Spatial Abilities in Virtual Environment's Learning Spaces

Costas Diplas, Vassilis Komis
cdplus@upatras.gr, komis@upatras.gr
Department of Educational Science and Early Childhood Education (DESECE), University of Patras, Greece

Abstract
The recent three-dimensional virtual environment applications of Virtual Reality have a strong impact on the way the users interact with computer-generated spaces and on the role of the computer as a supportive tool and as a mediator for learning, as well. The researchers in the field of Educational Technology are content to build conceptual frameworks to study the cognitive representations formed by the students in this new technological platform and the students' knowledge acquisition. Moreover, they provide the students with virtual environment applications for learning in various domains. Such an approach to the study of learning is presented here, concerning the investigation and evaluation of factors that seem to be important and particularly decisive for the spatial perception. The learners were engaged with specific tasks inside an interactive 3D virtual space modelled using desktop virtual reality technology for learning. The experimental processes that were designed provided our research team with useful data and first conclusions for further research.

Keywords: virtual environment, virtual world, 3D, spatial knowledge, education

Introduction

Virtual Reality

The framework of this study is the use of Virtual Worlds (VW), generated through Virtual Reality (VR) technology, as educational – learning virtual environments (VEs) aiming to enhance users' – learners' spatial perception. Focusing on the analysis of the effects of VR on user's spatial survey knowledge, the study will explore three different experimental cases regarding spatial problem solving tasks. This paper applies to the field of the "use of VR technology to enhance spatial behavior in the real world" as classified by (Durlach et al., 2000), for the four distinct categories of research on Spatial Knowledge and VR technology.

VR consists of interactive computer generated simulations, which detect the user's position and actions and replace of or enhance reaction aimed at one, or more, senses, producing the effect of user presence or "immersion" in the simulated Virtual Environment (VE) or Virtual World (VW). This research focuses on the use of *non-immersion* type of technology, also known as *desktop VR*, according to the definitions and the classification described in the papers of (Sherman & Craig, 2003; Chen, Toh, & Wan, 2004).

In recent years, three-dimensional VEs or VWs have been developed as educational supportive tools in various scientific fields, mainly but not exclusively pertaining to domains such as physics (Chittaro & Ranon, 2007; Diplas & Pintelas, 2000; Komis, 2004; Messinis, Vrellis & Pintelas, 2009); Mikropoulos &

Natsis, 2011; Mikropoulos, 2006; Huang, Rauch & Liaw, 2010; Trindade, Fiolhais & Almeida, 2002; Winn, 1993). Three-dimensional VWs developed with non-immersive VR technology are now used, widely, in applications for learning as well as in 3-D games (LaViola, 2008). Given the fact that this research focuses solely on spatial abilities and spatial features of 3-D interactive virtual environments and accepting the assumption that the space is visually depicted inside the VWs' graphical 3-D user interfaces as had been noted in the (Sanchez, 2009), regarding the common 3-D spatial features in both desktop VEs & VWs applications, the terms VE and VW could be used as synonyms in the remainder of our article. VEs and VWs can be used to enhance spatial perception and spatial knowledge (Dünser et al., 2006; Durlach et al., 2000; Noor, 2010; Wallet et al., 2009, Luo, Luo, Wickens & Chen, 2010, Mania, Badariah, Coxon & Watten, 2010).

Spatial abilities

Spatial abilities (Linn & Petersen, 1985; Hegarty, 2010) is a vital aspect of human cognitive ability, as it is, essentially, a process linked: a) to the interpretation of incoming data perceived visually by the individual, such as images, objects, maps, shapes, and, b) to the viewing of specific positions in an environment in relation to either a standard axis system, to other positions, or to the individual themselves. Research on spatial perception from the cognitive sciences perspective has contributed to the specification of the main categories of spatial ability *(*Carpenter & Just 1988; Lohman, 1997*)*, narrowing them down to the following three: spatial perception, mental rotation and spatial visualization (Linn & Petersen, 1985).

Spatial ability is essential to a wide range of everyday activities, which explains the fact that the development of spatial concepts and knowledge is part of the preschool and the first classes of school curriculums. As the inclusion of Information and Communication Technologies in education is rapidly increasing, it seems that the educators of the future will be required to incorporate to their teaching VWs of non-immersion VR technology rather than immersion VR technology, as the former is more cost efficient and can be easily applied in the classroom (Chen, Toh & Wan, 2004) as supportive learning tools for the teaching of various subjects other than spatial concepts. Therefore, the degree of familiarization of future educators with VWs is just as important as that of their students, as it is the teachers who will use VWs first, before their students.

In the next paragraphs we will be introducing the theoretical framework of this study, as well as related bibliographical research, and the writer's research framework, goals and questions. Also, we will present our research methodology, followed by an analysis of its data and results. The final points of this study contain its conclusion, completed by a few issues for further consideration.

Theoretical framework: VR and Spatial Knowledge

This research is focused on the evaluation of the survey knowledge acquired during the navigation in a 3-D VE and activities of spatial problems solving in a 3D and 2D representation. Bibliography has concluded that the acquiring of

Spatial Knowledge (SK) is related to the method and the means used in that purpose, whether that is achieved through the navigation of virtual environments, through the use of a map or through a combination the two (Darken & Peterson, 2002).

In this paper we will be using data from three models of SK representation: a) the LRS model (Siegel & White, 1975; Thorndyke & Goldin, 1983), b) the Room-Effect model (Colle & Reid, 1998; 2003; Stevens & Coupe, 1978) and c) the model of spatial thinking, storing & imaging (Hauptman, 2010).

The LRS (Landmark, Route & Survey knowledge) model pertains to the developmental process of SK and suggests that first comes the extraction of landmarks from an environment in the form of fixed and independent spatial points (vertices), followed by the construction of landmark knowledge. Afterwards, as the landmarks are connected to each other via open routes (edges), route knowledge is developed. Finally, as the graph of vertices and edges is completed, survey knowledge emerges. At this point, even if an individual has not tried every possible route in a specific environment, they can mentally create a route, as they possess the ability –in a smaller or greater degree– to evaluate the relative distances and directions between any two points. 2D imaging and maps allow us to omit the stage of gathering route spatial knowledge and move straight to the spatial survey knowledge, as they provide a full image of the space. However, survey knowledge acquired through 2D imaging or maps is inferior to that which develops through the knowledge of routes or direct touring, due to the vast importance of the spatial ability of orientation (Darken & Peterson, 2002).

The LRS model provides a useful means of conceptually dissecting SK to its components, since it is this dissection which allows us to study each of its components separately. Therefore it can be argued that acquired SK contributes to the enhancement of spatial education, as a result of an increase in the degree, accuracy and completeness of every type or element of SK developed (Whyte, 2002; Foreman & Gillet, 1997).

The Room-Effect model suggests a duple feature through which survey spatial knowledge (SSK) is acquired swiftly in small areas or spaces and more slowly in larger ones. The "room-effect" phenomenon is just that; the fact that SSK is quickly acquired in one room, but develops rather slowly and not as accurately in spaces with more than one room or in larger spaces. In this study, the VW used contains more than two rooms as well as outdoors or partly enclosed spaces (Images 1a & 1b).

Image 1a: an outside view of the VE

Image 1b: an internal view of VE

The concepts of spatial thinking, spatial storing or memory, and spatial images have been presented in the work of (Hauptman, 2010). Spatial thinking is described as a mental feature involving the mechanisms and cognitive activities which take place during the processing of information stored in spatial memory, by creating spatial images which are the results of the processing of this information and can aid in tackling spatial challenges when properly managed.
The aforementioned models were selected because: (a: *LRS*) the spatial concepts were described adequately and were founded clearly on the conceptual division of SSK to its components, (b: *room-effect*) considering the size and the complexity of the VE used in our research, and (c: *spatial thinking-images*) the usage of a common way with 2-D still images/photos for the display of both the real and the virtual environment.

Related research

In their article (Dalgarno, Hedberg and Harper 2002) review a number of studies in the research field of spatial representation and VEs. These studies have documented an enhancement in the SK of VE's users, as the users became able to develop spatial representations similar to those that would had been obtained if the users had explored a real environment. (Ruddle and Peruch, 2004) argue that although there was no difference in the users' exploration ability regarding distances and route knowledge, there were differences in their SSK. (Morganti et al., 2007) explore the evaluation of spatial abilities based on SSK and uses representation through maps and drawings. It also introduces a method of evaluating spatial abilities based on the acquisition and organization of SSK in a VE. SSK evaluation can be performed with a simple virtual tour in comparison to the study of spatial abilities like finding a route in a map or a drawing. Useful conclusions can be drawn, such as the fact that the ability to draw a map is far more related to an individual's performance in tasks involving SSK than to their performance in tasks which require route finding. Important research activity is described in the work of (Hurlebaus et al., 2008), where the proper use of a map is proven a reliable means of evaluating SSK in a VE.
Regarding the relationship between spatial knowledge and learning supported by VEs, it has been shown that they are actually related, initially, at the first level of interaction with the VE, which regards on the user's awareness and familiarity with the VW into which the educational processes will be held, whatever the gognitive subject (Kommers, 2002). Is has been proven appropriate for VE's designers to provide the end users with more features in order these users get familiarized with the VW used (Mikropoulos, 2010). Thus, the user would be able to construct a more complete mental representation of the VW's spatial properties, and the degree of SSK is of a big importance in this process. Moreover, there is a correlation in the second level of user-VE interaction which regards the cognitive subject, as the learning processes that lead to the development of enhanced representation of VW are facilitated (Dalgarno, Lee, 2010).

The results and conclusions of research presented in a much comprehensive overview of the research area of spatial skills in VEs (Mohler, 2001) are obviously issues for investigation and also strong motivation to conduct our own research.

Purpose of the research

In this article we will be comparing the results of users' performance in tasks before and after learning activities designed to enhance SSK, in 3-D VEs. The aim of this study is to determine which of the three experimental conditions / approaches (which are described in detail in next section) contribute to the acquisition of SSK, in a VE which simulates a playground (views of this VE are depicted in black & white images 1a and 1b).

Research questions and hypotheses

The field of spatial perception and spatial abilities contains issues regarding mental image representation, as in order for an individual to mentally explore an environment they need to be able to represent visual and spatial images in their mind. This means that the individual must be able to store 2D and 3D information in such a way that they will be able to mentally retrieve them later on and use them to tackle problems of space (spatial problems) (Lathrop & Kaiser, 2005; Hegarty, 2010). The questions that rise mainly concern the ways in which spatial abilities, as well as the ability to mentally recreate or visualize images, when developed through the use of VR, could possibly be put to use in the real world. This article will be specifically posing the following questions:

1. Is the ability to visualize the VE to its 2-D image differentiated depending on the kind of presentation and use of the VE?
2. Is the enhancement of SSK's development depending on the way the VE is used, and which is the optimal way?

The relevant hypotheses are:

1. The user-VE interaction with tasks for spatial problem solving in the VE increases the user's ability to visualize the VE to its 2-D image
2. The optimal way to enhance the development of user's SSK is based on tasks for spatial problem solving in the VE along with the use of paper-based floor plan of the VE.

Research methodology

The samples in each of the three experimental cases

In total, the study sample for this study comprised of 120 students from the six groups of the Department of Educational Science and Early Childhood Education (DESECE), aged from 18 to 23 years old, who were participating in the *Introduction to Information and Communication Technology* course of the department's first year of studies. It should, also, be noted here that the students participated in the research voluntarily and anonymously. The data collected are not used anywhere else other than this research. During the laboratory courses for the familiarization of the tomorrow pre-school education teachers (and currently university students of DESECE) with VEs and VWs, the students were requested to play a hide and seek game in a *virtual playground* which was delivered in VRML format, accessible through a URL with the use of internet explorer browser and mouse/keyboard. The students' computers were 3GHz Pentium4 equipped with 19-inch LCD monitor, mouse and keyboard and graphics card for rendering the scenes under 32 bits true color in 1024x768 resolution. There was no noticeable frame rate or network lag during the experiments. To avoid tampering of data and guarantee the reliability of the research, wooden panels were positioned between the workstations of the students. Everyone would deal with the learning activities, almost isolated and undisturbed, safely.

The selection of the individuals who participated in each of the three experiments was random, and was decided according to the order in which each groups appeared on the class' schedule. The first two groups participated in the first experiment, the second two in the second experiment, and the final two in the third experiment. Even though all 40 students on each group participated in the course of the research, the students who were selected in the end were those who had similar computer and spatial abilities.
After completing questionnaires, the students were grouped according to their abilities. Therefore the first group comprised of 35 students, the second group had 34 and the third group 38 students, as shown in table 1.

Table 1: Number of participants in each group

1st group	35
2nd group	34
3rd group	38

The selection of participants in each of the experiments was based on the questionnaires, and specifically on the questions that determined their familiarity with 3D software and VR, and their abilities on: spatial visualization, usage of maps/floor plan photos, everyday spatial problem solving.
The designing of experimental conditions aimed at providing a homogenous sample as far as spatial and computer skills were concerned. During this process we were forced to exclude individuals with performances on the far edges of the spectrum. The stability of experimental conditions is ensured. The gathering of results concerning common factors (*before* and *after* in all of the experimental conditions) as well as factors specific to each experiment is reliable, since the data were gathered and coded by two different researchers with minimal variations.

The stages of the research process

1st stage: Formation of samples. The selection of participants for the three (3) experimental conditions was realized. Participants had completed the initial questionnaires before the experiments: computer skills profiles (general and more specific in 3-D software / games, VR), Everyday Spatial Activities Test (ESAT)

(Lunneborg, & Lunneborg, 1986), visualization, spatial skills on aerial / maps / floor plan photos.

2nd stage: spatial problem solving in an aerial photo of the real world. (pre-test) A spatial problem was given to all participants. They were asked to mark the position of a specific object (the kiosk) on an aerial photo of the real world and specifically of a smaller area inside the university campus (Image 2) next to the first bus station and so it was familiar to them, and their performance was evaluated.

In the 3rd and 4th stage the three experiment cases were carried out, separately for each two laboratory groups. More specifically, our teaching intervention took place:

3rd stage: Complex spatial problem Solving into the 3-D VW. This stage included the navigation to find a virtual object (*blue boxes*) and return to starting position. A screen capture realized during participants' navigation (real time) to ensure the integrity of instructional intervention on the fact that each one participant actually found (or not) the requested object and, also, returned to his/her original position as they had been requested to do.

Image 2: A 2-D Aerial (photo) of a smaller area inside the university campus

4th stage: Complex spatial problem solving on the 2-D paper representation of the VE. **a)** to mark the location of the *blue boxes* which they were searching for in the VE on the previous stage and **b)** to sketch a virtual object (*red wall*) on the paper 2-D floor plan photo of the VW; this second object had not been, purposely, announced to the students and not even had been mentioned by the researcher in the previous stage.

5th stage: spatial problem solving in an aerial photo of the real world. (post-test). Similar to the 2nd stage, the participants were called to mark the position of the kiosk on the aerial photo. The research process is shown in Table 2.

Table 2: the stages of the research process

1st stage	2nd stage	3rd stage	4th stage	5th stage
		Teaching intervention		
Questionnaires	• **Spatial problem solving** in an aerial photo of the real world. (pre-test)	• **Complex spatial problem Solving into the 3-D VW**	• **Complex spatial problem solving** on the **2-D paper-based representation of the VW (floor plan photo)**	• **Spatial problem solving** in the aerial photo of the real world. (post-test)
• computer skills profile (general & specific in 3-D software / games / VR) • floor plan diagrams, aerial & maps skills profile • Visualization test • ESAT test	• **mark the position** of a specific object (the kiosk) on an **aerial photo of a small area inside the university campus**	• **navigation & search** for the first virtual object (*blue boxes*) and • **return to starting position**	• **mark the location of the first virtual object** (*blue boxes*) • **Sketch the second virtual object** (draw a line: position of the *red wall*)	• **mark the position** of a specific object (the kiosk) on an **aerial photo of a small area inside the university campus**
	• rating of the solution	• **Screen capture** during the navigation (realtime) for the recording of their performance on o finding the object & o way-finding to starting position • rating of the solution	• rating of the solution	• rating of the solution

The students performed spatial problem solving activities: **a)** navigate and search for a virtual object in the VE which simulates a playground, **b)** determine the location of a virtual object by pen marking and **c)** sketch/draw another one simple object; for the (b) and (c) a 2-D representation of this VE in a paper worksheet, with a floor plan photo - screenshot of the VE (Image 3) was used.

Image 3: floor plan photo of the VE

Our research approach is this of the spatial problems solving in VE and in its 2-D display, as a way to enhance the student's spatial abilities so as to be able to obtain SSK. The assessment of acquired SSK is investigated; the SSK was obtained through navigation and problem solving activities into the VE (searching / wayfinding) along with problem solving activities using a paper-based floor plan photo of this VE (recalling the location of virtual object, marking and sketching of virtual object) with criteria of position and direction accuracy.

The experimental conditions

The description of the experimental conditions or settings which were designed and implemented follows, in diagrams 1a, 1b, 1c. Three alternative modes of VE usage were selected for comparison: (1) non-active interaction or demonstration, (2nd) exploration without any specific goal and (3rd) active interaction aimed at solving spatial problems. Criterion for the comparison was the performance of students in solving spatial problems in the natural environment.

In all experimental conditions the "pre" and "post" tasks using the 2-D aerial photo of the physical environment were common. In the 1st experimental condition a pre-recorded navigation was used, without actual students' interaction. In the 2nd and 3rd experimental conditions the ***exploration*** and the ***naive*** modes were used respectively as the appropriate way finding types according to the classification of (Darken, 1995).

1st experimental condition

The students were watching in their personal computer's screen a pre-recorded navigation (by the research team), or, in other words, a demonstration of the VE's viewpoints, without participants' actual navigation.

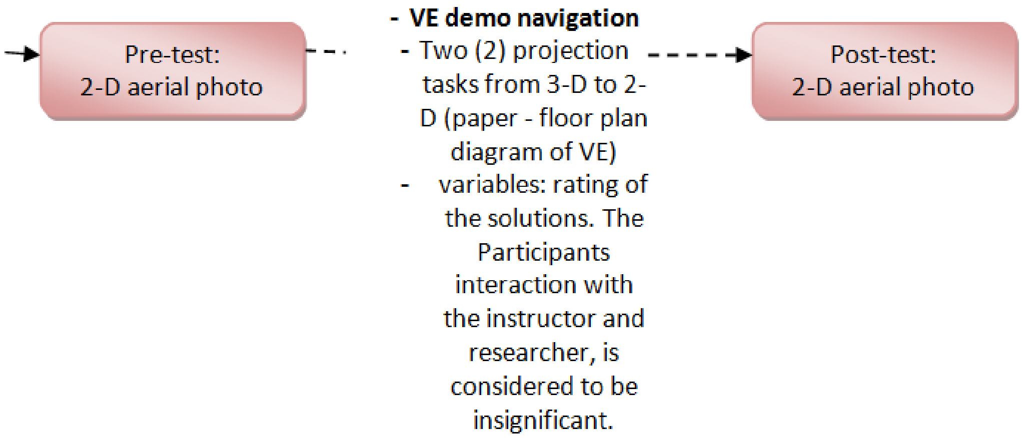

Diagram 1a: 1st experimental condition

2nd experimental condition

With participants' navigation, category of **exploration (**Darken, 1995) and without spatial problem solving task (SPST) in the 3-D VE.

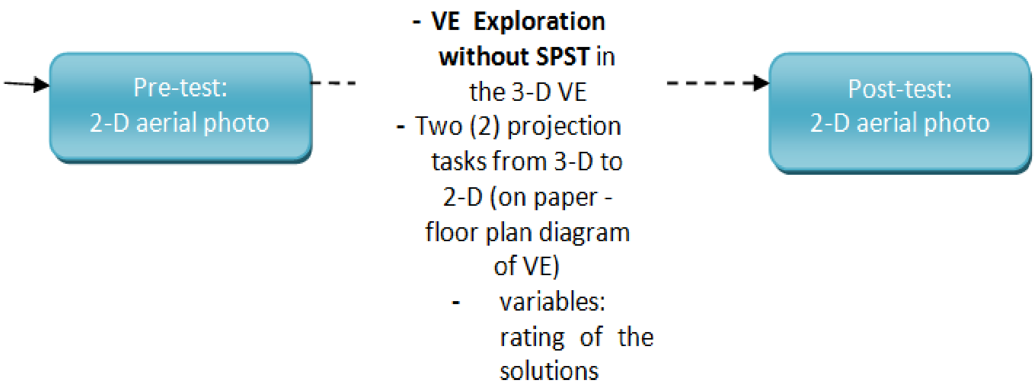

Diagram 1b: 2nd experimental condition

3rd experimental condition

With participants' navigation, category of ***naive*** **(**Darken, 1995), with spatial problem solving tasks (SPST) in the 3-D VE: to find a specific object without a priori knowledge of this object's location and return to their initial position.

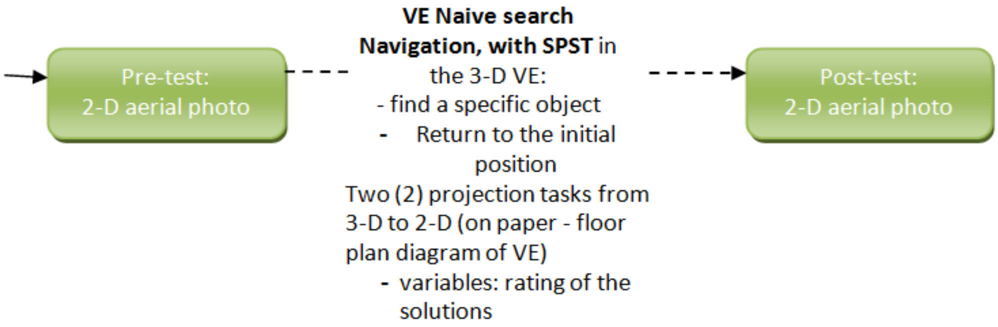

Diagram 1c: 3rd experimental condition

In the next section the descriptive analysis of the collected data for each category of experimental conditions is presented. The data concern the performance of the participants in:

a) the tests *before* and *after* the experiment (pre-test and post-test), regarding the adequacy of their SSK, where the aerial photo of the physical environment was used,
b) two (2) spatial problem solving tasks, regarding the transfer of spatial mental representation from 3-D to 2-D, where the paper floor plan photo of VE was used: **i**) the definition of the first virtual object's location (*blue boxes*) , **ii)** the sketching/drawing of the second virtual object (*red wall*).

All the above mentioned tasks and tests concern the ability for SSK acquisition (Hurlebaus et al., 2008).

Data Analysis and Findings

The prior assessment of students' SSK

The prior assessment is based on the student's estimation about the actual location of the university campus kiosk, using the aerial photo of the area. The assessment results for the three experimental conditions are depicted in Chart1: Only 28.6% of the students of the 1st experimental condition group were able to identify the correct location. In the 2nd group there was a similar percentage of 29.4%. Finally in the 3rd group the 23.7% of the students determined the correct position. However, the differences were not statistically significant ($\chi 2 = 0.355$ with $df = 2$ and $p = 0,837$) which means that concerning the constitution of the groups in the three experimental conditions, the equivalence is guaranteed.

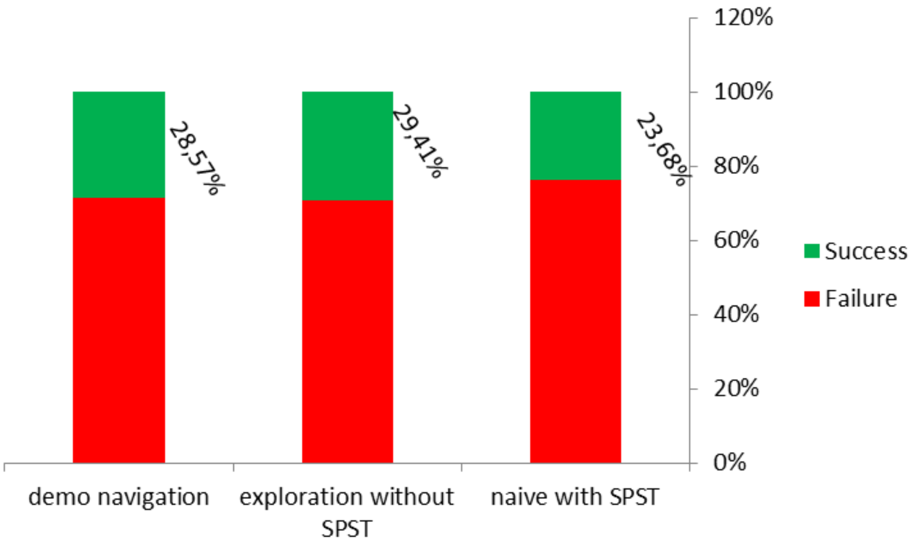

Chart1: The assessment of the correct positioning of the university campus' kiosk on the 2-D aerial photo, during the 2nd stage of the research process (pre-test)

The assessment of student's SSK after the experiments

The results of the three groups' assessment after the corresponding experimental condition's tasks and activities are depicted in chart 2.

It has been shown that the performance of the 1st experimental condition group has improved compared with the initial values before the experiments. The 37,1% of the students in this group were able to determine the correct location. In the 2nd experimental condition group there is also an improvement with the 35.3% of the students marked the correct location. Finally, in the 3rd experimental condition group the improvement is greater than the two other groups. The percentage of the students who marked the correct location is 81.6%. In addition, the difference is statistically significant ($\chi 2 = 20,22$ with $df = 2$, $p = 0.001$).

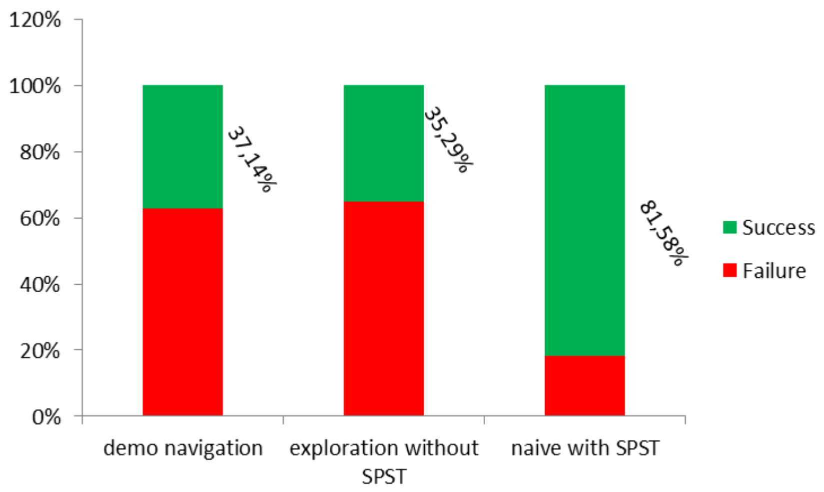

Chart 2: The assessment of the correct positioning of the university campus' kiosk on the 2-D aerial photo, in the 5th stage of the research process (post-test)

The differences between the prior and the final assessment to the determination of the kiosk's actual location in the aerial photography showed improvement especially in the third group (Table 3). The improvement concerns 22 subjects in the third group, even more than those with stagnation (16 subjects), while there are no subjects with decline. This finding is statistically significant (test sign, p = 0,0001). In the third experimental condition 22 participants from the total 38 had better achievement (rate 57.9%) versus 4 participants out of 35 (11.4%) and 2 out of 34 (5.9%) in the first and second experimental conditions. Therefore, the effect size (Cooper & Hedges, 1994) of the method utilized in the third condition versus the other two methods, is, respectively, 57.9/11.4 = 5.07 and 57.9/5.9 = 9.8.

Table 3: Progress of subjects in the experimental conditions

Groups of subjects in Experimental conditions			N
1st : demo navigation	after – before	decline	1^a
		improvement	4^b
		stagnation	30^c
		Total	35
2nd : exploration without SPST	after – before	decline	0^a
		improvement	2^b
		stagnation	32^c
		Total	34
3rd : naive with SPST	after – before	decline	0^a
		improvement	22^b
		stagnation	16^c
		Total	38

These findings suggest that the enhancement of SSK's development is depending on the way the VE is used, and, moreover, the optimal way is this on the third experimental condition, as had been expressed in the second research question.

For the confirmation of the above, we will check the students' performance on the two (2) paper-based tasks during the 4th stage for the three (3) experimental conditions: the **Marking location** and the **Sketching a virtual object** tasks. These tasks were given to the students immediately after a short familiarization time period (5-minutes in another VRML environment so as to get familiar with the mouse usage) and regard the transfer of SK from 3-D to 2-D representation. The following analysis includes descriptive statistics of observed data and exploratory analysis in each case.

Marking location task

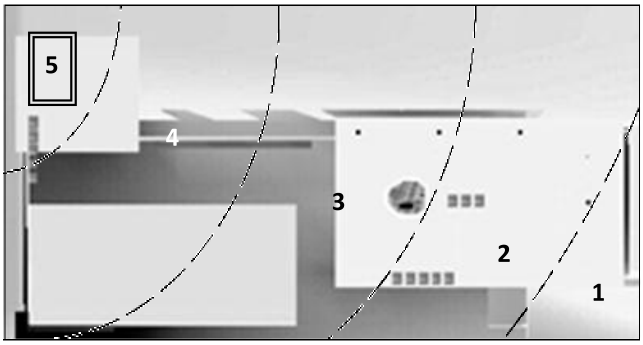

Image 4: The areas that correspond to the assessment scale

A five-point scale was used for the assessment of the students' performance on the marking location task and it was based on the relative position and distance between the location marked by the participants and the correct location on the VE's floor plan photo. In image 4 the dashed lines delimitate discrete areas that correspond to the scale: the "5" points area corresponds to the correct location and it was planned to include the case where not given any answer in the "1" point area, but such was not the case. As shown in Figure 3, the students who were able to determine correctly the point ("5") are more in the 3rd research condition (60,53%) than those in the 1st and 2nd (5,71% and 8,82% respectively).

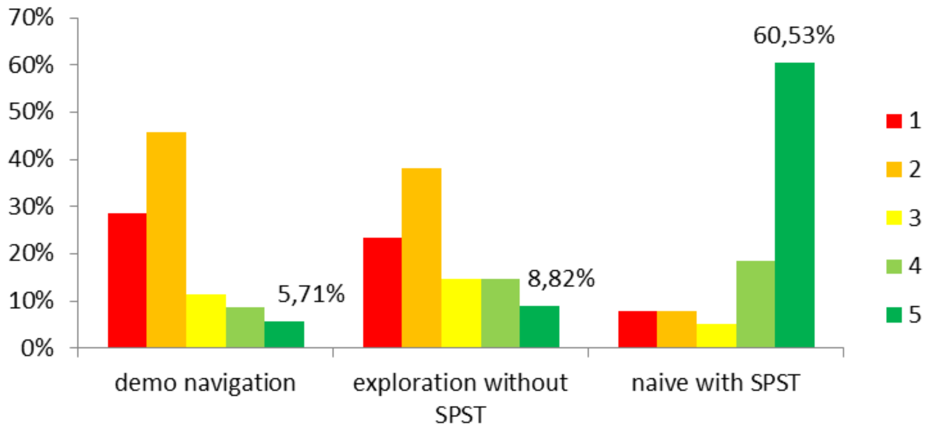

Chart 3: Assessment* of the determination of virtual object location using the floor plan photo, in the three experimental conditions

*five-point scale

Sketching a virtual object task

The participants were asked to sketch a virtual wall (so as not to require particular skills on drawing). For the assessment of responses a three-point scale was used: “1”: no drawing at all, “2": if the position of the wall was wrong, and “3”:correct. As shown in chart 4, the 71,05% of the students in the 3rd experimental condition were able to successfully sketch the wall, while in the 1st and in the 2nd the corresponding percentages are 11,43% and 14,71%.

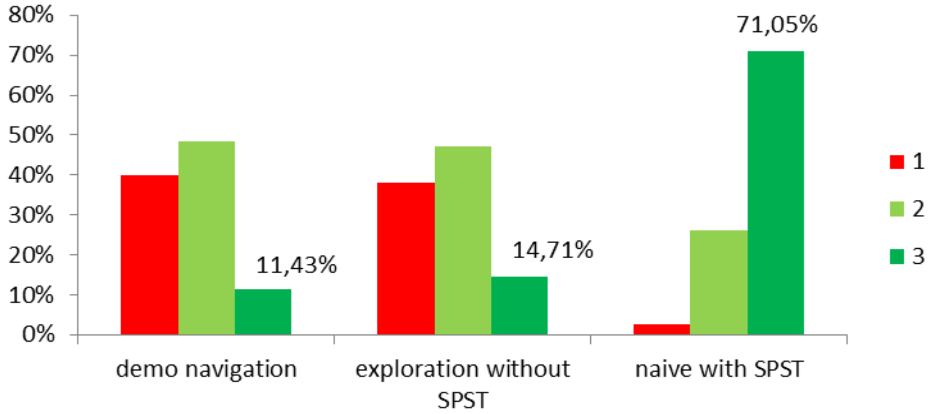

Chart 4: Assessment* of the virtual object sketching on the VE’s floor plan photo, in the three experimental conditions (*three-point scale)

These findings suggest that the ability to visualize the VE to its 2-D image differentiated is depending on the kind of presentation and use of the VE, as had been stated in the first research question.

Conclusions & discussion

According to the results it seems that our approach in the third experimental condition enhanced the students' ability to construct spatial representations regarding the SSK, and also, the transfer of SSK representation from the VE to the real environment was facilitated. The searching task in the VE followed by the identification of the locations on the 2-D image of the VE was shown to be beneficial. Actually, the process of the spatial images representation (Hauptman, 2010) was motivated by the spatial problems solving in the 3-D and 2-D display of the VE. The answer to the first question is that the ability to visualize the 3-D VE to a 2-D image differentiates, since the 3rd group scored better on the task of identification of the blue boxes location.

Also, there was a cognitive improvement in the participants' spatial ability since they were able to get higher scores in the post-test. This is the answer to the second question: the development of SSK was enhanced in the 3rd experimental condition.

The development of survey spatial knowledge concerns issues of learning, obviously. This, accompanied by the importance of transferring user's spatial skills from the virtual to the real world suggests that the VEs can be used in education in an appropriate and meaningful way. The results of our approach are consistent with what stated in the (Ruddle and Peruch, 2004) concerning the SSK. Our contribution is considered to be the facilitation of transferring the SSK construction ability from virtual to the real world. The active navigation of naive type (Darken, 1995) along with simple tasks of spatial problems solving using a combination of paper-based and computer-based 3D mode, which is similar to what stated in (Darken & Peterson, 2002) concerning maps & VEs, seems to facilitate a strong connection between *landmark* spatial knowledge and *route* spatial knowledge (Siegel & White, 1975; Thorndyke & Goldin, 1983) and finally lead to SSK strengthening.

Also it was shown that the student interaction with a VE even different from the natural environment of the aerial photography, when accompanied by the transfer of mental spatial representations from 3D to 2D help strengthen the SSK for the natural environment. The students' scores on the red wall sketching task are remarkable, since this virtual object, unlike the blue boxes, had not been even mentioned before, though many students managed to accomplish this task. Therefore it seems that the participants got familiar with the virtual world and also obtained a good level of spatial awareness, since their ability to imprint the location and the direction of the virtual wall was strengthened (Hauptman, 2010). The findings of our research also indicate the potential of VEs for the acquisition of skills which can be transferred to similar situations in the real world.

The contribution of our research is the proposal of a framework regarding the use of VEs for the enhancement of SSK, and more specifically in the metacognitive level of SSK activation and acquisition capabilities. Such a framework appears to be feasible and useful, taking into account the current situation in the research area focusing on the features of VR to improve spatial thinking and enhance spatial ability, which is in its infancy (Lee, Wong & Fung, 2009).

Our study is, certainly, limited by the small sample size (out of total 120 students, 13 of them were either excluded due to scores in the far edges of the spectrum or were absent in the pre/post tests, and finally the data from 107 students included in the analysis) and their specific profile (social sciences students, little experience with 3D/VR technology). We also focused on the acquisition of survey spatial knowledge, simple spatial problem solving and our basic material was a rather simple VE.

Concerning the limitations, we have also considered other possible explanations of the data. The observed improvement in the users' ability to visualize the VE to its 2-D image could be due to the size of the VE and not to the mode of presentation and use. Also, the improvement in the users' SSK could be due to that the students had a social sciences background with no particular experience on geometry, possibly. Further studies with larger sample sizes and students of different backgrounds, complex spatial problem solving activities, and an extensive VE, as well as use of augmented VR (Dünser et al., 2006; Durlach et al., 2000) with GIS could benefit research on the impact of VR on SK acquisition and transferring from virtual to the real world.

Aknowledgements

The research team would like to thank the students of the DESECE – Univ. of Patras for their participation in this study.

References

Carpenter, P. A., & Just, M. A. (1986). Spatial ability: An information processing approach to psychometrics. In R. J. Stemberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 3, pp. 221-252).Hillsdale, NJ: Erlbaum.

Chittaro, L., & Ranon, R. (2007). Web3D Technologies in learning, education and training: Motivations, issues, opportunities. *Computers & Education, 49*(1), 3-18.

Chen, C. J., Toh, S. C., & Wan, M. F. (2004). The theoretical framework for designing desktop virtual reality-based learning environment. *Journal of Interactive Learning Research*, *15*(2), 147-167.

Cooper, H., & Hedges, L. V. (1994). Research synthesis as a scientific enterprise. In H. Cooper & L. V. Hedges (eds.), The handbook of research synthesis (p.246). New York: Russell Sage Foundation.

Dalgarno, B., Hedberg, J., & Harper, B. (2002). The contribution of 3D environments to conceptual understanding. *Proceedings of ASCILITE 2002 Conference*, 44–54. Citeseer. Retrieved from http://ascilite.org.au/conferences/auckland02/proceedings/papers/051.pdf

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10-32. Wiley Online Library. Retrieved from http://blackwell-synergy.com/doi/abs/10.1111/j.1467-8535.2009.01038.x

Darken, R. P. & Peterson, B. (2002). Spatial orientation, wayfinding and representation. In K. M. Stanney (ed.), *Handbook of Virtual Environments: Design, Implementation, and Applications* (pp. 493-519). Lawrence Erlbaum Associates, Inc., Mahwah, New Jersey.

Darken, R. P. (1995). Wayfinding in Large-Scale Virtual Worlds. *Interface* (pp. 45-46). ACM Press. Retrieved from http://portal.acm.org/citation.cfm?id=223419.

Diplas, C. N., & Pintelas, P. (2000). Design of interactivity in virtual reality applications with emphasis on educational software using formal interaction specification. *Journal of Education and Information Technologies*, 5(4), 291-304.

Dünser, A., Steinbügl, K., Kaufmann, H., & Glück, J. (2006). Virtual and augmented reality as spatial ability training tools. *Proceedings of the 6th ACM SIGCHI New Zealand chapters international conference on Computerhuman interaction design centered HCI CHINZ 06*, 125-132. ACM Press. Retrieved from http://portal.acm.org/citation.cfm?doid=1152760.1152776

Durlach, N., Allen, G., Darken, R., Garnett, R.L., Loomis, J., Templeman, J., & von Wiegand, T.E. (2000). Virtual environments and the enhancement of spatial behavior: Towards a comprehensive research agenda. *Presence: Virtual Environments and Teleoperators*, *9*, 593-615.

Foreman, N. & Gillet, R. (eds.) (1997). *Handbook of spatial research paradigms and methodologies. Vol.1: Spatial cognition in the child and adult*. Taylor & Francis.

Hauptman, H. (2010). Enhancement of spatial thinking with Virtual Spaces 1.0. *Computers & Education*, 54, 123–135.

Hegarty, M. (2010). Components of Spatial Intelligence. *Learning*, *52*(10), 265-297. Elsevier.

Huang, H-M., Rauch U., Liaw, S-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach, *Computers & Education, 55(3), 1171-1182.*

Hurlebaus, R., Basten, K., Mallot, H. A., & Wiener, J. M. (2010). Route learning strategies in a virtual cluttered environment. *Spatial Cognition SC* (Vol. 5248, pp. 104-120). Springer. Retrieved from http://eprints.bournemouth.ac.uk/13806/

Komis, B. (2004). *Introduction to educational applications of Information and Communications Technologies*. Athens: New Technologies.

Kommers, P. (2002). Information and communication technologies in technical and vocational education and training, final report and selected materials. *Proceedings of Conference Information Communication Technologies in Technical and Vocational Education and Training Expert Meeting.* Moscow: UNESCO Institute for Information Technologies in Education. Retrieved 10 May 2010 from http://unesdoc.unesco.org/images/0013/001307/130736e.pdf

Lathrop, W. B., & Kaiser, M., K. (2005). Acquiring spatial knowledge while traveling simple and complex paths with immersive and nonimmersive interfaces. *Presence, 14* (3), 249–263.

LaViola, J. J. (2008). Bringing VR and Spatial 3D Interaction to the Masses through Video Games. *Computer Graphics and Applications IEEE*, *28*(5), 10-15. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18753029

Lee, E. A. , Wong, K. W., & Fung, C. C. (2009). Educational values of virtual reality: the case of spatial ability. *In World academy of science, engineering and technology 54 (*pp. 1162-1166*)*. Paris: WASET. Retrieved from http://www.waset.org/journals/waset/v54.php

Linn, M., & Petersen, A. (1985), "Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, Vol.56, No.6*, 1479-1498.

Lohman, D. (1996). Spatial ability and g. In I. Dennis and P. Tapsfield (Eds), *Human abilities: Their nature and measurement*, pp. 97-116, Hillsdale, NJ: Erlbaum.

Lunneborg, P & Lunneborg, C (1986). Everyday spatial activities test for studying differential spatial experience and vocational behavior. *Journal of vocational behavior*, *28*, 135-141.

Luo, Z., Luo, W., Wickens, C. D., & Chen, I-M. (2010). Spatial learning in a virtual multilevel building: Evaluating three exocentric view aids. *International Journal of Human-Computer Studies, 68(10),* 746-759.

Mania, K., Badariah, S., Coxon, M., Watten, P. (2010). Cognitive transfer of spatial awareness states from immersive virtual environments to reality. *ACM Transactions on Applied Perception*, 7(2), 1-14.

Messinis, I., Vrellis, I., & Pintelas P. (2009). Presence in stressful virtual environments. *International Journal of Teaching and Case Studies*, 2(2), 136-145.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education*, *56*(3), 769-780. Elsevier Ltd. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0360131510003052

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

Mohler, J. L. (2001). Improving spatial ability with virtual reality: A review of research and applications. *WebNet Journal: Internet Technologies, Applications & Issues, 3*(1), 28-35.

Morganti, F., Carassa, A., & Geminiani, G. (2007). Planning optimal paths: A simple assessment of survey spatial knowledge in virtual environments. *Computers in Human Behavior*, *23*, 1982-1996.

Noor, A. K. (2010). Potential of virtual worlds for remote space exploration. *Advances in Engineering Software, 41*(4), 666-673. Elsevier Ltd. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0965997809002762

Ruddle, R. A., & Peruch, P. (2004). Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *International Journal of Human-Computer Studies*, *60*, 299-326.

Sherman, William, R. and Craig, Alan, B., (2003). Understanding Virtual Reality—Interface, Application, and Design, *Presence: Teleoperators and Virtual Environments*, August 2003, *Vol. 12*, No. 4, Pages 441-442.

Whyte, J. (2002), *Virtual Reality and the Built Environment*. Architectural Press.

Winn, W. (1993). A conceptual basis for educational applications of virtual reality. Technical report (No TR-93-9). Retrieved 6 May 2010 from http://www.hitl.washington.edu/publications/r-93-9.

Sanchez, J. (2009). A Social History of Virtual Worlds. *Library Technology Reports, 45(2), 9-12.* Retrieved from http://search.ebscohost.com.molly.ruc.dk/login.aspx?direct=true&db=aph&AN=37251466

Trindade, J., Fiolhais, C., & Almeida, L. (2002). Science learning in virtual environments: a descriptive study. *British Journal of Educational Technology, 33(4),* 471–488. *Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21596885*

VRML. (1997). ISO 14772:1997. See also www.web3d.org/x3d/specifications

Wallet, G., Sauzéon, H., Rodrigues, J., & N'Kaoua, B. (2009). Transfer of spatial knowledge from a virtual environment to reality: Impact of route complexity and subject's strategy on the exploration mode. *Journal of Virtual Reality and Broadcasting*, *6*(4), 572–574. Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc /download?doi=10.1.1.163.2542&rep=rep1&type=pdf