A theoretical and a technical framework for the development of Virtual Reality Educational Applications

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Keywords: *3D games*, *constructivism, immersion, learning factors, virtual reality (VR)*

Abstract:
The paper examines virtual reality as an instructional tool from a theoretical and technical point of view. The main factors that participate in the educational process are defined. The importance of virtual reality in the learning process is determined, taking into account its compatibility with constructivism. The paper also analyses technical maters that concern the hardware and the software for the development of virtual reality applications. The main categories of software tools are presented. Finally, the reasons for which 3D games can offer satisfactory and cost effective solutions in the creation of virtual reality applications are pointed out.

1 Introduction

Computers are used for many years in education. The exceeding enthusiasm for their capabilities but also the excessive reservations for their pedagogical value, all symptoms of their initial stages of use in education, gave place to a fertile reflection regarding their role. Technology however, more than any other sector of human activity, develops with a rapid pace. This development on one hand and the new pedagogic perceptions on the other, bring us close to a turning point concerning how we conceive the learning process. This turning point involves the utilization of a group of hardware and software technologies under the general term “Virtual Reality (VR)”. VR can function as an instructive tool able to include many -if not all- parameters of the educational process. This happens because as a medium is particularly adaptable, ductile and flexible. We think that these attributes make it a powerful educational tool that can be used by almost all learning theories and in every educational environment.

2 Learning factors

Regardless of the way that we view the learning process, four main factors that participate in it can be identified. These are:

- Theoretical basis, which consists of the main principles of a learning theory. It sets the aims of the educational system and determines the methodology that is followed in order to accomplish them.
- Means of implementation that include all the tools that are used to implement teaching according to the way that the theoretical basis determines. Means can be separated into living and inanimate material. Educators/teachers constitute the living material. Their personalities, the thoroughness of their training, their relations with their pupils, are some of the factors that play an important role on the outcome of the educational process. In the inanimate material, we can classify all types of printed material, teaching aids, computers, etc.
- Pupils that are the target group of every educational system. Their performance can be influenced -among other- by their temperament, their economic and social background, and their attitude towards education.
- External factors that are all other factors that even though not immediately related with the above, can affect the training process. Such external factors are the social milieu (other pupils, friends, parents, relatives, etc), the environment (school, geographic region and climatic conditions), the period during which the educational process takes place and also political and economical conditions.

The complex relations between the above factors, their interdependences, as well as the many variables that can influence them, render learning an exceptionally delicate process. The slightest change in a variable of one and only factor, can lead to cognitive results that are very different if not opposite to the expected ones. For example, a learning theory that imposes a certain teaching methodology, which however does not match the temperament of certain students, results in non-effectiveness.

Usually, for research reasons, few variables from one or more factors are isolated and examined. Although this seems to be reasonable, it always leaves doubts for the accuracy of the experimental outcomes. An evidence for the correctness of this statement is the significant number of learning theories

[1]. All of them claim that they describe adequately knowledge acquisition and they propose effective models for the learning process, despite the fact that they have minor or major differences. Another clue of the doubtful catholic application of learning theories is the everyday practice of schoolteachers. Schoolteachers follow a wide range of teaching methods based on different theories, which they reshape dynamically according to the conditions that prevail in classroom at any given time. This can lead to the extreme conclusion that either all-learning theories are right, or that they are all wrong. The answer is somewhere in the middle. There is not only one theory, which perfectly describes the learning phenomenon.

3 Virtual Reality

The study of the ways according to which students interact with the content, gives rise to the hypothesis that knowledge is constructed and not simply transmitted through teaching. Constructivism, although not a single and recollected theory, supports this concept, admits that each individual creates his/her own representations of the world, acknowledges that we learn via active exploration and finally points out that learning is a dialectic and interactive activity with our social environment [2] [3]. Constructivism provides enough ideas on how we can archive the above using a computer, mainly not having pre-constructed interactions and limits in the exploration of the learning environment [4].

Virtual Reality (VR) places the user in a synthetic 3D environment without restrictions -same or completely different from reality- where she/he is free to select her/his own path, to freely explore anything, whenever and whichever way he likes. Thus, the user creates reconstructions of the synthetic world that she/he encounters. Learning in such an environment is a dynamic process determined by the user who sets the aims and changes them at will and the outcomes of the training process differ from individual to individual.

Also, one of the important characteristics of VR environments is the coexistence of more than one user. This coexistence is not limited in the simultaneous but separate exploration of the synthetic environment; instead users can talk, collaborate and guide each other. Therefore VR is compatible with the constructivist concepts. Causes of this compatibility are interaction and immersion.

There is a lot of debate between the experts engaged in VR for the role of immersion [5] [6]. Immersion is the phenomenon at which the senses of a user are manipulated in such a way, that she/he thinks she/he is actually present in the virtual world. The degree of immersion depends on the devices that are used and determines the type of VR (desktop, semi immersive, fully immersive). The experimental data lead to contradictory conclusions regarding the importance of the degree of immersion for the achievement of specific educational objectives. Thus, it is possible that the increased interaction with the virtual environment has the same or greater importance, or that the combination of both factors adds to the particular value of VR. In any case, what is certain is that an application does not need to be considerably modified in order to change the type of immersion in which it belongs.

Having such a powerful educational tool at our disposal, one would think that there would be a great number of VR educational applications. However this is not true. The cause is not the failure of applications to have satisfactory cognitive results but the cost of such applications and the cost of VR's equipment. The rule that each next computer generation is cheaper and yet more powerful than the previous one, does not apply in VR. For an electronic device to become more accessible at its cost, there should be an increased supply of it. Since VR is based exclusively on 3D graphics, powerful and expensive computers are required. Today a typical VR system (hardware and software) has an average cost of around 140,000€ [7] and the acquisition of a complete VR system is economically unaffordable for the average/typical user. Consequently, the initial high interest has been limited. In addition, the majority of research efforts were focused in certain types of VR (i.e. immersive VR, augmented VR) that required much more expensive equipment.

The last few years this situation seems to change. Powerful graphics cards with a reasonable cost equip home computers. Certain VR devices are promoted in the market for home entertainment (i.e. i-glasses). The driving force behind these developments is the entertainment industry that continuously seeks ways to attract consumers' interest. At the same time, there is also a change in the software that is needed for the creation of 3D applications, so that much more popular programming tools are used (C++, VRML). All these contribute to the rebirth of interest for VR and make us optimistic that shortly its applications will know a wider spread.

4 Creating a VR application: Hardware issues

We consider VR to be the long awaited evolution in educational technology. For this reason we must discover ways so that the necessary hardware and software is easily accessible not by few experts in the field, but by as many people as possible, allowing for a great number of its applications to be developed. Let us consider a typical VR application, for example a virtual city and for the argument's sake let us have as a prerequisite that this application will be executed not in an expensive multi-processor, multi-graphics card system, but in an advanced home PC. We will set the requirements from the hardware according to the demands of the application and examine if these requirements are met:

- Sound: As far as sound is concerned, we need multi-channel, multi-directional sound, in order to recreate sound conditions that prevail in a city (i.e. cars that pass over). Any typical sound card with a 5.1 or 6.1 outputs complies with Dolby Digital or DTS standards and thus directional sound is not a problem.
- Network: We need the presence in the application of two or more users. So, their computers must have network cards for a LAN connection, or modems for an Internet connection. A typical network card can handle 10 -100 Mbits traffic, which is adequate. On the other hand, only high-speed Internet connections provide the appropriate bandwidth in order to have real-time graphically intense applications.
- Display: According to the prerequisites of our scenario a 19" monitor or a video projector is enough.
- Processing speed-memory: All 3D graphics applications are processor and memory demanding ones. Therefore, there can be no compromises to the processor speed and the amount of memory.
- Graphics: As our setting requires, a virtual city has a lot of static (buildings) and moving objects (cars, people), multiple light sources (sun, car and road lights), realistic representation of objects and changing weather and light conditions. The ideal situation would be a graphics card to be able to handle: (i) 32-bit colour depth, (ii) at least 1024X768 screen resolution, (iii) 85Hz minimum refresh rate, preferably 100Hz or more, (iv) high resolution multi-layer textures, (v) multiple light sources, multiple shading of an object, (vi) high polygon count 3D objects, (vii) millions of moving polygons per second, (viii) 25 frames per second, preferably 50 or more, (ix) visual effects such as fog, smoke, reflections, (x) stereoscopic viewing, all at the same time.

The real problems arise by realizing that there is no graphics card that can handle all the above at the same time. To make things more complicated, one must consider that realism is a subjective parameter. For example, complex shading is important for some users and at the same time others can ignore it. For that matter, our hypothetical application will have to be capable for adjustments in the quality and realism of the virtual world and to use certain tricks to bypass the hardware problems such as:

- Colour depth can de reduced to 16bit. Resolution and refresh rate can also be reduced. It must also be possible for secondary shades and lights to be selectively ignored.
- High polygon count objects increase the number of calculations made by the graphics card. Different models of the same object will have to be used, in relation to their distance from the user (detailed models when the object is near, low polygon count models when the object is far). The same applies for the quality of textures.
- What the user does not see is not necessary to be drawn or calculated. Whole parts of our virtual city are invisible most of the time. Also, the initial world can be broken in smaller parts that are loaded only when the user "visits" them.
- Through the set-up of the application, the user must be able adjust hardware and especially graphics card settings in order to archive a good balance between performance and quality.

The only thing that cannot be compromised is the frame rate. 25fps is the minimum in order to create the sense of smooth and continuing movement, which is due to the after sensation phenomenon. This value must be archived even when there is a significant number of objects present in the viewpoint of the user. Concluding the presentation of hardware issues, we must underline the fact that in a few months period all the above will be probably obsolete due to constant developments in hardware technology and it is certain that less compromises will be necessary.

5 Creating a VR application: Software issues

After the analysis of hardware requirements, we should examine the various software categories for the development of VR applications, their advantages and disadvantages. One should still have in mind that like our initial hardware requirements, software must also be accessible by as many people as possible. We can distinguish five software categories:

Programming: Creating a virtual world using a programming language is the most difficult approach. The programmer has the absolute control over the various elements of the application, but excellent knowledge of the programming language is required. Among many languages, C++ and VRML are the most popular in creating virtual worlds. The former is a powerful language suitable for all kinds of applications and not only for VR. The later was created especially for VR applications and is an open source language. Despite good intentions of the VRML community, many of its goals are yet to be achieved. The main disadvantage is that VRML applications are Internet oriented. Due to limitations in users' bandwidth, VRML 3D models are not detailed ones, frame rates are low, and the realism of the virtual world is also low. Another drawback is that the browsers that are required in order to view VRML worlds leave a low sense of realism.

360º Panoramas: The general idea in these programs is that one can stitch together photographs so that they cover a complete circle. The usage of photographs allows a high degree of realism, but that's the only advantage of this method. 360º panoramas are not 3D applications, the user can only rotate his viewpoint, and there is no interaction and no exploration of the virtual world.

Rendered walkthroughs: A rendered walkthrough is a video/film of 3D objects, which are rendered along a pre-defined path. The designer can break the film into many scenes that have small duration. By doing so he can overcome the limitations of the hardware and he can use highly detailed models. The final product though, is not an interactive and explorable virtual world, but more or less a movie.

VR development software packages: From the above categories, the most satisfactory solution is provided by programming in C++, however it is the least practical. To overcome this problem, there are software packages that provide the designer with an ergonomic and windowed environment, while in the backstage the virtual world is compiled in C ++ or other C++ variants. The advantage of such an approach is obvious. A powerful programming language is used and at the same time good knowledge of it is not required. However, if the software package does not provide a feature the developer wants, the programmer can always access the programming language and write by him the necessary code. The development process is accelerated with libraries of 3D objects and object attributes, which are included within the software package. There are certain drawbacks though. Although these programs claim that the minimum requirements for running their applications are that of a typical-advanced PC, in reality, complex worlds with a significant size, require sophisticated Personal Computers (PCs). The cost of such programs is considerable. None of them includes all the features a designer would like. There are compatibility issues, so that the editing of a virtual world developed with one program is impossible by another. Finally, the economic crisis that struck VR software houses during the years 1999-2000 led many of them to bankruptcy and so supporting and upgrading of these programs is problematic, if not inexistent.

Supplemental programs: These are external programs (i.e. 3D Studio Max, Lightwave, Photoshop, etc) that allow the creation of 3D objects, images, sounds and music. These elements are then imported in the program that is used for the development of the virtual world. 3D content creation programs have a significant cost and are not addressed to novice users.

From this short presentation of VR software categories, one can understand that for the creation of interactive VR applications, the use of a software package seems to be the appropriate solution, mainly because of the friendly developing environments they provide. However, choosing among the available packages is not an easy matter and many variables must be weighted.

6 3D Games

It seems that there is a cul-de-sac concerning the mass development of VR applications. Even if we set aside hardware issues because of the constant development in this area, still the content development software is addressed to specialized systems and expert users. Yet there is an area of applications not related to VR, which is capable of providing relatively easy-to-use and cost effective tools for the development of VR applications. This area is computer games and specifically "first person shoot them up's". The general idea of these games -as the name implies- is the user to eliminate a number of "enemies", solve puzzles and avoid traps in order to "stay alive" and advance to the next level. The user is in a 3D environment and has a first person view of it. This means that he can only see his hands and parts of his body, as we do in the real word. Most importantly, this 3D environment is up to a degree interactive and can be partially or totally explored. One can recognize that these are also the fundamental characteristics of a VR application, which provide its important educational value. These similarities are not the only ones. There is a number of common characteristics that VR applications and 3D games share, that make the boundaries between the two very difficult to discern and in some cases 3D games offer more features than VR applications:

These characteristics are:

- World. The world is the area where all the objects reside and all the events take place. In both cases a common practice is to break the world in "levels" in order to archive better hardware performance and better handling of the world.
- Interactions, triggers, events and scripts. In a 3D game interaction with an object is closely related to the trigger-event concept. For example when the user touches a door, he activates a trigger, which results in opening it. Though there is no limit to the number of triggers and events, placing and setting their operation requires a great deal of work. In VR applications programming or scripts are used for defining the behaviour of objects and their function is the same as in trigger-event system.
- Non-playable characters. These are objects that bring the world to life and have certain behaviour, although they do not play a particular role in it and is not necessary to interact with the user (i.e. cars, people, animals, etc). Their actions are the result of the use of complex automatic trigger-event systems or scripts that also take care of their reactions in case of unforeseen situations (i.e. collision with another object).
- Sound and music. Usually in 3D games sound and music play an important role in creating the game's "atmosphere". Anyhow multi-channel sound is supported in both types of applications.
- Degrees of freedom, cameras. The user has 6 degrees of freedom of movement in both cases. He can look up or down, turn left or right and move forward or backwards. She/he can also walk, run or fly. The user can also have first or third person view of the world. All these are the result of a camera placed in front or behind the representation of the user. Cameras can also be placed in other objects, providing different aspects of the world.
- Network support. One of the most interesting features of 3D games is the support of multiplayer gaming and as in VR applications users can interact with each other. What is important is the way that games handle network traffic. Instead of transmitting graphics and sound, they constantly transmit the coordinates of each player in the world and the world is drawn locally in each player's computer. Therefore network traffic is minimal and there is no need for high-speed connections. An interesting side effect of this method is that the course of the game can be recorded and replayed not as a hard disk consuming video file but as a set of sequential coordinates that uses far less hard disk space. This feature can be very helpful either for research or for educational purposes.
- Hardware set-up. Fine tuning the user's hardware is a very detailed feature in 3D games. The reason is that they are addressed to the average user who usually has an average or advanced home PC. Hardware set-up is less detailed in VR applications, which are by default running in advanced systems.
- Ergonomics, special devices. VR applications use specialized equipment in order to make the computer invisible to the user. In games the same applies but not with the use of these devices. There is an effort to use just the mouse or few keys in order the game to have a small learning curve. In addition, joysticks or D-pads totally replace the mouse and the keyboard and their function is quite similar to that of VR navigation devices. Finally, glasses that are used for stereoscopic viewing are the same in both cases.

The differences between VR applications and 3D games are minor, can be easily eliminated and result from the different target groups they are addressed to:

- Plot. Games have a plot, a scenario that leads the player to certain actions and a predefined direction. She/he has to accomplish a given mission in order to advance to the next one. In essence, games are linear in their plot course, despite the fact that there are some games with random events or different endings. In educational terms this is unacceptable, because it contradicts to constructivist concepts. In technical terms, the plot is the result of the trigger-event system. If the user activates specific triggers in a specified sequence in some point of the game, then the scenario advances. Omitting these triggers eliminates the plot. The content developer has to decide if it is appropriate and how to use plot advancing triggers.

- Violence. This is the main element in almost all 3D games. The commercial success of the game depends on how impressive the "enemies" and how lethal the "weapons" are. As in plot, violence in a game is a technical matter. It depends on the use of a group of object's attributes that allow the infliction of damage to other objects. If the damage reaches a predefined value, the object is "killed". The developer can choose not to give values to these attributes, thus eliminating violence.
- Support. Technical support and documentation are crucial for the development software as well as for the functionality of the application under development. All VR software houses provide technical support for both in many forms (i.e. hot lines, on line help, FAQ, examples, users' fora, etc). In games, support provided by the software houses is substandard. The difference is that since games are more widespread applications, there are independent fora with thousands of users eager to provide help to those in need.

Games are created in two ways. The first is to use game development software packages. There are several types of such packages. If they are commercial, they have small cost compared to that of VR software packages and in some cases when they are used for educational purposes, they are free of charge. Their major disadvantage is that they usually are one step behind the hardware and software developments. If they are open source projects they are totally free of charge, but in various stages of development and immature.

The other way is to use the same software tools that the game company used for the creation of the game. These tools, most of the times, are included in the game package. One might wonder for what reason a company would reveal and allow the use of them. The answer is quite simple. It is done in order to extend the commercial life of the game and increase sales. After finishing the game, users can create their own levels and distribute them freely, thus keeping the interest for the game on high levels.

The major advantage of using such tools is that they utilize the latest developments in hardware and software. Another point worth mentioning is that one can use all object libraries that are included in the game or create new ones with the help of supplemental programs. Learning the use of these tools is easier in comparison to VR packages. Finally, what we have learned from our own experience in the field is that the users' fora can provide priceless help, especially when the game is very popular. For all these reasons we believe that 3D games provide satisfactory and cost effective solutions in the creation of VR applications.

7 Conclusions

We have set the theoretical framework for VR applications proving their compatibility with the philosophy of constructivism. However, we believe that VR is something more than a simple tool of implementing perceptions imposed by one and only learning theory. There are specific reasons that allow us this opinion.

VR affects immediately the senses and gives an active role to the students. Thus it acts in the initial phase of the training process, functioning more as "vehicle" of senses, an amplifier of experiences, and not as just as a cognitive tool. This fact and only renders it independent from educational theories [8]. A second reason is that with minor changes, a VR application can satisfy the characteristics of one or more learning theories. If the virtual environment can be completely explored and if it is fully interactive, then it satisfies the concepts of constructivism. If however, we limit interactions to certain objects or place triggers and events that create a plot, determining by this way specific paths, then the same environment satisfies the principles of cognitive theories. If we add elements of reward to students, such as the number of right answers, with the form of a score, perhaps somebody distinguishes influences from another learning theory. Parts of the application are possible to move to the one or the other direction.

It is important to have different instructive philosophies in the same application. So far we did not have at our disposal a single tool for the experimental comparison of various theories. Each researcher implemented an application having as a basis the pedagogical perceptions of his choice and applied them on a target group. Completely different applications were implemented by other researchers and applied to different target groups. Comparing the results of these applications is a very difficult -if not impossible- task. VR applications allow us to realize the same subject in different ways and combinations. Consequently we have the opportunity of obtaining comparable results.

As for shaping the technical framework, we have set as prerequisite VR applications to be easily accessed and developed by anyone interested. For this reason we specified the hardware requirements concluding that with some adaptations it is possible for an advanced home PC to run such applications.

The use of a VR environment by the student does not present particular problems, since that that there is no need to learn the use of a computer, but only the use of certain devices designed in such a way that they are compatible with our actions in the real world. However, it is true that it is very difficult -and economically unadvisable- to equip an entire classroom with such devices. Also, potential health problems [9] during the use stereoscopic viewing glasses and i-glasses make us careful, at least until important improvements take place. The use of common computer peripherals, such as joysticks or D-pads, significantly reduces the cost, without compromising the feeling of immersion.

Our major concern is the software that is needed for the development of VR applications. We examined the available solutions and found that the most complemented one is VR development software packages. Important disadvantages though, forced us to seek for a better solution in unconventional areas. What we found out is that "first person shoot them up" games and the tools that are used in creating them have many characteristics that belong to the field of VR. The analysis comes to the conclusion that this type of game developing tools has nothing to envy from the sophisticated -and costly- VR development software. Thus, we have already started using such tools with good results.

Contrary to what happened in the past, we are expecting important developments in the field of VR. When it comes to computers, developments need very little time in order to be expressed. Characteristic for the situation it is the Moore's "law" which states that the calculating power is doubled every eighteen months [10]. With this fact in hand and the concrete validation of the pedagogical value of VR, we expect it to play a decisive role in educational technology in the next years.

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ISBN
3-89958-029-X

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http://www.icl-workshop.org

Bibliographic information published by Die Deutsche Bibliothek

Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie;

Detailed bibliographic date is available in the Internet at http://dnb.ddb.de

Kassel university press GmbH

www.upress.uni-kassel.de

FACHHOCHSCHULE TECHNIKUM KÄRNTEN

International Workshop ICL

Interactive Computer Aided Learning

2003

Learning Objects & Reusability of Content

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Editors
Michael E. Auer, Ursula Auer