Learning by Doing and Learning Through Play: An Exploration of Interactivity in Virtual Environments for Children

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The development of interactive, participatory, multisensory environments that combine the physical with the virtual comes as a natural continuation to the computer game industry's constant race for more exciting user experiences. Specialized theme parks and various other leisure and entertainment centers worldwide are embracing the "interactive" promise that games have made users expect. This is not a trend limited to the entertainment domain; non-formal learning environments for children are also following this path, backed up by a theoretical notion of play as a core activity in a child's development. In this article we explore a central thread in learning, play, as well as an essential characteristic of virtual reality environments: interactivity. A critical review of examples of immersive virtual reality worlds created for children, with particular attention given to the role and nature of interactivity, is attempted. Interactivity is examined in relation to learning, play, narrative, and to characteristics inherent in virtual reality, such as immersion, presence, and the creation of illusion.
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1. INTRODUCTION

Virtual reality (VR), the three-dimensional multisensory, immersive, and interactive digital environment, has triggered public imagination as the technology that will dominate the way our work, education, and leisure are delivered in the future. To date, VR installations and applications have been the main concern of the scientific visualization communities, and of certain industrial research and development projects. However, in the past few years, there has been a proliferation of VR installations (in the form of exhibits) and VR applications (in the form of "experiences") available and accessible to the public.

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The entertainment market, traditionally concerned with the creation of spectacles and, more recently, multisensory experiences, was one of the first to embrace current achievements in VR, in order to advance the "art of experience" both through gaming machines and location-based entertainment. Other public settings, such as museums and informal educational institutions, generally hesitant in adopting cutting-edge digital technologies, are now considering various forms of VR to attract and motivate visitors, but also to ultimately deliver their educational agenda more effectively. Recent success stories that exemplify the "edutainment"[1] venue include the Hayden Planetarium's 400-seat all-digital dome system at the American Museum of Natural History in New York,[2] the Glasgow Science Center's immersive Virtual Science Theatre,[3] the VR Theatre in Korea (the largest immersive and interactive theater in the world) [Park et al. 2002], or the cubic immersive (CAVE®-like) displays installed permanently at "unusual" museums such as the Ars Electronica Center in Austria,[4] the ICC in Japan[5] or the Foundation of the Hellenic World in Greece [Gaitatzes et al. 2000]. Although these are high-cost semi- or fully immersive installations with interactive capabilities, it may not be long before appropriated scaled-down versions make their way into the schools and eventually into the home. The most notable example of an immersive system in such an everyday context is described in Johnson et al. [2001], which discusses the issues and reports the results of a project involving the multiyear deployment of an immersive VR display in an elementary school for science education.

Consequently, VR application development has increased its range of practice while advancing the techniques and art of constructing immersive worlds. On the other hand, techniques for developing interactivity, the process with which users act upon and even modify virtual worlds, are relatively unexplored. However, as the plethora of interactive systems of all kinds indicates, our culture, formerly one of immersive ideals is now a culture more concerned with interactivity [Ryan 2000]. Indeed, in every new application directed to the public, from computer games to educational software, interactivity is widely advertised, primarily for its recreational potential but also for its significance for learning. This is even more prominent in the case of virtual reality, since interactivity is largely seen as one of the medium's essential properties.

In this article we explore interactivity as an essential yet complex property of virtual reality environments, in its effects on leisure and learning. Examples of immersive virtual

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1 The term "edutainment" is indicative of a growing competition between the entertainment and informal education worlds in attracting visitors. Although it was coined by the computer industry about ten years ago, the term has also been adopted by the family entertainment industry in an attempt to "add depth" to exhibits that were made for pure recreation, and thus did not enjoy the credibility inherent to museum educational efforts or educational CD-ROMs. However, as museums and science centers become more popular family destinations and compete in the leisure marketplace, the word reflects an interesting convergence.

2 The American Museum of Natural History, Hayden Planetarium, New York, http://www.amnh.org/rose/haydenplanetarium.html [link last visited: June 2003].

3 Glasgow Science Centre, Virtual Science Theatre, http://www.gsc.org.uk/gsc/vst.htm [link last visited: June 2003].

4 The CAVE® at the Ars Electronica Center, Linz, Austria, http://www.aec.at/ [link last visited: June 2003].

5 NTT InterCommunication Center, Tokyo, Japan, http://www.ntticc.or.jp/index_e.html [link last visited: June 2003].

reality worlds for children, with particular attention to the role and nature of interactivity, are discussed. We also make an effort to place interactivity in a broader context, together with an exploration of its relationship to learning through activity and learning through play, but also through storytelling, immersion, realism, and illusion.

2. BUT WHAT EXACTLY IS INTERACTIVITY?

There is certainly an appeal in interactivity, shown by the attention the word has received in the media over the last several years. But despite great interest, there appears to be no consensus on what interactivity actually means and represents, to the point where the word has become confusing. What exactly is interactivity? What is the goal of interactivity? Is there one kind or many different types of interactivity? These questions alone illustrate the complexity and multidimensionality of the concept. *The Oxford English Dictionary* defines interaction as reciprocal action, action or influence of persons or things on each other. To interact is to act reciprocally, to act on each other, to act together or towards others or with others. Reciprocity can take place between people, people and machines, people and software, or even machines and machines. With respect to human–computer environments, interactivity can have many meanings, depending on whether the context is operational, mechanical, or practical (in which case its study involves the HCI and interface design fields), educational, social/communicational, artistic, or recreational.

On an operational level, interactivity has been defined as the function of input required by the user while responding to the computer and the nature of the system's response to the input action [Sims 1997]. Steuer [1992] regards interactivity as the degree to which users of a medium can influence the form or content of the mediated environment. However, this definition does not entail any form of response; a drastic and profound influence on an environment can be to turn it off, which involves no reciprocal action from the environment, and is generally not considered an interactive capability. Talin [1998] is more specific in distinguishing an interactive digital environment (such as a computer game) from a less interactive system (like a VCR), in that the more interactive system adapts to the user's actions and allows varied degrees of freedom (more control over factors like time, space, "plot" etc). In general, and due to the vague use of the term, interactivity is often confused with the ability to merely move a joystick or click on a mouse [Murray 1997].

In the context of public exhibits where emphasis is on a more social and affective perspective, Adams and Moussouri [2002] define the interactive experience as that which can actively involve the visitor physically, intellectually, emotionally, and/or socially. Ryan claims that an interactive medium opens its world after the user has made a significant intellectual and emotional investment [Ryan 2000]. Artists who have explored interactivity in their digital installations define the interactive experience as an active form of engagement [Rokeby 1998]. This connection between interactivity and engagement is also explored later in the context of games and play.

Finally, much of the above comes together in an educational context. There is general agreement among many educational technologists about the need for interactivity in learning. Barker considers interactivity in learning as "a necessary and fundamental mechanism for knowledge acquisition and the development of both cognitive and physical skills" [Barker 1994; Sims 1997]. G.R. Amthor's argument that people retain about 20% of what they hear; 40% of what they see and hear; and 75% of what they see, hear, and do. Amthor [1992] is cited widely in the literature to back up this belief (as is P.R. Halmos: “I hear, I forget; I see, I remember; I do, I understand”).

Interactivity is generally seen as an intrinsic feature of educational practice in the sense of social communication, but also as an inherent property of any interactive multimedia or virtual reality environment that promises physical and sensory, in addition to mental, activity and response. This belief derives from a more general view that characterizes learning as a process of making meaning through personally constructed or socially co-constructed knowledge [Jonassen 2000].

3. LEARNING THROUGH ACTIVITY

Current thinking about how learning takes place emphasizes the constructivist approach, which argues that learners must actively “construct” knowledge by drawing it out of experiences that have meaning and importance to them [Dewey 1966]. Participants in an activity construct their own knowledge by testing ideas and concepts based on prior knowledge and experience, applying them to a new situation, and integrating the new knowledge with pre-existing intellectual constructs; a process familiar to us from real-world situations. The individual continually constructs hypotheses, and thereby attempts to generate knowledge that must ultimately be pieced together.

Current education practices in both formal (i.e., schools) and informal (i.e., museums) settings have advanced constructivist theories in the design of curricula and exhibits. Due to their practical experience with interactivity, schools and museums can assert that understanding is gradually built up, step-by-step, through active involvement [DeVries and Kohlberg 1987]. A substantial body of literature backs this approach to learning: Dewey argued that education depends on action [Dewey 1966]. Piaget, known for his theory on the psychological development of children, believed in the role of action in development and the notion that children develop cognitive structure through action and spontaneous activity [Piaget 1973; DeVries and Kohlberg 1987]. Seymour Papert calls for further refinement of constructivist theory, by focusing on the involvement of the student in the actual design, construction, and erection of “external” products or artefacts [Papert 1980]. The reason for using raw data, primary sources, physical, and interactive materials in the real world is to help learners generate the abstractions that bind phenomena together. Papert and his colleagues coined the word “constructionism” to describe the knowledge-construction process that arises from the physical creation of objects.

Related principles apply to the discourse on activity theory [Nardi 1996], which adds a social aspect to constructivism by arguing that everyday practice is full of dynamic, context-dependent problems in need of tools to support high-level human activity. In activity theory it is assumed that consciousness and activity are inseparable: we cannot separate knowledge of something from our interactions with that something. In other words, knowledge that is integrated with an activity cannot be considered outside the context in which it was constructed [Jonassen 2000].

Most of these theories reflect student-centered learning practices, which have recently emerged to counter behaviorist and cognitive learning models. The shift from highly guided knowledge transfer to the more open-ended, activity-based, social learning process is also appropriated in the development of educational technology, namely in the way new media resources are formed to support new teaching and learning methods. A substantial body of literature in the learning sciences has been used to support interactive learning systems, both theoretically and practically. This is particularly true for constructivism, which has emerged in the last decade as an alternate pedagogy closely related to advances in educational technology, as reflected in the plethora of computer-based software that draws on constructivist premises. It has turned into a trend, and supplies technologists with the theoretical foundations to support development of open, informal, and virtual learning environments.

Museums have embraced these ideas by acting on them, primarily with the development of “hands-on” exhibits that can be touched and manipulated (one of the most famous being the Exploratorium[6] in San Francisco where users participate in hands-on scientific experiments). Moreover, as museums become more open and involved with interactive technologies, their conception of the audience as active participants or maybe even creators of the work also emerges. Paradoxically the creation of interactive experiences begins to converge with the entertainment industry’s push to develop edutainment-style exhibitions. An all-encompassing “active experience” has become key, in the sense of an "expanded metacinema," to borrow P. Greenaway’s term. While Greenaway (a film director) refers to cinema, he suggests integrating all manner of sophisticated cultural languages into a three-dimensional form with "stimulus for all five senses.” Here the viewer does not sit passively, but can create his or her own timeframe for viewing objects and can (as good as) touch the objects he or she is viewing, and certainly have a more physical / virtual relationship with them. [Pascoe 1997]. This can easily be adapted to a museum experience; and while museum audiences may not expect the sensorial richness of Greenaway's vision, they do expect the museum to provide a stimulating experience that, at the end of the day, will include a bit of its educational authority too.

In summary, many of the ideas rooted in activity theory, constructivism or theories of motivation and engagement can be directly related to the concept of interactivity. Constructivism is adopted as the basic driving force in the development of highly interactive and participatory environments, where the user is able to modify, build, appropriate elements, test ideas, and actively engage in problem-solving and critical thinking. These views have influenced the development of interactive and virtual learning environments, which seem to tie in well with the "learning by doing" and “hands-on” practices of modern museums. And since virtual reality technologies provide a wide range of possibilities for this kind of interactivity and support for active participation in the formation of the content, they become well suited, powerful media for use by schools, museums and edutainment centers.

4. LEARNING THROUGH PLAY

When it comes to children, the essential characteristics of the methods described above are that they inspire children and appeal to their spontaneity. Piaget's constructivism is rooted in stimulating *interest*, *initiative*, *experimentation*, *discovery*, *play*, and *imagination* as fundamental to the development of a child's capacity to learn [Piaget 1973]. Play, in particular, can unite imagination and intellect in more than one way, and help children discover things at their own pace and in their own way.

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6 Exploratorium http://www.exploratorium.org. Additionally, most science and technology centers adopt the same model (see www.astc.org for a list of such museums and centers).

Undoubtedly, play is a child's favourite activity, so the belief that learning occurs more readily in an environment of fun, challenge, and variety may seem obvious. However, concern has been raised regarding the drawbacks of learning through play, especially if learning is made to be "too much fun." According to this view, the goal is not to create fun-only environments but to create meaningful tasks, so that students take learning seriously and learn to do difficult tasks. Kay makes the distinction between soft fun (when the environment does most of the things for you) and hard fun (playing a musical instrument as opposed to listening to it) that encourage children to "stretch and grow."[7] According to Kay, soft fun is a very big industry; critics of edutainment centers use a similar argument to point out the shortcomings of edutainment models when they try to incorporate educational (or at least the impression of educational) elements in their productions.

Nevertheless, the non-formal learning world encourages the designers of its programs to focus around play, discovery, and engagement. Science and children's museums that are not bound by national standards and state-imposed curricula have freely embraced these ideas and use play as one of their principal learning tools. Many examples exist of hands-on exhibits that engage all the senses and of inventive methods that encourage children to speculate, manipulate, experiment, and imagine, inspiring them to discover and learn. Even art museums, traditionally more concerned with institutional credibility, include physical or web-based playgrounds for their young audiences as part of their outreach programs (Figure 1). The formal education curricula have also come to recognize play as an essential activity in a child's development.

This high value attributed to play as a component of learning subsides when it comes to computers and play. Computers and play automatically brings to mind the computer game industry, which, in public consciousness, excludes education and learning. Educational software design has attempted to include many of the tricks that characterize game design, such as the goal-directed nature of most games, ability to personalize the experience, advancement of complexity over time, etc., but has failed to equal the appeal and excitement that computer games bring to children. Hence, the division between tools for learning, represented by instructional or educational software, and tools for fun, represented by computer games, still holds.

Nevertheless, the rapid growth and popularity of games has triggered increasing interest among researchers, and a number of studies have been carried out as a result. Several theories tie the learning possibilities provided by games to motivation and engagement. Perhaps the best known is the work of Malone and Lepper, which considers games as providers of intrinsic motivations for learning [Malone and Lepper 1987]. The first four kinds of intrinsic motivations (challenge, curiosity, control, and fantasy) may be present in any learning situation, even those that involve only one person. The other elements of intrinsic motivation (competition, cooperation, and recognition) are categorized as interpersonal motivations, since they rely on the existence of other players. In some cases, these elements come together (as in projects where children

[7] See the interview with Alan Kay in *Government Technology Magazine*, Feb. 1998; http://www.govtech.net/magazine/visions/feb98vision/kay.phtml

Fig. 1. A growing number of museums developed interactive educational activities on the web that incorporate the idea of the playground for teachers and children. Courtesy of the Walker Art Center ©1999. http://www.artsconnected.org/

assume the role of game designers [Kafai 1999]). Interactivity can also be considered an intrinsic property of game design. Games hold the users' attention via interactive features, whether these are intended to advance the story or allow the development and exploration of social interactions and relationships (as in multiuser games).

Based on the above, we could argue that a strong connection binds *interactivity*, *engagement*, and *learning*. Together, they can form the foundation for the development of a successful virtual reality environment: an interactive VR "play space," which allows children to engage in creative and constructive play, and achieve the ideal blend of educational and recreational value. Successful examples, such as the KidsRoom project [Bobick et al. 1999] serve as excellent demonstrations of this model where the spontaneity and collaborative nature of real-world physical play come together in a fantasy story. Although the KidsRoom project was not designed as an educational project with explicit learning goals, and technically speaking has no virtual reality component, its combination of narrative, play, and both individual and group activity opens up vast pedagogical and educational possibilities.

In the following sections, we will first look at some of the issues concerning interactivity in virtual reality and then review a number of VR environments created in different educational contexts or for different purposes. In all of the reviewed examples, the ideas of interactivity, engagement, and learning are approached in a variety of ways.

5. THE NATURE OF INTERACTIVITY IN VIRTUAL REALITY

Many believe that interactivity is a *raison d'être* for a virtual reality world, one of its most important properties. Today's virtual reality interfaces and applications are designed with an awareness of interactivity by providing a means for the user to literally feel placed in the scene and be actively engaged with the surrounding environment. The development of larger projection-based systems such as CAVE® is one of the better examples in this direction. The more natural physical set-up of a CAVE-type display (typically a room rather than a device), the relatively non-intrusive display hardware (no helmets to wear, no isolation from the surrounding physical environment), and its relative multiuser support (while one user experiences total virtual reality in controlling the viewpoint and the interaction device, a number of others can “share” this experience at the same time) show promise as a VR setting for development of recreational/learning environments. On the other hand, the use of these systems in public settings continues to come with a number of practical problems. Apart from the obvious drawbacks of high cost and high maintenance, they suffer from a number of usability problems that inevitably impact their potential for interactivity: the displays must be designed to withstand breakage, short attention spans, greasy fingers, and large numbers of visitors of all ages; the special glasses are expensive and can break easily, as they do not fit everyone; they must also be cleaned after each use; the same applies to interaction devices, which must be ergonomically designed with rugged cables and visible buttons (preferably, color-coded). High-throughput 3D theatres, such as IMAX®, have been successful in overcoming some of these problems by creating custom-based solutions. But this is not necessarily feasible for smaller-sized, lower-budget venues. Nevertheless, high-tech attractions such as the DisneyQuest™ theme parks (the first to provide sophisticated interactive VR productions to a large public) have paved the way for careful engineering of interactivity, both on an interface and an applications level [Pausch et al 1998; Schell and Shochet 2001].

But assuming that technology and usability problems will be overcome by the continuous development of new and better hardware (and that market demand will drive development) let us focus on the nature of interactivity with respect to the user of a virtual environment. In the context of VR, interactivity is usually identified with the ability to choose a course within the virtual environment and to freely navigate in it. Spatial navigation with a joystick-like device is the most common “interactive” activity, equivalent to pointing and clicking with a mouse in a 2D environment. The user can explore from multiple points of view, fly, and go through walls, but cannot intervene in or modify the environment. The majority of architectural and cultural heritage virtual worlds have been designed on this principle.

There are two main problems with this. First, how can more than one user share the same experience at the same time with the same level of control? On a technical level, viewer-centered perspective and single-person tracked devices exclude the simultaneous participation of a group of people. Second, in terms of interactivity, a distinction must be made between mere navigation in a virtual space (or even examination of a virtual object from different viewpoints) and active participation by the user in what happens in it. Most VR applications made for the public advertise interactivity widely, when what this really translates to is the ability to explore and perceive a virtual world from different viewpoints. Cultural VR experiences, for instance, have become synonymous with passive walks through realistic (technology permitting) recreations of architectural worlds, in which the user is allowed little more than the choice of where to go and what to see.

Active participation means placing the user in a central active role with the ability to modify the environment. This complicates the conventional pattern of user versus creator of an interactive experience. The user assumes the role of both actor and audience [Laurel 1993], while the creator must understand how to manipulate the audience into becoming an actor [Anstey 1998]. The creators/authors of artistic virtual reality have been the ones to experiment most with the idea of user as active participant in the virtual experience. The four examples of CAVE-based virtual reality artworks below have been involved in this kind of exploration. Although their approaches and forms vary greatly, interactivity, or its absence, serves as a key element in the experience of virtual reality, in a way that affects the user's engagement, sense of presence, and development of the narrative. For example, Benayoun's *World Skin*[8] places the visitor in a very powerful position. Armed with a single interaction device (a tracked camera), visitors are positioned in a 3D land of war where they embark on a photographic safari. In this war landscape, every camera-click extinguishes a fragment of the virtual world; each photograph replaces a fragment from the virtual world with blank white space. The world falls victim to the viewer's glance, and everyone is involved in its disappearance. Technically, the interaction is limited to the simple click of a button. Conceptually, the system's response to this simple action is a complex sequence of social, political, and moral associations.

Fischnaller's *Multi Mega Book*[9] is a virtual reality piece that juxtaposes two periods in human history, the Renaissance and the electronic age. An idealized Renaissance city, including famous buildings such as the Duomo in Florence, an animated 3D representation of da Vinci's Last Supper, Gutenberg's printing press, and a fictional digital city, form the different parts of the world that the user is able to navigate and freely explore. An animated virtual character, a kind of tour guide, draws the user into the different spaces by moving about the virtual space and positioning itself at various points of interest (Figure 3). The user may choose to follow the "tour guide" or ignore it.
Mitologies,[10] a virtual reality artwork with an approach similar to the Multi Mega Book, is an attempt to adapt traditional narrative content and structure to a virtual experience (Figure 2). The film-like structure was selected both for its familiarity to viewers and as a mode of expression. The narrative draws inspiration from a pool of mythological and medieval literary and artistic sources, and takes an approach that almost intentionally ignores interactivity. The thematic content is loosely based on the Cretan myth of the Minotaur, the Apocalypse, or Revelations, of St. John, Dante's Inferno, Durer's woodcuts after the Apocalypse, and Borges' Library of Babel. Music from Wagner's Der Ring Des Nibelungen is used as a motif to structure the narrative. The work explores the

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8 Benayoun, M.: *World Skin*. In the catalog of Ars Electronica Festival 98, Linz, Austria (1998).

9 Fischnaller, F. and Singh, Y.: *Multi Mega Book*. In the catalog of Ars Electronica Festival 97, Linz, Austria (1997).

10 Mitologies, http://www.evl.uic.edu/mitologies/

Fig. 2. *Mitologies*: cinematic narrative in VR, where the user is allowed choices that determine the path taken in a virtual labyrinth. A view of the Bosch room. Courtesy of Maria Roussos and Hisham Bizri, 1997. http://www.evl.uic.edu/mariar/MFA/MITOLOGIES/

enigmatic relationships among these sources and captures them in a *mise-en-scene* rooted in the illusion-like narrative tradition of other media, such as cinema. Although created and exhibited on a virtual reality platform that allowed for a high degree of interactivity, in most cases the audience of Mitologies had no control. The cinematic narrative form preserves itself through the continuous slow pace and progression from one scene to the next. The virtual journey through a labyrinth presents its visitors with a narrow range of choices, yet all choices are in essence illusory, as they ultimately lead to the same final confrontation with the Minotaur, the fall through a trap door, and the return to the boat where the experience began, thus completing a circular journey [Roussos and Bizri 1998].

On the other hand, *The Thing* [Anstey et al. 2000] engages the user in interactivity through constant "conversation" with a virtual character rich in changing emotional states. The work is structured in three acts in order to take advantage of narrative tools like pacing, surprise, and movement through time. For the story to progress, the user must engage in activities and respond to the character's requests by dancing, moving, selecting objects, or performing actions (Figure 3). *The Thing* provides us with an example where interactivity is closely intertwined with narrative. In this case, storytelling serves as a driving force for a highly interactive experience, and, vice versa, interaction between real and virtual characters, plot, and emotion becomes central to the form of the story.

The approaches to virtual reality taken above are situated at opposite ends of the interactivity-immersion spectrum. *Mitologies* employs high-quality, visually complex scenes that take advantage of the immersive qualities of the medium at the expense of interactivity. Its cinematic form is familiar and safe. It does not allow much exploration

Fig. 3. Virtual characters that interact with the visitors of *The Thing Growing* and the *Multi-Mega Book in the CAVE*. Images courtesy of Josephine Anstey.

and does not require much activity on the part of the user (thus also eliminating the need to train the user). Similarly, the *Multi Mega Book* makes a strong impression on the user with its stunning visual form, in an environment with no apparent story or goal. The user is encouraged to explore by following the virtual character, which follows its own course and is not responsive to the user's presence in the virtual environment. On the antithetical side, *The Thing* bases all of its power on interactivity by maintaining a simple visual and aesthetic form. Visuals are used to set the scene rather than define the artistic process, while the constant demand for interaction between the participant and the virtual character helps the participant to almost entirely ignore the surroundings. Despite this fact, the participant's discourse with the "Thing" becomes so involved that a strong sense of presence is also achieved. Similarly, *World Skin* achieves a strong sense of presence without, however, using the default interaction capabilities of the given VR system or any sophisticated interaction engine. The interface and activity are so simplified that interaction is taken to another, more conceptual, level, perhaps even one that is realized after the virtual experience has ended.

In all the examples above, the creators have engaged in a sophisticated engineering of interactions, or more precisely, in engineering the illusion of interaction. No matter what choices the user makes, whatever the attempts to modify the world or cause a response, the final result is derived from a set of predefined options, predetermined by the creator. Further examples that demonstrate mastery of what Schell refers to as "indirect control" [Schell 2003], include the DisneyQuest virtual reality attractions of Aladdin, Hercules, and the more recent adventure of the Pirates of the Caribbean [Schell and Shochet 2001]. In all these cases, visitors assume the roles of central characters in the story and, for the duration of their experience, believe they control the progress of the story, which is rapidly building to a climax, when in fact every aspect of the experience has been carefully and intelligently planned in advance. Although none of these examples were created as learning environments for children, the underlying principles serve as different human-virtual system models to draw from when designing interactive VR experiences for learning.

6. VIRTUAL LEARNING ENVIRONMENTS

Virtual reality continues to be regarded as an emerging field, especially when it comes to its actual use in artistic, educational, and cultural contexts. Virtual learning environments, due to the use of high-end equipment and to the dispersed and non-standard ways in which applications are developed, are limited to projects with special funding, such as academic and research environments. The projects mentioned below were for the most part intended for children, and only in structured experiments. Many of the early VR projects for children were developed especially for head-mounted display systems (HMDs), while later projects began to explore the use of the physical space along with the virtual by employing projection-based or even mobile technologies.

Whatever the output medium, a large part of educational research has focused on science education, like the ScienceSpace projects, which set out to explore motion, electrostatic forces, and other physics concepts. The initial, formative evaluation reports on learners' engagement with, surprise at, and understanding of the alternative representations of the concepts in the ScienceSpace world.[11] In these projects, other than navigation and pick-and-place activity, the world was not dynamically altered by the learner's participation. Similarly, the Computer Museum in Boston created and tested a VR exhibit on cell biology. The Human Interface Technology Laboratory (HITL)[12] at the University of Washington is one of the early educational seedbeds for VR, with projects such as the Virtual Reality Roving Vehicle (VRRV), Water on Tap, and summer camp programs in VR for students. The VRRV and summer camp projects focus on "world-building," where students conceive and create the objects of their own virtual worlds, by using 3D modeling software on desktop computers. Although this sounds like a highly interactive process, it is focused only on the process involved in creating a virtual world, rather than interacting with one. The actual immersive experience is limited to a short visit of the predesigned virtual worlds (4 to 10-minute VR experiences). The concept that virtual reality is a process and not a product is important, but may not take advantage of VR's potential educational benefits and may not justify its use. One of the reasons students are not more actively involved with the actual virtual experience within the virtual reality system is that the systems used by these projects (HMDs) are not flexible enough to allow more than one participant at a time. The VRRV project attempts to overcome such restrictions in an interesting way, that is, by travelling to schools and giving students (in grades 4 to12) the possibility of experiencing VR, although still one at a time and for a short time.

Immersive projection-based VR displays, such as the CAVE®, the curved screen displays, and the single-screen immersive desks, are freed from the limitations of HMDs (unwieldy hardware, single-user participation, short and infrequent immersive experiences), but not the limitations of size and cost. Although these systems have been used successfully in scientific visualization, development of CAVE applications for education has been almost nonexistent. CitySpace,[13] a project in which children build their own virtual cities, was one of the early attempts demonstrated in CAVE®.

However, as in VRRV, the children's modelling activity was emphasized prior to incorporating the models into the virtual worlds. Although the tasks resemble highly constructivist physical play, a significant amount of guidance is required before

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[11] Information on the ScienceSpace projects can be found in publications by Chris Dede, Marilyn Salzman, and Bowen R. Loftin.

[12] See http://www.hitl.washington.edu/ for publications related to the HITL's VR projects.

[13] CitySpace, Visual Proceedings of ACM SIGGRAPH 95, p.142.

Fig. 4. An educational VR project where children interact with avatars to plant a virtual garden. Courtesy of the NICE project, Maria Roussos et al. http://www.evl.uic.edu/tile/NICE/

simultaneous construction of mental models along with the physical ones can take place [Sherman and Craig 2003].

The NICE (Narrative-based, Immersive, Constructionist/Collaborative Environments) project, an interactive virtual learning environment for young children, was one of the first educational VR applications designed and developed for CAVE [Roussos et al. 1999; 1997; Sherman and Craig 2003]. In NICE, children could collaboratively plant a garden and construct stories as a result of their activities. NICE served as a test bed for exploring virtual reality as a learning medium, focusing on informal education and domains with social content. As its acronym suggests, the NICE project embraced the constructivist approach to learning, combined with collaboration through telepresence, interactive "tools" that helped children to cultivate a virtual garden, and the development of a final story (Figure 4).

Lessons learned from the NICE project, helped to focus and form the design of the Round Earth project [Johnson et al. 1999]. The Round Earth project investigates how virtual reality can be used to teach young children that the earth is a sphere when their everyday experiences tell them it is flat (Figure 5). VR is used as part of a larger strategy to create an alternative cognitive starting point where this concept can be established before it is brought into contact with the learner's past experiences. Further projects focused on investigating the effectiveness of virtual environments as simulated data collection environments for children engaged in inquiry-based science activities. Ongoing work to

Fig. 5. Children interacting with the avatars of other learners in the *Round Earth* project, Courtesy of Andrew E. Johnson, Thomas G. Moher, et al. http://www.evl.uic.edu/roundearth/

move this effort out of the lab and into schools with an ImmersaDesk™ and other more consumer-driven technologies reflects a trend to finally take VR learning endeavours out of the laboratories and into the real world of the formal education system [Kafai 1995].

Both quantitative and qualitative studies for most of the projects above were not able to report much on children's conceptual learning in the virtual environments. However, most studies confirm a high level of enjoyment, especially compared to other media. In studies comparing immersive VR to two-dimensional desktop or even video instruction, the immersive users enjoyed their experience the most and reported the most desire to continue learning about the subject. Interactivity, here identified with control over the environment, scored as the most significant component of the virtual environments. Giving a child control meant that the child tended to be more engaged with the educational content and to learn more [Roussos et al. 1999].

These qualitative findings indicate that interactivity may be a defining component in a successful outcome of a virtual learning environment, and certainly call for further examination. Unlike the art projects mentioned previously, most educational virtual world projects have done little to explore interactivity, and, in most cases, used the default interactive capabilities provided by the technology. At best, these efforts resulted in glorified multiple-choice systems, making "choice" the fundamental means of expression for the user. This kind of interactivity may not be the kind to foster conceptual learning, at least in the constructivist sense; however, this remains to be examined.

7. VIRTUAL LEARNING ENVIRONMENTS IN THE CONTEXT OF A PUBLIC SPACE

As mentioned throughout this paper, museums continue to accept virtual reality technology in both theory and practice, due to the new possibilities it offers science, art history education, and cultural heritage representations. Museums, as the main authorities on cultural content, are adapting more and more interactive hands-on techniques and (those that can) virtual technologies for use in exhibitions and public programs.

Fig. 6. Children visit the CAVE-like installation at the Foundation of the Hellenic World ©1999-2003. http://www.fhw.gr/ and http://www.virtualreality.gr/

At the Foundation of the Hellenic World (FHW), a cultural heritage institution in Athens Greece, virtual reality is used both as an educational/recreational tool and as an instrument for historic research, simulation, and reconstruction. The FHW develops its own cultural and educational virtual reality programs that are shown to the public in the cultural center's two immersive VR exhibits/theaters: the *Magic Screen* (an ImmersaDesk™) and the *Kivotos* (a CAVE-like cubic immersive display for up to 10 people). The VR exhibits have been open to the public since 1999, and are the most popular attraction at the museum, with over 200,000 visitors, most of whom are students visiting the Center with their schools (Figure 6).

The programs range from highly detailed reconstructions of ancient cities that can be experienced as they were in antiquity to interactive educational programs that require active visitor participation [Gaitatzes et al. 2000]. The three-dimensional reconstructions, including the site of ancient Olympia and the city of ancient Miletus, were created with all the clichés of a passive virtual experience, but served as major attractors to the public. From all practical points of view, the 12-minute virtual tour (controlled by a museum guide) provides enough time to visit the virtual site without demanding anything from the visitors. This is enough to create and preserve a lasting impression on adult visitors (who, for the most part, do not wish to take on a more active role), but falls short of children’s expectations, both on the engagement level (the novelty wears off quickly) and the conceptual level (they do go to a museum expecting something creative and challenging after all).

The more interactive projects are also the most demanding in terms of human resources and time. Due to limitations of the VR equipment (single-viewer perspective and one interaction device), and for the programs to provide their full educational potential, students must take turns interacting while specially trained museum educators coordinate the experience. Due to these difficulties, the interactive programs are not attractive to

Fig. 7. *Olympic Pottery Puzzles*. Children assume the role of archaeologists by assembling the virtual pieces of vases in an immersive VR program. Foundation of the Hellenic World ©2000. http://www.fhw.gr/

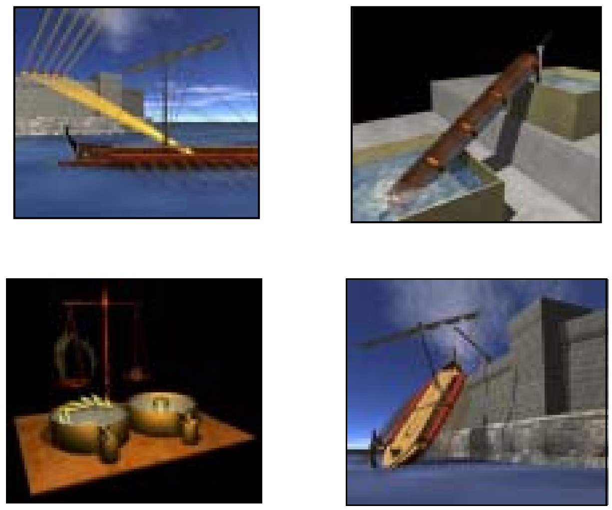

Fig. 8. *EUREKA!!! Stories from Archimedes*. Foundation of the Hellenic World ©2003.

museums on a cost-benefit basis. However, the more interactive projects are the more interesting ones from an informal educational perspective.

Olympic Pottery Puzzles (Figure 7) is one of the first programs developed on the basis of a simple idea: children assume the roles of archeologists who must piece together ceramic shards in order to restore ancient vases. Each vase depicts images of athletes taking part in Olympic games. By assembling pieces of the broken pottery, the renderings depicted on the front of the reconstructed vases come to life with 2D and 3D animation, rewarding the user for successfully completing the task. Through a very familiar and engaging learning-by-doing process, children learn about the process of restoration and details about ancient sports, athletes, and the Olympic games.

Similarly, *EUREKA!!! Stories from Archimedes* is a series of interactive "exercises" developed to complement an exhibition on ancient Greek mathematics. The program is

Fig. 9. *The Magical Wardrobe* is a museum virtual reality experience where children actively participate in exploring fairytale-like worlds inspired by different time periods in Greek history. By means of a game with a concrete educational goal, children learn about the significance of costume. Foundation of the Hellenic World ©2000-2001. http://www.fhw.gr/

based on Archimedes, one of the most important figures in ancient and medieval science. Through interactive virtual experiments, visitors of all ages can come to understand some of the most famous of Archimedes' discoveries, such as the method for measuring the volume of a sphere, the principle of hydrostatics' (our well-known EUREKA!), the invention of the water screw (a device to manipulate water levels for irrigation and drainage), and stories about burning mirrors and the iron hand or claw, both used to destroy Roman ships (Figure 8).

In the more involved interaction scenario of the *Magical Wardrobe* program, young users can select a garment from a set of virtual costumes, each from a different period of Hellenic history, and by "wearing" it, be transported to the corresponding time period. Once in this fairytale land of colorful scenery and virtual characters, the task is to search for costumes and accessories to help the virtual people of that time to prepare for a celebration. This process of searching for, discovering, and identifying different costumes, fosters inquiry that can lead to knowledge of the cultural, sociological, and political importance of costume at the time (Figure 9).

Finally, perhaps the most involved “constructivist” activity is an integral part of the design of the *Workshop of Phedias in Olympia*. This interactive virtual experience places young visitors in the workshop of the sculptor Phedias in ancient Olympia, in an accurate reconstruction of the famous statue of Zeus (one of the seven wonders of the ancient world), among the sculptor's tools and materials. According to the “scenario,” young visitors take on the role of the sculptor's helpers, who actively participate in the creation of the huge statue by means of virtual tools (Figure 10).

Through this activity, the museum hopes to give students a sense of the creative process involved in making an ancient Greek sculpture, about the tools, the materials, and procedures, but also an opportunity to learn about ancient Olympia and the Olympic games.

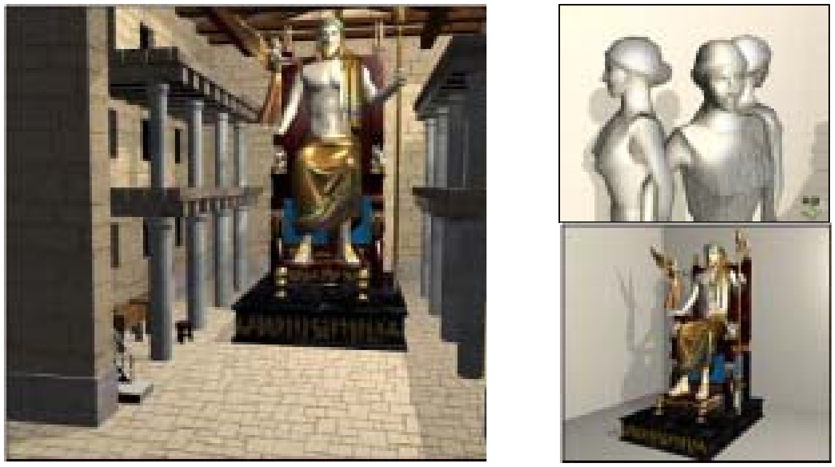

Fig. 10. *The workshop of Phedias in Olympia*. Children help the famous sculptor Phedias to create the statue of Zeus at Olympia. Foundation of the Hellenic World ©2003. http://www.fhw.gr/

A number of other interactive productions follow the same motif: for example, “Discovering Liquid Gold” where visitors interact with a reconstructed traditional mill to make olive oil. All productions have an embedded sense of narrative. In some programs it appears in a more literal and obvious form through recorded or “live” narration, while in others, it is implied in the interaction with the virtual environment and in the completion of tasks with a concrete goal.

8. DOES THE USE OF INTERACTIVITY WITH THE PUBLIC MAKE SENSE?

The use of interactivity in projects, like those above, has proved to be a strong public attractant, one that can redefine the relationships among the audience, the virtual experience, the context, and the real purpose of the experience. Whether it’s the novelty of interactive technology and virtual reality exhibits or the compelling nature of the applications themselves, visitors go to experience the new and cutting edge, even if the themes of the virtual reality content remain relatively unchanged. At the same time, most people do not understand how to deal with interactive computer-based environments, let alone with interactivity in immersive and, in many cases, complex virtual worlds. The virtual experience can be disorienting, unnatural, and difficult to be part of, even if the technology is as simple and natural as current development allows. Furthermore, the interactive part of most public experiences is inevitably controlled, structured, and brief. All this generates added complexity for “experience creators” who must design by synthesizing many different and sometimes conflicting parameters, including commercial considerations such as providing extra novelty, accommodating an increasing range of experience, and enhancing the visitor demographic.

The immediate implication, which can be drawn from the artistic, educational, and museum virtual reality examples in this paper, is the common belief that the effectiveness of a virtual environment with a high degree of interactivity is substantially better than where there is no interactivity. Likewise, the learning and learning technology communities believe that the need for interactivity is indisputable. However, little

Fig. 11. Pilot experiments in which children ages 7 to 11 are asked to complete various interactive tasks as part of a larger study carried out at the University College London to examine the effect of interactivity on conceptual learning. Maria Roussou, 2003.

systematic research is available to substantiate this assumption in the context of VR, and, to date, no clear evidence exists that interactive VR applications can bring "added value" to learning, especially for children. Hence, a central question emerges: Does interactivity, as an essential property of the virtual reality medium, aid in the learning goals that the context set out to achieve? And if indeed this can be proven, then how should interactivity be designed into the virtual experience in order to enhance learning? Numerous observations of adults, single viewers, groups, novice and even expert users in the leisure-based and informal education VR worlds, indicate that interactivity is a major attractor, but may not be what matters to visitors after all. It is certainly significant as a vehicle to suspend disbelief and provide stimulating experiences, but perhaps not much more [Pausch et al. 1998; Anstey 1998]. However, this may differ in the case of children. It is our belief that when combining learning and leisure for children, interactivity is essential, not as another tool but as the central model around which the experience should be structured. In this sense, it requires careful study, as the relationships among interactivity, learning, and all the other pieces of the "experience" puzzle are unavoidably complicated, and cannot be isolated from the plethora of contextual issues that surround it (Figure 11).

These contextual issues become even more complex in the case of museums. Museums "tell stories" through the collection, informed selection, and meaningful display of artifacts and the use of explanatory visual and narrative motifs in their exhibits and in the spaces between exhibits. This interpretative process is at the heart of the museum as an unassailable institutional authority, and remains the most significant factor that differentiates museums as informal education spaces from theme parks. In other words, authenticity is both an effect that exhibit makers strive to achieve and an experience that audiences come to expect from museums. It is crucial for museums to preserve this context of knowledge and credibility while providing memorable experiences that keep visitors coming back. Thus, the introduction of virtual technologies in museums runs up against a number of issues: among others, the physical context of the public space, support for the conceptual and aesthetic standards of the exhibition and its learning goals, and functionality and accessibility for its intended audience.

Interactivity in a museum VR exhibit has the challenge of preserving a balance among the following: accuracy, educational efficacy, high motivational and engagement levels, quality visitor experience, and seamless, natural, and customized modes of interaction. Ultimately, it must be designed to encourage visitors to question what they experience and to engage in "contradiction, confusion, and multiplicity of representations" [Pascoe 1997] inherent in the display of museum content, while at the same time avoiding the danger of a confusing and fragmented experience.

The entertainment world has devised many tricks to provide structure and tight control in its productions. The most common trick is the use of stories and characters with human-like behaviors and simulation of a perceptual, cognitive, and emotional level that can produce a predictable and consistent visitor response. The use of intelligent agents in virtual environments presents a similar attempt to simulate human qualities and create the illusion of a responsive environment. Characters in virtual worlds draw on codes heavily used and tested by the masters of fantasy and entertainment experiences. Their task is to deliver anthropomorphism, embodiment, and believability to a virtual experience. However, technical limitations have so far not allowed the development of agents intelligent enough to respond to the human users' wealth of emotional states and improvisational behaviors or the construction of meaningful interactive experience. In some cases, limitations in developing intelligent characters for virtual worlds are overcome by the use of avatars or actors; that is, virtual representations of real people. In the *NICE* project, intelligent agents were originally conceived to act as mentors, by helping students to complete tasks, as well as by being fun characters that keep interest alive and help progress the story. In NICE, the construction of the environment was designed to foster collaboration between remotely located users. Through the use of avatars, geographically separated learners are simultaneously present in the virtual environment. The ability to connect with learners at distant locations, enhanced by visual, gestural, and verbal interactions, was employed to develop unique interactive experiences for both students and educators. Initial research indicated that current technical developments were not advanced enough to construct "intelligent" agents that could respond to the needs of students from different locations. By replacing the agents with avatars of (real) people, teachers or parents were able to participate either as members of the groups or disguised as characters in the environment. This allowed teachers to mentor the children in person, to guide parts of the activity from “behind the scenes,” and to help shape more interesting and engaging experiences.[14]

The cultural heritage institution mentioned above adopted a similar method, one that complements virtual experience with the power of human mediation. The role of the museum educator, guide, or facilitator is critical in structuring the interactive experience so that children can build bridges between different perspectives and gain a deeper understanding of the content (Figure 12). Furthermore, the use of museum educators as guides in the virtual experience not only helps “externalize” the learning concepts built into the experience but promises the development of a unique “show” every time. Thus,

[14] The technique of using a human to simulate the intelligent component of a system is widely known in the HCI field as the Wizard of Oz (WoZ) technique. The teachers, in this case, interacted with the children in a way that made them believe that they were interacting with the virtual characters, not with real people.

Fig. 12. The role of the museum educator, guide, or facilitator as mediator is critical in helping the audience interact with the virtual environment in a meaningful way. It was shown to be essential in public settings in order for the audience to gain a deeper understanding of the content while having fun.

museums can maintain the potential for multiple, different experiences that respond to visitor needs rather than a single, repetitive, identical experience. Different people employ different processes and have different comfort levels with the technology. The multiplicity of approaches also means that the visitor experience depends on the skills of the educator/guide, in the sense that even unpredictable external reasons ("having a bad day") can change the quality of the experience dramatically, making it inconsistent. These processes are reflected in forming the visitor experience and the methods of structuring the interactive experience to encourage new forms of interactivity. The interaction varies with the guides' preferences and capabilities: some may choose to keep exclusive control of the interface and others to share the controller among all visitors; some prefer to direct the experience, others to suggest possible courses of action; some encourage interaction, while others prefer a more structured experience; some use the experience as a way to generate questions from the visitors, others as a vehicle for dramatic improvisation and magic. This is the ultimate interactive process, facilitated by the virtual environment, but contextualized and completed by humans. It is an almost ideal-world scenario of personalized, customized learning and entertainment, if it doesn't stumble on the economics of a continuously increasing competition between the entertainment industry and the museum world.

The question, whether intended or not, evoked by this limited review of virtual reality asks whether, before we speak of interactive virtual worlds for educating children, can we develop a whole new mindset? A mindset that takes into account interactivity as a central design component, one that explores the role of the child/learner/visitor/participant as an essential part of the experience, and regards interactivity, constructive play, motivation, engagement, and learning as interconnected.

Prevailing trends in education and leisure show an evolution of convergence, an evolution of museums as spaces with more attractive digital applications, and leisure centers as models of attraction with an enhanced educational flavor. Interactivity has great potential to unite these trends and become the basis for VR experiences that are engaging and educational at the same time. The exploration of the complex relationship among interactivity, learning, and the virtual reality medium should continue in order to provide insights as to how people interact in virtual environments and how interactivity should be designed to achieve meaningful leisure and learning experiences. A better understanding of the design and engineering of interactivity can lead to the design of better interaction methodologies to support formal and informal educational and entertainment contexts.

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