- *Trackers*. Trackers measure the movement of "objects" such as the user's wrist or entire body by referring to a fixed system of coordinates. The underlying physical devices can be magnetic, ultrasonic, mechanical, inertial/ultrasonic or vision-based. Relevant features are the measurement rate, sensing latency, sensor noise and drift, accuracy and repeatability, sensing degradation.
- "*Powered Shoes*" (Iwata et al. 2006). Powered shoes are a type of force platform that allows the user to walk in any direction in a virtual environment. The information the powered shoes provide exploits their ability to detect walking direction in a given coordinate system. They are motorised and can be disturbing (SIGGRAPH 2006). They are apparently not useful for VR Gameworlds, but are usable for VR training, immersion and data manipulation.
- The Nintendo Wii (2006) contains a motion sensor allowing measurements of six degrees of freedom movement of the hand to be transformed into an action on a screen. It is driven by ST's micro electro-mechanical systems (MEMS) technology. The Wii's controller was designed to withstand large temperature variations. It is immune to vibration and is shock resistant up to a force of 98 N. The controller even contains a small speaker assembly, allowing it to play sounds of events happening in proximity to the player-character.

7.3.3 Interaction and Reactive Feedback Devices

VirtuSphere (2006) consists of a giant mouse ball, which the user can enter. The user can move the mouse in any direction for virtually unlimited distances by making it do the following actions: walk, jump, roll, crawl, run. The ball, which is mounted on wheels, measures the distance and the direction of the user's steps. The system informs the user through a HMD about his/her movements in the virtual environment. Alternatively, the sphere can be installed inside a CAVE VR system and synchronized with it.

7.4 Some Relevant Applications to E-Learning

Nowadays, a number of applications of VR/AR that are specifically suited for E-Learning are available. A possible way to classify these applications is to subdivide them based upon their gross educational objectives, namely, individual learning, team learning (collaborative learning) or both.

Applications addressed to improve individual skill of the learners are, in general, based on complex simulation in which the key feature is the representation of the real world, which has to be as realistic as possible. These kinds of applications are aimed at reducing cost and improving safety during training.

Several applications are in biomedicine, in which practice is needed to develop students' knowledge and skills, and simulation is the better way to manage experiential training (Zajtchuk and Satava 1997). An AR system called Standardized Patients (SPs) (McKenzie et al. 2004) is available for training in three areas: doctor-patient communication, eliciting the history and performing the physical exams. Another example is a delivery simulator (Obst et al. 2004). This system comprehends direct haptic and auditory feedback and provides important physiological data such as blood pressure, heart rates and pain and oxygen levels.

VR has been used to build a liver surgery planning system (LSPS) (Reitinger et al. 2006). It aims to support radiologists during data preparation and to give surgeons precise information for optimal decision making. It combines medical image analysis and computer graphics, which allow for innovative problem solutions, especially when user interaction with complex 3D objects is needed.

In industry, many applications are diffused for training and competence development of people involved in safety-critical jobs. In the construction industry, a simulator of a hydraulic excavator based on a VR system was developed for training machine operators (Wang et al. 2004). Many applications are available to provide training in complex technical systems. An example is the prototype of an innovative interface developed for aircraft (Haritos and Macchiarella 2005) maintenance that assists novice aircraft maintenance technicians (AMTs) with job task training. The AR system has the potential to supply rapid and accurate feedback to AMTs with any information that the user needs to successfully complete a task.

Virtual museums have profited from VR technologies such as 3D visualization and rendering. Different applications, often devoted to educational purposes, have also been developed. The Arco Project (ARCO 2003), for example, has been developed by the University of Sussex and is aimed at furnishing the infrastructures for 3D virtual exhibitions of collections of museums over the web.

Specific applications have been developed in the educational field: Magic Book, MARS and MARIE. Magic Book (McKenzie 2004) is an AR application. It superimposes on the pages of a book 3D virtual objects whose animation is sensed during interaction by means of HMD. MARS (mobile augmented reality system) (Doswell 2006) is a recent AR E-Learning project in which a learner, immersed in the real world, wears a mobile see-through display that interacts with a training/learning software. This allows users to annotate real-world objects with digital content that may combine animation, graphics, text and video. The system adapts itself to the individual learner needs and dynamically distributes suitable instructions to improve learning performance. MARIE (Liarokapis et al. 2002) uses an augmented display for learner-teacher interaction. The various objects are proposed by the teachers and can be rotated and manipulated by the participants. At this time, students can only see the objects, but future developments may give them the opportunity to smell and touch.

Systems based on a collaborative learning approach use a shared-work environment. Each user interacts with a dynamic synthetic world that changes based upon the decisions made by other users. The current usage is for simulated war or business games, largely in the educational domain. Important projects have been developed by the MIT teacher education program in collaboration with "the education arcade". They created "AR" simulations to engage people in games that combine real-world experiences with additional information supplied by handheld computers. This mode of learning appears effective in engaging university and high-school students in large-scale environmental engineering studies and in providing an authentic mode of scientific investigation.

The first game was Environmental Detectives (ED) (2003). It is an outdoor game that can be run at three sites: MIT, a nearby nature centre and a local high school. The players use GPS-guided handheld computers to uncover the source of a toxic spill by interviewing virtual characters, conducting large-scale simulated environmental measurements and analyzing data. A further game generation moved indoors using Wi-Fi enabled Pocket PCs. Mystery @ The Museum (M@M 2003) runs at the Boston Museum of Science. Players search for a fake museum item. Working in teams and within a time limit, players use virtual clues, discover and understand information contained in the museum and catch a virtual criminal using their deductive skills.

The Star School Project (Kleefeld 2005) addresses urban middle-school students in Milwaukee and Madison. Started in January 2006 and planned to run up to 2008, it tries to fill the gap between formal and informal learning through AR games, which combine physical action with virtual action using a GPS-equipped PDA.

There are systems based on VR to promote learners' active study by integrating synchronous, asynchronous and cooperative learning. Examples are Studierstube Augmented Classroom (SAC 2002) and AVEE (Huang and Chao 2005). In the SAC, small groups of students and tutors share the same AR environment. Using HMD, they can engage in face-to-face collaboration and, by using tracked gloves, can perform 3D manipulations of the virtual objects. The system is applied to train students in spatial comprehension through the software Construct3D (Kauffmann and Papp 2006) and to train medical students in surgery planning.

AR systems based on 3D visualization are used for engineering design. Designers share a conference room using an AR display. One designer can modify a prototype and the changes and adjustments are shown to other users in real time.

Various applications are available in robotics to train engineers both individually and in teams. Most applications are based on augmented display systems and allow remote users to drive a robot using images of the remote workspace. Sometimes the virtual robot image is superimposed on the real scene. The remote operator simulates the experiment to decide whether to proceed with the motion of the real robot. In other systems, the commands of the operator are executed directly on the real robot, and the AR display is used to provide a sort of immersion.

In such a context, immersion can be specified as follows: remote users will experience the presence in a real-world environment, namely a laboratory, by means of a rich, perceptive Internet-based bi-directional interaction comprising vision, hearing and perception of current modification of physical quantities. The project is used to improve collaborative learning with the remote control of robotic systems through the web in the TIGER (Telepresence Instant Groupware for higher Education in Robotics) project (Fabri et al. 2004). The project involves several universities in Italy to train control designers of robotic systems within a framework of structured and/or continuous education. It aims to represent and communicate the knowledge that can be learned by attending a robotics laboratory. It allows students to access web laboratories in different universities and to interact with real robots to control their operation during practical experiments. Students have a realistic (apparent real-time and multi-sensorial) perception of the effects of their control on the robot so that they can speculate on the effectiveness of their choices. Their reflections can be captured, assessed by the teachers and re-used for further learning and implementing knowledge sharing and knowledge creation.

In synthesis, we see an increasing attention on technologies enabling "natural" interaction between user and the synthetic world, be it virtual or remote access through the web. Knowledge creation and sharing is considered too.

7.5 Perspectives

Our point is that VR/AR can be enabling technologies for E-Learning in the context of learning experiences in which the sense of presence has to be attained by a natural (ecological) interaction with the learning environment. In such a context, VR/AR technologies can also be integrated with knowledge management tools to create, share and re-use knowledge developed by the learners themselves, provided that the new knowledge is accredited by the assessment of an expert (teacher).

Therefore, we provide indications about possible technological improvement in the direction of a more natural human-computer interaction, bi-directional with reactive feedback. We refer to developments dealing with the empowerment and refinement of interfaces.

An example of empowerment is techniques aimed at integral imaging. Recent studies (Takaki 2006; Stern and Javidi 2006) show that it is possible to construct a natural 3D display system that enables a large number of images to be displayed simultaneously in different horizontal directions to produce natural 3D images. The following relevant results were obtained: no need to wear special 3D glasses, simultaneous observation by multiple persons, no restrictions on observation position, high-presence (smooth motion parallax) images, coherence with human 3D vision (without fatigue). This promising technology could be a valid alternative to holography (Frauel et al. 2006) that generates 3D images with full-parallax and continuous viewing, but involves coherent illumination and a system that is more complex, expensive and sensitive to various factors.

Refinement concerns the inclusion of stimuli belonging to more than one sense, as mixed visual-haptic and kinesthetic stimuli. Improvements in interaction can be foreseen because of the integration of emotional aspects detected by the collection and processing of neurological or physiological signals (so-called "affective computing"). In this case, we suggest that technologies should give the user coherent sensations and perceptions.

In our view, coherence among sensations is key. Coherence among sensations means that stimuli coming from the virtual world should conform to one's perceptive and cognitive inner representations. It follows that the artificial world should be as rich and detailed as possible on one side, while, on the other side, it should produce consistent and non-contradictory perceptual experiences. In fact, in AR systems for aviation industries, if contradictions arise with the psycho-motor model of the user, the user experiences fatigue and discomfort.

To sum up, important features to consider concern the richness of stimuli that provide feedback to the human actor in the VR/AR interaction. Stimuli should be integrated, multi-channel and coherent with the learner's inner perceptive and cognitive representations.

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