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Review

Spatial Orientation Skill Improvement with Geospatial Applications: Report of a Multi-Year Study

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Abstract: There are several competences and spatial skills to be acquired by the student related to the treatment of geo-information in Science, Technology, Engineering, and Mathematics (STEM) disciplines. Spatial orientation is the spatial skill related to the use of georeferenced information, and geospatial applications (on-line map interfaces) such as the spatial data infrastructure offer a great opportunity for development of this skill. In this report we present several experiments, carried out over five academic years with 559 university students, to improve the spatial orientation skill of the students. Survey learning and wayfinding activities were conducted. First- and second-year university students performed the experiments on a PC and also used digital tablet support. The statistical analysis showed that the students improved their spatial orientation skill with a range from 12.90 (minimum) to 19.21 (maximum) measured with the Perspective Taking Spatial Orientation Test, regardless of the academic year, the hardware (PC or Tablet-PC), or the orientation strategy (survey learning or wayfinding). The second year students improved more than those in their first year. The methodologies employed could be developed by teachers or researchers, and the results presented could be taken as a reference for comparisons in future research in the field of strategy planning with geospatial applications and location-based tools for spatial orientation skill improvement in education.

Keywords: education; geospatial applications; spatial orientation skill

1. Introduction

The educational model of the European Space for Higher Education is based on the acquisition of students' competences and skills. In STEM (science, technology, engineering, and mathematics) degrees, in the field of geospatial information, there are several competences and spatial skills to be acquired by the student related to obtaining and analysing geographic and cartographic information [1–4]. Some authors consider that having a high level of spatial skills is a guarantee of success for students in the STEM disciplines [5–11]. In American Higher Education, as early as 1964, spatial skills were present in at least 84 American university degrees [12].

There are different classifications of the components of spatial skills [13,14]. In the field of geospatial disciplines, through the use of maps and different forms of cartographic representation and georeferenced information, spatial orientation is the most commonly used component. It is defined as the ability to orientate physically or mentally in space [15]. Some authors consider that spatial orientation is one of the main components of spatial skills [1,16–18].

The interest in the importance of spatial skills and their recognition has been growing since the second half of the last century, although they have not received the same attention as other skills, such as those related to verbal and numerical abilities [19]. Numerous studies have shown that spatial skills can be developed using the appropriate material, and there is recognition that spatial skills can be developed with specific training [20–24], but in the field of geospatial applications for university education there are no specific actions planned for their development in formal teaching.

The increasing appearance of geospatial applications offers a great opportunity for the improvement of the spatial orientation skill of the students. These applications facilitate access to georeferenced information, and constitute a powerful and innovative tool for the design of teaching strategies in subjects related to the consultation, treatment, and analysis of geospatial information.

Therefore, in this paper, we present a report on experiments and empirical evaluations for educational purposes (workshops) in the field of the development of spatial orientation using a geospatial application (on-line map interfaces such as the spatial data infrastructure). The spatial orientation skill and the geospatial application are described in Sections 2 and 3, respectively. The workshops (described in Section 4) were carried out in several academic years, with PC and tablet-PC hardware, with first and second year university students, and performed with activities related to spatial orientation skill acquisition: survey learning and wayfinding. In the present report, in Section 5 we can observe the statistical analysis of these workshops, using descriptive statistics and mixed analysis of variance (ANOVA) with between-subjects factors.

This report offers methodologies that can be easily developed by teachers/researchers in their fields of teaching, as well as quantitative spatial orientation data. These can be taken as a reference for comparison in future research in the field of strategic planning with geospatial applications and location-based tools for spatial orientation skill improvement in education.

2. Spatial Orientation

Spatial ability is a component of intelligence [25–27], and it has been studied under different approaches. The factorial approach analyses intelligence as a set of components (including those of a spatial nature) that can be measured with intelligence tests to detect individual differences in human cognition.

In educational research, it is necessary to differentiate between spatial ability and spatial skills. Spatial ability is defined as an innate ability for visualization, which everyone has before any kind of proper training takes place (i.e., a person is born with a certain ability). Spatial skills are learned or acquired through specific training. Spatial skills start developing in infancy, while interacting with the environment [28]. Spatial knowledge includes all knowledge acquired by studying maps, charts, etc. [29]. Some people may have a higher degree of innate ability than others (which also happens in other skills such as writing, mathematics, etc.). However, most people can acquire the spatial skill through practice [7].

There is no consensus on a classification of the components of spatial skills [7,28–33], and different researchers propose different classifications. Smith (1964) [12] established three components: mental rotation, spatial visualization, and spatial perception (spatial orientation). Linn and Petersen (1985) [18] proposed three: spatial perception, spatial visualization, and spatial orientation. Maier (1998) [15] works with five categories: spatial rotations, spatial perception, spatial visualization, mental rotation, and spatial orientation. Other researchers [29] adopted a simplified classification of two categories: spatial relations and spatial visualization. As a result, several tests are currently in use to obtain a quantitative measurement of spatial skills. Some of the most commonly used are the Mental Rotation Test [34] and the Purdue Spatial Visualization Test: Rotations (PSVT: R) [35] for measuring the spatial rotation component, the Differential Aptitude Test-Spatial Relations Subset (DAT-SR5) [36] for measuring the spatial vision component, and the Perspective-Taking Spatial Orientation Test for measuring spatial orientation.

Spatial orientation is present in almost all of them, together with other components such as spatial perception, spatial visualization, mental rotation, spatial rotations, and spatial relations [12,17,18]. There are researchers who even consider spatial orientation to be one of the main categories of spatial skills [34,37].

Spatial orientation is defined as "the ability to evaluate how a sequence of spatial motion can be represented from different orientations" [16], "the sense of 3D orientation in space during motion", or "the ability to orientate oneself with respect to the environment and the conscience of self-location" [24], "the ability to imagine how a stimulus array will appear from another perspective" [38], "the ability to imagine the appearance of objects from different orientations of the observer" [39], or "the ability to stay orientated in a spatial context when objects are observed from different positions" [40]. Maier [17] defined it as "the ability to physically or mentally orientate in space".

There are three types of activity related to orientation: static orientation of the subject and objects, interpretation of three-dimensional object perspectives, and finally, orientation of the subject in space [41].

Static orientation of the subject and object refers to tasks involving a subject's orientation in relation to objects and the orientation of objects themselves. When we refer to tasks, we consider those that require an understanding of the body's structure and of the identity and use of corporal properties: up–down, left–right, front–back. The interpretation of objects seen three-dimensionally is identified with recognizing, describing, producing, and processing [42]. This includes tasks related to representing objects in both two and three dimensions. These are activities that require understanding and changing views (change of perspective), interpreting objects, rotating flat objects mentally, and interpreting different representations of three-dimensional objects.

In the third case (orientation of the subject in space), activities performed involve the recognition, description, construction, processing, interpretation, and representation of real space or movement. In contrast to the interpretation of three-dimensional object perspectives, where isolated objects are dealt with and the focus of attention is on an object's structure and composition rather than on its position in space, orientation of the subject in space deals with sizable spaces that can be perceived physically (where displacement provides a continuously shifting point of view) or mentally, through reading and interpreting maps: route-based learning in a ground-level perspective (navigation or wayfinding) and survey learning (or map learning) [43,44]. With the use of maps and plans, the orientation is perceived and refined through known links. This is a process called survey learning or map learning [45,46], in which the space is perceived from the North of the map [47]. Some authors affirm that the spatial orientation skill is used with cartography, maps, and street plans, because to work with maps it is necessary to learn to orient them in space [48,49]. In route-based learning (exploratory navigation or wayfinding), space learning is acquired from the perspective of a ground-level observer within the space. The orientation in the space occurs during movement, through the relative locations of objects within the environment. Therefore, the orientation comes through local information from different points of view, not with the Geographic North as in the case of maps (survey learning).

Research has been conducted that has shown a relationship between spatial orientation and 3D cartography [50]. Likewise, experiments related to wayfinding and the spatial orientation skill have been conducted by Roca-Gonzalez et al. [51].

Professionals in engineering, geomatics, geography, and architecture, among others, make use of spatial information, where the spatial orientation skill enables them to work more efficiently. Therefore, it is necessary to carry out activities related to spatial orientation at the beginning of university degrees, in order to stimulate and develop a competence that will be needed in the later years, in which specific subjects of the profession are dealt with. Hershkowitz, Parzsyc, and Van Dormolen [52] stated that a well-planned spatial education is needed for the acquisition of spatial reasoning and thinking, and they suggested activities related to the interpretation of maps and plans. Therefore, in this report, the results of different strategies performed through workshops are presented in which survey learning (map learning) and route-based learning (wayfinding) are used, since the spatial on-line map interface geospatial application allows access to both environments.

In addition to the professional world and university education, different educational institutions are interested in spatial orientation. It is a subject that must be taught by curriculum directives of the minimum teaching decree issued by the Ministry of Education and Science for Primary and Secondary education [1,53]. The National Council of mathematics teachers [54] believes that the development of spatial orientation is a necessary resource for description, modelling and geographical planning. Teaching and learning processes of spatial orientation are performed in fields such as didactic mathematics [55–57].

Spatial Orientation Skill Measurement

The test used in all the workshops conducted in the present report has been the Perspective Taking/Spatial Orientation Test designed by Kozhevnikov and Hegarty [38].

The Perspective Taking/Spatial Orientation Test—completed using paper and pencil—consists of 12 items, in which the students choose one direction from different options. A configuration of seven objects is drawn in the top half of an 8.5 × 11 inch sheet of paper. For each item, the participant is asked to imagine being at the position of one object in the display (the station point) facing another object (defining their imagined heading or perspective within the array) and is asked to indicate the direction to a third (target) object. The bottom half of the page shows a picture of a circle, in which the imagined station point is drawn in the centre of the circle, and the imagined heading is drawn as an arrow pointing vertically up. The task is to draw another arrow from the centre of the circle indicating the direction to the target object. Perspective-taking tasks involve mental transformation over two angles: (1) the angle between the orientation of the array and the perspective to be imagined and (2) the angle between the imagined perspective and the direction to the target object. Both of these transformations contribute to task difficulty. Electronic copies of this test package are available at https://labs.psych.ucsb.edu/hegarty/mary/.

Table 1 shows the overall scores as well as the quantified average improvement. The scores represent the absolute deviation in degrees between the participant's answer and the correct direction to target (absolute directional error). A participant's total score was the average deviation across all items. If a participant did not point to any target, a 90° score was assigned for that item [58].

Table 1. Workshops with the spatial data infrastructure (SDI) geospatial application for educational purposes: spatial orientation skill improvement average values.

No. Workshop (*Participants*)	Academic Year	Students	Hardware	Activity	Perspective Taking/Spatial Orientation Test Average Values		
					Pre-Test (s.d.)	Post-Test (s.d.)	Gain (s.d.)
I (*47*)	2009–2010	First year engineering course	PC	Survey learning	50.01 (31.40)	37.11 (29.05)	12.90 (19.47)
II (*52*)	2010–2011	First year engineering course	PC	Survey learning	50.36 (30.22)	35.29 (28.27)	15.06 (20.02)
III (*54*)	2010–2011	Second year engineering course	Tablet PC (iPad)	Survey learning	46.37 (24.49)	28.16 (18.97)	18.22 (16.53)
IV (*248*)	2009–2014	Second year engineering course	PC	Survey learning	46.93 (25.29)	27.72 (18.91)	19.21 (15.54)
V (*158*)	2010–2014	Second year engineering course	PC	Survey learning and Wayfinding	44.55 (21.74)	25.49 (16.73)	19.06 (16.13)

(s.d. standard deviation).

3. Resources

Nowadays, the number of queries on georeferenced information sent to Internet search engines exceeds 15% [59]. Geographic Information Technologies (GIT) (computer-based tools to analyse spatial information) are an emerging field of geographic information available online. GIT is composed of all those disciplines that allow the generation, processing, and sketching of georeferenced geographic information. It stands as one of the three largest growth industries in the United States, together with nanotechnology and biotechnology [60,61]. In fact, in the United States there is a growing number of educational institutions that teach subjects related to geo-technologies at several learning levels [62]. In a European context, Geographic Information Technologies are present in the curriculum of numerous degrees adapted to the European Higher Education area [63–66].

The advances in geographic information systems and technology have allowed the appearance of geospatial applications and location-based tools, which can be used in educational environments. Geographic Information Technologies such as spatial data infrastructures are examples of effective systems to share and use geospatial data and geo-referenced information [67]. A spatial data infrastructure (SDI) is a geographic information web system consisting of a set of resources (catalogues, servers, software, data, applications, and web pages) dedicated to the management of Geographic Information (maps, orthophotos, satellite images, location names, thematic information, among others). Since the appearance of spatial data infrastructure several years ago, there has been a tremendous increase in the spatial data available on the Internet [68].

A cyber infrastructure is a set of organizational practices, technical infrastructure, and social norms that collectively permit the smooth operation of scientific work at a distance. A spatial data infrastructure resource can be considered as a geospatial cyber infrastructure [69]. From an educational approach, the spatial data infrastructure allows unprecedented access to educational resources—including mentors, experts, online educational activities, games, and virtual environments—and provides learners with opportunities to interact with tools of professional science (scientific models, simulations, data sets, sensors, and instruments). The Computer Research Association concludes that there are substantial long-term benefits from using cyber infrastructure for learning. These include help in recruiting and educating the next generation of scientists, teachers, and citizens who are literate in STEM disciplines [70].

In the experiments carried out in this report, the spatial data infrastructure resource has been used given its versatility as an on-line map interface.

4. Experiences Using On-Line Map Interfaces

Since 2010, the research group in the development of spatial skills of the University of La Laguna (http://dehaes.webs.ull.es) has been developing strategies and methodologies aimed at the improvement of spatial skills such as mental rotation, spatial visualization and, finally, the spatial orientation skill (workshops performed in the present report). The pedagogical approach to spatial orientation skill development, carried out during the last eight years with a total of 559 university students in several workshops programmed into the laboratory program (as a part of the academic course), has been based on the use of on-line map interfaces as well as different supports, both pc and digital tablets (mobile geospatial applications). The acquisition of the spatial orientation skill has been analysed through map reading (survey learning) and route-based learning (wayfinding) activities.

All the experiments were carried out using geospatial applications (on-line map interfaces) such as the spatial data infrastructure resource. SDIs exist at the local, regional, national, and global levels [71,72]. In this case, given the geographical location where the research has been developed (Canary Islands), the resource used has been the Canary spatial data infrastructure, belonging to the INSPIRE Geoportal (Infrastructure for Spatial Information in Europe), available at http://www.idecanarias.es/.

Five workshops were conducted with the SDI on-line map interface in the 2009–2010 to 2015–2016 academic years, at the beginning of each academic year. Workshops I [73], II [74], IV [63], and V [70] were carried out using PCs, and in workshop III [75] digital iPad tablets were used.

The structure of all workshops was the same, but in workshop V new activities were introduced to be able to measure the results of spatial orientation with tasks related to wayfinding, in addition to map reading. A complete description of workshops I, II, III, and IV can be found in Carbonell et al. [64], and the complete description of workshop V in Carbonell [70]. In all of them, there was an introductory and improvement phase.

Introductory phase: divided into an Introductory session (2 h) (description of the Canary spatial data infrastructure and its applications; students learn commands and do measurement practice, they also practice with the database) and Training session (2 h) (students perform a geographic evolution analysis focused in a certain zone).

Improvement phase (3.5 h): practical exercises related to measurement, orientation, database query, positional scenario, and dynamic scenario.

In workshops I, II, III, and IV, the spatial orientation was acquired through survey learning (map learning); i.e., where the user needs to orientate in space using maps and cartography documents. Workshop V proposed the acquisition of spatial orientation from a dual approach: survey learning and route-based learning (wayfinding), in which the spatial orientation was acquired from local information composed of successive views, obtained through street-view vision combined with aerial views, 3D perspectives, and photographs. This viewing mode allowed the user to walk as if they were present in a ground level perspective navigation experience: a computer-simulated walk.

All the participants in each workshop carried out the Perspective Taking/Spatial Orientation Test individually before (pre-test) and after (post-test) the workshop, so as to verify the effect of the workshop on their spatial orientation skill. None of them had ever performed the test before the workshops.

To encourage effort, an extra mark was assigned to the total of the final scores of the students who participated.

5. Data Analysis

Table 1 shows the results of the five workshops carried out by the research group in the development of spatial skills of the University of La Laguna (http://dehaes.webs.ull.es), in which the Canary spatial data infrastructure on-line map interface has been used. The confidence level was set at 99%, so all p values equal to or less than 0.01 were considered significant.

It should be highlighted that the Perspective Taking/Spatial Orientation Test overall score is the deviation between the participant's answer and the correct one; so the lower the score obtained, the greater the success rate.

Students improved their spatial orientation skill. Participants in the five different workshops designed to improve the spatial orientation skill scored lower in the post-test than in the pre-test. In addition, these differences between the values of the Perspective Taking/Spatial Orientation Test were statistically significant ($p \leq 0.01$ in all cases), which means that the students improved their spatial orientation skill after performing specific training.

A mixed ANOVA was carried out, and the interaction of *Pre-Post* and *student-year (first or second)* was significant (F (1.558) = 6.449; $p \leq 0.01$; $\eta^2 = 0.011$). Before the workshops there were no significant differences between the students of the first and second year course, but after the workshops, the first year students had higher scores (M = 36.03; S.D. = 28.05) than second year students (M = 27.77; S.D. = 18.55) (t (558) = 3.90; $p \leq 0.01$). On the other hand, scores were significantly lower after the workshops than before for both groups (t (99) = 8, 38; $p \leq 0.01$ and t (459) = 23, 98; $p \leq 0.01$) for first and second year students, respectively).

To verify if there were differences between the academic years, a mixed ANOVA was performed. Only the effect of *Pre-Post* was significant (F (1.555) = 344, 07; $p \leq 0.01$; $\eta^2 = 0.383$), so it cannot be concluded that one academic year had better results than another.

In order to study if the hardware (PC vs. Tablet-PC) or the task (Survey Learning vs. Survey Learning and Wayfinding) had an effect, only the second-year students were selected because only in the second year was there an activity which was performed with a tablet-PC instead of the personal computer and an activity with the double task. For both mixed ANOVA results again, only the effect of *Pre-Post* (F (1.458) = 216.09; $p \leq 0.01$; $\eta^2 = 0.321$ and F (1.458) = 554.99; $p \leq 0.01$; $\eta^2 = 0.548$) were significant.

Analysing by gender in workshop I, both men and women improved their spatial orientation skill with increases of 14.13 and 11.39 points, respectively, but this difference was not statistically significant. In workshop II, the improvement in the spatial orientation skill was significantly higher for men (17.56) than for women (11.38). The results in Workshop III showed that females improved their spatial orientation skill more than males (16.91 and 20.27 respectively), although this difference was not significant. No gender study was done in workshop IV, and in workshop V the differences for improving the spatial orientation skill were not significant ($p \geq 0.01$).

In workshops IV and V, in addition to the students who carried out the workshops (experimental groups: 258 in workshop IV and 158 in workshop V), 35 students participated in each of the workshops as a control group. These control-group students belonged to the same student cohort as those who participated in the study.

These control groups were subject to the Perspective Taking/Spatial Orientation Test twice without taking part in the workshops. As in the experimental groups, none of them had ever performed the test before the workshops. They did not use any SDI, nor did they receive specific training, but they did take the same test as the experimental group at the same time. The control group captures what could have been the outcome if the activity had not been complemented. In turn, it serves to know if the possible improvement obtained is due to the effect of the specific training or if it is due to the so-called recall effect of the test. The research conducted in these two workshops showed that the 70 students (35 in workshop IV and 35 in workshop V) who did not participate in the workshops did not achieve a statistically significant gain in their spatial orientation skill ($p = 0.113$ and $p = 0.110$, respectively) [63,70].

6. Conclusions

Experiments on the use of geospatial applications in education, carried out with 559 university students over five years, show that the online map interface is a valid tool for educational purposes in the field of spatial competence development (spatial orientation).

Different workshops based on geospatial applications such on-line map interfaces like the SDI, with a strategic planning of activities related to spatial orientation, have shown that they are valid for the improvement of the spatial orientation skill. There has been a statistically significant improvement in the acquisition of spatial orientation by the effect of specific training in all the workshops conducted, with an improvement range from 12.90 (minimum) to 19.21 (maximum), although not one academic year had better results than any other. This improvement in the spatial orientation skill coincides with the recognition that spatial skills can be developed with specific training using appropriate material [20–24].

In spatial teaching practice, in accordance with the results of this report, a well-planned spatial education is needed in the first years of university degrees for the acquisition of spatial reasoning. After the workshops, first year students had higher scores (M = 36.03; S.D. = 28.05) than second year students (M = 27.77; S.D. = 18.55) (t (558) = 3.90; $p \leq 0.01$). That is, second-year students have had a greater improvement in the spatial orientation skill than first-year students (the lower the score on the test, the greater the success rate). This may be because the second-year students have studied subjects that have developed their spatial thinking in the first year. All the workshops performed in the present report have been held at the beginning of each academic year, and therefore the second-year students come with a better spatial reasoning than the first, since in the first course they studied subjects such as graphic expression. In this subject, the research group in the development of spatial skills of the University of La Laguna worked on the development of spatial skills such as spatial vision and mental rotation [74,76]. These skills—especially mental rotation—are related to spatial orientation, as Hegarty and Waller [58] showed in a study on the dissociation between mental rotation and Perspective-Taking Spatial Abilities.

The planned wayfinding and survey learning activities have not shown statistically significant differences in the development of the spatial orientation skill with respect to the activities in which only maps and cartographic documents (survey learning) have been used, regardless of the hardware used (PC or tablet PC).

The results from the control groups show that the spatial orientation skill does not experience a significant increase in students who do not participate in specific training. This coincides with the results of other research in the field of spatial skills development [50,51,63,70,76].

Regarding gender, different results are shown in the workshops carried out. Previous research carried out on gender differences in spatial orientation showed that males usually feel more orientated than females. Pazzaglia et al. [77] found that men obtained higher scores in orienting abilities and in the use of compass direction than women. Coluccia and Louse [78], and Coluccia, Louse and Brandimonte [79] found that males generally perform better than females in various types of spatial orientation activity, but situations in which males perform like females are also observed. Gender differences may be due to different degrees of familiarity that men and women may have with mentally operating the orientation material provided [80]. Given all this background and the potential of the new technologies for geographic information, future work could consider a study of gender and spatial orientation using geospatial and location-based tools for educational purposes.

This report studies the development of spatial orientation using on-line map interfaces. Other three-dimensional rendering technologies such as augmented reality [81–83] as well as 3D printing can be useful for the development of spatial thinking. These technologies have also proved to be motivating for students [84].

The activities and methodologies presented in this report could serve other researchers as a basis for the design of new activities related to the development of spatial orientation. The pre and post scores measured with the Perspective Taking/Spatial Orientation Test, as well as the gains obtained, could serve as reference for the planning, analysis, and possible implantation of future strategies for the improvement of the spatial orientation skill in which geogames, mobile geospatial applications, and location-based tools could be used.

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