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Development and Evaluation of a 3D Virtual Environment for Teaching Solar System's Concepts

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Abstract

The study examines the development and use of a 3D multiuser virtual environment for teaching solar system's facts and concepts. The objective was firstly to examine the environment from a technical and utilitarian perspective and secondly to examine whether the learning objectives of the teaching material were achieved. The virtual world was created with the use of the open source platform OpenSimulator. Two groups of randomly selected students from the Department of Primary School Education, University of the Aegean, were formed. The first group was given the application, while the second group was given the same cognitive material, but this time a much simpler online presentation program was used. The results are considered satisfactory. Both groups showed significant progress regarding their knowledge of the solar system, but the first group had better results compared to the second.

Keywords

Virtual Reality, 3D Virtual Environments, Solar System, Constructivism

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1. Introduction

Science subjects involve a wide range of different disciplines such as physics, mathematics, biology, computer science, etc. However, several surveys that have been conducted, show that school students, university students, as well as teachers, have difficulties in understanding science's concepts.

Focusing on the field of astronomy, it is worth mentioning that several surveys among students and adults, examined and noted several problems and difficulties in understanding concepts related to celestial phenomena and astronomy concepts in general [1, 2, 3, 4]. For example, first grade primary school students believe that the Earth is flat and on top of it lies the sky, the Sun, the Moon and stars. Older students know that the Earth is a sphere, but they still can not understand the motion of the Sun, the Moon, as well as the rotation of the planets [5].

Other research studies concluded that students are not usually able to realize concepts such as the size of the planets and the distances between them and the Sun. At the same time, students do not understand that the Sun is at the center of our solar system and they also believe that it is unique and qualitatively different from other stars in the galaxy. Finally, a difficulty was observed in correlating the Sun to the Earth, but also in understanding that the planets revolve around the Sun almost at the same direction [6]. Moreover, research shows that knowledge related to astronomy acquired by students, is not enriched after their graduation [7].

According to the literature review, the traditional teaching methods used in schools are not adequate to address these difficulties, mainly because of the lack of appropriate equipment and teaching materials. For this reason, the modern

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pedagogical approaches, seek new tools that can contribute to a better understanding of the aforementioned concepts and phenomena. In this context, Virtual Reality (VR) can be an important tool, since it is a 3D simulation, where students come in contact with artificial environments, which give them the ability to discover and use knowledge [8].

2. Virtual Reality and Education

VR is a relatively recent technology that started in the early '90's. It is associated with the development of systems that "fool" the human senses; users have the feeling of being in a real world [9]. It is important to mention that the VR is a concept that has preoccupied many scholars and several definitions and terminologies have been introduced in their effort to define what it is exactly. VR however, constantly acquires new features; therefore its various definitions are adjusted accordingly.

VR is the simulation of a real or imaginary environment with the contribution of the computer. Thus, from a purely technological perspective, VR is "a set of hardware (computers and special devices) and software (graphics and animation programs and special virtual world development projects) with which people are able to visualize and interact with highly complex data in three dimensions" [10].

VR is essentially an artificial high level 3D display where different synthetic realities can be created, based on three main features: immersion, interaction and imagination, the "3i":

• Immersion: Is the degree at which the person is integrated into the virtual world, the illusion of being in it, disregarding the external stimuli of the real world.

• Interaction: Is a key feature of VR, since if there is no reaction of the environment according to the user's movements and input, there is no VR.

• Imagination: Real as well as imaginary objects and environments can be realized in a VR application. So, the user can set his imagination free [11].

The introduction of Information and Communications Technology (ICT) in education radically changed the way teaching is conducted. Teachers adopt new ways of teaching, more constructive and effective than the traditional methods [12].

The ICT based learning environments contribute to a better understanding of a subject and in bridging the gap that exists between the activities within the school premises and the authentic cultural activities [9]. However, to promote the construction of knowledge, students should have opportunities to explore and influence the learning environment [13]. Constructivistic learning environments include opportunities for dialogue among students. Conversation and speech, not only strengthen cooperation, but also support social negotiation in learning [14, 15, 16]. This in turn, enables learners to share information, test ideas, and reflect on learning [15]. Moreover, the constructivist learning environments provide standards and templates for promoting the development of problem solving skills, as well as tools for collecting information so as to enable students to have a quick access to relevant information [16].

Here lies the significance of VR, since it enables users to create, manage and edit 3D virtual objects, encouraging students to express their personal thoughts about the world, but also to construct their knowledge [17].

In studies carried out on the use of VR in education, it was found that interactive 3D virtual worlds support constructivist learning activities, allowing students to become active learners [17, 18]. Furthermore, surveys that have been conducted found that both the sense of presence and activities in virtual environments enhance and attract the interest of students and as a result the educational process is more effective [19, 20, 21].

In a virtual environment, students can chat in real time with their distant classmates. They also receive immediate feedback from the remote teachers. Based on these shared virtual environments, the simultaneous display of educational material allows the active participation of all individuals in group discussions regarding the learning content [22].

Meanwhile, VR enables teachers to tailor the teaching material to the needs and learning styles of each student so that they can learn at their own pace, without having to follow the tight time framework of the school program [10, 15].

3. Rationale and Development of the Application

Having in mind the aforementioned, a questionnaire was formed in order to evaluate what pre-service teachers know about the solar system. It consisted of 23 questions, divided in 6 categories (1 question about the number of planets, 3 questions about the Sun, 9 questions regarding the planets (one of them splits into 2 parts), 2 questions about dwarf planets, 7 questions regarding satellites (one of them is open, so it is not included in the tables) and 1 question about planetary missions). This diagnostic questionnaire was given before the beginning of the research project to a random sample of students attending the Department of Primary School Education, University of the Aegean (N=48). The aim was to confirm previous research findings about the level of knowledge in astronomy topics.

Table 1. Students' performance in the initial questionnaire.

Category	Average of Correct Answers per Category (N)	Performance (N%)
Number of Planets	0.29	29
Sun	1.27	42.3
Planets	2.96	29.6
Dwarf Planets	0.46	23
Satellites	1.125	18.75
Total	6.1	27.7

Result analysis confirmed that most students' level of knowledge regarding the solar system is very low. For instance, only 18.75% of students answered correctly the questions about satellites of our solar system. Regarding the question about the missions carried out for the study of our solar system, 70.8% of students were not aware of any mission.

Having also in mind that 3D virtual environments facilitate knowledge acquisition, it was decided that such an environment regarding the solar system was going to be developed. The diagnostic questionnaire directed the application's content, since the focus was on subjects where students showed poor results.

The second step was the construction of the virtual world, using the platform OpenSimulator. OpenSimulator (Opensim) is an open source project that is based on the technology of Second Life (SL). It allows the construction of multiuser 3D virtual environments using various technologies, compatible to SL. The total area of the virtual world was 768 x 768 meters.

Three levels were created. The first has an observatory where the students got the first piece of information about the solar system through images (Figures 1 & 2).

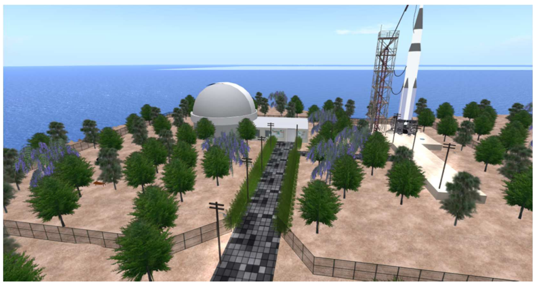

Figure 1. The first level of the application.

Figure 2. The interior of the observatory.

The second level was the first depiction of the solar system, including the Sun and the eight planets. Students could observe the movements of the planets, around their axis, as well as around the Sun (Figure 3). The planets were designed on a scale of 1:15.466.730, however, due to the limited size of the virtual world, the distances of the planets from the Sun remained relevant but not scaled.

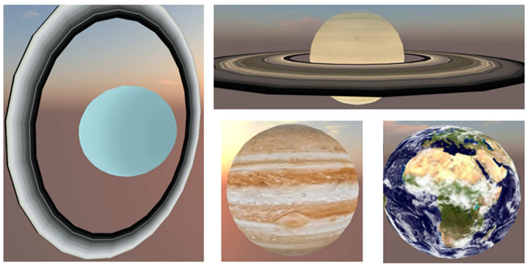

Figure 3. Uranus, Saturn, Jupiter and Earth, as seen from the second level of the application.

The third level was the second illustration of the solar system, including the Sun, the eight planets, Pluto, some satellites as well as the spacecraft Voyager. At this level, students were informed about the solar system, by reading the information, observing the objects, seeing slides and watching related videos.

At the final stages of the development, scripts were used, that added interactions to the application (i.e. welcoming and greeting the user, allowing the user to watch videos, etc.). Finally, instructions on how to use the application were added. After the application was completed, it was given to a small group of users to test its integrity and minor adjustments and improvements were made.

Below is the breakdown of the time needed for the development of the application (Table 2).

Table 2. Total construction period of the virtual world.

Construction Stages	Hours
Material Collection	20
Object construction	60
Script addition	30
Image addition, videos, web pages, NPCs	15
Application control	4
Minor adjustments-Improvements	6
Total	135

As one can observe in the above table, the most time consuming procedures were the collection of the cognitive material, the construction of objects and the addition of scripts. The development of a virtual environment is quite a lengthy process, however, long term benefits of its use may arise, since it can be used several times.

In parallel with the development of the virtual world, an online presentation was produced, containing the same cognitive material (images, videos and information) the virtual world had. As a result, two teaching methods were devised (virtual world and online presentation).

4. Research Design and Procedure

The sample of the study consisted of randomly selected students of the Department of Primary School Education, University of the Aegean, who were divided into two groups of 20. In both groups there were 17 women and 3 men. The first group was going to use the 3D application, while the second group was going to use the online presentation.

For data collection purposes a total of 3 questionnaires were formed. Questionnaires 1 and 2, were distributed to both groups, before and after the provision of information and the distribution of the virtual world, aiming to test the knowledge of students about the solar system. The second questionnaire was formed based on the first one, so that data could be comparable.

Questions in both questionnaires were organized in categories, as presented in the table below (Table 3).

Table 3. Questions categories in Questionnaires 1 & 2.

Category	Questionnaire 1	Questionnaire 2
Number/order of Planets	1	1
Sun	3	4
Planets	10	14
Dwarf Planets	2	3
Satellites	7	23 (grid questions)
Planetary missions	1	8

Questionnaire 3 included questions for the technical and utilitarian evaluation of the virtual world and explored the views of students regarding their experience. This questionnaire was given only to the first group.

Regarding the application's administration progress, a meeting with the first group was held, where a presentation of the virtual world was made, in order to familiarize students with the environment and its use. This process lasted about an hour.

Each group had at its disposal one week to study the information either by exploring the virtual environment or by viewing the online presentations. At the end of the week the students of both groups were given Questionnaire 2. To avoid possible “cheating” and to ensure the reliability of the survey, both groups were gathered at the University's Computer Laboratory at a specific day and time and completed the questionnaire. In addition, the first group was given Questionnaire 3 to assess their experience. Having completed the above procedure, data analysis followed.

5. Result Analysis

In order to calculate the performance in each category of questions, as well as the overall performance of students, the average (percentage) of the correct answers given by the students had to be calculated. As already mentioned, the questions of both questionnaires were organized into 6 categories: Number and Order of Planets, Sun, Planets, Dwarf Planets, Satellites and Missions (carried out for the study of our solar system).

Overall, in Questionnaire 1, students (N=88, students of both groups and the initial random sample) answered correctly 6.69 questions out of 22 (score 30.4%), on average. The performance of students per category and the overall performance is presented below (Table 4). It is worth mentioning that in the category on planetary missions, 73.9% of students were not aware of any mission at all (the question in this category was open, so it is not included in the table).

Table 4. Students' performance in the initial questionnaire.

Category	Average of Correct Answers per Category (N)	Performance (N%)
Number of Planets	0.43	43
Sun	1.33	44.3
Planets	3.15	31.5
Dwarf Planets	0.53	26.5
Satellites	1.25	20.8
Total	6.69	30.4

Regarding the progress of the first group of students, who had access to the virtual world, it is considered important. In Questionnaire 1, students answered correctly 7.9 questions out of 22 (score 35.9%), on average. In Questionnaire 2, the correct answers were 50 out of the 53 (score 94.3%), on average (Table 5).

Table 5. Performance of the first group.

Category	Questionnaire 1		Questionnaire 2	
	Average of Correct Answers per Category (N)	Performance (N%)	Average of Correct Answers per Category (N)	Performance (N%)
Number/order of Planets	0.65	65	0.9	90
Sun	1.4	46.7	3.75	93.75
Planets	3.55	35.5	13.15	93.9
Dwarf Planets	0.7	35	2.75	91.7
Satellites	1.7	28.3	22	95.65
Planetary missions	-	-	7.45	93.125
Total	7.9	35.9	50	94.3

With regard to students' progress in the second group, which had access only to the online presentation, it was also important (Table 6). In Questionnaire 1, students answered correctly 6.9 questions out of 22 (score 31.36%), on average, while in Questionnaire 2 the correct answers were 43.75 out of 53 (score 82.55%).

Table 6. Performance of the second group.

Category	Questionnaire 1		Questionnaire 2	
	Average of Correct Answers per Category (N)	Performance (N%)	Average of Correct Answers (N)	Performance (N%)
Number/Order of planets	0.55	55	0.45	45
Sun	1.4	46.7	3.5	87.5
Planets	3.2	32	11.7	83.57
Dwarf Planets	0.55	27.5	2.3	76.7
Satellites	1.2	20	19.65	85.4
Missions	-	-	6.15	76.875
Total	6.9	31.36	43.75	82.55

Table 7 shows the performance of the two groups per category, as well as overall performance (percentage of the average of correct answers), in Questionnaire 2.

Table 7. Students' performance in both groups.

Category	Average of correct answers of the first group (%)	Average of correct answers of the second group (%)
Order of planets	90	45
Sun	93.75	87.5
Planets	93.9	83.57
Dwarf Planets	91.7	76.7
Satellites	95.65	85.4
Missions	93.125	76.875
Total	94.3	82.55

As one can observe, the first group of students had relatively better overall performance compared to the second group. However, despite the performance of the two groups being similar, in some questions there were notable differences. In particular, significant differences were observed in the category of dwarf planets (91.7% and 76.7% respectively) and in the category of missions (93.125% and 76.875% respectively). The greatest difference was observed in the first category, about the order of the planets, where the first group had 90% correct answers, while the second group only 45%.

Finally, regarding the third questionnaire, students made positive remarks for the application (with 65% stating that its most "strong" point was the organizations of the virtual world). 55% claimed that they found no "weak" points, while 20% experienced application lagging (unsatisfactory application's display speed). 25% stated they did not encounter any difficulties, while a significant percentage (40%) had difficulties in handling the avatar.

Nevertheless, the majority of students (80%) did not face any problems regarding the virtual world. Moreover, students stated that the application did achieve its educational goals. The average time that students spent for the exploration of the virtual world was about two hours.

Overall, several positive and negative characteristics of the virtual worlds were acknowledged. Indicatively, regarding the positive characteristics the following were mentioned: they visualize situations that in reality their approach is difficult and/or impossible, they are attractive, they offer realistic visualization of situations, they stimulate the students' interest, the student chooses when and where to learn etc. On the negative side, the following were reported: specialized knowledge is required by the user, it takes a long time to be developed, it requires powerful computers and technical problems may arise. It is worth mentioning that 25% of the users considered that the 3D virtual environments have no negative aspects. Finally, 95% of the students stated that they would use a virtual world in their teaching.

6. Conclusions

Initially, students had very little knowledge on basic terms and facts about the solar system. This was evident in their initial performance in both the diagnostic questionnaire and in Questionnaire 1. This agrees with the aforementioned previous studies conducted on students and adults, which noted the problems and difficulties they have in understanding basic concepts in astronomy.

Regarding the results in the first group, which used the virtual world, progress has been made in students' performance. In particular, significant progress was noted on questions related to the observation of the solar system rather than in pure memorization of information. In addition, students acquired knowledge in areas where they initially had low performance, such as the missions to the planets of our solar system and the composition of the sun.

Regarding the results of the second group, who had access to the online presentation which had the same information about the solar system as in the virtual environment, progress was also noted. It is worth mentioning, however, that while in the initial questionnaire, the majority (55%) knew the number of planets in the solar system, in Questionnaire 2, only 45% knew the correct order of the planets. This may be due to the fact that students could read the information about celestial bodies in any order they wanted (although in order to maintain a fair research, presentations were numbered by the order of their distance from the Sun, corresponding to the application).

Comparing the above two teaching methods, it seems that both groups showed similar and high final results. The students of the first group had better ones, with a performance (average of correct answers) of 94.3%, versus the 82.55% of students in the second group.

The similar learning outcomes of both methods may be due to:

i. The fact that any intervention would have good learning outcomes, given the very low initial knowledge level and

ii. That both methods have constructivist learning elements.

The research project essentially is about two asynchronous distance teaching methods for adults, without the supervision of a teacher. In both cases, the user choses when to learn, when to enter the virtual world, in what order to learn, but also what to learn. The second method is closer to the traditional form of teaching; it is based on memorization of information. The first method, however, is closer to the modern pedagogical approaches, since it uses Virtual Reality as a learning tool, which gives the user the ability to visualize events and situations and discover knowledge through active participation in the learning process.

Regarding students' views of the 3D virtual environment, it is worth mentioning that most of them (95%) would use this kind of applications in their teaching. Furthermore, they are willing to develop their own virtual worlds. It seems that despite all the negative elements and the difficulties that students faced while using the 3D virtual world, these were not capable of changing their positive attitude towards this technological innovation.

Based on the aforementioned findings, it appears that the use of VR in teaching astronomy can lead to a better understanding of the relevant concepts. This may be due to the ability of the VR to visualize situations and concepts, whereas in real life it is impossible, as in our case. Although the project used a small sample of individuals and results can not be generalized, it shows a trend, which can be taken into account in future applications. It would be interesting to carry out a similar survey that would include a larger sample in order to have more concrete results.

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