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VR in Education:

An Introduction to Multisensory Constructivist Learning Environments

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Abstract:
For educational purposes, Virtual Reality (VR) has been proposed as a technological breakthrough that holds the power to facilitate learning. Though, most efforts within the VR community have focused on applications designed to fulfill purposes of training, such as vehicle simulators, medical and military training. While this area is not at all unimportant on university level, we believe it is also adequate to explore how this style of interaction could be used to help students develop understanding and more proper mental models of complex systems and processes, abstract models and other non-intuitive material. The hypothesis is that VR can successfully be used to support such complex understanding by stimulating and exploring all human senses whereas traditional notions of learning tend to focus on purely intellectual skills. We examine the constructivist philosophy of learning and discuss how it may be supported by the use of VR, and we provide examples of different classes of VR applications that for educational purposes focus on learning.

The main objective of this paper is to introduce the survey in progress and outline some of the initial findings of what has been done and what is currently being done in this field.

Introduction

The purpose of this paper is to outline educational uses of Virtual Reality (VR); primarily those that focus on higher education and are concerned with issues of learning and understanding as seen separated from training and simulation. The presentation and this paper’s main objective is to introduce the survey in progress and outline some of the initial findings of what has been done and what is currently being done in this field. As a starting point, we are primarily interested in exploring the ways in which VR may be used as a means of enhancing, motivating and stimulating students’ understanding of certain events, especially those for which the traditional notion of instructional learning have proven inappropriate or difficult. We believe that VR holds the potential to have serious impact on education, since it supports a number of important concepts that might make a difference to education as we know it during the next decade.

What is Virtual Reality?

Virtual Reality has been addressed by a large number of authors in the literature for decades, many of them introducing slightly different meanings to the term. Some years ago a common definition had it that VR should be looked upon as a situation where a person was immersed into a computer generated environment that bore strong similarities with reality [Keppell et. al., 1997]. Other authors tend to define VR from the point of view of what technological tools are being used, i.e. VR happens when head mounted visual display units and motion-tracking gloves are present. One could also define VR from a psychological perspective, where it becomes nothing of a technology but rather a state produced in the users' minds that can occupy their awareness in a way similar to that of real environments [Keppell et. al., 1997].

The problems involved in finding a definition of VR that can be agreed upon has produced a host of competing terms that some authors prefer, e.g. synthetic environments, cyberspace, artificial reality, simulator technology [Isdale, 1993].

A different way of defining VR, and perhaps the best so far, is to center around the user and look at the style of interaction that takes place between the user and the computer-generated environment. The users manipulate what is perceived to be "real" objects in the same manner as they would manipulate them in the real world, as opposed to the typing, pointing and clicking you traditionally use to manipulate objects when you interact in other computer environments. For example, to move an object in a VR environment, you may grab the object with your hands, lift it as you normally lift objects in the real world, and put it down wherever you want it inside the virtual environment.

There are basically three different kinds of VR, categorized by the quality of the immersion that is being provided [Cronin, 1997]. The first is desktop VR, which is by far the most common and least expensive form of VR there are, which typically consists of a standard desktop computer. This form of VR completely lacks any feelings of immersion on the part of the user. Second, a semi-immersive VR system attempts to give the users a feeling of being at least slightly immersed by a virtual environment, which is often achieved by different types of so called workbenches and reach-in displays. The third form of VR is usually referred to as being fully immersed. It typically consists of head mounted visual display units that allow users to be completely isolated from the physical world outside. Recently, a growing interest in building so-called Caves has been noted. A Cave is a room in which the walls surrounding the user produce the images, and thus deliver a sense of immersion. Not surprisingly, fully immersive VR is generally considered the best option for several reasons, including the ability to almost completely filter out interference from the outside world and thus allowing oneself to focus entirely on the virtual environment. However, even reasonable VR hardware and software designed to support full immersion is quite expensive and application development in this area is generally more difficult and time-consuming.

Educational Benefits of Using VR

There are several reasons why VR should be regarded adequate to deal with aspects that are important in education and knowledge construction, even at university level. Winn [1993] identifies three kinds of experiences that fully immersive VR allow and which are not available or even possible to achieve in the real world. These may all prove useful and important for learning. First, VR technology allows changes in the relative sizes of the user and the objects in the virtual environment. At one extreme, the user could interact with and even step into atoms and electrons, while at the other extreme acquire a sense of distance in the universe by visualizing planets and moons. Second, immersive VR makes use of multisensory cues to interact with the user which allows the designer of the virtual environment to use interface devices to present information that is not available to human senses in a direct and clear manner. For instance, variations in the intensity of sound may be used to indicate the current level of radiation, and different places could be given different colors that correspond to the current temperature in that area. Third, VR allows the creation and visualization of representations of objects and events that have no physical form in the real world, by combining aspects of the first and second category.

The ability to work with abstract and multidimensional information is a crucial skill in today's society [West, 1991], not only in the academic world but also for large parts of the workforce as a whole. Traditional methods of displaying and visualizing models and data, e.g. on computer screens or in books, are two-dimensional to their nature even though they seek to describe a reality that is often three-dimensional. VR allows students not only to visualize models and data in a more appropriate three-dimensional context, but also to interact with the models and take on several different points of view, including changing the models' relative sizes as well as the perspective from which the users experience the models.

In most academic areas, such as math, science, engineering and statistics, success on behalf of a student depends to a large extent on his or her ability to envision and manipulate abstract information [Gordin et. al. 1995]. Finding ways to help people recognize patterns; qualitatively understand physical processes; move among different frames of reference and more easily control dynamic models that may contain intangible information should be important and useful for many educational situations.

Salzman et. al. [1998] argues that being able to use different perspectives, or frames of reference, may be useful for highlighting different patterns and relationships in abstract information. Because of the flexibility and user control within the virtual environment, the number of possible perspectives a user can find is endless. However, all perspectives can be generalized down into two basic kinds of frames of reference; exocentric and egocentric. The first provides the user with a view of a phenomenon or a space from the outside looking in. The latter provides the same view but from within the phenomenon or the space itself. Salzman et. al. [1998] also recognizes a third view, the bicentric frame of reference, which allows users to alternate between the exocentric and the egocentric frames of reference. Her empirical study indicates that being able to change your frame of reference influence mastery in a positive manner, and it confirmed that the egocentric view supports local information while the exocentric view sheds light on information on a larger scale. Users who had not been exposed to the egocentric frame of reference had problems applying their knowledge from the exocentric view in an egocentric problem-solving domain. This may be important because abstract thinking, especially in the science domain, often tends to require the ability to adopt an egocentric perspective [Salzman et. al. 1998].

Learning, Training and Simulation

Up to now, much work within the VR community has focused on applications designed to fulfill purposes of training and simulation for educational purposes. This field of application includes a vast number of vehicle simulators, such as space shuttles, airplanes, cars etc.; medical training such as surgery and telemedicine; as well as a host of military utilization within combat simulation and group communication and training. As a means of training and simulation, it seems fair to state that use of VR applications and technology has proven useful and successful.

For educational purposes in general, VR has been widely proposed as a significant technological breakthrough that possesses an immense potential to facilitate learning [Youngblut, 1998]. Reasons for this are that VR allows students to visualize abstract concepts, to take part in and interact with events that for reasons of distance, time, scale, safety or money would not otherwise be conceivable. Despite this promising potential, there seems to be a very little amount of VR applications today that concentrate solely on learning as distinguished from training. Learning should in our view be seen as differentiated from training, even though these may be difficult to separate and also dependent on each other. Learning consists of acquisition of information that is provided by the, in this case, virtual environment. Training, on the other hand, involves mainly responses from the user on the environment itself. Training arises from actions carried out by the user on the environment, while learning results from contextual inputs [Gorzerino et. al. 1997].

While the area of training and simulation is not at all unimportant for university level education, we believe it also might be feasible to explore how VR could be used as an educational tool to help students gain understanding of complex systems and processes, abstract models and other non-intuitive material.

Constructivist Learning Through the Use of VR

In the traditional instructional learning environment students are expected to learn by assimilation, e.g. by listening to a lecture or reading a book on a given subject. However, several authors argue that this notion is not feasible in certain situations. Dede et. al. [1997] argues that mastery of abstract science concepts requires learners to build mental models about a phenomena that often must incorporate invisible factors that represent intangible concepts, items and abstractions. One problem involved in doing this is that students generally lack real-life analogies on which to build these mental models, simply because there are no such events that can be perceived in the world as we know it. Because of that, learners cannot draw on and relate to personal experiences for these phenomena.

On the other hand, the real-life experiences that actually exist often distort or contradict the principles science students need to master. As an example, Dede et. al. [1997] mentions that the presence of friction in the world as we know it makes objects in motion seem to slow down and stop on their own, thus contradicting Newton's First Law. Physics students may because of this erroneously base their mental models on the principle that motion itself requires force, when it is in fact a change in motion that requires force.

This class of misconceptions, which applies not only to physics and science education but also to most other academic areas, is based on a lifetime of experience and is deeply rooted within a student's mental model about a given phenomenon. It seems very difficult to influence these erroneous mental models with traditional instructional methods. Instead, it might be an idea to let the students discover their misconceptions and false beliefs by themselves. VR facilitates new kinds of learning experiences that are highly perceptual in nature, and which enable the students to be immersed within a phenomenon visually, auditory and haptically. In our view, it would be feasible to create virtual environments where difficult and abstract models, intangible phenomena or intellectually demanding processes are modeled and with which students can take part and interact.

The idea is that students are better able to master, retain and generalize new knowledge when they are actively involved in constructing the knowledge through learning-by-doing. This constructivist view of learning has gained considerable ground in recent years, with supporters that range from those who see it as a useful complement to traditional methods, to those that argue that the whole curriculum should be reinvented. [Youngblut, 1998]

In the traditional academic approach, students have to learn facts, rules and examples and from that as a basis form an understanding of a phenomenon in general. Many people have problems with this, because they tend to learn whatever they are supposed to (this applies to most fields, not only science). They are in the short term perhaps even able to pass tests and exams on it, but they do not really form an understanding of the subject and because of that that they are not able to later apply the knowledge. From this weakness of the instructional approach comes the idea of exposing students to experiences that trigger insights and thus lead to better understanding of the phenomenon as a whole. However, some academics worry about the fact that this kind of understanding is sometimes difficult to articulate and hence difficult to assess on the part of the teacher and the academic world. So, while learning-by-experience is a powerful way of acquiring knowledge and intuitive understanding, it does not necessarily lead to an explicit body of knowledge. Instead, the constructivist approach tends to lead to a deeper but more unconscious type of knowledge than the instructional, which cannot be expressed or tested—at least not with the methods of assessment developed to suit the instructional paradigm. This implies that in using a constructivist view of learning, one must also change the methodology of assessment to better suit the kind of knowledge that is being developed using the constructivist paradigm.

Dede et. al. [1997] tries to approach this challenge to learning-by-experience with what he call reflective inquiry. Through experience, students can construct, extend and modify their mental models through the discontinuities between expected and actual behaviors of a given phenomenon. Before students enter the virtual learning environment they are asked to describe the phenomenon they are about to experience, and predict its behavior. When the students have experienced the phenomenon they are once again asked to describe it, e.g. to explain why what they thought would happen did in fact not happen. In this way teachers are to some extent able to assess a student's knowledge and understanding of a phenomenon, and the student is at the same time is forced to try to make his or her understanding conscious and explicit.

Examples of VR Applications Designed for Learning

As mentioned earlier, surprisingly few examples exist in the educational world of VR applications that are explicitly designed to enhance learning. A possible reason for this may be the fact that the driving forces behind the development of both VR technology and software are traditionally based around military research and space exploration, where defined processes and known chain of commands are essential while the need for understanding might be considered secondary. However, we will try to introduce a few examples below that belong to different academic fields, and which to varying degrees make use of immersive VR and the constructivist philosophy of learning. The vast majority of educational uses of VR have involved predeveloped virtual environments which students visit alone to learn some basic concept. Other educational uses require students to develop their own virtual worlds in which to explore their knowledge of a given subject. A third category of virtual educational environments include multi-user spaces and distributed VR applications, where students in groups form knowledge [Youngblut, 1998].

ScienceSpace is a collection of virtual worlds designed to explore the potential of multisensory perception, physical immersion and constructivist learning in order to enhance science education [Dede et. al. 1997]. It consists of three worlds in various stages of development; NewtonWorld, MaxwellWorld and PaulingWorld. In NewtonWorld users experience the laws of motion from multiple points of view. In this virtual environment, neither gravity nor friction is present and the users can interact with bouncing balls and see, hear and feel collisions between the balls and the virtual environment.

In MaxwellWorld, users build electrostatic fields and are able to manipulate representations of force and energy within the virtual environment. They can change their frame of reference to an egocentric view by becoming a test charge that is influenced by the forces of the electric field, and they can also experience and manipulate the phenomenon through an exocentric field of reference. One reason behind the construction of this world is that students often seem to confuse the concepts of force and energy, indicating that they do not fully understand the meaning of the representations that are traditionally used [Dede et. al. 1997].

In PaulingWorld, users can explore the atoms and bonds of a set of five different molecules, ranging from simple to highly complex. Users can view, navigate through, superimpose and manipulate these molecules to gain a better understanding of how they appear, something that is much more difficult to achieve using two-dimensional interfaces and models.

A common identifier for the three ScienceSpace worlds is that they all utilize direct manipulation and multimodal interaction, allowing students to interact directly with objects in the virtual environment without having to shift their attention from the phenomenon of interest to manipulate a menu systems or other cumbersome interfaces. ScienceSpace worlds also produce multisensory cues to convey intangible information. These have been found to engage learners and direct their attention to important behaviors, patterns and relationships. Dede et. al. [1997] also recognizes that enabling students to experience phenomena from different frames of reference appears to facilitate the learning process, and being immersed in a three-dimensional environment appears to be highly motivating for students, inducing them to spend more time on a phenomena.

A project in a completely different field, archaeology, called the Vari House, makes use of simple desktop VR technology. Two linked virtual environments show the Vari site in Greece as excavated as well as the complete Vari house as reconstructed by archaeologist. The reconstruction shows both the interior and exterior of the building, and students are guided in their exploration of the environment by answering questions that are thought to help develop critical thinking about archeology and the findings. The goal of the project is to integrate archaeological data with advanced computer graphics to support education, data analysis and the preservation of the cultural heritage of the Vari region [Youngblut, 1998].

We might identify some aspects of the Vari House project that could be enhanced by the use of fully immersive VR, which the current use of desktop VR does not have the capability to fulfill. First, allowing students to be fully immersed by the virtual environment may enhance the application, providing the users with a richer and deeper experience that could provide a sense of "being there". Second, the desktop VR approach does not allow for complete user control and navigation within the virtual environment. Third, the Vari House does not allow multi-user cooperation and communication.

Another project in the same field is called the Learning Sites project, which encompass some of the limitations of the desktop VR approach of the Vari House project. In this virtual environment, users are able to explore a number of ancient archaeological sites that have been created by rendering of precisely recorded data from the real sites [Keppell et. al. 1997]. In this virtual environment students are able to fully control the interaction with the model. For example, if a specific wall painting interests a particular user, that user may investigate that specific area in more detail while completely ignoring the rest of the site. Highly developed virtual environments such as the Learning Sites may attract users from several different fields, ranging from small school children taking guided tours in groups with their teacher, to real archaeologist doing real work, on to tourists just having plain fun. The list could go on indefinitely, but even if this still remains in the realms of science fiction, work in this direction is being carried out and the utopia might not be so far away as one might imagine.

Yet another project worth mentioning is the Zengo Sayo. This is a virtual Japanese-style tatami room that is designed to provide an approach to teaching some basic aspects of the Japanese language. The Zengo Sayo makes use of immersive VR, and is aimed towards college students [Youngblut, 1998]. This field of application should prove a very promising area for VR, since it is a commonly held view that it is difficult learn to speak a language without being immersed into an environment where the language is spoken. VR opens up tremendous possibilities in this area. Imagine being able to put on your head mounted display and be immersed into a French café or why not a smoky English pub, and be able to interact and communicate within the environment.

As a last example, the Global Change project intends to develop knowledge and understanding of basic relationships among causes and effects of global environmental change. The immersive virtual environment contains different views of the Seattle area, and through inquiry based scenarios the users are allowed to change the levels of a host of variables such as industry and cars. The users can see the effect of these factors on the environment, and they are able to move back and forward in time. If not else, the Global Change project shows that learning and simulation is not always easy to differentiate between, and more importantly: this differentiation is not always necessary. This example expands the use of VR in education to the social sciences as well, and we may imagine numerous other possibilities in this field, including politics and economy to mention a few.

5. Summary

In this paper we have tried to describe an ongoing research survey on educational uses of Virtual Reality (VR). We are particularly interested in VR applications that focus on learning and understanding, while issues of training and simulation have been considered with less interest.

We have examined some of the benefits of using VR compared to other learning techniques. These include the ability to change one's frame of reference; the ability to make changes in the relative sizes of the user and the objects in the virtual environment; the multisensory nature of immersive VR that allows the user to interact with the virtual environment in several ways simultaneously; and the fact that VR allows for the creation and visualization of representations of objects and events that have no physical form in the real world.

We have found that the constructivist philosophy of learning and learning-by-doing often goes hand in hand with the possibilities virtual environments encompass. However, questions have been raised as to what extent it is possible to combine a constructivist learning methodology with assessment techniques that still remain in the traditional paradigm of instructional teaching. It has been noted that in order for the ideas of constructivist learning to succeed in education, we need to carefully examine and design assessment methods that make the deep but implicit knowledge students gain in constructivist learning conscious, visible and possible to assess.

The last part of the paper introduced some existing examples of applications where different aspects of the possibilities of VR were discussed. These examples include the ScienceSpace worlds, the Vari House project, the Learning Sites Project, the Zengo Sayo and the Global Change project. In the gaps that exist between the projects described, a host of new possibilities are not difficult to imagine.

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