EURASIA Journal of Mathematics, Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
OPEN ACCESS
2018 14(3):709-719
DOI: 10.12973/ejmste/79171

Virtual Learning Environments to Enhance Spatial Orientation

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Received 23 July2017 ▪ Revised 23 September 2017 ▪ Accepted 24 October 2017

ABSTRACT
The spatial orientation skill allows us to determine our location in relation to the environment. It can be developed through specific training, and is a competence to be acquired in STEM university degrees related to geospatial information. In addition to map reading, an activity that provides the spatial orientation skill is wayfinding. While wayfinding the information obtained from successive views of the environment provides spatial orientation. This research presents an immersive orientation experiment, in which an urban environment is displayed through a Smartphone installed in VR 3D glasses. The motion direction is controlled with a joystick. In the experiment 32-second year engineering students from La Laguna University participated, and the average gain in spatial orientation skill was of 12.81º, measured with the Perspective Taking Spatial Orientation Test. No gender differences detected. This gain is less than that obtained in previous experiments with GISc, Geoportals and Augmented Reality resources.

Keywords: science and engineering education, immersive environment, spatial orientation, virtual learning environments, virtual reality 3D

INTRODUCTION

Spatial reasoning enables us to behave, interact and orient ourselves in the environment where we live. Spatial cognition is acquired through information from successive views of activities at the ground level. This is known as wayfinding or route based learning: it is the intellectual process used to establish the route to get from point A to point B. Wayfinding, the cognitive element of navigation, has been a relevant element in spatial cognition research (Patel and Kumar, 2010). In these wayfinding activities, the spatial orientation skill is needed. (Howard and Templeton, 1966; Hill 1998; Gonzato et al., 2011; Gonzato and Godino, 2011).

The Spatial orientation skill is defined as the ability to remain oriented in a spatial environment when the objects in this environment are viewed from different positions (Fleishman and Dusek, 1971; Kozhevnikov and Hegarty, 2001), the three-dimensional orientation in space during movement or the ability to orient oneself towards the environment and to be aware of one’s position in space (Reber, 1985), or the ability to physically or mentally orientate in space (Maier 1998). There are different classifications of spatial skills in which spatial orientation appears (Smith, 1964; Linn and Petersen, 1985; Maier, 1998; Hegarty and Waller, 2004), and in the classifications of Bodner and Guay (1997) and Tartre (1990, a, b), spatial orientation is one of the main components of spatial skills. Spatial orientation is a subject that awakes great interest in teaching institutions such as the National Council of Teachers of Mathematics (NCTM, 2000), which contemplates the development of spatial orientation as one of the sources to describe and to model the physical world. The research in didactics of mathematics contemplates teaching-learning environments for spatial orientation (Battista, 2007; Presmeg, 2006). In the European Space for Higher Education, spatial orientation as a kind of spatial skill is a competence to be acquired in a large number of university degrees (Spanish Cabinet Office, 2007a, b).

While navigating (the aggregate task of wayfinding and motion), orientation is acquired through the information obtained from successive views where movement causes the point of view to change continuously. Wayfinding involves mental representations, route planning and estimation of distances. In maps, orientation is established through the geographic north, but while wayfinding there is not a north, and the orientation is established through the images of the environment (Lynch 1960). In the wayfinding process, the user perceives

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Contribution of this paper to the literature

- Research questions: Study the acquisition of the spatial orientation skill in a virtual learning environment through route-based learning activities.
- Employed methods: Virtual Learning Environment performed with Google Street View and VR glasses. Two groups with different levels of spatial orientation carried out the experiment.
- Findings: The VR orientation strategy performed developed the spatial orientation skill of the students. This gain was significantly higher for those participants who had a lower level of spatial orientation skill. No gender differences were found. The gain obtained is less (although not significantly) than that obtained with previous experiments carried out to enhance spatial orientation.

surrounding space and acquires spatial knowledge and orientation about it, known as cognitive mapping, defined by Downs and Stea (1973) as the acquisition, composition and maintenance of spatial information and spatial knowledge. This spatial knowledge, also called spatial reasoning, contains elements such as the identification of spaces, reference points and routes between different places, directions, angles and distances, among others. A cognitive map is the internal cartographic representation by a person of the surrounding environment. These cognitive maps make it easy to find a route in a real-world environment or virtual environment, and also help us to remember the route from one point to another if we are asked for directions (Patel and Vij, 2010).

There is research on spatial orientation development in real-world environments (Montello et al., 1999; Hegarty et al., 2006), and through virtual navigation in a 3D scenario created by computer (Dahmani et al., 2012; Lin et al., 2014; Carbonell, 2017). But real-world environments pose substantial and logistical problems (to transport the participants, weather conditions…) and even risk if there are participants with some degree of disability. Virtual environments can be a good alternative to avoid these risks (Darken and Banker, 1998). McKinnon and North (2004) concluded that users felt better within virtual environments than in real ones, because in virtual environments the users felt that they had better control over the space that surrounded them.

There are researches in the field of spatial skills in virtual environments: McComas et al. (1998), Wilson et al. (1996), and Rose et al. (2000) affirm that VR training allows the transfer of spatial knowledge to real-world environments, and conclude that training in a virtual world is equivalent (in cognitive load) to training in a real environment. Related to wayfinding, Farrell et al. (2003), Waller et al. (2004), Schinazi et al. (2009), and Rodrigues et al. (2010) claimed that spatial knowledge acquisition while navigating in a virtual environment is easily transferable to the real world. In terms of spatial orientation skill, Richardson et al. (1999) said that the cognitive process to be oriented in a real environment is also used when we are in a virtual environment. Waller, Hunt and Knapp (1998) concluded that for navigation in virtual and real-world environments the same skills are needed. Later, Düsner et al. (2006) affirm that spatial orientation in extensive environments can be carried out using Virtual Environments. Most recently, Kuliga et al. (2015) found that there is almost no difference in route-based learning (or wayfinding) between virtual and real-world environments.

Regarding virtual environments and spatial orientation, in previous research Carbonell (2017) presented an experiment in which the students worked with the Google Street View application displayed on a screen of a computer, among other resources such as orthophotos, maps and cartographic information. Thus, spatial orientation acquisition was analysed through route-based learning (Google Street View app) and survey learning (maps, cartography and orthophotos). The route-based learning activities were performed in a virtual environment, so it was really a virtual-route based learning activity. One of the future works proposed in that previous research was to study spatial orientation skill enhancement in a real-world environment activity. The present research, conducted with 32 engineering students, also studies spatial orientation skill development but from a different approach. Firstly, no maps are used (no survey learning acquisition), so the impact on the spatial orientation skill is analysed exclusively from route-based learning. Secondly, although the application is the same as the one used in the previous research (Google Street View), in this case a version for virtual reality is used. The immersive VR environment is created with the Google Street View app in smartphones connected to virtual reality glasses and locomotion sensors.

INNOVATIVE EDUCATIONAL TECHNOLOGY: VIRTUAL ENVIRONMENTS AND VE-BASED SPATIAL LEARNING

A virtual environment (VE) is a computer generated 3D environment that the user accesses through virtual reality. The user's view represents the view he or she would have if he or she were in the real environment represented (Allahyar and Hunt, 2003). Virtual environments are used in fields such as safety training simulation, engineering and manufacturing, architecture, healthcare, layout planning, education and entertainment among others (Barfield and Baird, 1998; Uddin, 1999; Rafi and Karboulonis, 2000).

Pantelidis (1995) defined virtual reality (VR) as an interactive 3D environment in real time in which the user becomes an active subject within that virtual environment. Virtual reality, therefore, is composed of a series of technologies and interfaces that allow the user(s) to interact with a computer-generated 3D environment, all in real time. Due to advances in hardware and software in this field, virtual reality can become a powerful tool for the training of spatial skills (Domínguez et al., 2013). VR creates a sensation of immersion, navigation and interaction (Helsel, 1992) and is divided into three main categories: text based, desktop and immersive VR. In text based the communication with the environment is via text. Desktop VR incorporates 3D images, but in a non-immersive mode. Immersive VR enables the user to interact with the computer generated 3D environment (Loeffer and Anderson, 1994). The 3D immersive virtual worlds (3D IVWs) arouse great interest in teachers and educational researchers (Mayrath et al., 2011; Johannesen, 2013). Oh and Nussli (2014) claim to integrate the 3D IVWs in teaching, and affirm: "The potential for this technology in a classroom setting seems limitless."

Immersive environments through VE, also called *immersive on-line real-time 3D environments* (Stock et al., 2008), provide a first person experience, which allows the users to feel immersed while interacting with the environment by using, for example, VR glasses and motion sensors. In this research the participants navigate in an urban VE using 3D VR glasses and a motion sensor. The Google Street View application installed on a smartphone provides the urban VE environment (this VE environment is a virtual environment generated by scenes obtained from the real world, it is not a virtual scenario generated by some CAD system or similar). The smartphone is inserted in the VR glasses (**Figure 1**). In this way, the user has a presence in the represented virtual world that simulates their physical presence (Björk and Holopainen, 2004). The participant, using virtual reality and interfaces like virtual 3D glasses and a remote control for movement, experiences a sensation of immersion (Wu et al., 2015).

Figure 1. Left. Woxter Neo VR glasses. Bluetooth remote control with joystick. Right: Virtual urban environment generated.

Exploratory navigation requires real time interaction (Riva 2006). A hand-held mouse or joystick, which provides the user the feel of an immediate return of their movements and position, usually does navigation through VEs. In the present research, the participant moves through the streets using a joystick that he/she uses with his/her hand and that allows him/her to advance, turn left, right and go back (motion direction). This output device is known as the locomotion interface. Waller (1999) affirms that navigation through VEs may depend on the user's ability to manipulate the locomotion interface. In this sense, the joystick allows a very intuitive and low price hand-on training setup for educational purposes.

Virtual environments allow the user to acquire spatial knowledge of a real architectural environment (Darken et al. 1999), like that represented by the Google Street View application. Waller (1999) states that the estimation of the distance during a process of immersion in a virtual world is similar to that obtained in a real-world environment. Moreover, Witmer et al. (1995), Bliss et al. (1997), and Koh et al. (2000) concluded that, for the acquisition of spatial knowledge, immersive VE environments are as effective as real-world environments. Spatial knowledge acquisition depends on the fidelity of the environments, the interfaces to these systems and the methods of training. In this connection, MacEachern and Kraak (2001) concluded that the development of tools and methods to assist navigation and preserve orientation in virtual environments was a major challenge for researchers. For this reason, the present research performs an orientation activity with a virtual environment generated through VR and Google Street View. This spatial navigation model provided by the Google Street View application in VR corresponds to the Multiscale Progressive Model (Zhang, 2008). This model considers that navigation with orientation is a process in which navigation tasks are redefined step by step, such as when you are looking for a street, and in order to find it, it is necessary to transit through other streets. The navigation is composed of a series of subtasks at different levels in which to perform a subtask it is necessary to finish the previous one. To complete these subtasks in the search for a street we need spatial orientation, through which we plan the objective, the path to be followed and a continuous evaluation of the results. In the wayfinding process the environment is perceived and our spatial perception is updated, so that if a subtask has not been completed, more movement is needed. "Spatial knowledge guides movement, and movement updates spatial knowledge" (Patel and Vij, 2010). This author proposed a list of quality factors for VR-based spatial learning techniques: "Speed of learning" (speed in the realization of cognitive maps), "Navigation Efficiency" (it is more efficient when fewer steps are taken and less distance is travelled to complete a task), "Accuracy" (nearness to the desired goal), "Spatial Awareness" (orientation and constancy of position within the environment during and after navigation), "Ease of Learning" (the ease of the user to deal with the technique), "Ease of Use" (the complexity of the technique perceived by the user), "Information Gathering" (the user's ability to obtain information about the environment while navigating), "Presence" (perception by the user of the immersive process in the environment), and finally, "User Comfort" (the possible effect of nausea or dizziness on the user).

In the experiment carried out in this research, VR Google Street View meets all quality factors except the last one. At the end of the present experiment the participants responded a questionnaire in which they were asked if they had been dizzy using VR glasses: 50% responded that they had not become dizzy, but 15% got a little dizzy, 12.5% got dizzy, 10% got relatively dizzy and 12.5% got very dizzy.

THE EXPERIMENT

Design

In the present experiment, the participants navigated along three predesigned routes using virtual reality 3D glasses, and completed a psychometric measure of spatial orientation before and after this training.

There are numerous applications and games in VR that occur in vehicles, but this experiment arises from the perspective of a user who is walking through a 3D urban environment looking for certain places. In this sense, Patel and Vij (2010) suggested that the estimation of distances and orientation is better achieved by walking than driving a vehicle. The urban environment is coincident with the "Landmark-Route-Survey" (or LRS) model of spatial knowledge representation, described by Siegel and White (1975), and Thorndike and Godin (1983). Objects typical of urban environments allow the construction or decomposition of any locality: significant milestones or signals, routes or paths that connect the landmarks and nodes (interchanges or junctions between routes).

In the present research, the user experiences a sensation of immersion in a 3D virtual environment through the smartphone integrated in 3D glasses, and moves around the environment (exploratory navigation) thanks to a joystick with Bluetooth connection. It is an experiment in VE as a preparation aid for real world navigation tasks.

Materials

The urban environment was displayed through the Google Street View application on Smartphones. The hardware for the experiment was 15 Woxter Neo VR glasses equipped with a joystick each one for remote control. The participants used their own Smartphone devices.

The spatial orientation skill can be measured through a test (Alinas et al., 2002), and in this research the Perspective Taking Spatial Orientation Test was used. This test was designed by Kozhevnikov and Hegarty (2001), and used by others such as Hegarty and Waller (2004), Carbonell et al. (2011, 2015), Carbonell (2017), and Carbonell and Bermejo (2017) in workshops similar to the one carried out in this research in which other technologies and methodologies for the development of spatial orientation have been used.

Completed using paper and pencil, it consists of 12 exercises, each on one page, to be done in 5 minutes. The participant sees a picture of a group of six objects in the top half of the page (cat, house, stop sign, car, stop light, tree and flower), and imagines that he or she is standing by one object (station point) and facing towards another object. The score for each item is the absolute deviation in sexagesimal degrees between the answer given for the participant and the correct direction to target. The total score is the average deviation across all items, so the lower the score obtained, the greater success rate.

In order to measure the gain obtained by the students in spatial orientation skill performing the workshop, the participants completed the test before (pre-test) and after (post-test) the activity.

Also, in order to know if the students felt dizzy when using the virtual reality glasses, the participants answered a questionnaire.

Participants

The participants were 32-second year engineering students from La Laguna University (19 males, 13 females) with a mean age of 21.5 and a standard deviation of 1.85, from the 2016-17 academic course. None of them had prior training in spatial orientation in VR environments. All participants signed a document called "informed consent" on the experiment to be performed, according to the 95/46/CE European Directive and Organic Law 15/1999 of the Spanish Cabinet Office number 298.

At the University of La Laguna there have been workshops for the development of the spatial orientation skill from the 2010-11 to the 2015-16 academic course, in which, as in this case, students from the second engineering course participated. These workshops had included a control group in each of them. A total of 95-second year engineering students belonged to these control groups. The control group captures what could have been the outcome if the activity had not been complemented. It serves, in turn, to know if the possible improvement obtained is due to the effect of the training or is due to the so-called recall effect of the test. The research conducted with these workshops (Carbonell, 2017; Carbonell and Bermejo, 2017) has shown that students who did not participate in the workshops did not achieve a statistically significant gain in their spatial orientation skill. The gains and *p*-values obtained where 5.29º degrees (*p*-level = 0.113) and 2.62º degrees (*p*-level = 0.202) respectively. Therefore, in the activity performed in this research no control group has participated because it has been sufficiently demonstrated that the spatial orientation skill does not experience a significant increase in students who do not participate in specific training.

Procedure

The activities to be carried out in the present workshop are based on previous research on spatial orientation with navigation in immersive virtual environments (Witmer et al., 1995; Waller et al., 1998; Koh et al., 2000; Darken and Peterson, 2001).

In the first phase (½ hour): students were provided with 30 minutes to connect the smartphone to the 3D VR glasses, and connect the joystick through Bluetooth. Once all the connections work, students familiarize themselves for a while with the interface. Prior to the activity participants were told to install the 3D Street View Application on their smartphones.

In the second phase (½ hour): this phase is performed without using the virtual reality glasses. A predefined two routes were given to the participants in a sketch. The two routes are from point A to point B (going) and from point B to point A (return) by different paths. They were instructed to remember the routes and the related information (streets, landmarks, turns…). They were told that once the process of learning the routes on the sketch were completed, they could not consult or display this information again.

In the third phase (1 hour): students put on virtual reality 3D glasses, started from the point of origin and followed the routes proposed according to the information acquired in the previous phase. Each time they reached a crossroad they had to turn to go to the next direction. In each route they were asked for successive control points, details (landmarks) that appeared on the route, like for example the colour of a house, the name of one street or the name of a shop. To get to the target, spatial orientation was acquired through the information obtained from successive views at the ground level perspective in a 3D urban environment. While navigating, students perceive surrounding space and they construct their own cognitive map (the internal cartographic representation that each person makes of the environment). In this process they identify places and landmarks, directions, routes and distances, among others. During the experiment, the instructor was listening the verbal reports of the participants on the landmarks, to verify if the route taken was correct. If the landmarks were not correct, the instructor would communicate it to the student in order to repeat the navigation until finding the correct landmark and thus continue the correct navigation task. All students completed the two routes, but some took longer time than others. No student exceeded the one-hour of phase 3 assigned to do it.

DATA ANALYSIS

The effect of the experiment carried out on the spatial orientation skill was analysed by the paired samples *t*-test since the assessment test provided a single score. The working hypothesis was: Urban virtual environments displayed with the VR Street View Application develop the spatial orientation skills of university students. Note that the lower the score the greater the success obtained, given that the score is the difference in degrees between the correct answer and the one given by the participant (**Table 1**).

Table 1. Perspective Taking/ Spatial Orientation Test average values

Perspective-Taking Spatial Orientation Test Average values and level of significance				
Participants	**Pre Mean Score (s.d.)**	**Post Mean Score (s.d.)**	**Gain**	***p*-level**
N=32	47.21 (28.43)	34.39 (22.18)	12.81 (13.97)	0.000006<0.01

s.d. Standard deviation

According to the *t*-test, the participants developed their spatial orientation skill in 12.81º sexagesimal degrees. The significance level (*p*-level<0.01) did not reach 1%, therefore the null hypothesis was rejected and stated, with a significance level over 99,9%, that the gain was statistically significant.

The average score in the Pre-test is 47.21. Therefore, taking into account that according to the score of the test, the higher score the lower spatial orientation skill, two groups (High level < 47.21 and Low level > 47.21) were considered according to their initial spatial orientation score (Pre). (**Table 2**).

Table 2. High / Low spatial orientation level (pre-test) groups

High / Low spatial orientation level (pre-test) groups				
Spatial orientation pre-level group	**Pre Mean Score (s.d.)**	**Post Mean Score (s.d.)**	**Gain**	***p*-level**
High spatial orientation level (*Pre*-score <47.21) N=17	24.56 (8.39)	17.18 (7.62)	7.38 (4.84)	0.0000<0.01
Low spatial orientation level (*Pre*-score >47.21) N=15	72.87 (19.52)	53.90 (15.97)	18.97 (18.14)	0.001<0.01

s.d. Standard deviation

Both groups, High and Low spatial orientation level, developed their spatial orientation skills in 7.38 (*p*-level = 0.0000) and 18.97 (p-level = 0.001) respectively. The difference in the gain between the two groups was significant (*p*-level = 0.0082), which allows us to state that Low spatial orientation level group improved more their spatial orientation skill than High spatial orientation level group in this experiment.

By gender (**Table 3**), both, males and females, developed their spatial orientation skill after the training session: 14.19 (*p*-level = 0.00178) and 10.80 (*p*-level = 0.00026), respectively. Males obtained a higher gain than females, although the difference was not significant (ANOVA results: *f*-ratio=0.44736, *p*-level = 0.509). This coincides with the experiment carried out by Carbonell et al. (2011), Carbonell et al. (2012), and Carbonell and Bermejo (2017).

Table 3. Perspective Taking/ Spatial Orientation Test average values by gender

Perspective-Taking Spatial Orientation Test Average values and level of significance by gender				
Participants	**Pre Mean Score (s.d.)**	**Post Mean Score (s.d.)**	**Gain**	***p*-level**
Male N=19	42.10 (30.71)	27.91 (17.36)	14.19 (16.89)	0.00178<0.01
Female N=13	54.67 (23.91)	43.88 (25.57)	10.80 (8.29)	0.00026<0.01

s.d. Standard deviation

Results of Previous Experiments for Spatial Orientation Skill Development

In order to contextualize these data, results of three workshops specifically designed for the improvement of the spatial orientation skill are described.

The participants who performed these workshops were second year engineering students of La Laguna University, such as those who participated in the experiment carried out in this paper. In addition, the measurement was performed with the Perspective Taking-Spatial Orientation test. In all of them the students took the test before the workshops (pre-test) and at the end of the workshops (post-test). The results of these workshops are in **Table 4**.

Table 4. Previous experiments for spatial orientation skill development

Previous experiments for spatial orientation skill development					
Technology	**Perspective Taking/Spatial Orientation Test**				**Spatial Orientation acquisition by:**
	N	**Pre-test (s.d.)**	**Post-test (s.d.)**	**Gain (s.d.)**	
SDI Geoportal	248	46.93 (25.29)	27.72 (18.91)	19.21 (15.54)	- Survey learning (map reading)
GISc Spatial Thinking	158	44.55 (21.74)	25.49 (16.73)	19.06 (16.13)	- Survey learning (map reading) - Wayfinding
Augmented Reality	63	46.01 (13.65)	25.87 (14.73)	20.14 (14.80)	- Survey learning (map reading) - Landform interpretation
Total	469	46.01 (23.42)	26.72 (17.68)	19.28 (15.62)	

s.d. Standard deviation

SDI Geoportal Workshop (Carbonell et al., 2015): the experiment was conducted during four academic years 2009-2010, 2010-2011, 2011-2012 and 2012-2013. The methodology employed to develop the spatial orientation skill was as a Geoportal: The Spatial Data Infrastructure (SDI-Workshop). In the instruction of the SDI-Workshop the participants determined locations and perspectives in urban environments using maps, plans, orthophotos and 3D displays.

GISc Spatial Thinking Workshop (Carbonell, 2017): carried out with 158 engineering students, using the geographic information science GISc resource, during the 2010-2011, 2011-2012, 2012-2013 and 2013-14 academic years. In this case, students performed activities related to spatial-thinking acquisition: survey learning (with maps) and route-based learning (with the Street View application on a pc screen).

Augmented reality Workshop (Carbonell and Bermejo, 2017): done with Augmented Reality technology and tablets with 63 engineering students during the 2014-15 academic year. Participants determined locations from landforms using their spatial orientation skill to make a 2D/3D interpretation through visualizing the appearance of scenes from different points of view.

The gain obtained in the present research using VE (12.81, 13.97 s.d.) is less than that obtained with the SDI resource (19.21, 15.54 s.d.), the GISc resource (19.06, 16.13 s.d.) and Augmented Reality technology (20.14, 14.80 s.d.). The results of the ANOVA analysis shows that these differences in gains are not significant at $p<0.01$ (*f*-ratio=1.80622, *p*-value=0.14507). In the SDI workshop participants developed their spatial orientation skill through map reading. With the GISc resource the spatial orientation acquisition was made through map reading and route based learning. For route based learning, the participants used the Google Street View app, in which the interface to the virtual environment was a desktop display with a keyboard and one mouse. It is the most similar experience to that performed in the present research, because the same app was employed but in a different virtual environment display. In the third case, the students worked with landforms represented in 2D (conventional relief representation with traditional cartographic techniques like contour lines, among others) and in 3D with augmented reality (in addition to map reading and wayfinding, other authors like Nardi et al. (2010), Newcombe and Shipley (2015), and Carbonell and Bermejo (2017) consider landform interpretation as an activity for which spatial orientation is necessary).

DISCUSSION, CONCLUSIONS AND FUTURE WORK

Planning an orientation activity in a real-world open environment is complex. It takes a lot of time to do it (participants 'round trip to where they are going to do the activity) and this is complex to fit into the students' academic schedules. In addition, it could be difficult by factors such as weather conditions and the level of disability that a student might present. The present research describes a Teaching/Learning strategy in a virtual urban environment using the VR Innovative educational technology as a training aid for real world navigation tasks.

Virtual Reality may be useful for training the spatial orientation skill. Virtual urban environments displayed with the VR Google Street View Application developed the spatial orientation skill of university students in 12.81º sexagesimal degrees (13.97 s.d.). The gain in spatial orientation was significantly higher (*p*-level = 0.0082) for those participants who had a lower level of spatial orientation skill at the beginning of the experiment (Pre-test). Virtual reality training, therefore, appears to be more effective for those with less spatial orientation skill compared to those with a higher spatial orientation skill. This could also be due to the fact that those with a higher level of spatial orientation have a lower profit margin. There is no research on this subject, so as a future work this issue could be studied. On the other hand, and also as future work, an additional post-test could be performed some weeks after the intervention to check if there is persistence in the results. In this way it could be known the long-term reach of this technology for the improvement of spatial abilities.

In relation with previous experiments, the average gain 12.81º (13.97 s.d.) obtained in the workshop carried out in the present research is less (although not significantly: *f*-ratio=1.80622, *p*-value=0.14507) than that obtained with other resources and/or technologies to enhance spatial orientation, with an average gain of 19.28º (15.62 s.d.). The common denominator of this 19.28º average gain is the use of maps along with other technologies and/or resources like GISc, Geoportals and Augmented Reality. The use of maps, therefore, continues to be a great complement along with other technologies for the development of spatial orientation, since in the present experience no maps have been used and the gain has been less.

This conclusion is similar with that obtained by Waller et al. (1998), who said that VR training is not more efficient than map reading for the acquisition of spatial orientation, although we must consider that virtual reality techniques are now much more advanced than in 1998. Most recent research (Roca-González et al., 2017) on the development of the spatial orientation skill, in which the use of maps was combined with VR, showed similar gains as those obtained with the SDI, GISc and AR workshops. This, together with the results obtained in the present research, confirms the importance of cartography as a complement to virtual reality and another methodologies and techniques for the acquisition of spatial ability.

Analysing the results by gender, there are no statistically significant differences in gain in spatial orientation obtained by women and by men after specific training (*f*-ratio=0.44736, *p*-level = 0.509). Some references have been cited in which the result by gender is similar (Roca-González et al., 2017; Carbonell et al., 2011; Carbonell et al., 2012; Carbonell and Bermejo 2017), although there is also other research that concluded otherwise (Carbonell, 2017). Liu et al. (2011) found, in study of gender with different orientation strategies, that there was no difference in tasks related to spatial orientation like landmark recognition and left-right orientation, and that males were better than females in path reversal and cognitive maps. They concluded that differences in gender might be due to operating with the orientation material provided. Other research (Coluccia and Louse, 2004; Coluccia et al., 2007) corroborates this claim. Therefore, for a gender study on spatial orientation, specific analysis should be carried out for each of the orientation activities and for each technology used.

As future work, pedestrian VR interfaces such as the treadmill-style interface or robot tiles with actuated shoes could be analysed from two points of view. One, to analyse their impact on spatial orientation and two, to study if they provoke dizziness in users, as in the case of the present research, in which 50% of participants felt dizzy, and even 12,5% got very dizzy during the experiment using VR glasses.

ACKNOWLEDGEMENTS

This work has been supported by the University of La Laguna: Innovative Educational Project number 12 for the academic year 2016/2017 called "Geomatics and Virtual Reality".

The research carried out is within the framework of the actions with the Spanish Ministry of Education, Culture and Sport, within the framework of the State Program for the Promotion of Talent and its Employability in I+D+i, State Mobility Subprogram of the State Plan for Scientific and Technical Research and Innovation 2013-2016.

REFERENCES

Alias, M., Black, T. R., & Gray, D. E. (2002). Effect of instructions on spatial visualization ability in civil engineering students. *International Education Journal, 3*(1), 1–12.

Allahyar M., & Hunt, E. (2003). The Assessment of Spatial Orientation Using Virtual Reality Techniques. *International Journal of Testing, 3*(3), 263-275. doi:10.1207/S15327574IJT0303_5

Barfield, W., & Baird, K. (1998). Future direction in virtual reality: augmented environments through wearable computers, Virtual Reality: Selected Tools and Applications. *Proceedings of VR 98 Seminar and Workshop on Virtual Reality*, Editor Khalid, Malaysia, pp. 9 – 15.

Battista, M. T. (2007). The development of geometric and spatial thinking. In *Second handbook of research on mathematics teaching and learning*. Charlotte, NC: Information Age Publishing.

Björk, S., & Holopainen, J. (2004). *Patterns in Game Design.* Charles River Media, Boston, MA.

Bliss, J. P., Tidwell, P. D., & Guest, M. A. (1997). The effectiveness of virtual reality for administering spatial navigation training to firefighters. *Presence: Teleoperators and Virtual Environments, 6*(1), 73–86. doi:10.1162/pres.1997.6.1.73

Bodner, G., & Guay, R. (1997). The purdue visualization of rotations test. *Chemical Education*, *2*(4), 1–18.

Carbonell C. (2017). Spatial-Thinking Knowledge Acquisition from Route-Based Learning and Survey Learning: Improvement of Spatial Orientation Skill with Geographic Information Science Sources. *Journal of Surveying Engineering*, *143* (1). doi:10.1061/(ASCE)SU.1943-5428.0000200#sthash.s5c5UD7c.dpuf

Carbonell C., & Bermejo L.A. (2017). Landscape interpretation with augmented reality and maps to improve spatial orientation skill. *Journal of Geography in Higher Education, 4*(1), 119-133. doi:10.1080/03098265.2016.1260530

Carbonell C., Saorín J. L., De la Torre, J., & Marrero G. A. M. (2011). Engineers' spatial orientation ability development at the European Space for Higher Education. *European Journal of Engineering Education, 36* (5), 505-512. doi:10.1080/03043797.2011.602184

Carbonell, C., Martín-Dorta, N., Saorín Pérez, J. L., & De La Torre Cantero, J. (2015). Specific Professional Skills Development for Engineering Studies: Spatial Orientation. *International Journal of Engineering Education, 31*(1B), 316–322.

Carbonell, C., Mejías, M. A., Saorín, J. L., & Contero, M. C. (2012). Spatial data infrastructure: Development of spatial abilities in the framework of european space for higher education. *Boletín de la asociación de geógrafos españoles*, *58*(2012), 157–175.

Coluccia, E., & Louse, G. (2004). Gender differences in spatial orientation: A review. *Journal of Environmental Psychology, 24*(3), 329–340.

Coluccia, E., Louse, G., & Brandimonte, M. A. (2007). The relationship between map drawing and spatial orientation abilities: A study of gender differences. *Journal of Environmental Psychology, 27*(2), 135–144.

Dahmani, L., Ledoux, A., Boyer, P., & Bohbot, V. D. (2012). Wayfinding: The effects of large displays and 3-D perception. *Behavior Research Methods 44*(2), 447-454. doi:10.3758/s13428-011-0158-9

Darken, R. P., & Banker, W. P. (1998). Navigating in natural environments: A virtual environment training transfer study. *Proceedings of the IEEE Virtual Reality Annual International Symposium* (pp. 12-19). IEEE. doi:10.1162/pres.1999.8.6.iii

Darken, R. P., Allard, T., & Achille, L.B. (1999). Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces II. *Presence, 8*(6), 3-5.

Dominguez, M. G., & Martin-Gutierrez, J., & Roca, C. (2013). Tools, Methodologies and Motivation to Improve Spatial Skill on Engineering Students. *Paper presented at 2013 ASEE Annual Conference & Exposition*, Atlanta, Georgia. Retrieved from https://peer.asee.org/22638

Downs, R. M., & Stea, D. (1973). *Cognitive maps and spatial behaviour. Process and products*. In R.M. Downs and D. Stea (Eds.), *Image and environment: Cognitive mapping and spatial behaviour* (pp.8-26). Chicago: Aldine.

Dünser, A., Steinbügl, K., Kaufmann, H., & Glück, J. (2006). Virtual and augmented reality as spatial ability training tools. *Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on Computer-human interaction: design centered HCI*, p.125-132, July 06-07, 2006, Christchurch, New Zealand. doi:10.1145/1152760.1152776

Farrell, M. J., Arnold, P., Pettifer, S., Adams, J., Graham, T., & MacManamon, M. (2003). Transfer of route learning from virtual to real environments. *Journal of Experimental Psychology Applied, 9*(4), 219–227. doi:10.1037/1076-898X.9.4.219

Fleishman, J. J., & Dusek, E. R. (1971). Reliability and learning factors associated with cognitive tests. *Psychogical Reports, 29*(2): 523–530. doi:10.2466/pr0.1971.29.2.523

Gonzato, M., & Godino, J. D. (2011). Aspectos históricos, sociales y educativos de la orientación espacial. *Unión: revista iberoamericana de educación matemática, 23*(2010), 24–45.

Gonzato, M., Fernández, T., & Díaz, J. (2011). Tareas para el desarrollo de habilidades de visualización y orientación espacial. *Números: revista didáctica de las matemáticas 77*(2011), 99–117.

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32*(2), 175–191. doi:10.1016/j.intell.2003.12.001

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence, 34*(2), 151-176. doi:10.1016/j.intell.2005.09.005

Helsel, S. (1992). Virtual Reality and Education. *Educational Technology, 32*(5), 38-42

Howard, I. P., & Templeton, W. B. (1966). *Human spatial orientation*. Wiley, New York.

Johannesen, M. (2013). The role of virtual learning environments in a primary school context: An analysis of inscription of assessment practices. *British Journal of Educational Technology, 44*(2), 302-313. doi:10.1111/j.1467-8535.2012.01296.x

Koh, G., von Wiegand, T., Garnett, R., Durlach, N., & Shinn-Cunningham, B. (2000). Use of Virtual Environments for Acquiring Configurational Knowledge about Specific Real-World Spaces: Preliminary Experiment. *Presence: Teleoperators and Virtual Environments, 8*(6), 632-656. doi:10.1162/105474699566530

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation, spatial ability and spatial orientation ability. *Memory and Cognition, 29*(5), 745–756. doi:10.3758/BF03200477

Lin, C., Chen, C., & Lou, Y. (2014). Developing spatial orientation and spatial memory with a treasure hunting game. *Journal of Educational Technology & Society, 17*(3), 79-92.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*(6), 1479–1498. doi:10.2307/1130467

Liu, I., Levy, R. M., Bartoni, J. J. S., & Iaria, G. (2011). Age and gender differences in various topographical orientation strategies. *Brain Research, 1410*, 112–119. doi:10.1016/j.brainres.2011.07.005

Loeffler, C. E., & Anderson, T. (eds.) (1994). *The Virtual Reality Casebook.* New York: Van Nostrand Reinhold.

Lynch, K. (1960). *The image of the city*. MIT Press, Cambridge, MA.

MacEachren, A. M., & Kraak, M.-J. (2001). Research challenges in geovisualization. *Cartography and Geographic Information Science, 28*(1), 3-12. doi:10.1559/152304001782173970

Maier, P. H. (1998). Spatial geometry and spatial ability: How to make solid geometry solid. *Proc., Annual Conf. of Didactics of Mathematics*, E. Osnabrück, E. Cohors-Fresenborg, K. Reiss, G. Toener, and H. Weigand, eds., Gessellschaft für Didaktik der Mathematik, Munich, Germany, 63–75.

Mayrath, M. C., Traphagan, T., Heikes, E. J., & Trivedi, A. (2011). Instructional design best practices for Second Life: A case study from a college-level English course. *Interactive Learning Environments, 19*(2), 125-142. doi:10.1080/10494820802602568

Mcgee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal and neurological influences. *Psychological Bulletin, 86*(5), 889–918.

McKinnon, L. D., & North, M. M. 2004. A comparative study of presence in virtual reality vs. presence in the real world. *Proceedings of the 42nd Annual Southeast Regional Conference* (pp. 253-254).

Montello, D. R., Lovelace, K. L., Golledge, R. G., & Self, C. M. (1999). Sex-related differences and similarities in geographic and environmental spatial abilities. *Annals of the Association of American Geographers, 89*(3), 515-534.

Nardi, D., Newcombe, N. S., & Shipley, T. (2010). The world is not flat: Can people reorient using slope? J*ournal of Experimental Psychology: learning, Memory and Cognition*, *37*(2), 354–367. doi:10.1037/a0021614.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: NCTM Ed.

Newcombe, N. S., & Shipley, T. F. (2015). *Studying visual and spatial reasoning for design creativity*. In John S. Gero (Ed.), *Thinking about spatial thinking: New typology, new assessments* (pp. 179–192).

Oh, K., & Nussli, N. (2014). Teacher training in the use of a three-dimensional immersive virtual world: Building understanding through first-hand experiences. *Journal of Teaching and Learning with Technology*, *3*(1), 33-58.

Pantelidis, V. (1995). Reasons to Use VR in Education. *VR in the Schools, 1*, 9.

Patel, K. K., & Kumar, S. (2010). *Advanced Knowledge Based Systems: Model, Applications & Research*. TMRF e-Book. Eds. Sajja & Akernar. Kolhapur, India.

Patel, K. K., & Vij, S. K. (2010). *Spatial navigation in virtual world. Advanced knowledge based systems: model, applications and research*. TMRF e-Book, 101-125.

Presmeg, N. C. (2006). Research on visualization in learning and teaching mathematics: Emergence from psychology. In A. Gutiérrez & P. Boero (Eds.), *Handbook of research on the psychology of mathematics education* (pp. 205–235). Dordrecht: Sense Publisers.

Rafi, A., & Karboulonis, P. (2000). The Re-Convergence of Art and Science: A Vehicle for Creativity. *Proceedings of the Fifth International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA)*, 497.

Reber, A. S. (1985). *Dictionary of psychology*. Penguin, London.

Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition, 27*(4), 741-750.

Riva, G. (2006). Virtual reality. *Encyclopaedia of Biomedical Engineering*. London: John Wiley & Sons.

Roca-González, C., Martín-Gutiérrez, J., García-Domínguez, M., & Mato, M.C. 2017. Virtual Technologies to Develop Visual-Spatial Ability in Engineering Students. *EURASIA Journal of Mathematics Science and Technology Education, 13*(2), 441-468. doi:10.12973/ eurasia.2017.00625a

Rodrigues, J., Sauzéon, H., Wallet, G., & N'Kaoua, B. (2010). Transfer of spatial-knowledge from virtual to real environment: effect of active/passive learning depending on a test-retest procedure and the type of retrieval tests. *Journal of Cybertherapy & Rehabilitation, 3*(3), 275–283.

Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., & Penn, P. R. (2000). Training in virtual environments: transfer to real world tasks and equivalence to real task training. *Ergonomics, 43*(4), 494-511. doi:10.1080/001401300184378

Schinazi, V. R., Epstein, R. A., Nardi, D., Newcombe, N. S., & Shipley, T. F. (2009). *The acquisition of spatial knowledge in an unfamiliar campus environment*, in *Proceeding of the 50th Annual Meeting of the Psychonomics Society*, Boston, MA.

Siegel, A. W., & White, S. H. (1975). *The Development of Spatial Representations of Large-Scale Environments*. In H. Reese (Ed.), *Advances in Child Development and Behavior, 10*. New York: Academic Press.

Smith, I. M. (1964). *Spatial ability: Its educational and social significance*. University of London Press, London.

Spanish Cabinet's Office (2007). *Royal Decree 1393/2007 from October 29th*. State's Official Bulletin. Retrieved on 1 May 2013 from http://www. boe.es/buscar/pdf/2007/BOE-A-2007-18770-consolidado.pdf

Stock, C., Bishop, D., O´Connor, A.N., Cehn, T., Pettir, C.J and Aurambout, J.P. (2008). SIEVE: Collaborative Decision-making in an Immersive Online Environment. *Cartography and Geographic Information Science, 35*(2), 133-144. Retrieved from http://www.tandfonline.com/DOI/abs/10.1559/152304008784090568

Tartre, L. A. (1990a). Spatial orientation skill and mathematical problem solving. J*ournal for Research in Mathematics Education, 21*(3), 216–229. doi:10.2307/749375

Tartre, L. A. (1990b). *Spatial skills, gender and mathematics*. Mathematics and gender, E. E. Fennena and G. C. Leder, eds., New York: Teachers College Press, 27–59.

Thorndyke, P. W., & Goldin, S. E. (1983). Spatial Learning and Reasoning Skill. In H. L. Pick & L. P. Acredolo (Eds.), *Spatial Orientation: Theory, Research, and Application*, (pp. 195-217). New York: Plenum Press.

Uddin, S.H. (1999). *Digital Architecture.* McGraw-Hill.

Waller, D. (1999). An assessment of individual differences in spatial knowledge of real and virtual environments (Doctoral dissertation, University of Washington, Seatle, 1999). *Dissertation Abstracts International*, 60(4-B), 1882.

Waller, D., Beall, A. C., and Loomis, J. M. (2004). Using virtual environments to assess directional knowledge. *Journal of Environmental Psychology, 24*(1), 105–116. doi:10.1162/105474698565631

Waller, D., Hunt, E., & Knapp, D. (1998). The Transfer of Spatial Knowledge in Virtual Environment Training. *Presence: Teleoperators and Virtual Environments, 7*(2), 129-143.

Wilson PN, Foreman N, Tlauka M. (1996). Transfer of spatial information from a virtual to a real environment in physically disabled children. *Disabli Rehabilitation, 18*(12), 633-7

Witmer, B. G., Bailey, J. H., & Knerr, B. W. (1995). *Training Dismounted Soldiers in Virtual Environments: Route Learning and Transfer*. (Technical Report 1022). U.S. Army Research Institute for the Behavioral and Social Sciences.

Wu, F., Liu, Z., Wang, J., & Zhao, Y. 2015. Establishment virtual maintenance environment based on VIRTOOLS to effectively enhance the sense of immersion of teaching equipment. *Proceedings of the 2015 International Conference on Education Technology, Management and Humanities Science (ETMHS 2015)*. Atlantis Press. doi:10.2991/etmhs-15.2015.93

Zhang X. (2008). A multiscale progressive model on virtual navigation. *International Journal of Human Computer Studies*, *66*(4), 243-256. doi:10.1016/j.ijhcs.2007.09.004