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How to improve geospatial competence: a quasi-experimental study with secondary-education students in the Balearic Islands

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Abstract

The limited level of geospatial competence shown by students in different educational contexts highlights the need to develop specific didactic strategies to improve such abilities. This study implements a quasi-experimental design using maps with third-year secondary-education students. The research was based on a sample of 221 students in the Balearic Islands (137 in the experimental group and 84 in the control group). A pre-test and a post-test were delivered through an online tool; students were to locate nine territorial units and estimate their surfaces. Between both tests, the experimental group performed map comparison activities using maps with equivalent projections, while the control group continued with regular teaching dynamics. The results show significant improvement in place location knowledge (PLK) in the experimental group, as well as a reduction of the initially detected gender differences. On the other hand, there is little variation in surface estimation results, which suggests the need for more specific or long-term interventions. These findings open new pathways for the design of teaching proposals that foster the sustained development of geospatial competence.

Keywords: Spatial Reasoning, Geospatial Competence, Place Location Knowledge, Surface Estimation, Secondary Education

1. Introduction

The terms spatial thinking, spatial abilities, and spatial competence have been widely debated in the academic literature (Hickman, 2023). Spatial thinking is central to contemporary geography education, as it allows students to understand the relations, patterns, and processes that structure geographic space (Bednarz and Lee, 2019; Lee and Jo, 2022).

On the other hand, the term geospatial competence refers to the ability to understand, interpret, represent, and reason about geographic space at multiple scales. It encompasses both geographical thinking and the use of cartographic, analytical, or technological tools to interpret territorial phenomena (Gómez-Trigueros, 2025). Certain studies have proven that students with low levels of geospatial competence have greater difficulty in using maps (Utami et al., 2018).

Levels of spatial competence have been assessed using different types of tools. In some cases, question surveys are used (Somantri, 2022) and, in others, mental maps (Binimelis et al., 2023). These tools assess a variety of parameters: orientation, spatial patterns, map overlays, spatial correlations, location, establishment of hierarchies, size comparison, etc. (De Miguel, 2015; Harwood and Rawlings, 2001).

Place location knowledge (PLK), understood as the ability to locate and name places on a map, is one of the fundamental components of geospatial competence (Zhu et al., 2016). According to recent studies, locating territorial units is a key indicator within the set of geospatial abilities, since it is one of the basic skills linked to geographic literacy and the development of geographic thinking (Gómez-Trigueros et al., 2025; Hickman, 2023). In fact, PLK is part of a broader framework of geospatial competence that includes the abilities of cartographic representation, spatial reasoning, and the use of analytical or technological tools to interpret territorial phenomena.

Despite its relevance, in terms of research, PLK has not always been given the attention it deserves (Torrens, 2001). Studies conducted over the last decades are consistent in noting a limited level of locational knowledge among students. Torrens (2001), for example, assessed the PLK of over 400 secondary education students in Dublin to find out what features of a place make its recognition easier and what student variables influence this knowledge. Similar results were obtained in the study conducted by Dal (2008) using a sample of students living in the suburbs of Paris: despite ongoing teaching efforts to improve their locational knowledge, the students only performed well on locating the immediate European environment, while their knowledge of the rest of the world was much more limited.

Surface estimation and relative size comparison of regions are useful indicators to explore how mental representations of space include cartographic and cognitive biases. The analysis of this component helps to identify the relationship between the estimated and actual areas, providing insights into the mental processes underlying spatial representation. Several studies have proven that the perception of a place's size can be affected by factors such as familiarity, media impact, or distortions deriving from map projections. At the same time, geospatial interface development and extended reality offer pathways for designing tasks and visualizations that can reduce metrical ambiguity and favor more accurate comparisons between territories (Montello and Battersby, 2022). As a whole, evidence suggests that area estimation is not only proof of factual knowledge but also a sensitive indicator of geospatial competence and the efficacy of the teaching methods used.

One of the aspects that is highlighted in many studies on geographic literacy is the existence of a significant gender bias: as a rule, male students score higher than female students. Torrens (2001) reported a 6-point difference in PLK scores between boys and girls. In their analysis of the differences in mapping knowledge in secondary education students, Raento and Hottola (2005) also found noticeable differences. However, such differences only seem important in PLK studies, as when other geographic literacy variables are studied, differences decrease and are hardly significant (Bednarz and Lee, 2019).

Given the low levels demonstrated by students in various countries, there is a need to implement teaching strategies to enhance spatial skills. One of the main challenges faced by geographic literacy research is understanding how individuals develop geospatial thinking and acquire spatial competence, processes in which maps play a crucial role. The use of GIT and maps in the learning process can encourage the acquisition of spatial skills, such as recalling paths or analyzing and predicting the impact of interrelations between phenomena (Hilman and Mainaki, 2013). In a study by Harwood and Rawlings (2001), the mental maps of 26 English students were analyzed, and significant improvement was reported after 6 lessons using a practical atlas.

However, merely working with maps does

not ensure the proper development of geospatial competence, but students must be provided with the appropriate skills and knowledge to read, interpret, and produce maps (Bednarz et al., 2006). On the one hand, students should know the names of places and locations, which is something that is traditionally addressed in geography teaching; on the other hand, they should acquire the ability of spatial reasoning. The capacity of locating elements on a map can improve if the underlying reasoning process is taken into account (Bednarz et al., 2013). Seeking a geographic explanation encourages and motivates students to find out where places are located, and knowledge of their location helps to explain them (Stimpson, 1991). Hence, one of the main goals of the subject of geography should be to provide students with spatial reasoning skills (Favier and van der Schee, 2014). Accordingly, comparing maps becomes an extraordinarily powerful tool (Gersmehl, 2023) that allows students to build discovery-based learning, fostering critical and creative thinking (Ortiz, 2020).

This article is the second phase of a line of research that began with a previous study that is published in this journal (Pons et al., 2024). While that research focused on the initial diagnosis of the geographic literacy of students in their third year of compulsory secondary education, this work addresses the next stage of the Diagnosis-Intervention-Assessment cycle (Harwood and Rawlings, 2001), analysing the impact of an intervention that is designed to improve geospatial competence.

The pre-test, conducted in October 2023, yielded a modest competence level (global mean of 4/10), with limited PLK (43.55% correct answers and gender differences) and slightly better results in surface estimation (65.29%). These data justified the design of a specific learning situation focused on the use of maps and spatial reasoning that would only be implemented in the experimental groups, while control groups continued with their everyday teaching routine. The aim of this study is to assess students' progress in two dimensions of geospatial competence —PLK and area estimation— after the intervention. For this purpose, three main questions are posed: Does the learning intervention designed yield significant improvements regarding the pre-test results? Are there differences in the degree of progress made between the two examined components? And, does the intervention contribute to reducing the previously detected gender gaps?

2. Methodology

This project uses a quasi-experimental research strategy. Work involves an experimental group and a control group, but participants are not randomly assigned to either group (Taylor and Plewe, 2006). Sampling is limited by the way schools assign students to classes. Besides, using different timetables, classrooms, facilities, teachers, and centers with different student profiles may introduce distortions in the final results that must be corrected (Liu et al., 2010).

The pre-test implemented in October 2023 involved designing an instrument that consisted of a questionnaire and an online map editor tool whose purpose was to assess the geographic knowledge and geospatial competence of the participating students. The proposed structure was similar to the one used in other studies (Raento and Hottola, 2005). It included a total of 86 questions arranged into 5 sections: students' demographic, educational, and socioeconomic data; surface estimation; local dimension measurement; global dimension measurement; and location of elements on a digital map (PLK) (Figure 1). The instrument was validated by a panel of experts and through a pilot test in Spring 2023. To diagnose surface estimation, 9 questions related to the dimension of large units on Earth were included, inspired by the work of Battersby and Montello (2009). The students were asked to mentally compare the area of the 9 selected regions with the surface of Spain without using a reference map, only indicating whether each of the regions was larger or smaller than Spain. Russia, Antarctica, Greenland, Japan, Sweden, Austria, Italy, South Africa, and North Korea were the chosen territorial units. The selection was based on several criteria: variety of sizes, variety of distances from Spain, and position in different latitudes. It was expected that regions that are clearly larger than Spain would be easier to identify than smaller or similarly sized ones. Likewise, it was predicted that geographically closer units would be more easily recognizable than distant ones. In the case of high-altitude regions —whose size tends to become distorted in commonly used map projections— the hypothesis posed was that students would overestimate their surface. Once they had estimated their surfaces, the students were to locate the nine territorial units on the map using the online map application developed for this study. This tool made accurate registration of the position marked by each participant possible, following methodological procedures used in recent research on geographic competence (Binimelis et al., 2024).

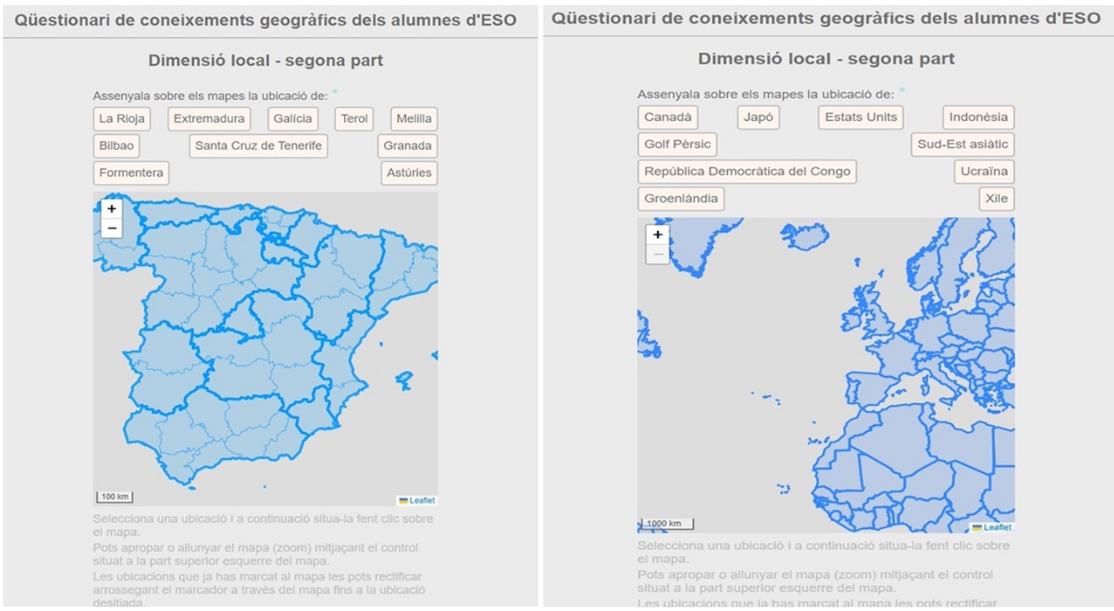


Figure 1. Interface of the online tool designed for locating elements on digital maps. Source: Prepared by the authors.

The intervention phase involved designing a spatial reasoning learning situation based on map comparison which was implemented in the experimental groups in 15 sessions that took place between January and March 2024. The activities designed were used to verify how phenomena of different natures were related to each other, and that space was their connecting link, thus making maps privileged tools for detecting such relations. The activities were based on the pre-test's questions and answers, and several interrelated maps were introduced for each of them so that students, with the help of guiding questions, could understand and interpret the spatial relationships between them (Table 1). Not only was the location of the different topics worked on, but also the reasons and causes for such locations. Although the most recent literature recommends the use of GIT because of their capacity to boost spatial thinking, IT limitations in the experimental centers (limited computer availability, poor internet connectivity, etc.) precluded their use. Instead, analogue materials that attempted to reproduce their main advantages, as far as possible, were prepared.

In the experimental groups, the activities were carried out by four secondary school teachers who were members of the project and had participated in its design. Meanwhile, in the control groups, another four secondary school teachers, who volunteered to participate in the experiment, developed the course content using traditional teaching and learning methods. In these groups, the textbook was used, and the identification of elements on blank maps was done without providing additional information— in other words, the elements were located without explaining the reasons for their placement.

The post-test, which was aimed at assessing the knowledge and abilities acquired by the students, was carried out in May 2024. The same tool used in the pre-test was applied to both the experimental and control groups.

Designed activities	Territorial units worked on
Activity 1. Climate and climate change	Japan, Russia, Greenland, Antarctica
Activity 3. Population and migratory flows	South Africa, Japan
Activity 6. The processes of offshoring and producing minerals	Japan, South Africa
Activity 9. Cultural diversity and languages	South Africa
Activity 10. Who threatens peace?	Russia, Italy, Sweden

Table 1. Designed activities and territorial units addressed in each of them. Source: prepared by the authors.

The test was administered at the end of the school year to allow a reasonable interval between the conclusion of the intervention activities and the post-test in the experimental centers, and to ensure that the control centers had enough time to cover most of the course content.

The study sample consisted of third-year compulsory secondary education (ages 14-15) students from four experimental and four control centers. The pre-test was completed by 275 students, 159 from the experimental group and 116 from the control group. The post-test was completed by 286 students, 162 from the experimental group and 124 from the control group. The main issue that arose was that not all students who took the pre-test completed the post-test, and vice versa, for various reasons: some were absent on the day of the test, while others had transferred to different schools during the school year. This level of complexity resulted in only 221 students completing both tests correctly, 137 from the experimental centers and 84 from the control centers. The data and results contributed by this study correspond to those 221 students only.

In order to carry out the study, the participation of the students was requested, always on a voluntary basis. In addition, the commitment to not reveal personal data and its exclusive use for research purposes was expressed through a letter of consent to the management of the centers and to the parents' associations, which was approved by the Research Ethics Committee of the University of the Balearic Islands.

This work analyzes a part of the data obtained from the third phase of the project that frames the research, namely the development of the post-tests and the assessment and comparison of results. The analyzed variables are as follows: percentage of correct answers to the nine surface comparison questions and percentage of correct locations for the same units in the PLK questions. There are two values for each variable, one corresponding to the pre-test and another to the post-test, whose differences have been appropriately examined and compared. Besides, the differences between the experimental group and the control group have also been compared in all cases.

The data analysis has been conducted using parametric statistical procedures similar to those implemented in similar studies (Bikar et al., 2016). The significance of the differences observed was tested using techniques such as one-way analysis of variance and mixed ANOVA. One-way ANOVA is used to contrast the hypothesis that several means are the same for a quantitative dependent variable with respect to a single factor variable (the independent variable). Mixed ANOVA, on the other hand, allows the study of the effects of different variables on a given result. It is used when there are at least two independent variables, one of them a between-subjects factor (experimental and control groups) and the other a within-subject factor (pre-test and post-test).

Aimed at further examining how the analyzed competences develop, a complementary analysis based on the detection of territorial patterns was added. This was done using two independent procedures —one for surface estimation and one for PLK— focused on the variations that had been registered in the initial and final tests, both for the experimental and the control groups. This approach, which is also implemented in recent research on geographic literacy and spatial assessment (Bednarz and Lee, 2019), allows the exploration not only of improvements but also of their differentiated distribution across the territory.

The units were classified using the *multivariate clustering* tool integrated into ArcGIS Pro 3.2, which enables the identification of emerging groups from the internal structure of the dataset. In this study, the activities involved the nine territorial units, and the percentual variations in the performance of each group were used as input parameters. The choice of the *k-means* algorithm was based on its suitability for datasets and its capacity to reveal spatial configurations that are not easily discernible using standard descriptive techniques.

Finally, the gender-based differences observed were examined to be able to verify whether the difference between male and female students that had been detected in the pre-test persisted in the post-test, or whether the intervention carried out in the experimental centers had contributed to reducing or mitigating such bias.

3. Results

The main findings of the research are presented in three sections that correspond to each of the different analyzed aspects.

3.1 Surface estimation

The overall results show a slight improvement in the score for the area comparison questions between the pre-test and the post-test, both in the control groups, from 65.3% to 67.4%, and in the experimental groups, from 67.2% to 70.5% (Figure 2). According to the mixed ANOVA, the differences observed between the two tests are significant, although when such a relationship is analyzed based on the type of group (experimental or control), the results are inconclusive, since the significance levels are greater than 0.05 (Table 2). The one-way ANOVA analyses show an F-value for both the experimental and control groups that is below the critical F-value, which does not allow for the rejection of the null hypothesis (Figure 2). In summary, the intensive work with maps conducted in the experimental groups did not lead to an improvement in students' performance when estimating surfaces.

The detailed analysis for each of the territorial units corroborates that there is no significant progress in any of them (Figure 2). Only Greenland (12.4%), Antarctica (9.5%), and Japan (11%) show significant increases in the percentage of correct answers in the experimental groups. The first two are units whose area is clearly larger than Spain, and, therefore, students do not hesitate when estimating their area. Moreover, they were both addressed in the classroom in the learning situation as part of a climate and climate change activity with maps.

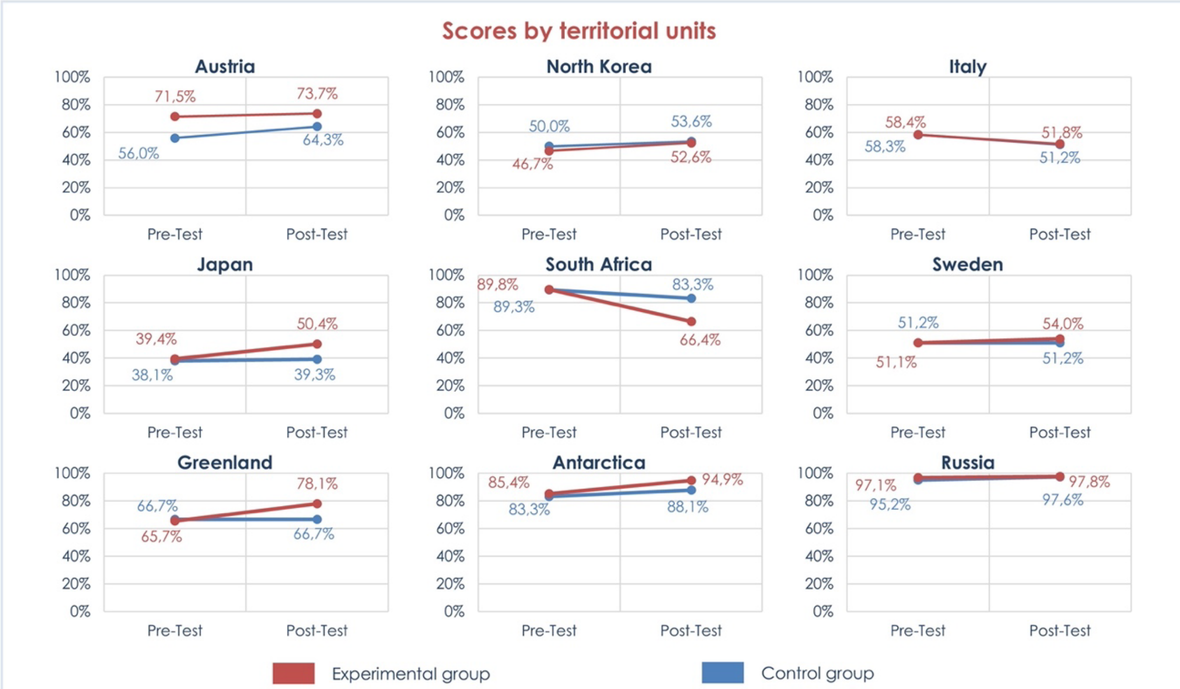
At the other end, gathered under cluster 1 (Figure 2) are Italy (-6.6%) and South Africa (-23.4%), with larger decreases in the percentage of correct answers in the experimental groups than in the control groups. This is difficult to explain, especially considering that PLK scores have increased for both units (Figure 3). The results show that the better the location of these units is known, the worse the estimation of their areas. The fact that their areas are more similar to that of Spain could hinder students' correct estimation. The case of South Africa is quite interesting; the three activities of the learning situation were worked on and PLK clearly improved (+37.2%). However, the score for its surface estimation, in turn, dropped considerably. In the post-test, the students recognize South Africa as a country located in the south of the continent, but they also find it harder to estimate its surface. One of the reasons that might contribute to this is the fact that the country is far from Spain, which makes mental comparison of the areas of both countries difficult.

Factors	Type II sum of squares	gl.	Root mean square	F	Sig.
Intra-subject effects					
Tests (Pre-test, Post-test)	485583.04	1.00	485583.04	4499.88	0.00*
Tests – Group (experimental group, control group)	252.00	1.00	252.00	2.33	0.128
Inter-subject effects					
Intersection	504622.24	1.00	504622.24	4592.95	0.00*
Group	258.16	1	258.16	2.35	0.127

Table 2. Mixed ANOVA. Surface estimation. Source: prepared by the authors.

Global scores. Surface estimation

Type of grup	Score Pre-Test	Score Post-Test	ANOVA	
			F Value	Critical value of F
Control group	65.34 %	67.38 %	0.65	3.90
Experimental group	67.23 %	70.51 %	3.43	3.87



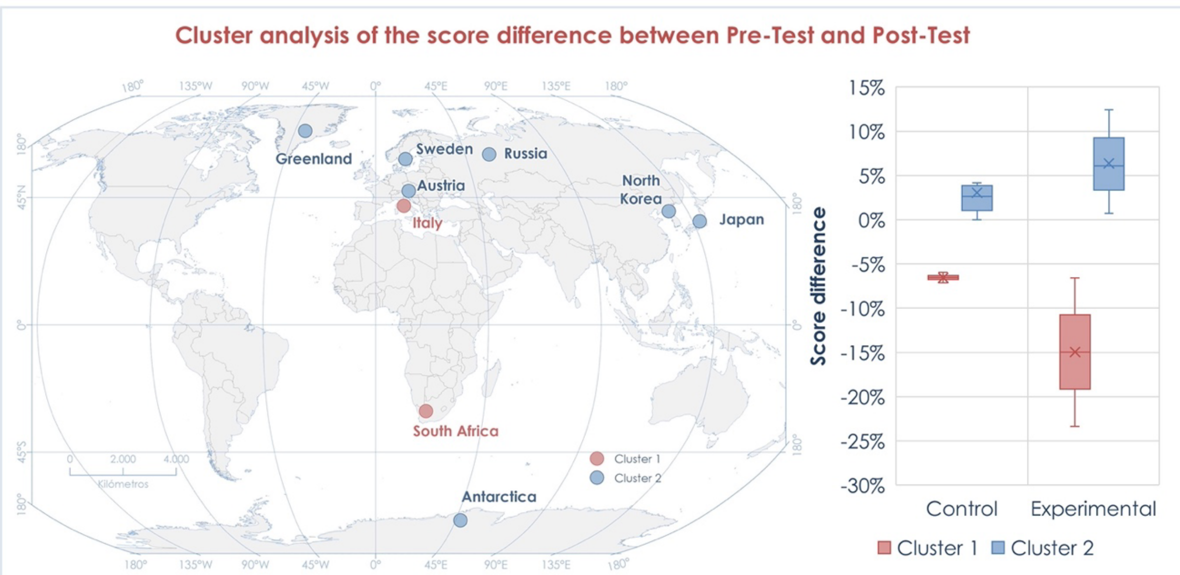


Figure 2. Results for the surface estimation questions. Source: prepared by the authors.

3.2 Place Location Knowledge (PLK)

The overall results show a clear improvement in PLK scores, especially in the experimental groups, where percentages increased from 48.7% of correct answers in the pre-test to 63.7% in the post-test (Figure 3). According to the mixed ANOVA, the differences between the pre-test and the post-test are significant, and so are the differences between the experimental and control groups. The significance levels of all the results are below 0.05, which allows the rejection of the null hypothesis (Table 3). As regards the experimental groups, the one-way ANOVA used on the pre-test and post-test scores yielded an F value (23.77) that is greater than the critical value (3.88), which allows the rejection of the null hypothesis and confirms the significance of the observed differences (Figure 2). On the other hand, when applied to control groups, the analysis of variance yields an F value (3.65) that is slightly lower than the critical value (3.90), which means that, in this case, the null hypothesis cannot be rejected. In view of the results, it can be stated that the impact of the spatial reasoning activities designed and implemented in experimental groups on the students' ability to locate places on a map has been significant.

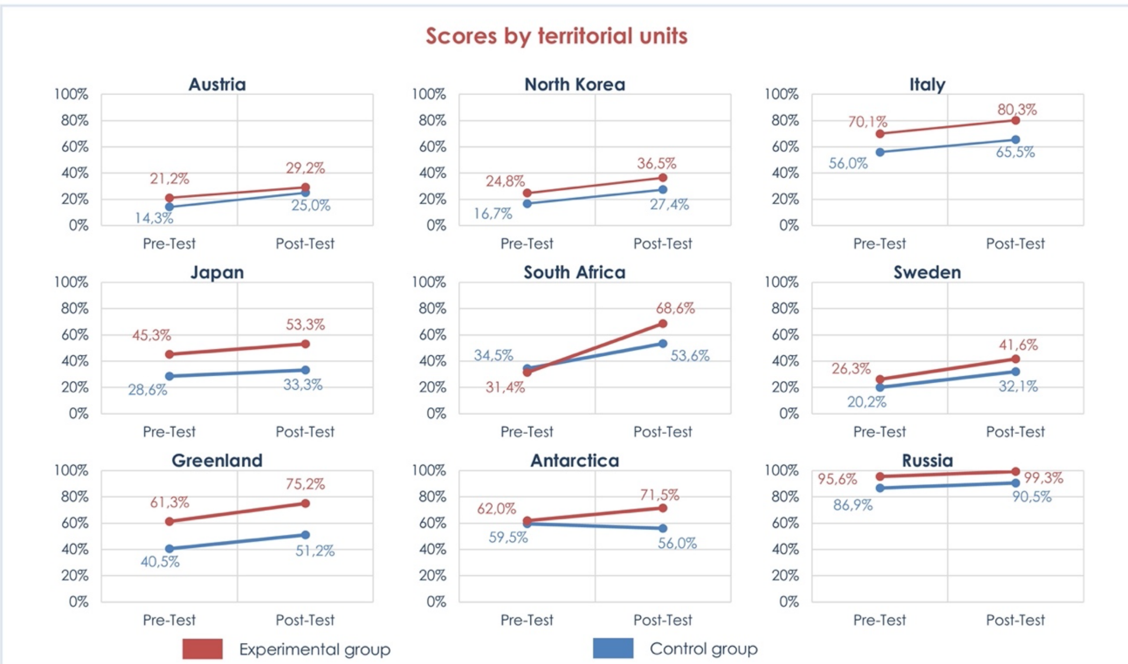
The detailed analysis by territorial units contributes noteworthy results (Figure 3). As mentioned in previous sections, South Africa (cluster 3) is the element with the greatest increase in the percentage of correct answers, especially in the experimental groups (+37.2%), for the reasons that have already been explained above. There is a slight improvement in scores for the units that make up cluster 1 (Greenland, Sweden, Austria, Italy, and North Korea), both in control and in experimental groups. The difference between the pre-test and the post-test is significant in the experimental groups for Greenland and Korea, whereas there are no significant differences between the two types of centers in the results for the rest of the elements. Each of the units in cluster 1 had been worked on in only one activity of the learning situation, and, as for North Korea, it had not been directly addressed in any of the activities (Table 1). There are no significant improvements for the units in cluster 3 (Russia, Antarctica, and Japan), although greater increases can be observed in the scores of the experimental groups, as compared to the control groups. Antarctica had been worked on in a single activity, while the others, Japan (3) and Russia (2), had been addressed in a larger number of activities (Table 1). It follows from the above that the units that the students locate the easiest are those for which they had performed a larger number of spatial reasoning tasks, comparing maps and locating elements.

Factors	Type II sum of squares	gl.	Root mean square	F	Sig.
Intra-subject effects					
Tests (Pre-test, Post-test)	321789.94	1.00	321789.94	912.66	0.00*
Tests – Group (experimental group, control group)	6094.41	1.00	6094.41	17.28	0.00*
Inter-subject effects					
Intersection	332099.76	1.00	332099.77	916.35	0.00*
Group	6238.32	1	6238.32	17.21	0.00*

Table 3. Mixed ANOVA. Place location knowledge (PLK). Source: prepared by the authors.

Global scores. Place location Knowledge (PLK)

Type of center	Score Pre-Test	Score Post-Test	ANOVA F Value	ANOVA Critical value of F
Control centers	39.68%	48.33%	3.65	3.90
Experimental centers	48.66%	63.72%	23.77	3.88



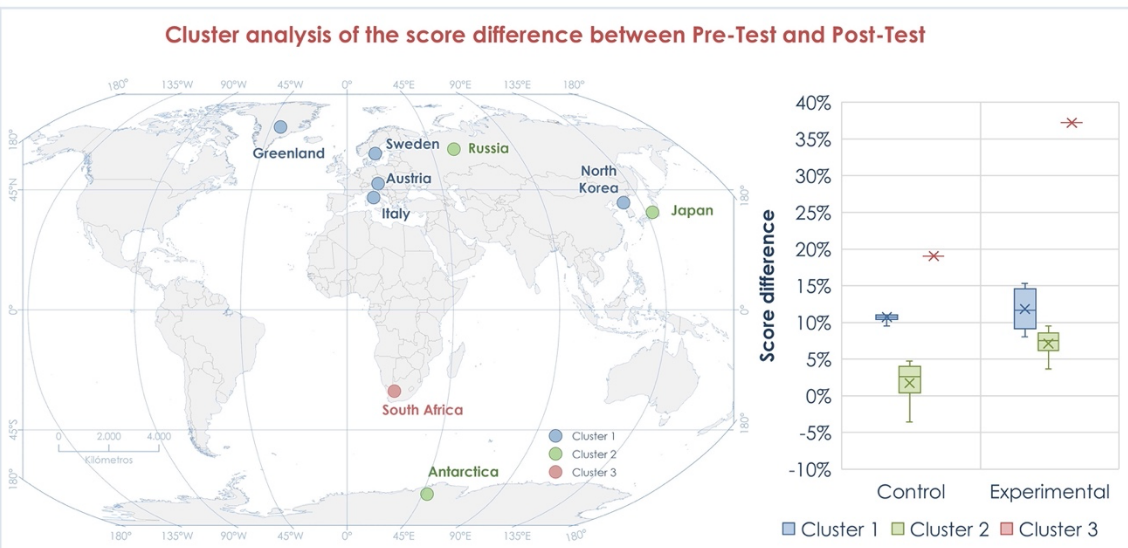


Figure 3. Results for the place location knowledge questions (PLK). Source: prepared by the authors.

3.3 Geospatial competence according to gender

Once the PLK and surface estimation variables had been examined, the influence of gender on the results was analyzed. As regards surface estimation, the differences between male and female students are hardly relevant, neither in the pre-test nor in the post-test, nor for each of the group types (Figure 4). The one-way analysis of variance performed only yielded significant results in the post-test and in the control groups, with an F value (10.82) greater than the critical value of F (3.97). In the rest of the cases, the differences are not significant, since the null hypothesis cannot be rejected (Table 4).

On the other hand, as regards locating elements on a map (PLK), there are noticeable differences. Male students obtain higher percentages of correct answers than female students in the 4 shown scores (Figure 4). The one-way ANOVA tests performed (Table 4) show how the differences between male and female students in the pre-test were significant both in the control groups (F= 6.73, critical value of F = 3.97) and in the experimental groups (F= 5.91, critical value of F = 3.91). In neither case could the null hypothesis be rejected. The differences remain significant in the post-test in the control groups, with an F value (5.91) greater than the critical value (3.97). Meanwhile, the was a considerable reduction in the difference between male and female students in the experimental groups, where male students achieved 67% of correct answers and female students 60%. In this last case, the analysis of variance reveals the difference as nonsignificant, since the F value (3.09) is smaller than the critical value (3.91), and the null hypothesis cannot be rejected (Table 4). Therefore, in light of the results, it can be stated that the work with maps that was carried out in the experimental groups has considerably improved female students' abilities, since their results, although still below, are closer to those of male students.

Variable	Type of group	Pre-Test		Post-Test	
		F value	Critical value of F	F value	Critical value of F
Surface estimation	Control	1.67	3.97	10.82	3.97
	Experimental	1.68	3.91	0.72	3.91
PLK	Control	6.73	3.97	5.91	3.97
	Experimental	5.91	3.91	3.09	3.91

Table 4. One-way ANOVA of the results according to gender. Source: prepared by the authors.

Figure 4. Main results of the test according to gender. Source: prepared by the authors.

4. Discussion

The quasi-experimental research strategy has been frequently used in the field of education due to the difficulties entailed by the use of experimental methods in school environments (Liu et al., 2010; Bikar et al., 2016). In this study, using a quasi-experimental methodology with a non-equivalent control group has elicited satisfactory results, minimizing the potential distortions that could arise from this type of analysis. For this purpose, certain corrections to the research design were made. A pre-test was included to assess the prior knowledge of the students, both from the control and from the experimental groups. This measure corrected the bias that can take place when assigning individuals to either group. In studies where a pre-test and a post-test are used, it is common to find participants who do not complete one or the other and are therefore removed from the data analysis so that their particular scores do not distort the global results (May and Luth, 2013). This step could be taken in the present study via the identification of such individuals in both tests so that the pre-test and the post-test results for each student were available. The selection of the dates for each of the two tests is another of the corrective measures introduced into the research design. The pre-test was conducted at the beginning of the academic year so that students would not have had time to acquire the knowledge that they are expected to learn in the subject of geography of the third year of compulsory secondary education. The post-test was delivered at the end of the academic year so that the contents of the subject had already been taught at both the experimental and the control groups. This type of measure has been used in similar studies to correct the distortions that are inherent to quasi-experimental methodology (May and Luth, 2013). Finally, although the teachers were not the same in all experimental groups, being members of the project work team and being provided with all the material of the learning situation contributed to minimizing the differences.

The main purpose of studies on surface estimation is to determine the influence of cartographic projections on the building of cognitive maps of the world. Battersby and Montello (2009) used university students for their research with quite positive results, obtaining a correlation of 0.82 between estimated and real values. Other studies have also yielded similar results (Lapon et al., 2019), leading to the conclusion that the tendency to overestimate regions' areas weakly correlates with latitude increases, which does not seem very relevant to map projecting as regards surface estimation. The methodology used in this study is somewhat different: students were asked to indicate whether the surface of the selected territorial units was larger or smaller than Spain's. In the learning situation, an attempt was made to ensure that maps used equivalent projections in order to verify whether this aspect had any influence on students' spatial skills. As regards the thematic maps provided, Robinson's projection was used, whose aim is to find a compromise between shapes and areas. The blank maps that students were provided with to locate the different phenomena used the world on Wagner VII projection, which is a variation of the equivalent Lambert azimuthal, where the relative area of regions is maintained while shape becomes slightly distorted. In the post-test, the students in the control groups averaged 67.4% of correct answers, while those in the experimental groups averaged 70.5%. In light of the results, it can be stated that the projections used have not influenced surface estimation ability. The only surfaces that were correctly estimated were those of clearly larger territorial units, while units whose area is similar to that of Spain yielded lower percentages of correct answers. The distance between the units compared is another factor that influences students' answers, since they find the areas of regions that are further away more difficult to estimate. This ultimately confirms that the spatial reasoning activities using maps that were conducted in the classroom have not contributed to improving students' performance in this aspect.

Regarding place location knowledge (PLK), the students of the experimental groups achieved a significant increase of 1.5 points out of 10 between the pre-test and the post-test, reaching 63.7% correct answers on the second test. Although there are numerous studies on the topic, their methodological differences hinder the systematic comparison of results. In a PLK test delivered to secondary education Irish students, the percentage of correct answers was 40.5% (Torrens, 2001), which is a very similar value to those obtained in the pre-test by the control centers in this study. All of this leads to the assumption that the development of map comparison activities has contributed significantly to improving the students' PLK level. The regular use of maps as support instruments allows students to acquire significant and important information (Verdi and Kulhavy, 2002), and the ability to locate elements on a map improves when the spatial reasons for such locations are known (Bednarz et al., 2013; Stimpson, 1991). One of the main goals of the subject of geography should be to provide students with the ability of spatial reasoning through map comparison (Favier and van der Schee, 2014). When the maps of two phenomena are similar, it is logical to believe that there must be some kind of causal relationship (Gersmehl, 2023), and research on how to effectively teach geography should take such considerations into account (Bednarz et al., 2013).

The territorial units with the highest location scores were the largest (Russia and Antarctica) and those that are on the ends of land masses with clearly distinguishable shapes (Italy, South Africa, and Greenland). Vaster regions are more easily identified than smaller ones (Torrens, 2001), and elements that are close to the coastline are recalled in a more precise way than inland features, the latter being known as the "border effect" (Verdi and Kulhavy, 2002). Torrens (2001) also mentioned other factors that condition success in place location, such as media presence or being insular territories. Thus, for example, in his study, Australia, a unit where several such factors converge, was among those that scored the highest percentage of correct answers (94.2%). Proximity to the area of study is also an explanatory factor (Reynolds and Vinterek, 2016), which, in our study, seems to be supported by the case of Italy, which shows above-average PLK scores.

The differences according to the participants' gender are replicated in many reviewed studies, with boys obtaining higher values than girls. Henrie et al. (1997) designed an experiment that was tested among 1,564 secondary students in Michigan, and the results showed significant differences between boys and girls in mapping skills. Torrens (2001) noted a 6-point difference in PLK between both genders. Raento and Hottola (2005) examined cartographic knowledge in secondary education students and also observed significant differences. Despite differences found across some, but not all, types of spatial tests, there is actually only very mixed support for biological causality. Most importantly, there is conclusive evidence that spatial skills can be improved through training and education (Newcombe and Stieff, 2012). The findings of this study suggest that a teaching-learning strategy based on map comparison activities contributes to reducing the gap, even managing to make such differences nonsignificant.

5. Conclusions

This study delves into the line of research on geographic literacy in secondary education, moving beyond its initial diagnosis to systematically assess the impact of a teaching proposal focused on spatial reasoning using maps. This article contributes empirical evidence on the real effectiveness of the designed activities, offering an applied analysis framework to understand how they can improve the ability to locate elements on a map, as well as surface estimation skills.

The results prove surface estimation as a skill that is resistant to short-term change. Despite the introduction of maps with equivalent projections and comparative activities, students maintain very similar answer patterns between the pre-test and the post-test. This finding is consistent with recent studies that point out the cognitive complexity of metric estimation tasks and the need for more specific, long-term, or interactive technology-supported interventions to achieve significant improvement. In this regard, this study paves the way for designing future proposals based on dynamic visualization or digital manipulation of region sizes, which could contribute to a more accurate understanding of spatial magnitude.

On the other hand, significant progress in place location knowledge (PLK) is observed in the experimental groups, which confirms the educational potential of activities involving map comparison, phenomena mapping, and relational analysis of space. These tasks seem to activate cognitive processes that favor the building of stable spatial landmarks and the overcoming of the initial difficulties detected in the diagnosis. Moreover, the results support the idea that systematically working with maps contributes to reducing the gender differences that are traditionally observed in this kind of competence. Although certain gaps remain, their narrowing after the intervention suggests that explicit teaching of spatial reasoning can play a compensating role.

Beyond the specific findings, this study enables advancement towards a more integrated understanding of geospatial competence at the school level. On the whole, the studies conducted to date show that progress in this competence requires sustained interventions, supported by adequate resources and methodologies that link the comparison and building of significant spatial relationships. The proposal for the subsequent phases of the project is to extend the intervention, including activities that are specifically focused on metric estimation, as well as to introduce digital tools for direct map manipulation, and to explore how the teaching of spatial reasoning can contribute to greater equality of results among students.

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References

1. Battersby S. and Montello D., “Estimation of World Regions and the Projection of the Global-Scale Cognitive Map”, *Annals of the Association of American Geographers,* 99, 2, 2009, pp. 273-291.
2. Bednarz S., Acheson G. and Bednarz R., “Maps and Map Learning in Social Studies”, *Social Education,* 70, 7, 2006, pp. 398-404.
3. Bednarz S., Heffron S. and Huynh N., *A road map for 21st century geography education: Geography education research (A report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project),* Washington, DC, Association of American Geographers, 2013.
4. Bednarz R. and Lee J., “What improves spatial thinking? Evidence from the Spatial Thinking Abilities Test”, *International Research in Geographical and environmental education,* 28, 4, 2019, pp. 262-280.
5. Bikar S., Rathakrishnan B., Sharif S., Talin R. and Eboy O., “The Effects of Geography Information System (GIS) Based Teaching on Underachieving Students’ Mastery Goal and Achievement”, *TOJET: The Turkish Online Journal of Educational Technology,* 15, 4, 2016, pp. 119-134.
6. Binimelis-Sebastián J., Gómez-Trigueros I., Gómez-Gonçalves A. and García-González J., “Assessment of future teachers’ geographic knowledge of the territorial organization of Spain using mental maps”, *International Research in Geographical and Environmental Education*, 2023.
7. Binimelis J., Gómez A., Gómez I. and Muntaner J.J., “Geographic Literacy in Third-Year Compulsory Secondary Education Students”, *Journal of Baltic Science Education*, 23, 6, 2024, pp. 1119-1133.
8. Dal B., “Assessing Students’ Acquisition of Basic Geographical Knowledge”, *International Research in Geographical and Environmental Education*, 17, 2, 2008, pp. 114-130.
9. De Miguel R. “Tecnologías de la geoinformación para el desarrollo del pensamiento espacial y el aprendizaje por proyectos en alumnos de secundaria”, in de

la Riva J.I. (Ed.), *Análisis espacial y representación geográfica: innovación y aplicación,* Universidad de Zaragoza-AGE, 2015, pp. 1321-1327.
10. Favier T. and van der Schee J., "The effects of geography lessons with geospatial technologies on the development of high school students' relational thinking", *Computers & Education*, 76, 2014, pp. 225-236.
11. Gersmehl P., "Tour of a Map-Reader's Brain, Part 4: Regions and Associations", *The Geography Teacher,* 20, 4, 2023, pp. 154-162.
12. Gómez-Trigueros I., Mateu G., Sastre B. and Binimelis J., "La competencia geoespacial y la alfabetización digital de la dimensión global en el alumnado de secundaria", *Documents d'Anàlisi Geogràfica*, 70, 2, 2025, pp. 219-239.
13. Guallart C. "Competencia espacial, pensamiento geográfico y ciudadanía crítica: un enfoque integrado en educación secundaria", *Espacio, Tiempo y Forma. Serie VI Geografía,* 18, 2025, pp. 151-180.
14. Harwood D. and Rawlings K., "Assessing Young Children's Freehand Sketch Maps of the World", *International Research in Geographical and Environmental Education*, 10, 1, 2001, pp. 20-45.
15. Henrie R., Aron R., Nelson B. and Poole D., "Gender-Related Knowledge Variations Within Geography", *Sex Roles*, 36, 9/10, 1997, pp. 605-623.
16. Hickman J., "Spatial thinking and GIS: developing and assessing student competencies", *International Research in Geographical and Environmental Education*, 32, 2, 2023, pp. 140-158.
17. Hilman I. and Mainaki R., "Advantage of map as geography learning media to enhance students spatial intelligence", *J-READING (Journal of Research and Didactics in Geography)*, 1, 2, 2013, pp. 57-66.
18. Lapon L., De Maeyer P., Vanhaeren P., Battersby S. and Ooms K., "Evaluating Young People's Area Estimation of Countries and Continents", *ISPRS International Journal of Geo_information,* 8, 3, 2019.
19. Lee J. and Jo I., "Assessing Spatial Skills/Thinking in Geography", in Bourke T. et al. (Eds.), *Assessment in Geographical Education: An International Perspective, Key Challenges in Geography*, Springer, Cham, 2022, pp. 77-97.
20. Liu Y., Bui E., Chang C. and Lossman H., "PBL-GIS in Secondary Geography Education: Does It Result in Higher-Order Learning Outcomes?", *Journal of Geography,* 109, 4, 2010, pp. 150-158.
21. May D. and Luth M., "The Effectiveness of Ethics Education: A Quasi-Experimental Field Study", *Sci Eng Ethics*, 19, 2013, pp. 545-568.
22. Montello D. and Battersby S., "Another Look at the "Mercator Effect" on Global-Scale Cognitive Maps: Not in Areas but in Directions", *Annals of the American Association of Geographers*, 112, 2, 2022, pp. 468-486.
23. Newcombe N. and Stieff M., "Six Myths About Spatial Thinking", *International Journal of Science Education*, 34, 6, 2012, pp. 955-971.
24. Ortiz E., "Aplicación didáctica de los mapas y la cartografía como instrumentos de formación en el aula", *Revista de Ciencias Sociales*, 167, 2020, pp. 193-205.
25. Pons A., Binimelis J., García-González J. and Mateu G., "Assessing spatial competence in secondary education students in the Balearic Islands (Spain)", *J-READING (Journal of Research and Didactics in Geography),* 1, 13, 2024, pp. 55-70.
26. Raento P. and Hottola P., "Where on Earth is New York? Pedagogical Lessons from Finnish Geography Students' Knowledge of the United States", *International Research in Geographical & Environmental Education*, 14, 1, 2005, pp. 5-27.
27. Reynolds R. and Vinterek M., "Geographical locational knowledge as an indicator of children's views of the world: research from Sweden and Australia", *International Research in Geographical and Environmental Education*, 25, 1, 2016, pp. 68-83.
28. Somantri L., "Indonesian spatial intelligence for geography teachers", *JPPI (Journal*

Penelitian Pendidikan Indonesia, 8, 2, 2022, pp. 267-274.

29. Stimpson P., "Is It a Long Way to Tipperary?: Suggestions for Improving Students Locational Knowledge", *Journal of Geography*, 90, 2, 1991, pp. 78-82.
30. Taylor W. and Plewe B., "The Effectiveness of Interactive Maps in Secondary Historical Geography Education", *Cartographic perspectives*, 55, 2006, pp. 16-33.
31. Torrens P., "Where in the world? Exploring the factors driving place location knowledge among secondary level students in Dublin, Ireland", *Journal of Geography*, 100, 2, 2001, pp. 49-60.
32. Utami W., Zain I. and Sumarmi. "Geography literacy can develop Geography skills for high school students: is it true?", *IOP Conf. Series: Materials Science and Engineering*, 296, 2018.
33. Verdi M. and Kulhavy R., "Learning With Maps and Texts: An Overview", *Educational Psychology Review*, 14, 1, 2002, pp. 27-46.
34. Zhu L., Pan X. and Gao G., "Assessing Place Location Knowledge Using a Virtual Globe", *Journal of Geography*, 15, 2, 2016, pp. 72-80.