PsychNology Journal, 2008
Volume 6, Number 1, 83 -98

Being inside the Quantum Atom

Assimina M. Kontogeorgiou[*♦], Joan Bellou [♦] and Tassos A. Mikropoulos[♦]

[♣] The Educational
Approaches to Virtual
Reality Technologies Lab,
University of Ioannina
(Greece)

ABSTRACT

This article explores the possibility of using dynamic Educational Virtual Environments (EVEs) for helping students with limited background in physics and mathematics to deeply understand Quantum Mechanics principles and create the correct mental images of atomic models. Taking under consideration the results of our pilot study we have created "The Quantum Atom", an educational environment with which 38 students interacted during well-designed learning tasks based on the social constructivist approach. The sense of presence seems to play an important role in our positive learning outcomes. Further research must be done in this domain focusing on the main features of Virtual Reality as many researchers argue that they support knowledge construction.

Keywords: *Quantum Mechanics, Atomic Model, Educational Virtual Environments, Presence, Learning Outcomes*

Paper Received 21/03/2008; received in revised form 30/04/2008; accepted 30/04/2008.

1. Introduction

Virtual reality (VR) is expected to bring dramatic changes in the educational process and learning environments as it provides first-person, non-symbolic experiences that are specifically designed to help students learn material (Winn, 1993). Learning in VR has been proposed since 1990, when Bricken specified "natural semantics" and "cognitive presence" as the main features of virtual environments (1990) and constructivism as the theoretical model supporting Educational Virtual Environments (EVEs) (Mikropoulos, 2006).

Cite as:
Kontogeorgiou, A. M., Bellou, J., & Mikropoulos, T. A. (2008). Being Inside the Quantum Atom. *PsychNology Journal, 6*(1), 85 – 101. Retrieved [month] [day], [year], from www.psychnology.org.

[*]Corresponding Author:
Assimina M. Kontogeorgiou
Research Associate, The Educational Approaches to Virtual Reality Technologies Lab, University of Ioannina, University Campus, GR 45110, Greece
E-mail: kontogeorgiou@grads.uoi.gr

Presence, in relation to synthetic environments, has been defined by many authors. Although there are some differences among these definitions researchers agree with the description of presence as “the sense of being there”. One of the most important subjects in presence research is the factors, attributes, results and consequences of presence. These are useful and applicable in practical situations and designate the influence of “being there” in VR applications (Mikropoulos, 2006). Researchers have developed a number of both objective and subjective methods in order to study and investigate the sense of presence in numerous VR applications (Slater, Usoh, & Steed, 1994; Witmer & Singer 1998; Schubert, Friedman, & Regenbrecht, 1999; Kim & Biocca, 1997; Lessiter, Freeman, Keogh, & Davidoff, 2001; Lombard & Ditton 2000; Mikropoulos, Tzimas, & Dimou, 2004).

Although the evaluation studies for the educational benefits of using Educational Virtual Environments (EVEs) are insufficient, it has been reported that VR is a new challenging technology that increases student interests, understanding, and creative learning (Winn, 1995; McLellan, 1996; Olson, 1998; Barab, Hay, Barnett, & Squire, 1998; Shin, 2002; Kealy, Chitra, & Subramaniam, 2006). Moreover, presence seems to play an important role in EVEs although there is no much research in the educational domain concerning its learning effects (Mikropoulos, 2006). In general, the minority of research reports on specific VR features and the sense of presence that EVEs exploit. Thus, the essential features that designate VR as a promising and powerful educational tool, such as free navigation, first-person point of view, natural semantics, size, transduction, reification, autonomy and presence, are not yet very clear (Mikropoulos, 2006; Mikropoulos & Bellou, 2006).

Physics and Chemistry deal with three dimensional (3D) objects and phenomena. Since students learn more efficiently if the instructional methods and tools match their learning style and support the creation of mental images and models, then the ability to visualize and manipulate shapes is very helpful in their learning. In fact, much of what physics and chemistry students know takes the form of images. However, little attention has been given to the pedagogical effectiveness of visual stimuli in those disciplines. Computer-based environments contribute to the visualization of physical and chemical processes allowing for better conceptual understanding (Trindade, Fiolhais, & Almeida, 2002).

In particular, the structure of matter is a fundamental topic in science education from the primary school up to the university level. Students from the advanced high school classes up to the last university years have difficulties in grasping the main notions and principles for describing an atom according to Quantum Mechanics (QM) as they demand an important level of abstraction, a reconceptualization in intellectual activity and strong competences in physics and mathematics. Many researchers have already shown that students in all levels have difficulties in understanding the concepts associated with the nature of matter and especially with atomic models (Harrison & Treagust, 2000; Olsen, 2003; Taber, 2003; Dimopoulos & Kalkanis, 2005). To overcome these obstacles researchers propose the use of Information and Communication Technologies (ICT) that help students to qualitatively approach the QM principles and the microscopic models resulting from them (Dori & Barak, 2001; Trindade, Fiolhais, & Almeida, 2002; Trindade, Kirner, & Fiolhais, 2004; Dimopoulos & Kalkanis, 2005). Trindade and his colleagues have shown that 3D virtual environments may help students with high spatial aptitude to acquire better conceptual understandings (2002). Features such as interactivity, navigation and 3D perception seem to contribute to scientific concepts such as molecular orbitals and densities, molecular geometry, and the phases and phase transitions of water itself in the “virtual water” learning environment.

The aim of this article is to argue that presence is a unique sense experienced in EVEs that contributes to positive learning outcomes. We use some questions to investigate the sense of presence, following the statement of Slater (1999) saying that presence can be estimated by “the extent to which participants, after the VE experience, remember it as having visited a place rather than just having seeing images generated by a computer”.

Unfortunately, most of the software packages that are available concerning the 3D representations of the Quantum Atomic Model (QAM) do not help students to understand the main physical concepts for describing it when they have been used as educational tools. According to our pilot study there are no positive learning outcomes (Kontogeorgiou, Bellou, & Mikropoulos, 2007). This might be because of the piecemeal description of the orbitals and electron clouds given in these visualizations. In addition, our students have not reported a sense of presence during their interaction with the software packages proposed by Winter (2002) and Blauch (2005).

Taking these results into consideration, we are interested in designing EVEs in order to help students assimilate Quantum Mechanics in a qualitative way. These EVEs integrate meaningful learning activities and enable users to become participants in abstract and notional 3D spaces.

The objectives of our study were:

- to create 3D dynamic visualizations of the atom by taking advantage of EVEs main features, so as to give a total and integrated picture of the atomic model avoiding misconceptions coming from the Bohr atomic model. In the Bohr model the neutrons and protons occupy a central region, the nucleus, and the electrons orbit the nucleus much like planets orbiting the Sun;
- to investigate if students are able to connect the dynamic visualizations with the basic principles of Quantum Theory;
- to explore students' mental models for the atom after interacting with the dynamic visualizations in an EVE with well designed learning tasks.

2. Method

2.1 The Virtual Environment

An Educational Virtual Environment (EVE) or Virtual Learning Environment (VLE) can be defined as a virtual environment that has one or more educational objectives, pedagogic metaphors, provides users with experiences they would otherwise not be able to experience in the physical world and redounds upon specific learning outcomes (Mikropoulos, 2006).

In this perspective we have created the dynamic EVE "The Quantum Atom", using the Virtools software package. The hydrogen atom was visualized at the ground, the first and second excited states according to QM, based on scientific calculations (Figures 1 - 5). The EVE consisted of six parts. The atom was developed and presented at a desktop VR system supporting immersion and following the theoretical approach of social constructivism according to which meaningful learning occurs when individuals are engaged in social activities. This pedagogical model is the most dominant in educational technology, and VR characteristics such as 3D spatial representations, autonomy, sensory modality, first-person point of view, freedom in navigation and interaction arise from this approach (Mikropoulos, 2006). The social activities in our EVE occur in the scheme student-EVE-researcher. "The Quantum Atom" gives the possibility of a first-person point of view using stereoscopic glasses and involves students in well designed learning tasks. More specifically, our visualizations have the following characteristics:

- giving a sense of the 3D space and of the spatial distribution of electron clouds;
- giving students the possibility to freely navigate outside and inside the atom;

- giving students the possibility to interact and change energy states;
- giving students the possibility to comprehend the electron's properties.

Our pilot study's outcomes (Kontogeorgiou, Bellou, & Mikropoulos, 2007) led us to design "The Quantum Atom" so that the electron cloud is created step by step in every energy state. As a result, the student realizes that the electron cloud consists of different positions within which it is probable to locate the electron. Moreover, a surface in space on which the probability of the electron to be located is the same (isodensity surface plot) is supposed to represent the atom shape according to QM. This surface in space comprises a space where the probability for the electron to be localized is about 90%. So the isodensity surface plots (Figure 6) replace the image of the atom according to the classical theory (Bohr's atomic model) that students keep in their mind even at the end of their university studies (Johnston, Crawford, & Fletcher, 1998).

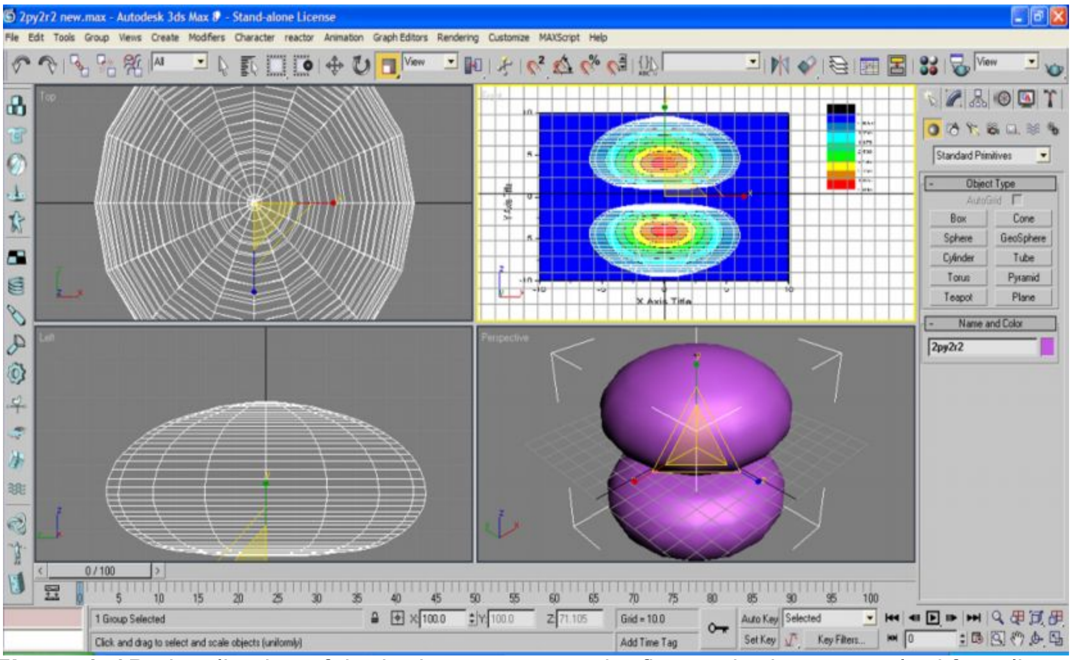


Figure 1. 3D visualization of the hydrogen atom at the first excited state resulted from linear polarized electromagnetic radiation.

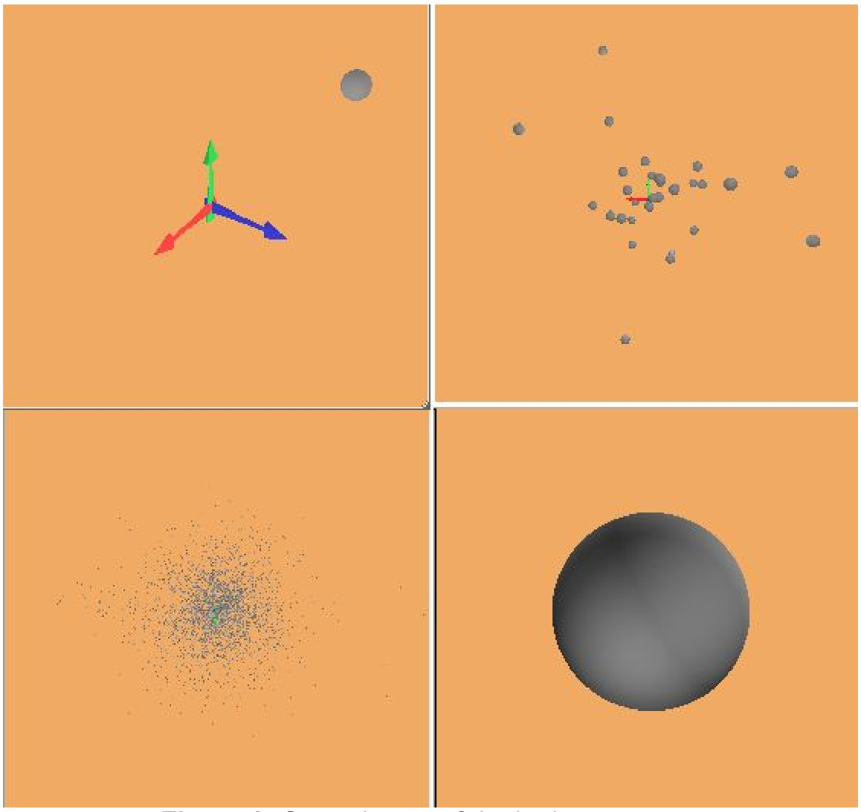


Figure 2. Ground state of the hydrogen atom.

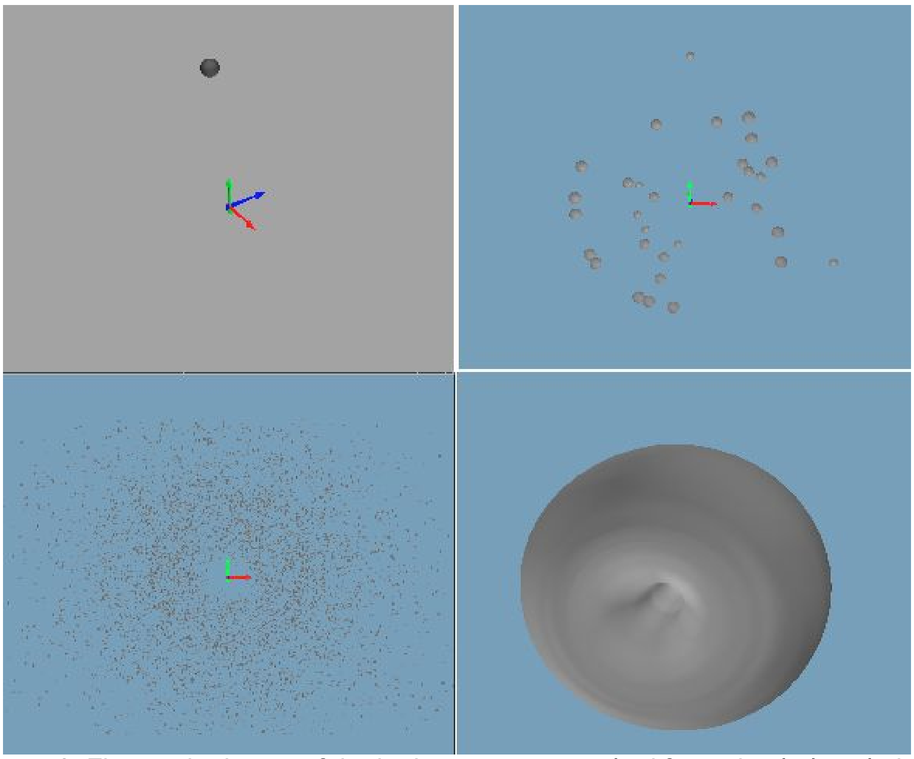


Figure 3. First excited state of the hydrogen atom resulted from circularly polarized electromagnetic radiation.

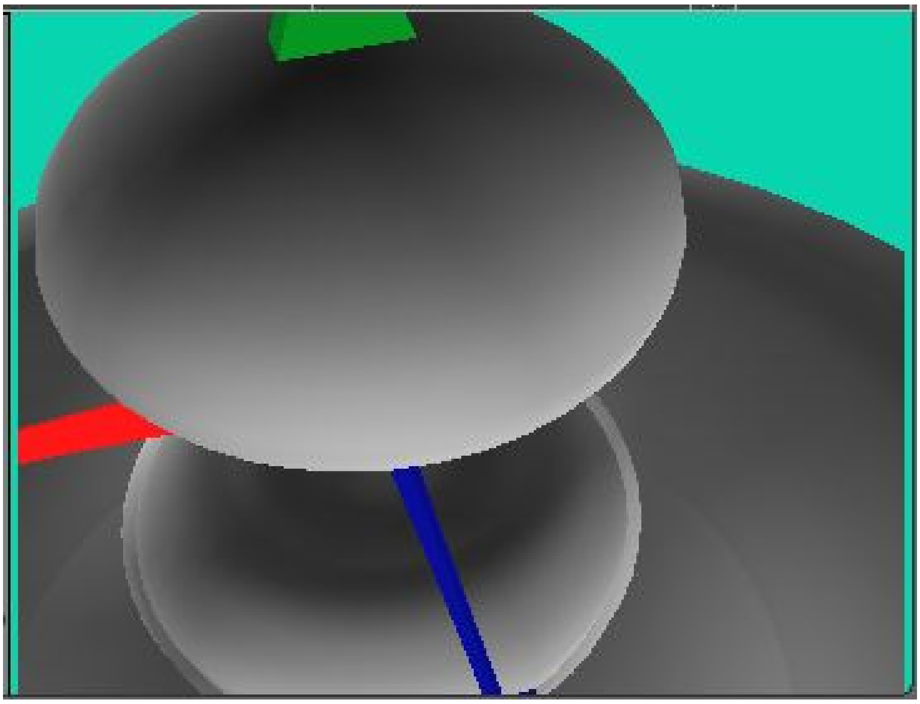


Figure 4. Second excited state of the hydrogen atom resulted from linearly polarized electromagnetic radiation; a viewpoint close to nucleus.

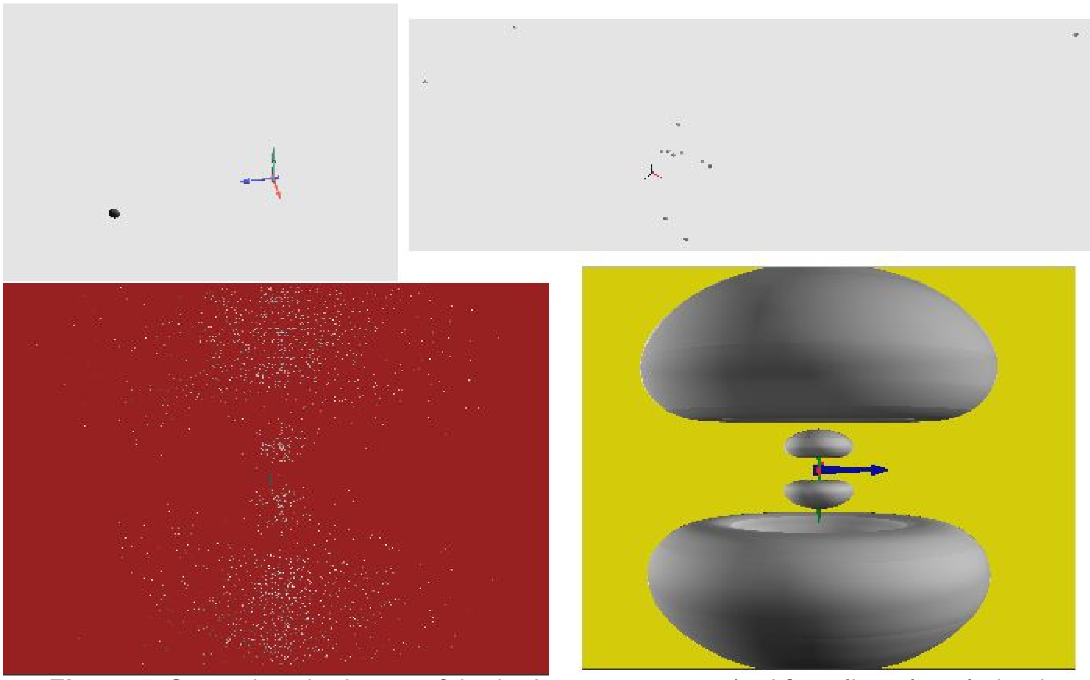


Figure 5. Second excited state of the hydrogen atom resulted from linearly polarized electromagnetic radiation.

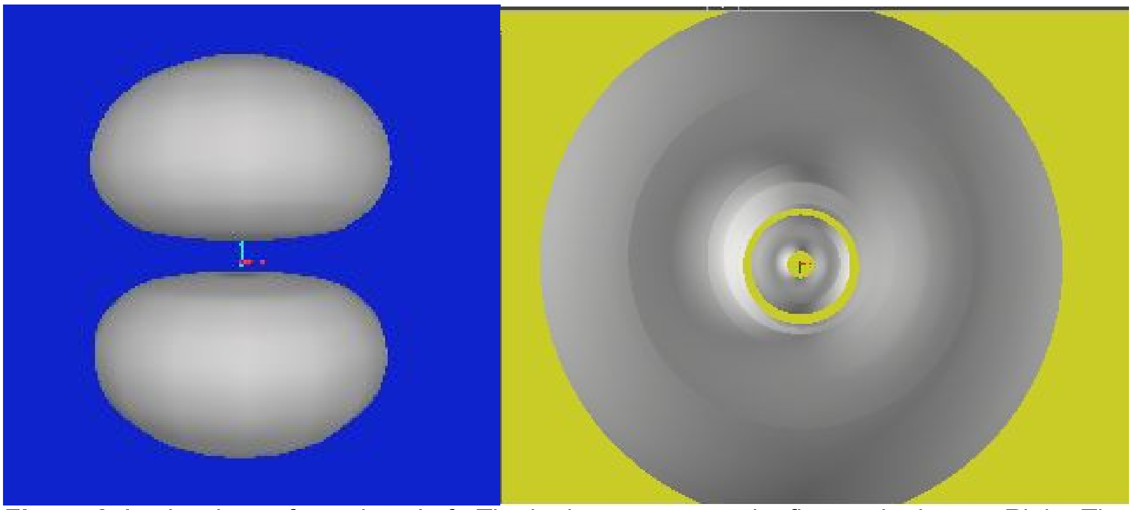


Figure 6. Isodensity surface plots. Left: The hydrogen atom at the first excited state. Right: The hydrogen atom at the second excited state.

2.2 Sample and Procedure

An empirical study was conducted with thirty-eight (38) first year students of the Department of Primary Education, University of Ioannina. The learning tasks were related to the students' mental images for the hydrogen atomic model at its ground, first and second excited states in accordance with QM principles.

Firstly, the students answered a questionnaire about the QAM of hydrogen, the electron attributes and atom shape. After that, each of them interacted with "The Quantum Atom" EVE during a semi – structured interview, whose questions depended on their mental images as revealed from the answers to the first questionnaire. After the interaction, a second questionnaire was administered. Two months later a similar questionnaire was administered in order to investigate the retention of knowledge (see appendix).

In order to investigate the role of presence in the educational activities the students interacted with the EVE during the first three parts without wearing stereoscopic glasses. Afterwards, they used the glasses with the three last parts of the EVE and described their experience. In an abstract 3D virtual space like the Quantum Atom, we expect that stereoscopic view will be a discretive factor concerning the sense of presence. The questions concerning the sense of presence were included in the second and third questionnaires. They were the following:

1. Do you realize any differences in the depiction and position of objects when you wear the glasses and when you do not wear them?
2. Do you feel that the atom became the reality for you, and you almost forgot about the real world?

3. Do you think that you were inside the atom or you have seen images generated by the computer?

3. Results

3.1 Cognitive Content: The Quantum Atomic Model

The learning outcomes of our study were positive as most of the students assimilated the main principles and notions of QM. Therefore, after the interaction with "The Quantum Atom" students sketched the hydrogen atom in different energy states according to the QAM, using the isodensity surface images. Thirty two students (84.2%) formed a mental image compatible with Quantum Mechanics having abandoned the planetary atomic model after the interaction with the EVE. Two months later 31 students (81.6%) had kept this image for the atom shape. We base the creation of student's mental images to their sketches, since sketches are considered to be tools for knowledge representation (Friedman & diSesa, 1999; Jonassen, 2000).

Furthermore, 32 students (84.2%) explicitly expressed their point of view on the electron's behavior, stating that "it is impossible to determine the electron's position every moment with accuracy, so it is impossible to draw its trajectory. This is not due to the effect of our method to perform a measurement, but it is a main attribute of QM Theory". Concerning the electron cloud, all the students affirmed that it consists of "thousands of probable positions, where the electron of the hydrogen atom could be located. The probability of the electron localization depends on the density of the electron cloud". Two months later thirty students (78.9%) did not change these concepts that had constructed embedded into the EVE.

3.2 The Sense of Presence

Our study revealed that 32 students answering the two first questions reported very enthusiastically a sense of presence during their interaction with the EVE as a result of the use of stereoscopic glasses. In that case they had a very strong sense of presence during their free navigation inside the hydrogen atom. Some of their expressions were: "I see different possible positions for the electron like in the real world", "I think that I can touch the electron in different possible positions", "the electron is real".

Five students stated that they found no big differences with and without the stereoscopic glasses, although they reported a sense of presence inside the atom.

Finally, one student did not observed any difference. It is noteworthy that the answer of one of the students who found no big differences in the sense of presence shows the restriction coming from the existence of the surrounding real world: “OK there is a difference; however, it is not so intense because the screen limits my optical field. Moreover, I can see other objects around, in the real world. This is something that influences the way we see the depiction of objects in the computer. You can distinguish this characteristic if you have interacted with virtual environments under other conditions”. Only this student had experienced a virtual environment before our study.

Concerning the third question, almost all the students (35) stated that they remembered the EVE as a place they had visited. Their experience was like they have been inside the atom. Interacting with our EVE nobody described it as images generated by the computer. Some of their statements were: “I am into the space”, “I am close to the nucleus of the atom”, “I can see inside the atom”, “I am inside the atom”.

Two months later 31 students expressed a very strong sense of presence in the third questionnaire too, still remembering the EVE as a place they have visited, while 29 of them insisted that wearing the stereoscopic glasses the atom was much more “live”, “real” or “impressive”. They felt to be “present” in the microcosm.

In general, the students had a high sense of presence interacting with our EVE and this helped them perform their learning tasks successfully and work in a constructive learning environment. This is in line with Winn’s and his colleagues’ findings on student – built virtual environments. They have reported that students’ enjoyment, ability to work in VE, success and their sense of presence were all interrelated (Winn et al., 1999).

The visualizations of the atomic model of hydrogen via the proposed EVE helped them to acquire stable mental images which remained two months later. Their initial mental representations replaced from other compatible to Quantum Theory. We suppose that presence has positively contributed in overcoming the students’ difficulties about QAM.

4. Conclusions

The present study investigates the effect of students’ interaction with an Educational Virtual Environment (EVE) on learning outcomes in Science Education, as well as their sense of presence inside the EVE. According to Sanchez and colleagues “scientific visualization in virtual environments is the art of making the unseen visible: torsion forces inside a body, heat conduction, flows, plasmas, earthquake mechanisms, botanical structures or complex molecular models" (Sanchez, Barreiro, & Maojo, 2000). Towards this perspective we have designed an EVE which gives students the possibility to freely navigate inside and outside the atomic model of hydrogen in order to experience the microcosm while they would not be able to practice that in the real world. Students immerge in a virtual environment and get the feeling that they are actually inside the atom, they are transferred to an environment of pure information that they can 'see' and even manipulate.

It seems that the EVEs' features and the sense of presence are pedagogically exploited during a well structured learning procedure and improve students' understanding in order to create mental images consistent with scientific knowledge. The results of our study reveal that the students grasp the main notions for describing the QAM. So they are in coherence with other researchers' conclusions reporting that VR features and the sense of presence play an important role in the learning outcomes (Salzman, Dede, Loftin, & Chen, 1999; Dede, Salzman, Loftin, & Ash, 2000; Bakas & Mikropoulos, 2003).

It seems that the content of the VE together with specific learning tasks is an important factor affecting presence and task performance. Further research is needed regarding the contribution of personal presence and students envolvment in learning outcomes concerning the microcosm, for which explanations are given only by scientific theories and two dimensional models, as humans cannot enter this world. We are working towards this direction.

5. References

Bakas, Ch., & Mikropoulos, T. A. (2003). Design of virtual environments for the comprehension of planetary phenomena based on students' ideas. *International Journal Science Education*, 25, 949–967.

Barab, S. A., Hay, K. E., Barnett, M. G., & Squire, K. (1998, May). *Constructing knowledge and virtual worlds: Knowledge diffusion in future camp 97.* Presented at the annual meeting of the American National Research Association, San Diego, CA.

Blauch, D. (2005). Retrieved April 29, 2008, from http://www.chm.davidson.edu/ChemistryApplets/AtomicOrbitals/AtomicOrbitals.html

Bricken, W. (1990). *Learning in Virtual Reality, Technical Report (No. HITL-M-90-5).* Retrieved April 29, 2008, from www.hitl.washington.edu/publications/m-90-5.

Dimopoulos, D., & Kalkanis, G. (2005). Simulating Quantum States of the Atom of Hydrogen: A simulation program for non-physics major's students. In R. Pintó & D. Courso (Eds.), *Proceedings of the fifth International ESERA Conference on Contribution of Research to Enhancing Students in Learning Science* (pp. 548–552). Barcelona: Cresils.

Dede, C., Salzman, M. Loftin, B., & Ash, K. (2000). Using virtual reality technology to convey, abstract scientific concepts. In M. J. Jacobson & R. B. Kozma (Eds.), *Learning the sciences of the 21st Century: Research, design, and implementing advanced technology learning environments* (pp. 361-413). Hillsdale, NJ: Lawrence Erlbaum.

Dori, J.Y., & Barak, M. (2001).Virtual and physical molecular modeling: Fostering model perception and spatial understanding. *Educational technology and society*, *4*, 61-74.

Friedman, J.S., & diSesa, A.A. (1999). What students should know about technology: the case of scientific visualization. *Journal of Science Education and Technology*, 8(3), 175-195.

Johnston, D., Crawford, K., & Fletcher, P. (1998). Students difficulties in learning quantum mechanics. *International Journal of Science Education*, 20, 427-446.

Jonassen, D.H. (2000). *Computers as mindtools for schools*. NJ: Prentice Hall.

Harrison, A., & Treagust, D. (2000). Learning about atoms, molecules and chemical Bonds: A case Study of Multiple-Model use in Grade 11 Chemistry. *Science Education*, *84*, 352-381.

Kealy, W.A., Chitra, Z., & Subramaniam, P. (2006). Virtual realia: maneuverable computer 3D models and their use in learning assembly skills. *Virtual Reality, 10*, 283-292.

Kim, T., & Biocca, F. (1997). Telepresence via television: two dimensions of telepresense may have different connections to memory and persuasion. *Journal of Computer-Mediated Communication, 3*(2). Retrieved April 29, 2008, from http://jcmc.indiana.edu/vol3/issue2/kim.html.

Kontogeorgiou, A., Bellou, J., & Mikropoulos, T. A. (2007). Visualizing the quantum atom. In R. Pinto & D. Couso (Eds.), *Contributions from Science Education Research* (pp. 465-475). The Netherlands: Springer.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2000). Development of a new cross-media presence questionnaire: The ITC-sense of presence inventory. In IJsselsteijn, W.A., Freeman, J. & de Ridder, H. (Eds.), *Proceedings of PRESENCE 2000 - 3rd International Workshop on Presence*. The Netherlands: Delft. Retrieved April 29, 2008, from http://www.presence-research.org.

Lombard, M., & Ditton, T. (2000). Measuring presence: A literature based approach to the development of a standardized paper and-pencil instrument. In: IJsselsteijn, W.A., Freeman, J. & de Ridder, H. (Eds.), Proceedings of PRESENCE 2000 - 3rd International Workshop on Presence, Delft, The Netherlands, Retrieved April 29, 2008, from http://www.presence-research.org.

McLellan, H. (1996). Virtual reality. In: D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 457-487). MA: Kluwer-Nijhoff Publishing.

Mikropoulos, T. A., Tzimas, E., & Dimou, G. (2004). Objective presence measures through electric brain activity. In MA Raya & BR Solaz (Eds), *Proceedings of the 7th annual international workshop on presence* (pp 259–265). Valencia: Universidad Politecnica de Valencia.

Mikropoulos, T. A. (2006). Presence: A unique characteristic in educational virtual environments. *Virtual Reality*, *10*(3-4), 197-206.

Mikropoulos, T. A., & Bellou, J. (2006). The Unique Features of Educational Virtual Environments. In P. Isaias, M. McPherson, & F. Banister (Eds.), *Proceedings e-society 2006, International Association for Development of the Information Society: Vol.1* (pp. 122-128). Dublin: IADIS.

Olsen, R. (2003). Introducing quantum mechanics in the upper secondary school: a study in Norway. *International Journal of Science Education, 24*, 565–574.

Olson, S. (1998). Stargazing. *Teacher Magazine*, 25–28.

Salzman, M. C., Dede, C., Loftin, R. B., & Chen, J. (1999). A Model for Understanding How Virtual Reality Aids Complex Conceptual Learning. *Presence*, *8*(3): 293-316.

Sanchez, A., Barreiro, J. M., & Maojo, V. (2000). Embodying cognition: a proposal for visualizing mental representations in virtual environments. *In Proceedings of the 3rd International Conference on Disability, Virtual Reality & Associated Technology* (pp. 319 -325). UK: ICDVRAT/University of Reading.

Schubert, T. W., Friedman, F., & Regenbrecht, H. T. (1999). *Embodied presence in virtual environments, visual representations and interpretations*. London: Springer.

Shin, Y-S. (2002). Virtual Reality Simulations in Web-Based Science Education. Retrieved April 29, 2008, from www.stanford.edu/dept/SUSE/projects/ireport/ articles/3D/ fulltext_ID=96516896&PLACEBO=IE.pdf.

Slater, M., Usoh, M., & Steed, A. (1994). Depth of presence in immersive virtual environments. *Presence: Teleoperators Virtual Environment*, *3*(2),130–144.

Slater, M. (1999) Measuring presence: a response to the Witmer and Singer Presence questionnaire. *Presence: Teleoperators Virtual Environment, 8*(5), 560–566.

Taber, K. S. (2003). Mediating Mental Models of Metals: Acknowledging the Priority of the Learner's Prior Learning. *Science Education*, *87*, 732 -758.

Trindade, J., Fiolhais, C., & Almeida, L. (2002). Science learning in virtual environments: a descriptive study. *British Journal of Educational Technology*, *33*, 471-488.

Trindade, J., Kirner, C., & Fiolhais, C. (2004). An augmented Reality application for studying atomic orbitals. *In Proceedings of IADIS International Conference on Cognition and Explanatory Learning in Digital Age*, *IEEE Computer Society, Lisboa, 1*, 1 -2.

Winn, W. (1993). *A conceptual basis for educational applications of virtual reality. Technical report (No TR-93-9).* Retrieved April 29, 2008, from http://www.hitl.washington.edu/publications/r-93-9.

Winn, W. (1995). The Virtual Reality Roving Vehicle Project, Technological Horizons. *Education Journal, 23*(5), 70–75.

Winn, W., Hoffman, H., Hollander, A., Osberg, K., Rose, H., & Char, P. (1999). Student-built virtual environments. *Presence*, *8*(3), 283–292.

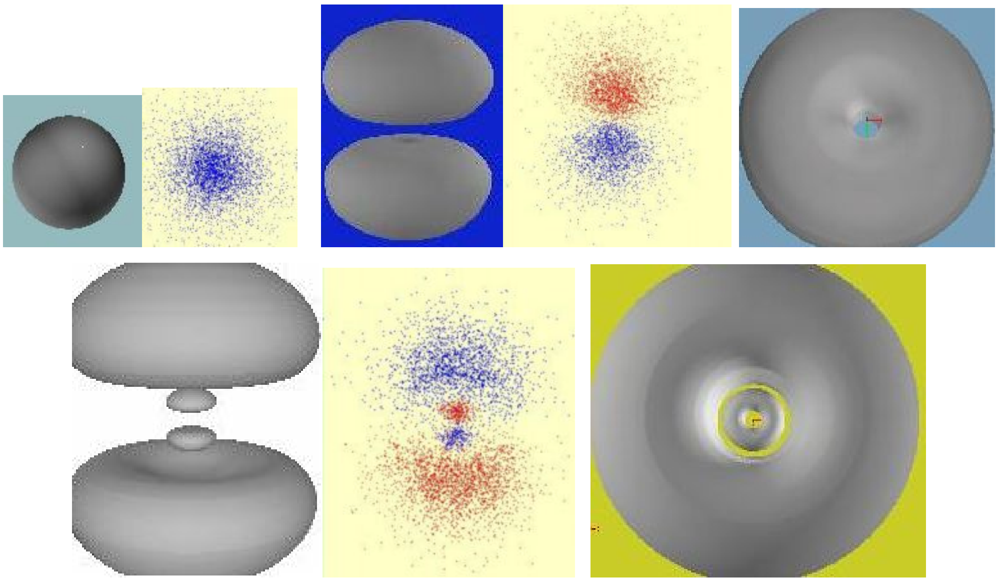
Winter, M. (2002). Orbitron. Retrieved April 29, 2008, from http://www.shef.ac.uk/ chemistry/orbitron/

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: a presence questionnaire. *Presence, 7*(3), 225–240.

6. Appendix

The Questionnaire

1. Draw the hydrogen atom. Explain the atomic theory you followed.
2. Using an experimental device, we determine the position of an electron. Show two positions where the electron can be found. Justify your answer.
3. Is it possible to determine the electron's orbit?
   a. If yes, draw the orbit for the hydrogen atom.
   b. If no, justify your answer
4. a. What do the following images represent? What kind of information do we get from these?



   b. Describe how you conceive the notion of the orbital.
   c. Describe how you conceive the notion of the charge cloud.
5. Do any of these images represent an atom? Where is the nucleus?
6. According to the uncertainty principle it is not possible to determine the position and velocity of a particle with accuracy. Why does it happen? Is there any relation between this principle and the images you have seen?

7. Do you realize any differences in the depiction and position of objects when you wear the glasses and when you do not wear them?
8. Do you feel that the atom became the reality for you, and you almost forgot about the real world?

9. Do you think that you were inside the atom or you have seen images generated by the computer?