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Spatial Orientation Skill Performance with a Workshop Based on Green Infrastructure in Cities

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Abstract: Better training of spatial skills of green infrastructure managers will contribute to better planning practices in this field. The professionals using geo-spatial technologies in sustainable city planning require, in their curriculum, specific training focused towards the acquisition of spatial skills. Using maps and geo-spatial technologies, spatial orientation skill is needed. In this research, a workshop based on a green infrastructure has been carried out. A specific teaching strategy for the improvement of spatial orientation skill has been performed. In the workshop, 3D technologies of graphic representation of an urban environment were used such as Cad Mapper, Sketch Up Make 2017 and Google Street View. Thirty-two students (22 treatment group, 10 control group) of agronomic engineering participated. The impact on spatial orientation skill was measured with the Perspective Taking-Spatial Orientation test, through pre- and post-tests. No gender differences were found. The Treatment Group obtained a significant increase of 19.27% in their spatial orientation skill. Participants of the Control group did not significantly increase their spatial orientation skill (3.21%). Specific teaching strategies such as those performed in this research can be effective for the training and development of spatial orientation skill, needed for geospatial planning in the field of Green Infrastructures.

Keywords: Higher Education; green infrastructure; spatial orientation

1. Introduction

In the 21st century, the human being must be fully aware of the impact of his actions on the environment. It is necessary that our decisions guarantee sustainability for a future, that is, to adopt patterns for sustainable development, as already stated since 1987 in the definition of sustainability: "meeting the needs of the present without compromising the ability of future generations to meet their own needs " [1] (p. 24).

The challenges posed by sustainable city planning are now controlled more efficiently thanks to advances in geo-spatial technology [2]. Geo-spatial disciplines related to the representation of the Earth's surface are increasingly focusing on aspects related to sustainability [3]. In the field of geo-spatial analysis in sustainable city planning, different disciplines such as Geography, Engineering and Architecture, among others, make decisions around maps, plans and geo-spatial information. A professional spatial skill directly related to the use of maps and geo-spatial information is the spatial

orientation skill, defined as "the ability to physically or mentally orientate oneself in space" [4] (p. 71). Other authors define it as the ability to imagine what a scene will look like from different perspectives [5] or the ability to perceive visual stimuli from multiple spatial perspectives [6]. These visual stimuli, in city environments, can be singular points (landmarks), which help us to orient ourselves.

The professionals who will use geo-spatial technologies in sustainable city planning need, therefore, specific training focused towards the acquisition of professional skills related to spatial orientation, so it is necessary to play special attention to spatial orientation in the educational field. Researchers in the fields of mathematics and geography and geospatial disciplines recommend the inclusion of spatial orientation development in educational environments [7–9]. In this regard, the "Learn to think Spatially" report of the National Research Council [NRC] [10] already stated the importance of spatial orientation skill in educational settings.

Higher education is an ideal environment to provide spatial skills within the framework of sustainable development [11,12]. According to the Association for Advancement of Sustainability in Higher Education (AASHE) [13], academic content and programs related to sustainable city planning are increasing, although specific plans for the development of spatial orientation skill are missing.

An example of a teaching strategy in Higher Education for the development of spatial orientation skill in a context of a green infrastructure planning in a city is shown in the present research. Thirty-two agronomic engineering students participated in a workshop in which they worked with geo-spatial technologies in a 3D CAD environment, using Cad Mapper, Sketch Up Make 2017, and Google Street View applications. These tools allow undertaking geospatial planning and green infrastructure studies in new ways [14]. In addition, these applications are free and work on Windows and MacOs operating systems, which is a great advantage for use in teaching environments. In the workshop, participants worked with 3D representations of an urban environment in order to represent graphically a green infrastructure (vertical garden), performing tasks related to spatial orientation skill.

Numerous researchers have long emphasized taking environmental aspects of urban life into consideration, which builds cities as environments to study from a sustainable urbanism approach [15–17]. In this sense, the present research has taken a vertical garden as an example of an action of water-sensitive urban design (WSUD). A vertical garden is a type of green infrastructure that Tzoulas and colleagues [18] classify as small-scale green amenities to improve the urban environment by providing an aesthetic change. In addition, these types of actions, framed within what many authors [19–21] call vertical greening systems, open up new research fields such as thermal regulation of buildings [22] microclimate regulation, air quality improvements and stormwater management [23]. Although in the present research no technical-constructive aspects of vertical gardens were developed. The goal of the present study was to analyze the impact on the spatial orientation skill of a workshop performed within the framework of a sustainable urban development action (vertical garden). In the workshop, the participants performed a series of exercises for which it is necessary to use the spatial orientation skill. To measure the impact of the activities of the workshop on the spatial orientation skill of the participants, they carried out, before and after the workshop, the Perspective Taking-Spatial Orientation test (PTSOT) [5,24]. Therefore, the working hypothesis was:

Can a green infrastructure specific teaching strategy increase spatial orientation skill?

Numerous authors affirm that 3D technologies are a powerful tool that makes spatial planning easier and more understandable [25–27]. In the present research, the example of vertical gardens as a green infrastructure has been used since, due to its location characteristics, it requires a three-dimensional representation environment.

There are two recent researches in which engineering students have also participated and the same measurement tool, the PTSOT, has been employed. In these researches, a geo-spatial technology such as Spatial Data Infrastructure (SDI) [28] and 3D technology such as Augmented Reality [29] was used. The results of these works can serve to contextualize the data obtained in the present research in terms of development of spatial orientation skill, although in these works no tasks related to green infrastructure have been carried out.

2. Materials and Methods

This research was carried out within the framework of the "Geo-spatial Thinking" project, an Educational Innovation Project of the Vice-Rectorate for Teaching Innovation and Quality of the University of La Laguna for the 2019-20 academic year [30].

2.1. Hardware and Software

To carry out the proposed activity were used Cad Mapper website (https://cadmapper.com/), the free version of Sketch Up Make 2017 (https://www.sketchup.com/download/all), and the Google Street View application.

The Cad Mapper website resource is a powerful tool for architects, designers and urban planners, among others. It transforms data from public sources such as OpenStreetMap, NASA, and USGS into neatly organized CAD files. It allows the user to download a 3D model of up to 1 km^2 for free and in different formats, such as AutoCAD, Rhinoceros 5+, Illustrator 8+ and Sketch Up.

Sketch Up Make is a 3D CAD modeling software. Software requirements to install Sketch Up Make 2017: for Windows was needed a 64-bit version of Windows. Additionally, Windows 8.1 (or higher) had to be updated through Windows Update. An Internet connection was necessary for both Windows and Mac.

Google Street View is a Google Maps and Google Earth feature that provides street-level panoramas (360 degrees of horizontal movement and 290 degrees of vertical movement), allowing users to view parts of selected cities and their surrounding metropolitan areas. It has no specific hardware requirements; only an Internet connection is necessary.

The availability offered by both Sketch Up Make and Cad Mapper and Google Street View application to work under Windows and/or MacOs interchangeably means a great advantage in the planning of teaching activities. Students could use their own devices, a trend included in the Higher Education New Media Consortium Horizon Report [31]. In the event that a student had a computer that did not meted the minimum hardware requirements, the teacher had laptops with which to carry out the activity.

2.2. Perspective Taking Spatial Orientation Test

The Perspective Taking Spatial Orientation Test (PTSOT) [5,24,32], is a measure of spatial orientation performance. In this test, participants see an array of objects along with an answer circle. On each trial, participants are asked to imagine standing at one object in the array, facing a second, and then to point to a third. The participants "point" by drawing a line on the answer circle indicating the direction to the third object from the given standing position and facing direction. In the present research, the test was carried out in paper format, where the students drew their answer. Following the test instructions, during the test, the students cannot rotate the paper. The performance measure is the angular error (difference between participant's estimated angle and the correct angle formed by the three objects in the trial), so lower scores on the PTSOT indicates better performance. If a participant did not point to any target, a 90° score is assigned for that trial. This test is composed of 12 items, and the standard time limit is five minutes. An example of one item of the PTSOT is shown in Figure 1. The PTSOT test (paper version) and the instructions are available at https://www.silc.northwestern.edu/object-perspective-spatial-orientation-test/.
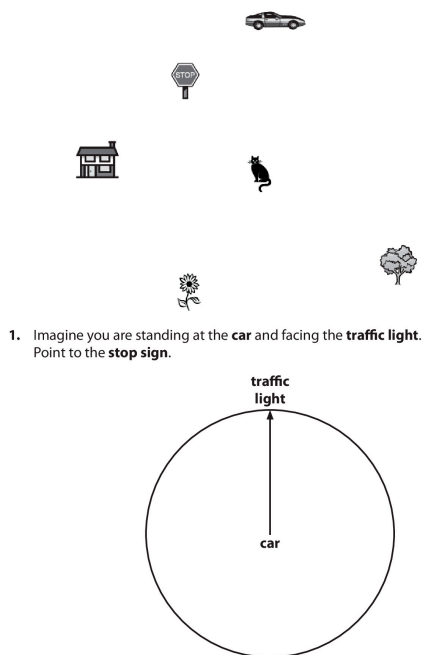
Figure 1. Example of an exercise of the Perspective Taking Spatial Orientation Test (PTSOT).

2.3. Participants

Thirty-two students in the second year of agronomic engineering participated in the workshop. Agronomic Engineering is an engineering specialty with professional competences in the field of green infrastructures. Twenty-two belonged to treatment group (10 female, 12 male), age 19–30, (M = 21.50; SD = 2.94), and ten belonged to the control group (5 female, 5 males), age 19–27 (M = 21.90; SD = 2.96). A Student's *t*-test showed that both groups are equivalent in their means of age (t_{30} = 3.56; p = 0.724) and a Chi-square independence test showed that gender distributions in both groups are equal (χ^2_1 = 0.57; p = 0.811). Those in the treatment group carried out all the activities of the workshop. Those of the control group only performed the pre and post-tests at the same time as those of the treatment group; they did not do any of the activities of the workshop. The study had a Quasi-experiment Pretest-Posttest design. All students voluntarily participated in the workshop, and were free to leave at any time. None had previous experience in the use of 3D modeling and 3D-visualization tools. None of the students had taken the PTSOT before the pre-test.

2.4. Procedure

The student had to work within an urban environment in which there were buildings with different characteristics such as different heights, orientations, shape of the facades, etc. In the case of the present study, we worked with Trinidad Avenue, located in the city of La Laguna, Tenerife, Spain. In the center of this avenue there is a tram, whose tracks are embedded in a lawn. This lawn, with the tram tracks, runs along the Trinidad Avenue (see Figure 2). The activity sought to visually harmonize some facades of this avenue with the garden that extends along its entire length. On the facades of some of these buildings of Trinidad Avenue there were large painted murals (the entire painted facade). The practice was that, in two of these facades with large painted mural, students replaced the murals with vertical gardens and offered 3 views from different points (front, left and right) to examine the visual-landscape impact.
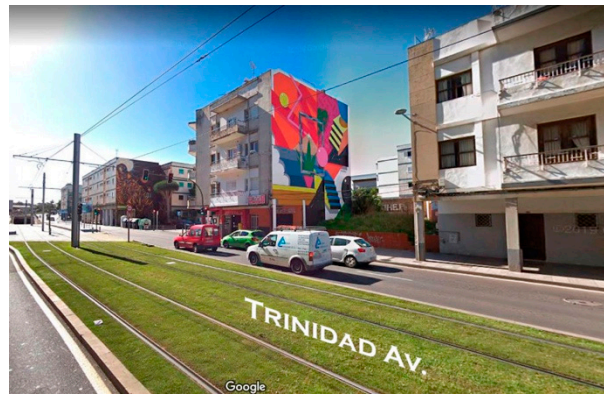
Figure 2. Example of a Google Street View perspective of a facade with a painted mural on Trinidad Avenue.

2.4.1. Phase 0

Participants carried out the Pre-test of the Perspective Taking-Spatial Orientation Test. Then, they installed the Sketch Up Make application on their laptops and checked that it worked correctly. In this phase the participants received training on the main Sketch Up commands, focusing on those necessary to carry out the practice.

2.4.2. Phase 1

The participants had to select, within the area defined by the teacher, two facades in which there were large murals painted (the entire painted facade), and that each had a different orientation. That is, a facade with a north orientation and another with an east orientation, for example. The two selected facades were not allowed to have the same orientation. To select the two facades, the students used the Google Street View application. They virtually toured the work area, being able to visualize the facades of the buildings in their real surroundings and locating those in which there were murals in all their extension (Figure 2). These facades will have to be located later (Phase 2) in a 3D city representation provided by Cad Mapper, for which they will use their special orientation skill.

2.4.3. Phase 2

Students, through the Cad Mapper website, downloaded the 3D cartography file in Sketch Up format, which not only contains the digital terrain model, but also the volumetry (Building height) of the buildings. Then they opened this file with the Sketch Up Make program (Figure 3).
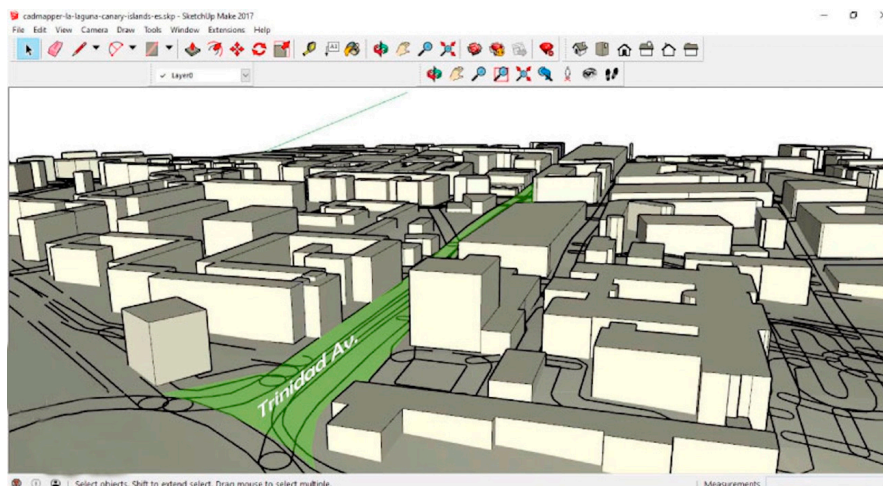

Figure 3. 3D file from Cad Mapper of Trinidad Avenue opened with Sketch Up.

2.4.4. Phase 3

Sketch Up allows the user to edit the facades of buildings. In this phase the participants started to work with the Sketch Up file. First, the students identified the facades selected in the previous phase. On the two selected facades, participants had to replace the mural with a vertical garden. For this purpose, the teacher made available to the students a folder with different garden textures. This folder was on the virtual campus to which students have accesses. Through the "Import" tool of Sketch Up, students selected each of the two facades and incorporated the texture adapting the image to the size of each facade. They replaced, therefore, the mural with a vertical garden.

2.4.5. Phase 4

Exercises 1 to 6. In this phase the students had to present 3 different views of the new two facades (facade 1 and facade 2) to analyze the visual-landscape impact of the facade with the new ornamentation. Therefore, the exercise 1 of the workshop was the 1st view of the facade 1; the exercise 2 was the 2nd view of the facade 1, and so on until exercise 6, which was the 3rd view of the facade 2.

To offer images that allow a more realistic view of the effect, it is necessary that these views represent the new facade and its real surroundings. In the Cad Mapper file in which the students have been working, all the facades appear with flat faces, in gray/white, that is, a schematic representation of the facade (e.g., Figure 3). In order to offer a more realistic view of the new facade and its surroundings, it is necessary, therefore, to replace those gray/white facades with their real appearance. The teacher made available to the students a folder on the virtual campus to which students have accesses, with the real images of all the facades of Trinidad Avenue. Figure 4 shows an example of the facades represented with Cad Mapper and its corresponding image in reality. Proceeding in the same way as for the inclusion of the garden texture, the participants adapted each of the adjoining facades to the new vertical garden.
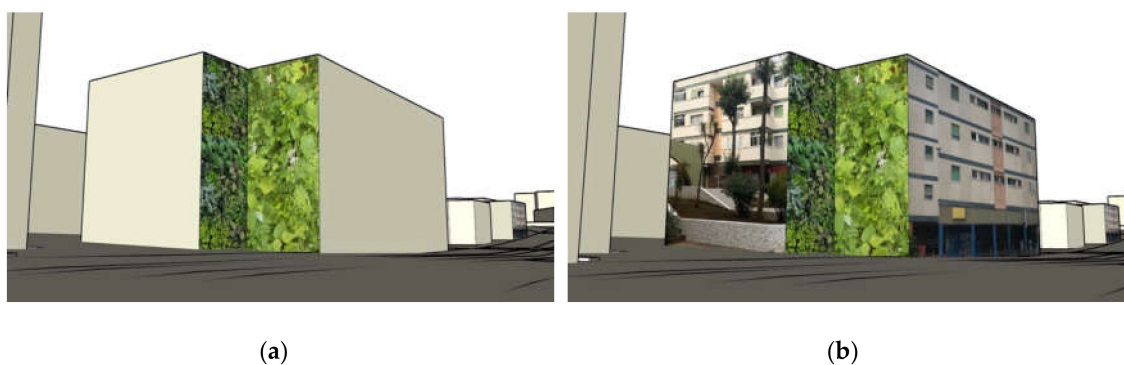

(**a**)   (**b**)

Figure 4. (**a**) Facades represented with Cad Mapper and (**b**) its corresponding image in reality

Once the textures of the 2 vertical gardens and the real images of the adjacent facades have been added, it is when the students obtained the 3 different views in order to check the visual impact at street level of the new ornamentation. For this purpose, it is necessary to use the Sketch Up Camera toolbar, which provides options to rotate, move and zoom on the camera. It also includes three options that allow the user to set the camera at a given point at a certain height, move the camera and move it around the stage.

With these last three options, the camera can be placed where the user chooses, and thus offer a view of the vertical gardens and be three-dimensional environment from different points of view and heights: front, left and right. Participants had to submit 6 screenshots on the virtual campus. That is, 3 screenshots per facade from the front, left and right viewpoints. The name of these 6 files for each participant should be File 1, 2, 3, 4, 5 and 6 respectively.

2.4.6. Phase 5

It consists of solving 4 exercises (exercises 7, 8, 9 and 10) by activating the "Shadow Settings" dialog box of Sketch Up Make. This dialog box offers the possibility of representing shadows. The user can control the shadow projection functions of Sketch Up Make including parameters such as date and time. The Date option allows the user to adjust the day of the year that Sketch Up Make uses when generating the shadows to determine the position of the sun. The time option allows the user to adjust the time of day that Sketch Up Make uses when generating the shadows to determine the position of the sun. At the end of the exercises 7, 8, 9 and 10, the participants took the post-test of the Perspective Taking-Spatial Orientation Test.

- Exercise 7

Participants must indicate the orientation of Trinidad Avenue: they must choose between two options: North-South Orientation or East-West Orientation. For this, the student was asked to activate the shadows on the afternoon of June 21, time of sunset on that date, and to respond depending on the shadows. In the workshop planning, this Avenue was selected because it has a North-South orientation. In this way, a dichotomous question (North-South or East-West?) can be posed with an unambiguous result. Participants had to submit a file containing the answer (North-South or East-West) in text and a screenshot to justify it on the virtual campus. The name of that file that each participant had to deliver should be file 7.

- Exercise 8 and 9

Students must indicate the orientation of each of the two facades (exercise 8: facade 1; exercise 9: facade 2) in which they have made the vertical gardens. In the statement of the exercise, it was reported that the line perpendicular to said facade determines the orientation. The participants had to submit two files on the virtual campus. Each of them should contain the answer in text (orientation of the facade) and a screenshot that justified it. The name of those two files for each exercise should be File 8 and 9 respectively.

- Exercise 10

Students were asked to reasonably justify which of the two facades on which they designed the vertical garden received more hours of Sun throughout its length throughout the day. For this, the students had to illustrate their response with screenshots of the two facades at different times of the day. Each participant had to deliver on the virtual campus a single file containing the answer, as well as the screenshots at different times of the day to justify that response. The name of that file for each participant should be File 10.

The workshop was held in three days: day 1 for phases 0 and 1, day 2 for phases 2 and 3 and, finally, day 3 for phases 4 and 5. Table 1 shows the phases of the workshop, the activities carried out and the timing.

Table 1. Phases of the Workshop.

Phase	Time (Min)	Activity	Delivered by the Students
	5	Pre-test PTSOT	PTSOT Pre-test
0	30	Installation of Sketch Up Make	
	45	Training on the main Sketch Up commands	
1	30	Selection of the two facades using Google Street View	
2	20	Download, from Cad Mapper website, the 3D file in Sketch Up format	
3	60	Replacing mural with vertical gardens	
4	90	Obtaining three views of the two facades: front, left and right	Exercises 1-3 Facade 1: File 1.pdf, File 2.pdf, File 3.pdf Exercises 4-6 Facade 2: File 4.pdf, File 5.pdf, File 6.pdf
5	90	Orientation of Trinidad Avenue	Exercise 7 File 7.pdf
		Orientation of the 2 facades	Exercise 8 Facade 1: File 8.pdf Exercise 9 Facade 2: File 9.pdf
		Hours of Sun	Exercise 10 File 10.pdf
	5	Post-test PTSOT	PTSOT Post-test

3. Results

The obtained data were subjected to descriptive analysis, ANCOVA, Pearson's correlations, Linear Regression and Mediation Analysis. In all tests, the level of significance was set at 0.05. All statistical analyses were performed using SPSS, v.21.0 [33].

An ANCOVA of repeated measures (Pre and Post) was performed on the measurements obtained with PTSOT including Gender as independent factor and Age as a covariate. The multivariate effect of Age is significant ($F_{1,27} = 8.95$, $p = 0.006$, $\eta^2 = 0.249$), acting as a covariate; that is, Pre- and Post-scores could be explained partially by Age. Therefore, the model neutralizes this effect and we obtained a significant interaction between Pre-Post and Group ($F_{1,27} = 6.76$, $p = 0.015$, $\eta^2 = 0.200$). This is the difference between Pre- and Post-scores depends on the Group: for the control Group the difference is not significant ($p = 0.538$) but the treatment Group has a significant improvement of their performance (the higher the score, the greater the error) in PTSOT ($p < 0.001$). Gender has no significant effect. Table 2 displays the correspondent descriptive statistics.

Table 2. Statistics for PTSOT as a function of Group and Pre-Post.

Group (n)	Treatment (22)		Control (10)	
PTSOT	Pre-PTSOT	Post-PTSOT	Pre-PTSOT	Post-PTSOT
Mean score	57.89°	40.55°	53.52°	50.63°
(Standard deviation)	(23.42)	(18.12)	(16.13)	(17.29)
Gain	17.34°		2.89°	
(Standard deviation)	(16.73)		(4.52)	
p-value	<0.001		0.538	

PTSOT score: the lower the score, the lower the error.

Focusing on the treatment group ($n = 22$), in order to explain the relations of the scores and mean score of the exercises with the PTSOT scores, we performed correlations, regressions and a mediation analysis. Table 3 shows the correlations between the PTSOT scores, the mean score of all exercises and

the scores of each exercise. We can see that all correlations are negative, confirming that better (lower) PTSOT scores are related to better scores and mean score of the exercises. PTSOT-Pre correlate positive with PTSOT-post: better Pre-scores are associated with better Post-scores ($r = 0.70$; $p < 0.001$).

Table 3. Correlations for PTSOT Pre and Post with Exercises and Mean scores of exercises.

Treatment Group n = 22		Exercise Number						
		Mean Score	**1-3**	**4-6**	**7**	**8**	**9**	**10**
PTSOT_pre	Pearson's Correlations	−0.845 *	−0.681 *	−0.549 *	−0.585 *	−0.883 *	−0.798 *	−0.682 *
	p	0.000	0.000	0.008	0.004	0.000	0.000	0.000
PTSOT_post	Pearson's Correlations	−0.456 *	−0.341	−0.291	−0.266	−0.646 *	−0.647 *	−0.268
	p	0.033	0.120	0.188	0.232	0.001	0.001	0.228

* Significant correlations

A Regression Analysis to predict the PTSOT-post score based on all exercises, accounts for 62.8% of variance ($R = 0.793$; $p = 0.011$). Exercise 8 and 9 are the best predictors as shown in Table 4 ($p = 0.029$ and $p = 0.047$, respectively). For each more point in exercise 8 or exercise 9, the PTSOT-post will decrease 5.409 and 4.285 points, respectively. It is necessary to remember that, in the PTSOT, the lower the score, the lower the error.

Table 4. Regression coefficients for PTSOT-post as dependent variable.

Exercise	B	Standard Error	Beta	t	p	Pearson-Correlation	Partial-Correlation	Semipartial-Correlation
Constant	48.179	8.732		5.518	0.000			
1_3	4.533	6.011	0.451	0.754	0.463	−0.341	0.191	0.119
4_6	−1.305	4.556	−0.157	−0.286	0.778	−0.291	−0.074	−0.045
7	0.634	1.577	0.095	0.402	0.693	−0.266	0.103	0.063
8	−5.409	2.247	−0.733	−2.407	0.029	−0.646	−0.528	−0.379
9	−4.285	1.977	−0.590	−2.167	0.047	−0.647	−0.488	−0.341
10	2.797	1.991	0.349	1.405	0.180	−0.268	0.341	0.221

Finally, a simple Mediation Analysis [34], shows that the relation between the PTSOT-pre and PTSOT-post score, is significantly mediated by the mean score of all exercises. Figure 5 shows the corresponding diagram and coefficients. The Total effect that the Pre-score has on the Post-score ($\beta = 0.544$; $p = 0.0003$) could be divided into a Direct ($\beta = 0.860$; $p = 0.001$) and an indirect effect ($c'_1 = -0.408$; $p = 0.001$; $a_1 = -0.845$; $p < 0.001$ and $b_1 = 0.483$; $p = 0.105$).
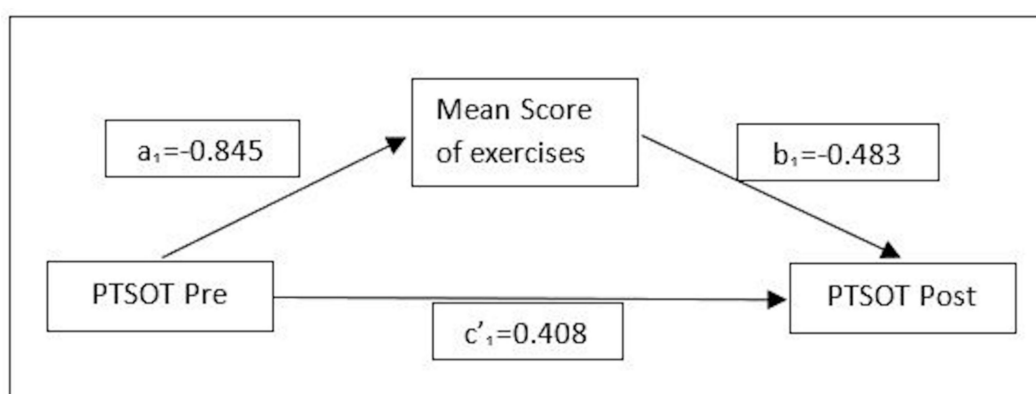

Figure 5. Mediation of Mean-score in exercises in relation between PTSOT-Pre and PTSOT-Post.

That is, not only the Pre-score determines performance Post-treatment, but also performance in exercises plays an important mediator role.

4. Discussion and Conclusions

For the project and design of green infrastructures, urban engineers, architects and planners make use of both 2D and 3D maps, as well as applications and tools to represent the topography of the environment in which the spatial orientation skill is needed. In Higher Education, in the framework of sustainable city planning, specific teaching strategies for the development of spatial orientation skills are necessary, like the one that has been carried out in this research. It has involved university students of Agronomic Engineering, an engineering specialty with professional competences in the field of green infrastructures. Participants have conducted a workshop in which, to carry out the design of a vertical garden, they have made use of geo-spatial tools and 3D CAD applications. The exercises that have been proposed in the workshop have been specifically designed for students to work with spatial orientation skill.

In response to the working hypothesis, the teaching strategy carried out in this research has had a positive impact on the development of the spatial orientation skill of the participants, who have obtained a significant increase of $17.34°$ (16.73 s.d.; $p < 0.001$) in their spatial orientation skill. This gain, in percentage terms within the scale of the measuring instrument used, the Perspective Taking Spatial Orientation Test (PTSOT), was 19.27%. No gender differences were found. PTSOT-Pre correlated positive with PTSOT-post: better Pre-scores were associated with better Post-scores ($r = 0.70$; $p < 0.001$). That is, the students who started the workshop with a better spatial orientation skill (that is, they obtained a low score in the pre-PTSOT) are the ones who got better scores also in the Post-PTSOT. In relation to the exercises, these better PTSOT scores (lower) are related to a better average exercise score. That is, according with the result of the Mediation Analysis performed, not only the Pre-PTSOT score determines performance Post-treatment, but also performance in exercises plays an important mediator role. The exercises proposed in the workshop have, therefore, demonstrated its effectiveness for the development of spatial orientation. Specifically, exercises 8 and 9 were the best predictors of improvement in spatial orientation skill. These types of exercises in which the use of spatial orientation is predominant, can be extrapolated to other types of teaching strategies aimed at the development of spatial orientation skill in the field of geospatial planning of green infrastructures.

The results of the control group have confirmed, in turn, that those participants who did not carry out the workshop activities did not increase their spatial orientation skill. These students obtained a lower improvement ($2.89°$; 3.21%) and not significant ($p = 0.538$).

The works cited in the introduction [28,29] based on the development of spatial orientation skill can serve to contextualize the results of the present research in terms of spatial skill development. Although none of the two workshops carried out activities related to green infrastructure, the same measurement tool was used (the Perspective Taking Spatial Orientation Test), and also engineering students participated. For this reason, we understand that this contextualization is interesting, since there are no previous works related to the development of spatial orientation skill in the field of green infrastructure.

In the first one [28], a geo-spatial application (Spatial Data Infrastructure, SDI) was used as a tool to perform different teaching strategies throughout five academic courses. Participants also performed tasks related to spatial orientation, but instead of 3D representations (such as those used in the present research) they used 2D representations. Significant gains ranging from $12.90°$ (14.33%) to $19.21°$ (21.34%) were obtained. An SDI is a set of resources (maps, satellite images, databases of geo-referenced thematic data among others) dedicated to the management of Geographic Information. This resource can also be of great help for geo-spatial analysis in sustainable city planning. Authors such as Nowak et al. [35] highlighted the role of the so-called green information systems (green IS) as part of the green infrastructures and SDI. Spatial Data Infrastructures has already demonstrated its positive impact on the development of spatial orientation [28].

The second of them [29] used augmented reality (AR). A study on landscape interpretation was carried out, using augmented reality as a tool for 3D graphic representation of the land. Identification of locations and routes were the activities performed by the participants. In this case, the gain obtained

in spatial orientation was 20.14° (22.37%). A correct interpretation and 3D visualization of the land is necessary for landscape and environmental planning, and augmented reality facilitates these tasks.

In both cases [28,29], the results obtained in the respective control groups are in line with the results obtained in the present research, which is also coincident with other studies on spatial skills enhancement [36–38].

SDIs and Augmented Reality have already been used as good practices in the classrooms in the education in sustainable development goals [39,40]. Given the potential of SDI and Augmented Reality in planning actions for a sustainable environment, a future direction of research could be based on teaching strategies in which these technologies were used for spatial skills acquisition in the framework of green infrastructures in cities.

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