Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia
Social and Behavioral Sciences
ELSEVIER
Procedia - Social and Behavioral Sciences 31 (2012) 145 – 149

WCLTA 2011

The impact of 3D visualization types in instructional multimedia applications for teaching science

George Korakakis [a] *, Andreas Boudouvis [a], John Palyvos [a], Evagelia A. Pavlatou [a]

[a] School of Chemical Engineering, National Technical University of Athens, 9, Heroon Polytechniou Str., Zografos Campus, GR-15780, Greece

Abstract

This study reports research findings on whether the use of 3D visualization types i.e. Interactive 3D Virtual Environment (I3DVE), 3D Animations Interface (3DAIF) and 3D Static Illustrations Interface (3DSIIF), combined with narration and text in multimedia applications, contributes to the learning process of 12th grade students in science. A total of 111 students participated in the research that utilized three different versions of an interactive multimedia application called "Atomic Orbitals". The research results provide convincing evidence that I3DVE have a greater contribution to the learning process than the other two types of visualization.

Keywords: Interactive learning environments; 3D visualizations; Secondary education; Science;

1. Introduction

In recent days educational science has not yet been able to provide a clear and coherent collection of guidelines for designing effective multimedia instruction. In most cases, designers' intuitions on what might work and aesthetic considerations are the main driving forces behind the development of these kinds of learning materials.

Theories about learning with multimedia can be positioned at different levels. At a basic level, psychological theories describe memory systems and cognitive processes that explain how people process different types of information and how they learn with different senses (Van Merriënboer & Kester, 2005). Examples of such theories are Paivio's dual coding theory (1986; Clark & Paivio, 1991) and Baddeley's working memory model with a central executive and two slave systems, the visuo-spatial sketchpad and the phonological loop (1992; 1997).

Spatial ability is an important factor in multimedia learning as the learner needs to encode spatial information from sensory memory, maintain an internal representation in working memory, and perform spatial transformations in order to integrate the information in long term memory (Milik et al., 2008). Also the representation, rotation and inversion of objects in three dimensions when they are presented in two dimensions, are involved in spatial ability (Barnea, 2000). Moreover, Barnea structured the visualization skills according to the different levels of difficulty, as : (a) 'spatial visualization', the ability to understand accurately three-dimensional (3D) objects from their two-

* George Korakakis.
E-mail address: gkor@chemeng.ntua.gr.

1877-0428 © 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of Prof. Hüseyin Uzunboylu.
doi:10.1016/j.sbspro.2011.12.032

dimensional (2D) representation, (b) ‘spatial orientation’, the ability to imagine what a representation will look like from a different perspective and (c) ‘spatial relations’, the ability to visualise the effects of operations such as rotation, reflection, and inversion, or to mentally manipulate objects (Ferk et al., 2003).

The support of 3D information representations is succeeded by different means in computer-based multimedia environments (Huk, 2006). The main assumption of Wu and Shah (2004) is that with 3D animation students can change and improve their incomplete mental models. Nevertheless, different researchers (Gerjets & Scheiter, 2003; Paas et al., 2003a) have demonstrated that in hypermedia-learning environments cognitive overload problems may arise from the use of 3D models, as they generate a heavy cognitive load. On the other hand, Ferk’s et al. (2003) research revealed that some representations of molecular 3D structure are better understood and used by students in solving tasks of different complexity. To all students, the concrete representations seemed to be more useful than abstract representations. In particular, primary school students scored better when using concrete 3D model, whereas secondary school students and university students achieved the best results when using illustrated graphics of 3D molecular models or computer-generated models.

In modern educational practice within a real school environment, building an instructional virtual environment (VE) system to match the human perceptual and motor system is essential (Sylaiou et al, 2010). Moreover, it is evident that well-designed educational environments, which take both human cognitive architecture and multimedia principles into account, ensure that learners will work in an environment that is goal-effective, efficient, and appealing. Following that direction, the results of prior research (Korakakis et al., 2009) that was conducted with 13 and 14 year-old students, confirmed that multimedia applications with interactive 3D animations as well as, with plain 3D animations, do in fact increase the interest of students and make the material more appealing to them. The findings also suggest that the most obvious and essential benefit of static visuals (3D illustrations) is that they leave the time control of learning to the students and decrease the cognitive load.

2. Overview of the three versions of the multimedia application

Based on the latest educationally acceptable theories and research in various multimedia visualizations, an interactive multimedia application titled “Atomic Orbitals” was created. The application is addressed to 12th grade students in Greece and was created in three different versions, each one differing from the other two with regards to the type of visualization.

All three versions of the multimedia application were created from scratch, and the particular steps followed were: *the creation of all static 3D illustrations, 3D animations, and interactive 3D animations (using appropriate programming and drawing), the elaboration of the text and sound speech and, finally, the careful assembly of all of the above elements in the final form of the multimedia application, using the most suitable authoring programme.*

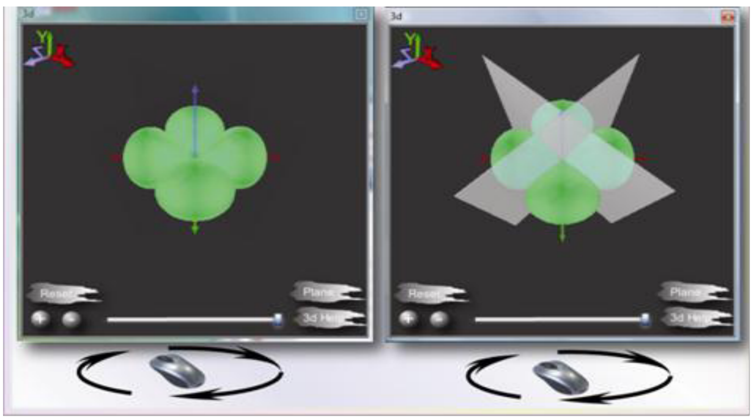

Figure 1. I3DVE - The student is able to: observe the changes that are presented in the animation, use the interactive controls (zoom, diminution and reset, brightness, or additional auxiliary forms such as plane), and freely rotate by using keyboard and mouse.

In particular, the first version employs visualizations in Interactive 3D Virtual Environment (I3DVE) (Figure 1), the second version utilizes visualizations in 3D Animations Interface (3DAIF) (Figure 2), and the third version employs visualizations in 3D Static Illustrations Interface (3DSIIF) (Figure 3). All the rest of the application components (narration, text, navigation, auxiliary tools, etc.) are common in all three versions.

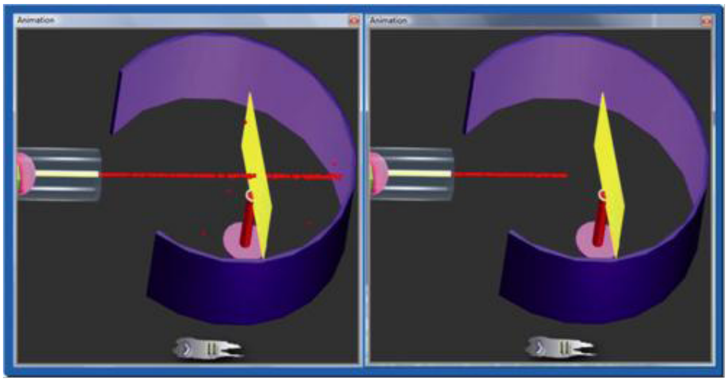

Figure 2. 3DAIF - The student is able to: observe the animation (loop) and use the controls (pause, play) without the choice of rotation.

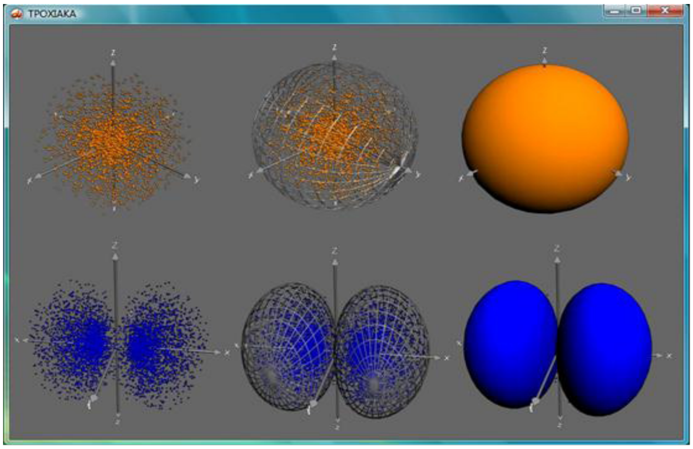

Figure 3. 3DSIIF - The student can observe the changes from the static illustrations.

Also is must be noted that in the last part of each version of the multimedia application students are called to answer questions of various types. A total of nine questions were divided into three groups. The first group includes multiple-choice questions, the second involves questions of completion of blanks, while in the third group the questions are visualised. The percentage of correct answers is recorded and presented at the end of the application. The questions in all three versions are precisely the same and are presented in the same way.

While each one of the three versions of the multimedia application runs, three files are stored in the computer's hard disk. In the first file, the results of the evaluation test are registered. In the second file, the time that each user spends in each screen of the multimedia application as well as the number of visits in the same scene are registered. Similarly, in the third file the time that each user needs to answer each question is recorded. These three files are stored as text-files (*.txt) and can be imported into an Excel spreadsheet.

3. Research-results

A statistical research study was designed, which aimed at finding out which type of visualization (I3DVE, 3DAIF and 3DSIIF) contributes to the learning process of 17 and 18 year-old students in science. A total of 111 students participated in the main research (37 in the first sample, 34 in the second, and 41 in the third). The sample was selected randomly in clusters, from various schools of Greece. The random selection of each sample was dictated by the fact that in every classroom there were students of different intellectual ability, gender, economic status, etc. Seated at separate computers, each student worked one version of the multimedia application during one school hour. In order for the outcome of our research to be as thorough as possible, a pilot research was made, in which 45 students (15 from each sample) were used.

In the case of the questions after the correction and the modification of them, their reliability and validity were checked and all nine questions were found suitable.

In the main research, the necessary corrections at the percentages due to random answers were carried out. Then a check followed of the dependent variables regarding their regularity. In this phase, the Kolmogorov–Smirnov, Shapiro-Wilk, and Levene tests were used. The Levene test was used in order to check the equivalence of scatter. On the basis of the above tests it was found that all the assumptions were not valid for the use of ANOVA analysis (parametric test). Therefore, a different non-parametric test ought to be chosen, e.g. the Kruskal-Wallıs test (H) and the Mann-Whitney U Test (taking into account the Bonferroni correction). Finally, the above tests have shown that for the control of correlations the Spearman's rho indicator should be used.

As far concerning the percentage of correct answers that students gave, in the three versions of the multimedia application, the highest success rates in answering the questions were observed in the version I3DVE. In particular, as the Kruskal-Wallis gave $H=9.837$, $df=2$, $p=0.007<0.05$, it was evident that statistically significant differences appeared. Then, the performing tests of Mann-Whitney-U gave statistically significant differences between the versions with: I3DVE and 3DAIF ($U=419.500$, $N_1=38$, $N_2=35$, $p<0.017$), and also I3DVE and 3DSIIF ($U=463.500$, $N_1=38$, $N_3=41$, $p<0.017$). On the other hand, the version with 3DAIF and 3DSIIF gave no statistically significant difference ($U=618.500$, $N_2=35$, $N_3=41$, $p>0.017$).

4. Discussion

In this research study the most essential conclusion is that the interactive 3D virtual environment in science contributes more effectively to the learning process. This could be associated with the fact that 12th grade students have completely developed the spatial ability. Thus, they can conceive and understand interactive 3D animations, by passing possible cognitive overload problems, for it is well known that such multimedia-learning environments generate a heavy cognitive load - as it was observed with 8th grade students (Korakakis et al., 2009).

It is noteworthy that in the questions section, the highest success rates were achieved in the case of «I3DVE» version. Consequently, a major finding of this research is that interactive 3D virtual environment makes learning more efficient for 17 and 18 year-old students in science. The above result is in agreement with the results of Ferk, Vrtacnik, Blejec & Gril (2003), which indicate that certain representations of interactive 3D structures are better understood and can be more readily used by students in performing tasks of different complexity, like the case of concepts involved in "atomic orbitals" thematic unit. Also as Huk (2006) pointed out, the 3D models are used more by students of high spatial ability than by students of low spatial ability, as it is in this case. Additional research has also shown that spatial ability has an impact on the comprehension of 3D computer visualizations (Keehner et al., 2004), and that learners with high spatial ability have a more positive attitude toward 3D content than learners with low spatial ability. So, only 17-18 year-old students have developed completely the necessary metacognitive abilities (Veenman & Spaans, 2005), as well as the spatial ability (Ferk et al., 2003) and the visualizations skills (Gilbert, 2005).

In concluding, the use of interactive 3D virtual environment in science addressed to 17-18 years old students is distinctly recommended, as suggested by the present results. However, taking into consideration similar studies in literature, it is revealed that in order to evaluate the effectiveness of 3D types of visualization (I3DVE, 3DAIF, and 3DSIIF) in supporting teaching and learning in science, the age of the students is a crucial factor in science education.

References

Baddeley, A. D. (1992). Working memory. *Science,* 255*,* 556-559.

Baddeley, A. D. (1997). *Human memory: Theory and practice* (Rev. Ed.). Hove. UK: Psychology Press.

Barnea, N. (2000). Teaching and learning about chemistry and modelling with a computer managed modelling system. In J. K. Gilbert & C. J. Boulter (eds.), *Developing Models in Science Education.* Dordrecht: Kluwer Academic.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review,* 3*,* 149-210.

Ferk, V., Vrtacnik, M., Blejec, A., & Gril, A. (2003). Students' understanding of molecular structure representations. *International Journal of Science Education,* 25(10), 1227– 1245.

Gerjets, P., & Scheiter, K. (2003). Goal configurations and processing strategies as moderators between instructional design and cognitive load: evidence from hypertext-based instruction. *Educational Psychologist,* 38*,* 33–41.

Gilbert, J. (2005). Visualization: A metacognitive skill in science and science education. Visualization in Science Education (pp. 9-27). Netherlands: Springer.

Huk, T. (2006). Who benefits from learning with 3D models? the case of spatial ability. *Journal compilation & 2006 Blackwell Publishing Ltd Journal of Computer Assisted Learning,* 22, 392–404.

Keehner, M., Montello, D. R., Hegarty, M., & Cohen, C. (2004). Effects of interactivity and spatial ability on the comprehension of spatial relations in a 3D computer visualization. *In Proceedings of the 26th Annual Conference of the Cognitive Science Society.* (eds K. Forbus, D. Gentner & T Regier), pp. 1576, Mahwah, NJ: Erlbaum.

Korakakis, G., Pavlatou, A. E., Palyvos, A. J., & Spyrellis, N. (2009). 3D visualization types in multimedia applications for science learning: A case study for 8th grade students in Greece. *Journal Computers & Education,* 52(2), 390–401.

Milik N., Mitrovic A., and Grimley M. (2008) Investigating the Relationship between Spatial Ability and Feedback Style in ITSs. B. Woolf et al. (Eds.): ITS 2008. LNCS 5091. pp. 281-290 Springer-Verlag Berlin Heidelberg.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist,* 38(1), 1-4.

Paivio, A. (1986). *Mental representation: A dual coding approach.* New York: Oxford University Press.

Sylaiou, S., Mania K., Karoulis, A., White M. (2010). Exploring the relationship between presence and enjoyment in a virtual museum. *Int. j. Human-Computers Studies*, 68, 243-253.

Van Merrienboer, J. J. G., & Kester, L. (2005). *The Four-Component Instructional Design Model: Multimedia Principles in Environments for Complex Learning.* In R. E. Mayer. The Cambridge handbook of multimedia learning. New York: Cambridge University Press.

Veenman, M., & Spaans, M. (2005). Relation between intellectual and metacognitive skills: Age and task differences. Learning and Individual Differences, 15(2), 159-176.

Wu, K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education,* 88*,* 465–492.