

12 VR Learning: Potential and Challenges for the Use of 3D Environments in Education and Training

Fabrizia MANTOVANI

Abstract. There is some evidence that Virtual Reality (VR) can contribute to raise interest and motivation in students and to effectively support knowledge transfer, since the learning process can be settled within an experiential framework. However, the practical potential of VR is still being explored: understanding how to use Virtual Reality to support training and learning activities presents a substantial challenge for the designers and evaluators of this learning technology. This chapter has the main aim of discussing the rationale and main benefits for the use of virtual environments in education and training. A number of key attributes of VR environments will be described and discussed in relationship to educational theory and pedagogical practice, in order to establish a possible theoretical basis for VR learning. Significant research and projects carried out in this field will be also presented, together with suggestions and guidelines for future development of VR learning systems. However, further research is required, both on technological side and on key issues such as transfer of learning, appropriate curriculum implementation, elements of effective VR design, and the psychological and social impact of the technology use.

Contents

12.1	Introduction.....	208
12.2	”Learning by constructing knowledge”: a rationale for the use of Virtual Reality in education and training.....	209
12.3	From technological components to educational features: towards a model for design and implementation of educational VEs.....	213
12.4	VR learning applications.....	215
12.5	Transforming the potential of Virtual Reality into Real Educational Efficacy: insights and guidelines	218
12.6	Conclusion	221
12.7	Acknowledgments	222
12.8	References	223

12.1 Introduction.

"Learning is the development of experience into experience." (James, 1892), [1]

In education and training, Computer-Based Learning (CBL), or Computer-Assisted Learning (CAL) has been representing since the '70s an important source of innovative learning tools [2, 3]. With the diffusion of the World Wide Web and many other hardware and software technologies, this influence is reaching a wider and wider audience and is no more limited to providing support and aid tools for learning: as Bonk and colleagues [4] point out, "recent technological developments have converged to dramatically alter conception of teaching and learning process" (p.25).

As suggested by several authors [5-8], Virtual Reality (VR) represents a promising area with high potential of enhancing and modifying the learning experience: Virtual Environments (VEs) can provide a rich, interactive, engaging educational context, supporting experiential learning. As Bruner underlined [9], performing the task enhances the learning process; VR can provide a medium to learn by doing, through first-person experience.

Current use of Virtual Reality Environments (VREs) extends to a wide range of activities, from training people to acting in dangerous environments (e.g. training for space missions or military interventions) to experiencing contexts that in physical reality would be too expensive or impossible to access (e.g. travelling around Mars or visiting a castle in the Middle Age).

The use of Virtual Reality gradually broadened from teaching simple tasks to the acquisition of complex skills, such as abstract reasoning, visualization and management of complex information spaces [10]. This shift has brought new challenges to educators and developers, since it becomes more and more important to understand what characteristics and features such environments should have in order to fit established educational goals.

As Osberg [11] underlines: "Technology does not, by itself, improve education, and even the most promising educational innovation needs skilful application to be effective."

In order to build effective VR learning systems, collaborative and iterative design is key issues: educators, developers and students should be cooperatively involved, at different development stages.

According to Osberg [11], "The role of educators, in this context, is to keep the focus on the needs of learner, not on the technology itself. The general aim is that of empowering the learner by maximizing the opportunity for learning; creating environments, materials, and processes to make learning interesting, motivating and effective for everyone". In this process, the main tasks are: fixing precise learning objectives and educational goals; reflecting on the rationale of use of VR; evaluating what VR features are more pertinent and useful for learning enhancement within "that" specific application.

Designers and developers, on the other hand, should be concerned with the creation of ergonomic and usable environments, as well as with the integration of educational and pedagogical guidelines. These guidelines will come from interaction with teacher and students according to a user-centred and goal-based design [12].

Although "there is clearly the potential that VR learning environments can be powerful educational experiences" [11], many technological, theoretical, economical and cultural challenges still have to be faced for further integration of VR into educational and training contexts.

This chapter has the main aim of discussing the rationale and main benefits for the use of virtual environments in education and training. A number of key attributes of VR

environments will be described and discussed in relationship to educational theory and pedagogical practice, in order to establish a possible theoretical basis for VR learning.

In order to transform the potential of VR features into educational efficacy, a number of issues will be investigated, focusing on the complex web of relationships within which VR learning occurs. The link between VR and learning outcome will be analysed through a model [10] which considers the influence and interaction of many other factors such as the concepts to be learned, learners' characteristics, usability, motivation, etc.

Significant research and projects carried out in this field will be then presented, and insights and guidelines suggested by the review of these examples will be provided.

12.2 “Learning by constructing knowledge”: a rationale for the use of Virtual Reality in education and training.

12.2.1 Experiencing learning in Virtual Environments.

What is Virtual Reality? And how can its use enhance the learning process? Gaddis [13] defined Virtual Reality (VR) as:

“a computer-generated simulation of the real or imagined environment or world”

According to Fitzgerald and Riva [14], “the basis for the *Virtual Reality* 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” (p.327).

Key feature of the VR experience is also the possibility to actively interact with the created environment; this is allowed by the use of external input devices responding to the user's reactions and motions.

Although many authors have defined VR essentially as a technology [15], more recent approaches [16] forward a more complex vision, considering VR as a human experience [17] and underlining how “the essence of VR is the inclusive relationship between the participant and the virtual environment” [14] (p.328).

In this context, the concept of presence is a crucial one: according to Slater [18] it includes three aspects:

- “the sense of being there in the environment depicted by the VE
- the extent to which the VE becomes the dominant one, i.e. that participants will tend to respond to events in the VE rather than in the real world
- the extent to which participants, after the VE experience, remember it as having visited a place rather than just having seen images generated by a computer” (p.550-561)

As we can note from this description, the sense of presence relies on two different factors: immersion and interaction.

- *Immersion* in the Virtual Environment can be defined as an “intense feeling of self-location within the computer-generated reality with which the user interacts” [19]. But what are the elements contributing to this feeling? Immersion can be considered as the

product of the match between the technologies and the subjective feeling of involvement experienced by the user in the interaction process.

Immersion can be also defined, following Cronin [19], as a human factor:

“Effective immersion requires the ability on the part of the participant to control attention and focus on what is going on in the VE while simultaneously excluding all interference from the outside world”.

- *Interaction*: According to Sastry and Boyd [20], the feeling of presence, especially within real world applications, is more influenced by the level of interaction/interactivity that actors experience within the simulated environment than by the richness and faithfulness of available images. The focus is much more on the possibility for the user “to navigate, select, pick, move and manipulate an object much more naturally”. (p.235)

This is very important within educational contexts, since it highlightens how the added-value is represented by the experiential and intuitive nature of learning in the VR environment.

12.2.2 *Looking for a theory of VR learning*

Actually, we cannot say that there is a general theory of VR learning. Nevertheless, as Winn [5] suggested, constructivist theory provides a valid and reliable basis for a theory of learning in virtual environments. Adapting what Gabbard [21] said about hypermedia, VR provides a tool for developing instruction along constructivist lines and an environment in which learners can actively pursue their knowledge needs. The attraction that constructivists have for Virtual Reality is that VR provides the perfect tool or technology to apply their theories in the “real world”. The attraction that VR supporters have for constructivism is that it provides a philosophical foundation for their activities.

Trying to give a comprehensive definition of constructivism is not an easy task: according to Scheurman [22], constructivism can be considered as a group of theories dealing with the nature of knowledge; their common ground relies on the idea that people, grounded in a societal and cultural setting, actively create knowledge.

McGuire [23] suggests that “constructivist learning theorists purport that there is no true representation of knowledge but that each individual constructs sense out of new information as it is encountered.” (p.257)

Constructivism [24] claims that we construct our own reality through interpretation of personal perceptual experiences and that reality is in the mind of the knower rather than in the object of our knowing. According to this perspective, each of us builds up a personal model of reality, which we can communicate but not entirely share with other people.

According to Winn, [5] the key to the compatibility of VR with constructivism lies in the possibility for students, by the means of interaction and immersion, to learn through first-person, non-symbolic experience. First-person experiences play a central role in our activity in the world and our learning about it. Within first-person experiences, our interaction with the world does not involve conscious reflection or the use of symbols.

Learning process, as suggested by Osberg [11], is about the development of meaning: “meaning about the world, about patterns and relationships, about themselves”. According to this point of view [11], “meaning may be constructed from information outside of the learner, or may be constructed by each individual using information from the environment, and from within”.

VR provides exactly this opportunity of making first-person, non-symbolic experiences: immersive environments allow to construct knowledge from direct experience by giving

the participants the “perceptual illusion of nonmediation” [25] between them and the computer. VR technology provides learners with the possibility to reflect and get a deeper understanding of the process through which a person can reach a knowledge of the world.

In order to better focus this convergence between VR and Constructivism, we point out a few key concepts of constructivist theory and show how these principles and practices of learning and teaching can be found in Virtual Environments [5, 7].

- *Constructionism*: constructivism [26, 27] holds that students learn best when they build their own understanding of content by directly interacting with it, rather than receiving pre-structured content from an external source, such as a teacher or a text. According to Papert et al. [28], the term "constructionism" is used to describe knowledge construction arising from physical interaction with objects in the world. Nicaise and Crane [29] point out how, within constructivist perspective, physical engagement with material is central in the learning process. Students reach an understanding of the material under study through object manipulation and building of physical artifacts. To the extent that “immersion in a virtual world allows the same kind of natural interaction with objects that participants engage in the real world” [5], action in VEs can support this process of knowledge construction. Furthermore, since this process and its output are highly individual and can be only partially shared with other people, the possibility to experience different points of view and frames of reference is very important. Virtual Reality environments provide learners with the possibility to take up multiple perspectives and can thus represent a valuable support to develop awareness of the constructed nature of our own reality.
- *Exploratory learning*: students assimilate knowledge more effectively when they have the freedom to move and engage in self-directed activities within their learning context. Finding and structuring content autonomously, they invest mental effort for the construction of conceptual models that are both consistent with what they already understand and with the new content presented. According to McGuire [23], this active process allows students to reach understanding of the world through an “ongoing process of making sense out of new information- by creating their own version of reality instead of simply receiving the author’s view” (p.257). The effective adaptation of old knowledge to new one leads to understanding and, when the students are in charge of this process of “accomodation”, success is also intrinsically motivating. Simulation of the real world provided by VR offer students the opportunity to learn while they are situated in the context where what they learn is to be applied; this results in more meaningful and effective learning, as compared with learning out of context [30, 31].
- *Collaboration*: as noted by Roussos et al. [7], “one of the most important purposes of an education environment is to promote the social interaction among children located in the same physical space” (p.251). Vygotsky underlined the central importance of social interaction in cognitive growth [32] and suggested that efficacy of collaborative learning is to be considered in a broader framework, where the final creation of a learning product is but one element. Constructivists emphasize the importance of providing opportunities for learning where students are involved to work in groups and reach a consensus about meaning [33]. Within distributed multi-user environments, there is the possibility for a group of students to interact and take part into the learning activity at the same time. This is possible through the use of *avatars*, representing users geographically separated but simultaneously present in the virtual environment; through activities such as verbal interaction, collective decision making, conflict

resolutions, peer teaching, understanding is reached through negotiation and consensus-building.

12.2.3 Potential benefits from the use of Learning Virtual Environments

The possibilities provided by the use Virtual Environments, such as 3D immersion, multiple perspectives and multisensory cues [10] offer a number of potential benefits to education and training [8, 34]:

- *Experiential and active learning.* VR provides experience with new technologies through actual use: learning in VEs requires interaction, thus encouraging active participation rather than passivity.
- *Visualization and reification.* VEs can be an alternate method for presentation of material, new forms and methods of visualization. Its use can be very important in domains where information visualization is needed, such as manipulating and rearranging information using graphic symbols; it is useful also when it is needed to make perceptible the imperceptible (for example, using and moving solid shapes to illustrate clashes of ideas in group processes).
- *Learning in contexts impossible or difficult to experience in real life.* Virtual reality allows observation and examination of areas and events unavailable (such as underwater, historical scenes, reconstructions of archaeological sites) or impossible (for example, exploring Mars, traveling inside human body, moving among molecules) by other means. Furthermore, it allows extreme closeup examination of an object, as well as observation from a great distance. VEs can also be a good solution when teaching or training using the real thing is dangerous, (for example, there is risk of injury to learner, bystanders, and/or instructor is possible), or for logistic reasons (for example, training about a process during working hours: travel, cost, and/or logistics of gathering a class for training make an alternative attractive). VR can furthermore provide effective training in situations requiring the use of equipment prohibitively expensive or impossible to obtain otherwise. Another potential of learning in Virtual Environments is that it allows the disabled to participate in an experiment or learning environment when they cannot do so otherwise.
- *Motivation enhancement.* Interacting with a VR model can be as motivating or more motivating than interacting with the real thing, for example, using a game format. It can be a good solution to make learning more interesting and fun, for example, when working with boring material or with students who have attention problems.
- *Collaboration fostering.* Shared VR can encourage collaboration and foster the learning of skills that can be better developed through shared experiences of a group in a common environment. It is most useful when the experience of creating a simulated environment, or model is important to the learning objective.
- *Adaptability.* VR learning offers the possibility to be tailored to learner's characteristics and needs (different students are characterized by different learning rates and styles). Learners are allowed to proceed through an experience at their own pace, and during a broad time period not fixed by a regular class schedule. Furthermore, well-designed Virtual Environments can flexibly present students a

broader, deeper set of experiences than those that can be found in the "standard" educational environment.

- *Evaluation and assessment.* VR itself offer a great potential as a tool for evaluation, since every session in the virtual environment can be easily monitored and recorded by teachers, thus facilitating assessment tasks.

12.3 From technological components to educational features: towards a model for design and implementation of educational VEs.

How to develop an effective educational virtual environment? What properties and features should it have in order to enhance the learning experience and to provide a real added-value as compared to traditional classroom? Answers to these question are essential to provide designers and educators with useful guidelines to drive their practice.

Dillon [35] underlines how “theoretical insights into learning are crucial to improve our designs and understanding how we can advance education... [since]... there can never be a purely empirical approach to design” (p.100). Nevertheless, it seems that current theories could not yet provide a reliable basis upon which build up practice, whether design, assessment or teaching. This essentially because they were more concerned with offering broad conceptual frameworks of learning than with explaining the findings of learning outcome with various media, thus failing to provide concrete guidelines that could inform practice.

On the other hand, too little research was carried out up to now and there is no common framework for effective integration of their results. As Salzman underlined [10], “unfortunately, although researchers have many ideas concerning how VR might facilitate the understanding of complex concepts, the field has little information concerning which of virtual reality’s features provide the most leverage for enhancing understanding or how to customize those affordances for different learning environments” (p.294). The investigation of a more complex web of relationship than the one between VR features and learning outcome is especially required when the focus shifts from the training of specific abilities and contents to teaching more abstract contents and higher-level skills.

Designing and delivering VR learning requires thoughtful analysis and investigation on how to use the VR’s potential in concert with instructional design principles. Facilitation of the design of meaningful learning environments and relevant learning opportunities can be achieved by gaining an understanding of the (real) capabilities of VR components and features. (and how they relate to learning efficacy) and by carefully examining crucial issues.

What is clear is that VEs are not effective or ineffective by themselves. The point is no more to establish whether VR is useful or not for education; the focus is instead on understanding how to design and use VR to support learning process. Many research questions are of great importance for the development of VEs for education and training; among these are the following:

- What kind of learning contents can be better conveyed through the use of VR environments?
- What kind of skills can be enhanced through VEs (cooperation and negotiation)?
- How to do this? What are the technical requirements (Head-Mounted Display or not, etc.)?
- How does cognition-transfer from VEs to real-life contexts vary with learner’s characteristics such as age, experience and gender?

- How can VR offer specific (and competitively effective) solutions in different areas and for different people (e.g. the disabled)?

Before we can build effective Virtual Environments (VEs) for education and training, we must understand the nature of this technology. Following Fitzgerald and Riva [14], VR can be presented in at least five ways:

- 1) *“Desktop VR.* Uses subjective immersion. The feeling of immersion can be improved through stereoscopic vision. Interaction with the interface can be made via mouse, joystick or typical VR peripherals such as Dataglove.
- 2) *Fully Immersive VR.* With this type of solution the user appears to be fully inserted in the computer generated environment. This illusion is rendered by providing a head mounted display (HMD) with 3-D viewing and a system of head tracking to guarantee the exact correspondence and co-ordination of user’s movements with the feed-backs of the environment.
- 3) *CAVE.* A Cave is a small room where a computer generated world is projected on the walls. The projection is made on both front and side walls. This solution is particularly suitable for collective VR experience because it allows different people to share the same experience at the same time.
- 4) *Telepresence.* Users can influence and operate in a world that is real but in a different location. The users can observe the current situation with remote cameras and achieve actions via robotic and electronic arms.
- 5) *Augmented.* The user’s view of the world is supplemented with virtual objects, usually to provide information about the real environment. In military applications, for instance, vision performance is enhanced by providing the pictograms that anticipate the presence of other entities out of sight.” (p.329)

We can see that VR systems differ a lot according to many technological components, such as hardware and software configurations (obviously with different costs and usability issues), interaction modes, the use of the Internet, support of single/multi-user interaction, multimedia components embedded in the 3D worlds. These components influence many VR features such as the levels of immersion, graphic fidelity and interactivity, multisensory cues, possibility of collaboration, number and complexity of tasks supported.

How well these feature are conducive to learning and instruction depends a lot on the quality and sophistication of the VE design. In fact, features of a learning environment do not act in isolation. Elements such as the concepts to be learned, individual characteristics, the learning experience and the interaction experience all play a role in shaping the learning process and learning outcomes.

A very good example of the efforts in this direction is represented by the work of Salzman and colleagues [10]: according to their model, the link between VR’s affordances and learning occurs within a web of other relationships. The first important factor is surely the *concept* the student/user is trying to understand.

Different VR features are appropriate for different concepts. In other words, the relative effectiveness of VR features such as immersiveness or multisensory representations may depend on the concept being learned.

Moreover, *learner characteristics* (e.g., domain knowledge), play an important role in shaping the learning process and may also interact with VR’s features in influencing the student/user experience. A number of important learner characteristics have been identified: age, gender, domain experience, spatial ability, computer experience, motion sickness history, and immersive tendencies. As Gabbard [21] points out, “instructional designers must take into account the range of kinds and types of [...] users when

the learning environment. Instructional professionals must also be aware that not all students will be able to make effective use [...] in the learning environment” (p.107).

Evaluations to date also suggest that the *interaction experience* is affected by VR features: Designing effective and ergonomic strategies for navigation, object selection and manipulation, as well as trying to minimize sickness is a central task for designers. As far as “simulator sickness” [36] is concerned, some users have experienced side effects (such as ocular problems, disorientation and balance disturbances, and nausea) during exposure to VR environments [37]. Although the latest VR tools have fewer or no side effects [38, 39], further research is needed to confirm these results.

Another important factor in this complex framework was pointed out by Owston [40] and concerns *teaching style*. In his study about two online programs’ efficacy, he underlined how teacher-related dimension play a key role in determining success or failure of a program. “These factors were (1) the teachers’ perceptions of the value of the program for students and (2) the congruence between the pedagogy implicit in the program and the teachers’ own practices” (p.81).

12.4 VR learning applications

In recent years, a number of virtual reality platforms were designed and implemented to support education and training in different learning domains.

Identifying the situations where learning in VEs can represent a real added value to traditional education and understanding how to use and adapt virtual reality to support the learning of different concepts and skills has represented (and actually still represents) a challenge involving educators and developers at the same time.

12.4.1 VR in training

As Stansfield [41] underlines, the use of VR-based trainers for structured task training is being explored in many application areas. In addition to the long-standing use of partial trainers for training vehicle operation (aircraft, tanks, helicopters, and the like) within both the military and civilian sectors, researchers have begun to explore VR as a means to train other, fairly structured, tasks. Tate et al. [42] explored VR-based training of shipboard fire-fighting. Johnson et al. [43] developed a VR system for training equipment operation, with an emphasis on incorporating intelligent agents for tutoring and feedback.

Training concerning more complex processes were explored by Loftin and Kenney [44], who developed an immersive VR system to train the flight team on the procedure for repairing the Hubble Space Telescope, and by Stansfield [45], who describes a VR system for training teams in the disassembly of a subcomponent of a nuclear weapon.

Most of these systems, while providing an experiential learning environment, are still focused primarily on the training of the specific steps that are involved in accomplishing a fairly structured procedure.

Two areas that received relevant interest in these years are the military and the medical, as far as individual training, distributed system and model simulators are concerned.

12.4.1.1 Military training

The military has long used simulation-based experiential training systems to augment live exercises: a number of applications in this field concern the design and implementation of flight simulators, distributed battlefield environments and simulation-based acquisition models.

Within the training systems focusing on critical decision-making in unpredictable environments, we can cite the SIMNET/DIS, an architecture [46] for training and rehearsing battlefield operations, which has been in use now for many years. Closely related systems, such as the High-Level Architecture [47] and NPSNET [48], continue the research into large scale, distributed mission training systems for warfighting.

12.4.1.2 Medical training

Satava and Jones [49] presented a possible categorization of virtual environments in (medical) education and training based upon application and distinguished individual training, medical crisis training, and medical virtual prototyping.

According to the authors, individual training systems represent at the moment the majority of Vr medical applications. These task-specific individual medical trainers, which are also referred to as “partial trainers”, seek to train a single (or a limited) set of skills within a simulation that is highly realistic and anatomically correct. Kaufman and Bell [50] discuss the potential of VR-based partial trainers for teaching and assessing task-specific clinical skills. It is a promising area, which is being addressed by researchers working in a number of different clinical areas. Common to all such partial trainers is their focus on a specific task and anatomical region: VR-based training system for debridement of a gunshot wound to a leg [51], simulator for temporal bone dissection [52], virtual endoscopy simulator [53, 54], trainer for arthroscopic knee surgery [55], simulation for training palpation of subsurface breast tumors [56].

Medical crisis training systems focus on complex training tasks in which the individual must act directly and manually on the environment and in which the responses to an action may be very subtle (such as a change in skin colour). Doing so requires the design and implementation of several interaction and simulation methodologies, from distributed-system support for high-fidelity simulations to the development of clinically realistic virtual patients and, perhaps most importantly, to the creation of techniques that permit a user to act naturalistically upon the virtual environment. Stansfield and colleagues [6] developed BioSimMER, a fully immersive distributed virtual reality platform developed to train medical emergency-response personnel. Small and his team [57] presented an emergency medical trainer similar a flight simulator: a customizable mannequin with realistic anatomical features represents the patient, whom users act upon using physical instruments that interface the mannequin to a computer control system that drives the appropriate clinical state and response. Such systems, although highly sophisticated, can be expensive and limited in their programmability. Other researchers [41, 58, 59] developed the entire training scenario via software, with dynamic virtual patients presenting changing physical condition and responding to the clinician/trainee, who interacts with the system via a series of menus.

12.4.2 VR in education

12.4.2.1 Virtual Environments for Science

The use of VR as a means to teach abstract physics concepts was investigated by researchers at George Mason University and the University of Houston [60] who developed “NewtonWorld” and “MaxwellWorld”. These systems provide immersive learning environment in which students may explore the kinematics and dynamics of motion, electrostatic forces, and other physical concepts. VEs’ potential to help students develop correct mental models of the abstract material is identified in three key features: multisensory cues, multiple frames of reference and multimodal interaction.

Researchers at the Computer Museum [61] developed an immersive VR application designed to teach children about biology concepts, in particular the structure and function

of cells. In the application, users were asked to construct cells from component parts, with successful completion indicated by an animation of internal cell function.

NICE (“Narrative-based, Immersive, Constructionist/Collaborative Environments”) project [7] was the first immersive, multiuser learning environment designed specifically for children. Started in 1996, it was designed to support children’s learning of simple relationships between plant growth, sunlight and water. NICE implements a persistent virtual garden in which children may collaboratively plant and harvest fruits and vegetables, cull weeds, and position light and water sources to differentially affect the growth rate of plants.

An exhibit-based research project, the Virtual Gorilla Project [62] was aimed at teaching middle-school students about gorilla behaviors, vocalizations, and social interaction. The study re-created the gorilla exhibit at Zoo Atlanta, allowing users to adopt the role of an adolescent gorilla, navigating the environment and observing other gorilla’s reactions to their approach.

12.4.2.2 Virtual environments for design

A further application developed from the Atlanta Virtual Zoo was designed in order to teach college students about habitat design. The learning goal in this case thus shifted to fostering students’ understanding of the philosophy of environmental design and of the specific design decisions made for the exhibit.

The Human Interface Technology Laboratory (HITL) at the University of Washington has been one of the early educational seedbeds for VR, with projects such as the Virtual Reality Roving Vehicle (VRRV) [5, 63] and summer camp programs in VR for students [64]. The VRRV was experienced by a large number of students, while the summer camp focused on “world-building” activity, in which students conceived and created the objects of their own virtual worlds, using a 3-D modeling software on desktop computers. This gave the opportunity for students to understand the process involved in creating a virtual setting.

12.4.2.3 Augmented reality and educational toys

As far as augmented and mixed reality systems are concerned, we can cite “EQUATOR-Technical innovation in physical and digital life” [65], a EPSRC Funded Research Project running for 6 years as an interdisciplinary collaboration between 8 academic institutions in UK. Its central goal is to promote the integration of physical and digital worlds by uncovering and supporting the development of Mixed Reality Environments (MREs). They affect different aspects of people’s everyday life, such as education, leisure, home, work, community etc. For what concerns educational technologies the University of Sussex, Bristol and Nottingham are exploring and extending current forms of playful interaction by developing a combination of digital toys and collaborative playgrounds for young children.

Researchers’ interest is also focused on evaluating, from a psychological point of view, the potential of MREs for learning and education at different levels: how easily children can discover new relationships between actions and effects in MR spaces, what kind of concepts and causal links they might develop and use to produce creative behaviours, how MREs provide external support to the experiences of traversing viewpoints and spaces so as to improve children’s decentering/authoring abilities and socio-cognitive development.

12.4.2.4 Virtual Environments for Second-Language Learning

Researchers at the HITL (Human Interface Technology Laboratory) of the University of Washington, have designed and developed “Zengo Sayu”, an immersive educational environment for Japanese Language Instruction [66]. It is an immersive, interactive VE designed to teach Japanese prepositions to students with no prior knowledge of the

language. The immersive aspects of this virtual environment are aimed at helping students to develop an understanding of Japanese through natural, physical interaction. This should strengthen both linguistic acquisition and recall abilities, while reducing the need for translation into their first language. The prototype application uses full immersion with a head-mounted display, digitized voice samples for natural speech reproduction, voice recognition and body tracking technology to allow the user to interact and affect the world.

12.4.2.5 VR in ethical education

Another interesting application domain was suggested by Ruggeroni [67]. The purpose of his study was to investigate the possibility to support the activity of ethical education by the means of VR softwares, assessing whether the use of a life-simulation game could enhance understanding and learning the ethical principles found in everyday life.

In “The Sims”, a people simulator, users can interact with characters and environments and are involved in a non-immersive 3D scenario to experience and act on ethical dilemmas, observing potential consequences and take part in the decision making to solve concrete situations where ethical dilemmas need a response.

12.4.2.6 Special-Needs Education

As noted before, VR can be very useful in Special-Needs Education [68, 69]: students with Special Educational Needs (SEN) can experience problems in dealing with abstracts and often learn directly through experience with the real world. On the other hand, the ability to learn directly from experience depends on the range and complexity of the experiences that are offered. In an educational environment, these experiences may be restricted due to the limited number of real-world artifacts that can be provided in a classroom setting, and there are certain logistical problems in regularly taking a group of SEN students out of school in search of richer environments. The LIVE project, from the Sheperd School in Nottingham, UK, developed twenty VEs in three application areas: experiential environments in which students can practice everyday life skills; communication environments in which students are encouraged to develop their speech, signing and symbols skills; personal and social education environments, in which students can investigate appropriate behavior in public situation.

Obviously, such experiences are not intended to replace their real-world counterparts, but they “could be used to prepare the students for them by filling in educational “experience gaps” that are caused by factors such as overprotective parenting, mobility problems and cognitive deficits” [69] (p.265).

12.5 Transforming the potential of Virtual Reality into Real Educational Efficacy: insights and guidelines

12.5.1 Evaluation and assessment

Evaluation is undoubtedly a crucial issue for future integration of VEs in educational and training contexts.

Given both the intrinsic multidimensionality of learning and the novelty and dynamic nature of VR learning tools, the evaluation of VR learning efficacy requires “a sound conceptual framework that would encompass, rather than restrict, the multiple dimensions of the issues that need to be examined in a virtual learning environment” [7] (p.254).

What is required is a shift of focus from learning outcomes to learning process; Windschitl [70] very clearly pointed out the limits of “black-box-type” classroom research, where “inputs are operationally defined (e.g., learner characteristics or instructional

interventions), learning experiences occur (unexamined), then the outputs are measured (e.g., objective achievement tests, posthoc interviews)” (p.90). Shifting the attention to the dynamics of the learning experience provides evaluators with precious information for the comprehension of “*why* rather than simply *if* certain learning contexts are more robust than others” (p.90). Of course, such a perspective requires researchers to assume as object of their analysis a much more complex web of relationships, involving people and not just variables.

In order to capture this complexity, it is important to apply multiple measures of learning and performance [63]. Measuring different aspects of learning and interaction experiences may help explaining outcomes beyond what VR’s affordances explain, and help understand the strenghts and weaknesses of VR’s capabilities in shaping the learning process and learning outcomes. As suggested by a number of authors [7, 71] different technical, orientational, affective, cognitive, pedagogical issues should be included.

- The *technical aspect* examines usability issues, regarding interface, physical problems, and system hardware and software.
- The *orientation aspect* focuses on the relationship of the user to the virtual environment; it includes navigation, spatial orientation, presence and immersion, and feedback issues.
- The *affective parameter* evaluates the user’s engagement, likes and dislikes, and confidence in the virtual environment.
- The *cognitive aspect* identifies any improvement of the subject’s internal concepts through this learning experience.
- Finally, the *pedagogical aspect* concerns the teaching approach: how to gain knowledge effectively about the environment and the concepts that are being taught.

As far as the methodological approach is concerned, integration of quantitative and qualitative methodologies seems the best way to face and to catch this complexity. Riva and Galimberti [72], in this book, presented a complex model of data analysis for Internet research called CEMDA (Complementary Exploratory Multilevel Data Analysis) and supported the value of the mixed use of quantitative and qualitative tools: different techniques can highlighten different and complementary features of the VR experience, and they are thus suitable to different levels of analysis. As Windschitl [70] suggests, “research methods act as lenses to reveal or obscure, and [...] drawing upon a variety of methods can help clarify phenomena that are not interpretable using a single paradigm” (p.90).

A last issue to be addressed concerns standardization of assessment techniques in order to allow researchers in the area to confront themselves on crucial themes. To this aim, a valuable approach could be the one proposed by Kozma and Quellmalz [73] for Web-Based Instruction, consisting in clustering network-based projects with generally similar goals for evaluation. This would allow evaluators to make use of common instruments and data collection procedures, and aggregate the projects for most analyses and interpretations. “Cluster evaluation” could not only represent a cost-effective method of evaluating several projects simultaneously, but also a way to promote sharing of information among the projects’ stakeholders to improve performance and effectiveness. Furthermore, this apporach is likely to foster the development of communities of practice “that can share effective project strategies and lessons learned” [73].

12.5.2 Tuning the learning environments

Experience gained in past projects makes it possible to propose some general reflections useful to design and implementation of VEs in educational contexts. Analysis of these issues, in fact, is important for designers and educators in order to manage VR potential and transform it into an effective learning tool.

First of all, as Roussos [7] suggests, in VEs' design for education, "the *balance among reality, abstraction and engagement* is particularly difficult to achieve" (p.260) and this often requires a trade-off among these elements. Especially when designing for young children, it is important to carefully define the level of abstraction. When teaching science concepts, for example, great attention should be paid to the adequacy of the underlying model; the introduction of familiar and simplified elements for children to enhance engagement and fun (such as, in the NICE project [7], umbrellas or sunglasses on the plants to signal the wet/dry status) can, at the same time, risk to engender misconceptions and reductive bias about the concepts taught.

The focus of the teachers should be to support complementary discussion and instruction in order to contextualize the use of VEs; this to help students to understand general principles underlying the virtual experience and creating relationships between the VE and their previous knowledge background.

On the other hand, Draper and colleagues [74] remind us that despite the ability of a VE to develop a rich computer-mediated world, designers have a great responsibility in tailoring interfaces to meet the task-dependent needs of the user. The possibility for rich and immersive interfaces to display much more information and in a more compelling way as compared to non-immersive technology introduce a question about *whether* this is always useful. In fact, we should not forget that, "in some cases, simple map reading ...[can be]... more effective in imparting knowledge about an environment than experience in a virtual representation of that environment" [74].

A second issue to be considered [7, 75] concerns the *open-ended exploratory nature* of many educational environments; the basic assumption that the learning process will take place naturally through the simple exploration and discovery of the Virtual Environment should be reviewed. Despite the undoubtful value of the exploratory learning provided by VR, when the knowledge context is too unstructured, learning process can become very difficult. This is especially true for younger students [21]. Experience by itself is not enough: as constructivism underlines, learning takes place when students can build conceptual models that are both consistent with what they already understand and with the new content. As suggested by Bowman et al. [75] "it seems that experience can take a student only part of the way to learning and understanding a subject. In most cases, it is necessary to have background knowledge, peripheral information, reflection, and experience before the subject can be comprehended by the student" (p.317). In order to ensure successful adaptation of old knowledge to new experience, flexible learning direction should be provided; this can be done in two ways: a) through the integration of other types of information and educational supports other than the 3D representation (such as audio and text annotations, images etc.) and/or b) in carefully defining specific tasks to the users/students through interaction with the teacher.

A last concern is about *collaboration* in distributed educational environments: as noted above, VR can encourage collaboration and foster the acquisition of skills developed through shared experiences of a group in a shared environment. Networked, web-shared Virtual Environments, where more users can experience a common learning context, represent one of the most promising applications of VR. These systems have all the potential to enhance VR efficacy by meeting the main constructivist principles of both

experiential learning (“learning by doing”) and collaborative learning (learning by sharing and negotiating knowledge).

Nevertheless, as Roussos [7] points out, this can prove a double-edged sword. The presence of avatars representing remote users is a strong boost to social interaction, sometimes at the expense of the intended concept learning. As distributed VEs support collaboration through the provision of a shared virtual space, it is necessary to make efforts to structure cooperative learning [76, 77] in a way that fosters positive interdependence among learners, or supports reflection and planning. Social interaction is intended as a mechanism to support learning and thus should not become an end by itself.

12.6 Conclusions

Technological advances have made it available to the educational and training world a wide set of innovative learning tools. Among these, Virtual Reality seems to have a great potential to enhance the learning process [8, 10].

First of all, VEs can provide modes of *experiential learning*; to the extent that VR provides *high-level interaction* with the learning content, it can foster *active engagement* by students. This contributes to raise *motivation* and interest, conditions which are recognized as crucial in the learning process. VR learning also allows entirely new capabilities and experiences, that would be too difficult, too costly or simply impossible to have in the real world. Finally, VR environments can be tailored to individual learning and performance style. They are highly *flexible* and programmable, thus enabling the teacher or the trainer to present a wide variety of controlled stimuli and to measure and monitor a wide variety of responses made by the user.

Current educational theories such as constructivism seem to present convergence and be consistent with learning in VEs, and this surely represents a further strength for the use of this technology in education and training [5].

Nevertheless, the potential of each VR feature needs careful reflection in order to be actually translated into educational efficacy. The matter is not establishing whether VR is useful or not to enhance learning, but understanding how to effectively exploit its potential.

In order to design effective learning environments, a model is needed to integrate the theoretical insights about VR educational potential and the principles of design and development; such a model could be useful to generate research questions, stimulate new studies and should be gradually implemented by their results.

When looking at the current use and integration of VR tools in educational and training contexts, we can see how a number of problems limit their actual application and effectiveness. These problems represent challenges for future development of learning VEs and encompass various VR-based learning issues, including: pedagogical, technological, institutional, cultural, economical, management, interface design.

- *Costs*: At the moment, cost surely represents one important limit to VR penetration into educational context. Although some attempts have been made to use PC-based VR systems (and current efforts in this direction are encouraging), most of the existing VEs are based on VR systems such as CAVEs or high-end platforms (such as Onyx Silicon Graphics) whose cost is beyond the reach of the average school, university, not to talk about single students.
- *Lack of reference standards*: almost all applications in this sector can be considered “one-off” creations tied to a proprietary hardware and software, which have been tuned by a process of trial and error. This makes them difficult to use in contexts other than

those in which they were developed. Furthermore, this lack of reference standards does not only concern technological aspects but extends to the lack of common reference framework in design, implementation, evaluation and assessment.

- *Educational culture*: 3-D graphics technology is not intended to entirely replace conventional classroom teaching techniques; nevertheless, as Dean and colleagues [78] point out, “properly implemented virtual environments can serve as valuable supplemental teaching and learning resources to augment and reinforce traditional methods” (p.505). Anyway, good design and implementation are surely not enough to ensure effective results: the learning potential of the actual VR experience must be constantly integrated and managed by the teachers within the actual educational context. Teachers themselves must develop specific expertise and sufficient practical experience of VR learning in order to effectively support learning process in 3D environments.
- *Safety*: some users have experienced certain side effects during and after exposure to immersive VR environments [37], collectively referred to as “simulator sickness” [79]: ocular problems (e.g. eyestrain, blurred vision, and fatigue), disorientation and balance disturbances, and nausea. Though the latest VR tools seem to have minor or no side effects, future researchers have to confirm these results.
- *Usability*: another crucial issue for integrating VR into classrooms is system *usability* - by students of various ages, by teachers, and by curriculum developers. This is surely not an easy task, seen the multidimensional nature of learning process and the complexity and novelty of VR technology. Interface experts stress the value of involving end-users in the development of computer technology during the design phase. There is a need for collaborative and iterative design of these environments, that should involve, repeatedly at different stages of the project, designers, teachers, and end-users.

Professionals in this field must be aware of the crucial importance of *research and co-development*: by sharing information about their experience as they continue to explore, observe, evaluate and refine VR, they can expedite suitable developmental work in this field and increase professional and public understanding of the technology.

Further research is required, both on technological side and on VR issues such as transfer of learning, appropriate curriculum implementation, elements of effective VR design, and the psychological and social impact of the technology use.

12.7 Acknowledgments

I thank Giuseppe Riva, Andrea Gaggioli and Gianluca Castelnuovo for their help and support, as well as for their useful comments on earlier versions of this chapter.

The present work was supported by the Commission of the European Communities (CEC), in particular by the IST programme (Project VEPSY UPDATED, IST-2000-25323 – <http://www.psicologia.net>; <http://www.vepsy.com>).

12.8 References

- [1] W. James, *Talks to Teachers*. New York: W.W. Norton, 1958. (originally published, 1892).
- [2] National Research Council, *How people learn: Building research and practice*. Washington, D.C.: National Academy Press, 1999.
- [3] J. E. Newhagen, Why communication researchers should study the Internet: A dialogue, *Journal of Communication* 46 (1996) 4-13.
- [4] C. J. Bonk, N. Hara, V. Dennen, S. Malikowsky, and L. Supplee, We're in TITLE to Dream: Envisioning a Community of Practice, The Interplanetary Teacher Learning Exchange, *CyberPsychology & Behavior* 3 (2000) 25-39.
- [5] W. Winn, A Conceptual Basis for Educational Applications of Virtual Reality, *Technical Report TR 93-9*: <http://www.hitl.washington.edu/publications/r-93-9/> (1993).
- [6] S. Stansfield, D. Shawver, A. Sobel, M. Prasad, and L. Tapia, Design and Implementation of a Virtual Reality System and Its Application to Training Medical First Responders, *Presence* 9 (2000) 524-556.
- [7] M. Roussos, A. Johnson, T. Moher, J. Leigh, C. Vasilakis, and C. Barnes, Learning and Building Together in a Immersive Virtual World, *Presence* 8 (1999) 247-263.
- [8] V. S. Pantelidis, Reasons to Use Virtual Reality in Education, *VR in the Schools*: <http://www.soe.ecu.edu/vr/reas.html> 1 (1995 (Revised 2000)).
- [9] J. Bruner, *Towards a theory of instruction*. New York: WW Norton, 1966.
- [10] M. C. Salzman, C. Dede, R. B. Loftin, and J. Chen, A Model for Understanding How Virtual Reality Aids Complex Conceptual Learning, *Presence* 8 (1999) 293-316.
- [11] K. M. Osberg, Virtual Reality and Education: A Look at Both Sides of the Sword, <http://www.hitl.washington.edu/publications/r-93-7/> (1992).
- [12] R. C. Schank, The Virtual University, *CyberPsychology & Behavior* 3 (2000) 9-16.
- [13] T. Gaddis, *Virtual reality in the school*. *Virtual reality and Education laboratory*: East Carolina University, 1998.
- [14] M. Fitzgerald and G. Riva, Virtual Reality, in *Telemedicine Glossary*, L. Beolchi, Ed.: European Commission-DG INFSO, 2001, pp. 327-329.
- [15] M. Heim, *Virtual Realism*. New York: Oxford University Press, 1998.
- [16] G. Riva and G. Mantovani, The Need for a Socio-Cultural Perspective in the Implementation of Virtual Environments, *Virtual Reality* 5 (2000) 32-38.
- [17] J. S. Steuer, Defining virtual reality: dimensions determining telepresence, *Journal of Communication* 42 (1992) 73-93.
- [18] M. Slater, Measuring presence: a response to the Witmer and Singer Presence Questionnaire, *Presence* 8 (1999) 560-565.
- [19] P. Cronin, Report on the application of virtual reality technology to education, University of Edinburgh 1997.
- [20] L. Sastry and D.R.S. Boyd, Virtual environments for engineering applications, *Virtual Reality* 3 (1998) 235-244.
- [21] R. B. Gabbard, Constructivism, Hypermedia, and the World Wide Web, *CyberPsychology & Behavior* 3 (2000) 103-110.
- [22] G. Scheurman, From behaviorist to constructivist teaching, *Social Education* 62 (1998) 6-9.
- [23] E. G. McGuire, Knowledge representation and construction in hypermedia and environments, *Telematics and Informatics* 13 (1996) 251-160.
- [24] D. H. Jonassen, Objectivism vs. constructivism: Do we need a new paradigm?, *Educational Technology: Research and Development* 39 (1991) 5-14.
- [25] M. Lombard and T. Ditton, At the heart of it all: the concept of presence, *Journal of Computer Mediated Communication* 3 (1997).
- [26] J. Dewey, *Democracy and Education*. New York: Free Press, 1966.
- [27] S. Papert, *Mindstorms: Children, Computers and Powerful Ideas*. New York: Basic Books, Inc., 1980.
- [28] S. Papert, Situating Constructionism, in *Constructionism*, I. Harel and S. Papert, Eds. Norwood, NJ: Ablex, 1991.
- [29] M. Nicaise and M. Crane, Knowledge constructing through hypermedia authoring, *Educational Technology, Research and Development* 47 (1999) 29-50.
- [30] J. S. Brown, A. Collins, and P. Duguid, Situated cognition and the culture of learning, *Educational Researcher* 18 (1989) 32-43.
- [31] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press, 1991.
- [32] L. Vygotsky, *Mind in society*. Cambridge, MA: Harvard University Press, 1978.
- [33] H. McMahon and W. O'Neill, Computer-mediated zones of engagement in learning, in *Designing environments for constructive learning*, T. Duffy, J. Lowyck, and D. Jonassen, Eds. New York: Springer, 1993.

- [34] V. S. Pantelidis, Suggestions on When to Use and When Not to Use Virtual Reality in Education, *VR in the Schools 2* (1996 (Revised 2000)).
- [35] A. Dillon, Designing a better learning environment with the Web: Problems and prospects, *CyberPsychology & Behavior 3* (2000) 97-101.
- [36] R. S. Kennedy and K. M. Stanney, Postural instability induced by virtual reality exposure: Development of a certification protocol, *International Journal of Human Computer Interaction 8* (1996) 25-47.
- [37] J. R. Lackner, Multimodal and motor influences on orientation: implications for adapting to weightless and virtual environments, *J Vestib Res 2* (1992) 307-322.
- [38] G. Riva, *Virtual Reality in neuro-psycho-physiology: Cognitive, clinical and methodological issues in assessment and rehabilitation*. Amsterdam: IOS Press, 1997.
- [39] G. Riva, B. K. Wiederhold, and E. Molinari, *Virtual Environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist interaction*. Amsterdam: IOS Press, 1998.
- [40] R. D. Owston, Evaluating Web-Based Learning Environments: Strategies and Insights, *CyberPsychology & Behavior 3* (2000) 79-87.
- [41] S. Stansfield, D. Shawver, and A. Sobel, MediSim: A prototype VR system for training medical first responders, presented at Virtual Reality Annual International Symposium, 1998.
- [42] D. Tate, L. Silbert, and T. King, Virtual environments for shipboard firefighting training, presented at IEEE Virtual Reality Annual International Symposium, 1997.
- [43] W. Johnson, J. Rickel, R. Stiles, and A. Munro, Integrating pedagogical agents into virtual environments, *Presence 7* (1998) 523-548.
- [44] R. Loftin and P. Kenney, Training the Hubble Space Telescope Flight Team, *IEEE Computer Graphics and Applications 15* (1995) 31-37.
- [45] S. Stansfield, Applications of virtual reality to nuclear safeguards, presented at Joint ESARDA/INMM Workshop on Science and Modern Technology for Safeguards, 1998.
- [46] J. Calvin, A. Dickens, R. Gaines, P. Metzger, D. Miller, and D. Owen, The SIMNET virtual world architecture, presented at IEEE Virtual Reality Annual International Symposium, 1993.
- [47] J. Dahmann, J. Calvin, and R. Weatherby, A reusable architecture for simulations, *Communications of the ACM 42* (1999) 79-84.
- [48] M. Macedonia, M. Zyda, D. Pratt, P. Barham, and P. Zeswitz, NPSNET: A network software architecture for large-scale virtual environments, *Presence 3* (1994) 265-287.
- [49] R. Satava and S. Jones, Virtual environments for medical training and education, *Presence 6* (1997) 139-146.
- [50] D. Kaufman and W. Bell, Teaching and assessing clinical skills using virtual reality, *Medicine Meets Virtual Reality/Studies in Health Technology and Informatics 39* (1997) 467-472.
- [51] S. Delp, P. Loan, C. Basdogan, and J. Rosen, Surgical simulation: An emerging technology for training in emergency medicine, *Presence 6* (1997) 147-159.
- [52] R. Koppersmith, R. Johnston, D. Moreau, R. Loftin, and H. Jenkins, Building a virtual reality temporal bone dissection simulator, *Medicine Meets Virtual Reality/Studies in Health Technology and Informatics 39* (1997) 180-186.
- [53] R. Robb, Virtual endoscopy: Evaluation using the visible human datasets and comparison with real endoscopy in patients, *Medicine Meets Virtual Reality/Studies in Health Technology and Informatics 39* (1997) 195-206.
- [54] G. Wiet, R. Yagel, D. Stredney, P. Schmalbrock, D. Sessanna, Y. Kurzion, L. Rosenberg, M. Levin, and K. Martin, A volumetric approach to virtual simulation of functional endoscopic sinus surgery, *Medicine Meets Virtual Reality/Studies in Health Technology and Informatics 39* (1997).
- [55] S. Gibson, J. Samosky, A. Mor, C. Fyock, E. Grimson, T. Kanade, R. Kikinis, H. Lauer, N. McKenzie, S. Nakajima, H. Ohkami, R. Osborne, and A. Sawada, Simulating arthroscopic knee surgery using volumetric object representations, real-time volume rendering and haptic feedback (Technical Report TR96-19), (1996).
- [56] M. Dinsmore, N. Langrana, G. Burdea, and J. Ladeji, Virtual reality training simulation for palpation of surface tumors, presented at IEEE Virtual Reality Annual International Symposium, 1997.
- [57] S. Small, R. Wuerz, R. Simon, N. Shapiro, A. Conn, and G. Setnik, Demonstration of high-fidelity simulation team training for emergency medicine, *Academic Emergency Medicine 6* (1999) 312-323.
- [58] M. Stytz, B. Garcia, G. Godsell-Stytz, and S. Banks, A distributed virtual environments prototype for emergency medical procedures training, *Medicine Meets Virtual Reality/Studies in Health Technology and Informatics 39* (1997) 473-485.
- [59] D. Chi, J. Clarke, B. Webber, and N. Badler, Casualty modeling for real-time medical training, *Presence 5* (1996) 359-366.

- [60] C. Dede, M. C. Salzman, and B. Loftin, ScienceSpace: Virtual realities for learning complex and abstract scientific concepts, presented at IEEE Virtual Reality Annual International Symposium (VRAIS '96), 1996.
- [61] E. Gay and D. Greschler, *Is virtual reality a good teaching tool?*: Boston Computer Museum, 1994.
- [62] D. Allison, B. Wills, D. Bowman, J. Wineman, and L. F. Hodges, The virtual reality gorilla exhibit, *IEEE Computer Graphics and Applications* (1997) 30-38.
- [63] H. Rose, Assessing learning in VR: Towards developing a paradigm virtual reality roving vehicles (VRRV) project. (Technical Report TR-95-1), Human Interface Technology Laboratory-University of Washington 1995.
- [64] M. Bricken and C. Byrne, Summer students in VR: A pilot study, *Virtual Reality: Applications and Explorations* (1993) 178-184.
- [65] M. Scaife and R. Y., Traversing between the digital and the physical: what does it mean?, presented at Abstract of the talk presented at the 1st Equator Workshop, Porto, Portugal, 2001.
- [66] H. Rose and M. Billinghamurst, Zengo Sayu: An Immersive Educational Environment for Learning Japanese, *Technical Report No. TR-95-4*: <http://www.imprintit.com/Publications/HRPubs/TR-95-4/> (1995).
- [67] C. Ruggeroni, , and E. by, Virtual Reality in Ethical Education, in *Communications through Virtual Technologies. Identity, Community and Technology in the Communication Age*, F. Davide and G. Riva, Eds. Amsterdam: IOS Press, 2001, pp. 119-133.
- [68] D. J. Brown, P. J. Standen, and S. V. Cobb, Virtual Environments: Special Needs and Evaluative Methods, in *Virtual Reality in Clinical Medicine*, G. Riva, B. K. Wiederhold, and E. Molinari, Eds. Oxford: IOS Press, 1998, pp. 91-102.
- [69] H. R. Neale, D. J. Brown, S. V. G. Cobb, and J. R. Wilson, Structured Evaluation of Virtual Environments for Special-Needs Education, *Presence* 8 (1999) 264-282.
- [70] M. Windschitl, Using the WWW for teaching and learning in K12 classrooms: What are the interesting research questions?, *CyberPsychology & Behavior* 3 (2000) 89-96.
- [71] C. Lewin, Test driving CARS: Addressing the issues in the evaluation of computer assisted reading software, presented at International Conference on Computers in Education, 1995.
- [72] G. Riva and C. Galimberti, Complementary Explorative Multilevel Data Analysis, in *Towards Cyberpsychology*, G. Riva and C. Galimberti, Eds. Amsterdam: IOS Press, 2001.
- [73] R. B. Kozma and E. Quellmalz, Issues and needs in evaluating the educational impact of the National Information Infrastructure, *Online document*: <http://www.ed.gov/Technology/Futures/kozma.html> (1996).
- [74] J. V. Draper, D. B. Kaber, and J. M. Usher, Speculations on the value of telepresence, *CyberPsychology & Behavior* 2 (1999) 349-362.
- [75] D. A. Bowman, L. F. Hodges, D. Allison, and J. Wineman, The Educational Value of an Information-Rich Virtual Environment, *Presence* 8 (1999) 317-331.
- [76] R. E. Slavin, Cooperative learning, *Review of Educational Research* 50 (1980) 315-342.
- [77] D. W. Johnson and R. T. Johnson, *Cooperative learning*. New Brighton, MN: Interaction Book Co., 1984.
- [78] K. L. Dean, X. S. Asay-Davis, E. M. Finn, T. Foley, J. A. Friesner, Y. Imai, B. J. Naylor, and S. R. Wustner, Virtual Explorer: Interactive Virtual Environment for Education, *Presence* 9 (2000) 505-523.
- [79] R. S. Kennedy, L. J. Hettinger, D. L. Harm, J. M. Ordy, and W. P. Dunlap, Psychophysical scaling of circular vection (CV) produced by optokinetic (OKN) motion: individual differences and effects of practice., *J Vestib Res* 6 (1996) 331-341.

