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 virtual environment for teaching solar system's concepts. The objectives were to examine the environment from a technical perspective and whether the learning objectives were achieved. Two groups of randomly selected students were formed. The first group used the application while the second group was given the same cognitive material, but by using an online presentation program. The results are considered satisfactory. Both groups showed significant progress in knowledge acquisition, but the first group had better overall results.

virtual reality, 3D virtual environments, solar system, constructivism

1. Introduction

In general, school students, university students, as well as teachers, have difficulties in understanding concepts related to celestial phenomena and astronomy in general (Chen, Yang, Shen, & Jeng 2007; Gazit, Yair, & Chen, 2005; Hollingworth, & McLoughlin, 2001; Sun, Lin, & Wang, 2010). For example, first-grade primary school students believe that the Earth is flat. Older students know that the Earth is a sphere, but they still cannot understand the rotation of the planets (Ozsoy, 2012). Students are not usually able to realize concepts such as relative sizes and distances, or that the Sun is at the center of our solar system (Spyratou, 2008). Moreover, knowledge related to astronomy is not enriched after finishing secondary education (Simitzoglou & Halkias, 2007).

Modern pedagogical approaches seek new tools that can contribute to a better understanding of the aforementioned concepts. 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 (Barnett, 2005).

2. Virtual Reality and Education

In VR, users have the feeling of being in a real world (Hew & Cheung, 2008). 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" (Fokides & Tsolakidis, 2011). Three are its main features: immersion, interaction, and imagination:

• Immersion: Is the illusion of "being" in the virtual world.
• Interaction: User's actions result in reactions of the environment and vice versa.
• Imagination: Real, as well as imaginary objects and environments, can be realized, the user can set his imagination free (Kokotos, 2007).

In general, ICT-based learning environments contribute to a better understanding of a subject, in bridging the gap between activities at school and the authentic cultural activities (Hew, & Cheung, 2008) and in the promotion of knowledge construction (Huang, Rauch, & Liaw, 2010). Constructivistic learning environments include opportunities for dialogue among students. Conversations not only strengthen cooperation but also support social negotiation in learning (Dalgarno & Lee, 2009; Lee & Wong, 2008; Vygotsky, 1978). This, in turn, enables learners to share information, test ideas and reflect on learning (Lee, & Wong, 2008). Moreover, the constructivist learning environments promote the development of problem-solving skills (Dalgarno & Lee, 2009).

VR 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 (Pan, Cheok, Yang, Zhu, & Shi, 2006). It supports constructivist learning activities, by allowing students to become active learners (Mikropoulos & Natsis, 2011; Pan, Cheok, Yang, Zhu, & Shi, 2006). Furthermore, 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 (Girvan & Savage, 2010; Martin, Diaz, Sancristobal, Gil, Castro, & Peire, 2011; Mikropoulos, 2006).

3. Rationale and Development of the Application

During the study's preliminary phase, a questionnaire was used in order to evaluate what pre-service teachers know about the solar system. It was administered to a random sample of students attending the Department of Primary School Education, University of the Aegean (N=48). Result analysis confirmed that most students' knowledge level regarding the solar system is very low (Table 1.). For instance, only 18.75% of students answered correctly the questions about satellites of our solar system. As for the missions for the study of our solar system, 70.8% of students were not aware of any. These results directed the application's content since the focus was on subjects where students showed poor results.

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

The second step was the development of the virtual world, using OpenSimulator. OpenSimulator 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).

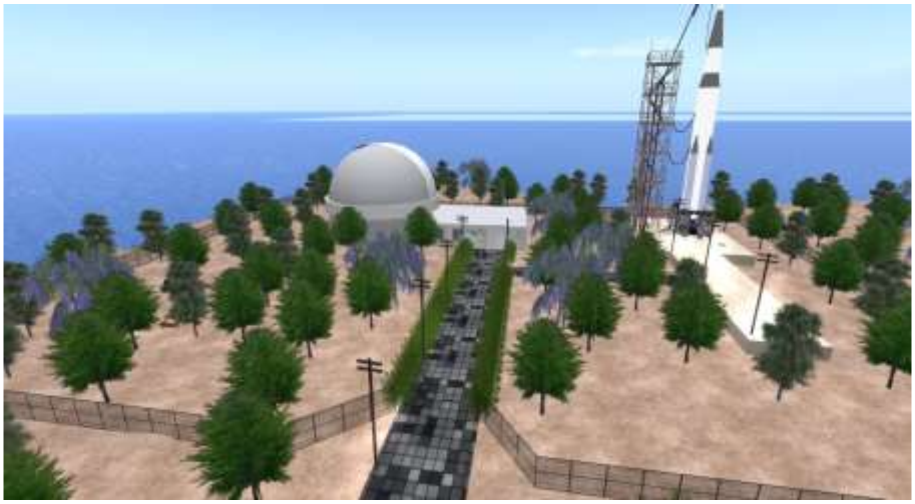

Figure 1. The first level of the application.

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.

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 added, that allowed interactions (i.e. welcoming and greeting the user, allowing the user to watch videos, etc.).

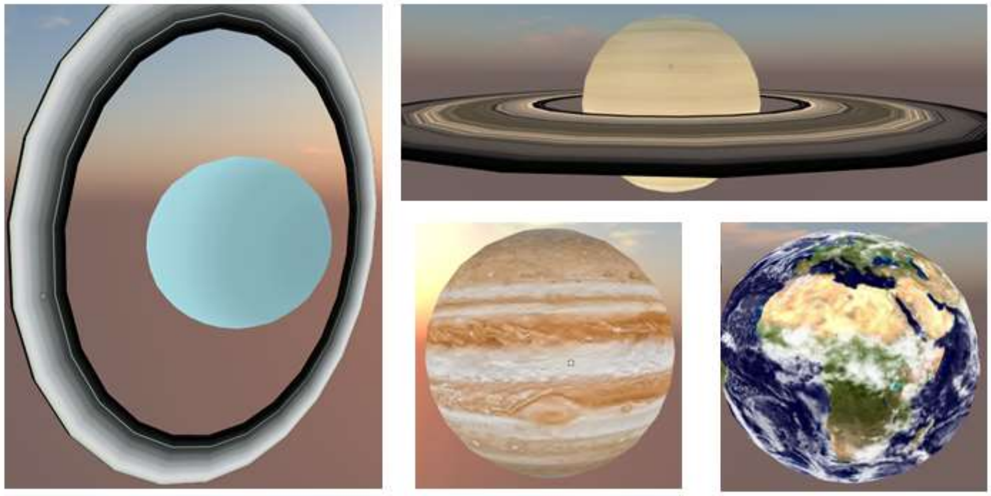

Figure 3. Uranus, Saturn, Jupiter, and Earth, as seen from the second level of the application.

The most time-consuming procedures were the collection of the cognitive material, the construction of objects and the addition of scripts (Table 2). 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.

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

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 consisted of randomly selected students of the Department of Primary School Education, University of the Aegean, divided into two groups of 20. 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 administered to both groups, before and after the use of both applications, aiming to test the knowledge acquisition. The second questionnaire was formed based on the first one so that data could be comparable (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 was given only to the first group.

Prior to using the VR application, a meeting with the first group was held, 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 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.

5. Result Analysis

Overall, in Questionnaire 1, students, students of both groups and the initial random sample(N=88) answered correctly 6.69 questions out of 22 (score 30.4%), on average (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 (VR application), 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

Students' progress in the second group (online application), 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

The first group of students had relatively better overall performance compared to the second group (Table 7). 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%.

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

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 it is difficult and/or impossible to do so, they are attractive, they offer realistic visualization of situations, they stimulate the students' interest, 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

Students had very little knowledge of 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 previous studies, which noted the problems and difficulties they have in understanding basic concepts in astronomy.

Regarding the results of the first group (virtual world), progress has been made in students' performance 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 (online presentation), 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 teaching methods, it seems that both groups showed similar and high final results. However, the first group had an average of 94.3% correct answers compared to 82.55% of the second group.

The research project essentially is about two asynchronous distance teaching methods for adults, without the supervision of a teacher. In both cases, the user chooses when, how, and 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 the difficulties that some students experienced, 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. Although the project used a small sample of individuals, 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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E-BOOK (PDF)

5.6. Development and evaluation of a 3D virtual environment for teaching solar system's concepts

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