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Research Article

When GIS Succeeds: Fostering Critical Spatial Thinking through Geography Education on Rural Depopulation

Maria de los Angeles Rodriguez-Domenech [1]✉ **&**
Angel Ignacio Aguilar-Cuesta [2]

[1] University of Castilla La Mancha; Department of Geography; Ciudad Real, Spain. CP: 13002
[2] National Distance Education University; Department of Geography; P.º de la Senda del Rey, 7, Moncloa - Aravaca, Madrid, CP: 28040

✉ Correspondence: mangeles.rodriguez@uclm.es

Abstract: Rural depopulation is one of the most significant territorial challenges facing many European regions and provides a relevant context for geography education. This study examines the impact of a GIS-based teaching intervention on the development of geographical competences among pre-service primary teachers. A quasi-experimental pretest–posttest design was implemented with 95 students enrolled in a Primary Education Teacher Training Degree. The intervention combined geohistorical sources, official demographic data, GIS tools, scientific literature, and the creation of Story Maps. Learning outcomes were assessed across five dimensions: conceptual understanding, spatial thinking, quantitative competence, digital competence, and metacognitive awareness. The results show substantial improvements in digital (g = 0.71), quantitative (g = 0.62), and conceptual (g = 0.57) competences. In contrast, spatial thinking (g = –0.53) and metacognitive awareness (g = –0.43) did not show immediate gains. Rather than indicating learning loss, these findings suggest a process of cognitive readjustment associated with more complex spatial and reflective tasks. The study indicates that GIS-based approaches are effective for strengthening technical and procedural competences in teacher education. However, the development of higher-order geographical thinking and critical territorial awareness appears to require longer interventions and more explicit reflective strategies. These findings contribute to powerful geography education by providing evidence on both the potential and limitations of GIS for addressing complex territorial issues and by offering a transferable teaching model for European educational contexts.

Keywords: powerful geography; pre-service teachers; Story Maps; geographical competencies; demographic decline; geospatial technologies

Highlights:

- GIS improves teachers' digital, quantitative and conceptual skills
- GIS empowers future teachers to tackle demographic vulnerabilities
- Deep spatial thinking requires more time and reflective strategies

1. Introduction

Rural depopulation is widely regarded as one of the most significant territorial, social and educational challenges of the 21st century in Europe. The phenomenon is intricate, enduring and multi-causal in nature, manifesting in observable impacts that include the erosion of public services, population ageing, the deterioration of social capital and the

emergence of a divide between connected and excluded territories. Rather than being a homogeneous process, depopulation has an uneven impact on specific regions of southern Europe, leading to the European Commission's characterisation of these areas as “areas with structural demographic disadvantages” (European Commission, 2023).

In the case of Spain, the region of Castilla-La Mancha is of particular pertinence for the educational analysis of this phenomenon. A significant proportion of its municipalities have been confronted with persistent population decline since the year 2000, exhibiting densities that fall short of 10 inhabitants per square kilometre. These municipalities demonstrate a pronounced demographic reliance on their provincial capitals (Rodríguez-Domenech, 2016; JCCM, 2022). This region has been a pioneer in the formulation of institutional responses, such as Law 2/2021 on Economic, Social and Tax Measures against Depopulation, and its Regional Strategy to Address the Demographic Challenge, which makes it a suitable territorial laboratory for teacher training from a contextualised, critical and committed perspective.

Geography education is positioned as a key area for addressing these challenges. Various studies (De Miguel, 2016; De Lázaro, 2015; Gryl & Jekel, 2012) state that teaching geography in times of territorial uncertainty requires not only the conveyance of content, but also the development of integrated skills that enable students to critically interpret territorial processes and act on them in an informed manner. This vision aligns with the principles advocated by the International Geographical Union (IGU-CGE) and the robust geography approach proposed in Europe and the United States (Bednarz & Solem, 2008), which emphasise the integration of disciplinary knowledge, advanced spatial thinking, technological expertise and civic engagement.

In this context, teaching geography in schools and universities assumes a pivotal role. The current Spanish Organic Law on Education (LOMLOE, 2020) has explicitly introduced skills related to spatial thinking, territorial analysis, digital literacy and commitment to the Sustainable Development Goals. However, recent studies (Bendl et al., 2025; Gómez Valenzuela, 2024; Kerski, 2015) have revealed significant deficiencies in initial teacher training in key areas such as multiscale spatial thinking, interpretation of geographical data, metacognitive reflection and the pedagogical use of GIS.

The present study addresses this gap through the implementation of an educational intervention applied to 95 students enrolled in the Primary Education Teacher Training Degree at the University of Castilla-La Mancha, regarded as a paradigm of declining European rural territories. The proposal is structured around the analysis of depopulation as a socio-spatial phenomenon, used as a pedagogical context to foster the development of integrated geographical competences.

In this study, rural depopulation is not treated solely as curricular content, but as a pedagogical context and analytical framework for the development of geographical competences in initial teacher education. It functions simultaneously as a case study, grounded in a real and territorially situated problem, and as a didactic means through which future teachers engage with key disciplinary skills, including spatial reasoning, data interpretation and critical territorial analysis.

The present work presents a meaningful, territorially situated and methodologically innovative intervention to address the demographic challenge from the perspective of geography education. The study adopts a quasi-experimental intervention design to evaluate the impact of a territorially contextualised teaching sequence on the development of geographical competences. The study aligns with the principles of powerful geography and with educational policies focused on strengthening critical thinking, territorial citizenship and the pedagogical use of geotechnologies as a contribution to this Special Issue on teaching geography for a world in transition.

Despite the broad consensus regarding the educational potential of geotechnologies in geography education, empirical evidence remains limited concerning their differentiated impact on higher-order skills, such as advanced spatial thinking and metacognition, particularly in initial teacher education and in real territorial contexts shaped by structural processes such as depopulation. This gap is especially significant within the European context, characterised by marked territorial inequalities and the need to foster critical spatial citizenship.

Against this background, the present study proposes to analyse the effectiveness of a territorially contextualised teaching sequence based on the use of GIS, Story Maps and geohistorical sources for the development of key geographical competences in initial teacher education. It aims to evaluate the differentiated impact of the intervention across five dimensions of geographical learning: conceptual, spatial, quantitative, digital-technological, and metacognitive-territorial awareness. It also seeks to identify which dimensions are most receptive to methodologies grounded in the analysis of depopulation and the use of geotechnologies, and which require greater instructional time or pedagogical depth. Finally, the study explores the contribution of initial teacher education to a critical and situated approach to

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geography teaching aligned with international challenges relating to territorial cohesion and, sustainability and spatial justice.

Building on these objectives and informed by national and international curriculum frameworks for geography education in contexts of territorial transition, the following research questions are proposed. The study has a twofold objective: firstly, to ascertain the effectiveness of the proposed intervention, and secondly, to examine its capacity to cultivate integrated geographical skills in future teachers. Additionally, explore its potential to contribute to a more critical, territorially situated education that is committed to the challenges arising from rural depopulation. The research questions, aligned with the dimensions evaluated and the international debate, are as follows:

- **RQ1.** To what extent does the intervention, based on the analysis of rural depopulation as a global territorial challenge, improve students' geographical competences?
- **RQ2.** Which dimensions of geographical learning (conceptual, spatial, quantitative, digital/GIS, and metacognitive/attitudinal) show the greatest and least improvement when rural depopulation is used as a learning context?
- **RQ3.** What do these results reveal about the potential and limitations of GIS-based interventions, using rural depopulation as a case study, for developing higher-order geographical thinking in initial teacher education?

The article is structured as follows: Section 2 presents the theoretical framework on rural depopulation, geographical competences, and the educational use of GIS. Section 3 describes the methodology and the intervention design. Section 4 presents the results. Section 5 discusses the findings in relation to existing literature. Finally, Section 6 outlines the main conclusions and implications for geography education.

2. Theoretical framework

2.1. Rural depopulation as a structural territorial challenge: implications for geographical education

Rural depopulation has become firmly entrenched in Europe as a long-term structural process, intricately interwoven with the dynamics of territorial inequality, economic restructuring, and the progressive weakening of service provision systems. The extant literature concurs that this phenomenon cannot be interpreted solely as a quantitative loss of population, but rather as a systemic transformation of the territory that affects social cohesion, demographic sustainability and spatial justice (European Commission, 2023; Pinilla & Sáez, 2017; Rodríguez-Lachica et al., 2025).

From a broader theoretical perspective, rural depopulation can be understood within the framework of *shrinking regions* and territorial restructuring processes, widely discussed in European and international literature as manifestations of uneven spatial development, demographic decline and increasing territorial inequalities (Kühn, 2015). These processes are closely linked to spatial inequalities, uneven development, and the concentration of economic and social opportunities in urban areas. In this sense, depopulation is not only a demographic issue, but also a manifestation of territorial imbalance and spatial injustice, with significant implications for social cohesion and regional sustainability.

Within the European context, the inland regions of the southernmost regions of the continent are experiencing the most severe impacts of this process. Spain is a particularly illustrative case study, with Castilla-La Mancha emerging as a region of vulnerability within the national context. Since the year 2000, more than 70% of its municipalities have experienced sustained population loss, with densities below 8 inhabitants per km² in large areas, marked ageing and a structurally negative migration balance (Martínez-Carrasco & Colino, 2024; Rodríguez-Domenech, 2016). This dynamic is further exacerbated in municipalities with fewer than 2,000 inhabitants, where depopulation assumes qualitatively more severe forms, associated with the closure of services, functional isolation and the risk of territorial exclusion (Aparicio Guerrero & García Marchante, 2016).

The relevance of Castilla-La Mancha as a study area is reinforced by its pioneering role in the formulation of public policies to address the demographic challenge, such as Law 2/2021 and the Regional Strategy against Depopulation (2022), which incorporate criteria for zoning and territorial prioritisation (Ruiz-Pulpón, 2024). This institutional framework renders the region an ideal territorial laboratory for analysing how education, and in particular geography education, can contribute to a critical understanding of the processes of decline and to training educational agents capable of acting in contexts of territorial transition.

From this standpoint, depopulation emerges as a particularly salient subject in geography instruction, as it facilitates engagement with diverse spatial scales, authentic data sets, and contemporary territorial conflicts. This approach is congruent with the imperative for robust geography instruction in periods of uncertainty.

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2.2. From the curriculum to the classroom: geographical skills, teacher training and persistent gaps

The importance of geographical skills in contemporary education has been emphasised by both international frameworks and national curriculum reforms. In the case of Spain, the LOMLOE (2020) legislation explicitly incorporates territorial analysis, spatial thinking, digital literacy and commitment to global challenges as core elements of the school curriculum. Nevertheless, numerous studies point to a persistent discrepancy between these curricular requirements and the competencies actually developed by students entering initial teacher training.

Recent research indicates that students commencing primary education degree programmes exhibit notable deficiencies in complex spatial thinking, critical map reading, the interpretation of socio-economic indicators, and the reflective utilisation of geospatial technologies (Bendl et al., 2025; Gómez Valenzuela, 2024; Kerski, 2015). These shortcomings reflect prior educational trajectories characterised by fragmented approaches, minimal connection to real territorial issues, and a fundamentally descriptive geographical literacy.

These limitations are particularly significant in rural and demographically vulnerable contexts, where teachers play a key role as territorial mediators and agents of social cohesion. Difficulties in interpreting complex spatial processes, such as depopulation, restrict the ability to design contextualised educational responses and may contribute to the persistence of territorial invisibility (Gryl & Jekel, 2012).

In response to this situation, international geographical education frameworks—such as those promoted by the IGU-CGE, the Geographical Association, and the GeoCapabilities approach—insist on the need to develop integrated geographical competencies: conceptual understanding, spatial thinking, quantitative reasoning, digital competence, and critical spatial citizenship (Brooks, 2018; De Miguel & De Lázaro, 2024; Hindmarsh & Budke, 2023). This perspective requires assessment tools capable of analysing learning from a multidimensional standpoint, moving beyond approaches focused solely on declarative knowledge.

In this study, spatial thinking is conceptualised as a higher-order skill that integrates the ability to analyse spatial relationships, operate with multiple scales, interpret complex territorial patterns, and transfer geographical reasoning to new situations. Consequently, the interpretation of maps is not confined to the technical reading of cartographic representations. Instead, it encompasses a range of cognitive processes including inferential, relational and metacognitive skills that necessitate extended periods of cognitive development.

Based on this framework, five key dimensions of geographical learning were selected for analysis: conceptual understanding, spatial thinking, quantitative competence, digital competence, and metacognitive awareness. These dimensions were chosen because they represent core components of contemporary geographical education and are consistently highlighted in international frameworks.

Furthermore, the development of action competence in teacher education involves enabling future teachers not only to interpret territorial processes, but also to design pedagogical responses to them. This includes the ability to create contextualised-based learning activities, promote critical discussion on socio-spatial issues, and foster students' engagement with real territorial challenges such as depopulation. In this sense, geography teachers are expected to act as mediators between knowledge, territory, and civic responsibility.

2.3. Geotechnologies, spatial narratives and powerful geography teaching in contexts of uncertainty

Geographic Information Technologies (GIT/GIS) have assumed a pivotal role in the revitalisation of geography pedagogy, facilitating the utilisation of official data, the visualisation of intricate spatial patterns, and the construction of integrated territorial narratives. It is evident that tools such as Story Maps and Spatial Data Infrastructures (SDI) facilitate the articulation of cartography, quantitative indicators, and interpretive discourse in interactive digital environments, thereby promoting situated and applied geographical learning (De Lázaro & Morales, 2023; Velilla Gil & Guallart Moreno, 2021).

However, the extant literature does agree that the educational potential of these tools depends on their critical integration into structured teaching proposals. The exclusive utilisation of GIT/GIS has the capacity to engender technical enhancements, yet it does not invariably translate into the effective cultivation of profound spatial reasoning or critical territorial awareness (De Miguel, 2016; Donadelli, 2017). In this sense, the TPACK model has established itself as a reference framework for articulating technological, pedagogical and disciplinary knowledge, which is especially relevant in addressing complex socio-spatial issues such as the demographic challenge (Álvarez Otero & De Lázaro, 2018; Gómez Triguero, 2018, Pamuk, 2023).

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From the perspective of effective geography teaching, the use of geotechnologies should be geared towards fostering not only procedural skills, but also interpretative, metacognitive and civic abilities. This is especially pertinent in contexts of territorial uncertainty, where phenomena such as depopulation necessitate critical, multi-scale and socially committed interpretations (Fadjarajani et al., 2024; Nursa'ban et al., 2020).

The teaching proposal analysed in this study is situated within this theoretical framework: a methodological sequence that combines conceptual instruction, analysis of real spatial data, critical reading of scientific literature and the development of territorial narratives through Story Maps. The evaluation of its impact across five distinct dimensions provides empirical evidence on the scope and limitations of geotechnologies for building powerful, critical and territorially situated geography teaching in a world in transition.

3. Materials and Methods

3.1. Design and participants

A quasi-experimental pretest-posttest design was implemented with a single group, without a control group, in the Social Sciences Teaching course in the fourth year of the Primary Education Degree at the University of Castilla-La Mancha (academic year 2025-2026). The sample comprised 95 students (32 male and 63 female), predominantly aged between 20 and 24 years (82%), all of whom completed both tests. With regard to relevant contextual variables:

- Rural family background: 12 students (12.6%; 2 males, 10 females) stated that their family comes from municipalities with fewer than 2,000 inhabitants.
- Last stage completed in Geography/Social Sciences: 78 in Compulsory Secondary Education (ESO), 25 in Baccalaureate.
- Online teaching experience due to COVID-19: 12 students studied Geography/Social Sciences exclusively online during secondary school/sixth form.

Given that the design adopted does not include a control group, the changes observed should be interpreted as effects associated with the intervention and not as strictly causal relationships, which reinforces the exploratory and formative nature of the study. This design is consistent with intervention-based research aimed at assessing the effects of pedagogical innovations in real educational settings.

3.2. Justification of the sample and contextual relevance

This section provided a justification for the representativeness of the sample. The selection of this population is informed by specific geographical and professional criteria. The University of Castilla-La Mancha is in the most vulnerable NUTS-2 region in Spain in terms of depopulation. The demographic indicators for Castilla-La Mancha reveal a situation of high vulnerability to depopulation, characterised by accelerated ageing, a structurally negative migration balance and extremely low densities in large rural areas (Rodríguez-Domenech, 2016, p. 178). These future teachers will be employed primarily in the 300+ rural municipalities of Castilla-La Mancha, where 85% of municipalities exhibit depopulation dynamics according to validated demographic vulnerability criteria (Rodríguez-Domenech, 2016, pp. 189-192). The composition of the sample – with 12.6% from rural families – accurately reflects the profile of the teachers who will serve these critical territories, ensuring the ecological relevance and transferability of the findings.

Although the sample is not statistically representative, it is considered appropriate for the purposes of this study, as it reflects the profile of future teachers who are likely to work in rural and demographically vulnerable contexts.

3.3. Educational intervention

The intervention was conducted over a period of 12 teaching sessions (24 hours in total) and was structured into four sequential phases, integrating direct instruction, critical analysis and practical work with geotechnologies.

Conceptual foundation (3 sessions): A master class on depopulation was delivered, supported by guided readings from Pinilla and Sáez (2017) and Rodríguez-Domenech (2016). The sessions introduced demographic determinants, scales of analysis and regional specificities.

Critical reading of scientific literature (3 sessions): Seminars were conducted on articles addressing ageing, rural migration, spatial dependency and anti-depopulation policies, with guided discussion on multi-scale territorial narratives.

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Municipal case study (4 sessions): Each student analysed a municipality in the province of Ciudad Real using a Story Map designed ad hoc based on ESRI ETRS89-LIM Administrativos-IGR-CLM Base Map structure. Data from the D2CR project (https://alarcos.esi.uclm.es/d2cr/fuentes/) (Ciudad Real Provincial Council-UCLM), INE and the National Atlas of Spain were integrated to examine: (a) demographic evolution 1900-2025; (b) key indicators (density, ageing, net migration, natural growth); (c) municipal, regional, national and European comparisons.

Design of educational proposals and metacognitive reflection (2 sessions): Teaching sequences for primary education were developed based on analyses conducted, accompanied by written reflection on the role of teachers in territorial cohesion and spatial justice.

Each phase of the intervention was explicitly aligned with specific learning objectives and competence dimensions. The initial sessions focused on developing conceptual understanding of depopulation, while the intermediate phases emphasised quantitative and digital competences through the analysis of real spatial data using GIS tools. The final sessions were designed to foster metacognitive awareness and pedagogical reflection, although the limited duration of these activities may explain the more modest impact observed in these dimensions.3.4. Assessment tool

The instrument consisted of a 14-item questionnaire with a maximum score of 10 points, which developed in accordance with the fundamental knowledge, assessment criteria and specific competencies defined in Royal Decree 157/2022 (BOE, 2022). The geographical and historical domains were used as reference areas within the LOMLOE (2020), framework, which promotes spatial thinking, territorial analysis, digital literacy, and engagement with global challenges as key subject-specific competencies (Art. 10.2, RD 157/2022).

The validation process was conducted through expert judgement (comprising five specialists in geography teaching), resulting in a content validity index (CVI) of 0.89 and a Cronbach's alpha internal consistency of 0.82.

The questionnaire was structured around five key dimensions of geographical learning, each with its associated descriptor, assessed content and corresponding regulatory reference from the LOMLOE (Table 1):

Table 1. Dimensions, descriptors, and LOMLOE competencies of the geographical learning assessment tool

Dimension	Items	Descriptor	Content evaluated	LOMLOE reference
I. Conceptual understanding of depopulation	3	Definitions, multiscale causes	Identification of structural and contextual factors of depopulation	Specific competency 1: Analyse the transformations and challenges of today's world from a spatial perspective
II. Spatial and cartographic thinking	3	Reading thematic maps, spatial analysis	Interpretation of territorial patterns and spatial relationships	Specific competency 2: Use cartographic resources and technologies to represent and analyse the territory
III. Quantitative competence and indicators	3	Calculation and interpretation of demographic indicators	Analysis of birth rates, migration, unemployment rates and population density	Specific competency 3: Interpret and communicate quantitative and qualitative information about social phenomena
IV. Digital competence and use of GIS	3	Using Story Maps, integrating data and narrative	Application of GIS to represent and analyse territorial processes	Specific competency 5: Use digital tools to explore, represent and communicate geographical processes

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V. Attitudinal and metacognitive dimension	2	Attitudes and proposals for educational solutions	Critical reflection, territorial awareness and proactive capacity	Specific competency 6: Develop critical, responsible and committed attitudes towards the environment and citizenship.

Source: Regulatory reference: Royal Decree 157/2022, of 1 March, establishing the organisation and minimum teaching requirements for Compulsory Secondary Education. Official State Gazette, no. 52, 2 March 2022. Validation: Expert judgement (5 specialists in geography teaching); content validity V.A.I. = 0.89; internal consistency α Cronbach = 0.82 (overall).

3.5. Data analysis

The analyses were performed using SPSS v.30 software. Initially, an exploratory analysis of the students' responses to the items in each dimension was performed, considering the total sample. Subsequently, exploratory and inferential analyses were performed based on the variables gender (male/female), place of origin (rural/urban) and educational stage (secondary education/sixth form) using the Mann–Whitney U test (the results below detail the parametric assumptions of homoscedasticity and normality that determined the choice of this test).

In order to evaluate the impact of the programme, a quasi-experimental pretest–post-test design was employed, utilising a validated methodology (V.A.I. = 0.89; α = 0.82) that analyses five key dimensions of geographical learning:

1. Conceptual understanding: identifying causes, consequences and scales of depopulation from a geographical perspective.
2. Spatial thinking and cartographic analysis: ability to interpret thematic maps, establish spatial relationships, and apply geographical reasoning.
3. Quantitative competence: handling demographic data and socio-economic indicators applied to territorial analysis.
4. Digital and technological competence: thoughtful and independent use of GIS and web viewers (Story Maps) as educational tools.
5. Metacognition and territorial awareness: critical reflection on the territory and one's own geographical learning as a future teacher.

The assumptions of normality and homoscedasticity were assessed prior to selecting the appropriate statistical tests, which justified the use of non-parametric procedures. Baccalaureate) using the Mann–Whitney U test (the parametric assumptions of homocedasticity and normality that determined the choice of this test are detailed below in the results). In conclusion, a correlation test (Pearson's r) was conducted between the dimensions constituting the questionnaire to ascertain the extent of the relationship between them.

4. Results

The results obtained after the analysis were structured into three sections. In the initial section, the data underwent a general analysis and comparison, distinguishing between the pretest and posttest phases (95 students). In the subsequent section, a comparative statistical analysis was conducted between each of the evaluated dimensions. The final section involved a comparison based on gender, the highest level of education attained (secondary education or sixth form), and the subjects' geographical origins.

In order to analyse the distribution of the scores obtained by the students in each of the competency dimensions after the intervention, descriptive statistics and indicators were calculated for the post-test (see Table 2).

The results indicate that the distributions deviate significantly from normality in most dimensions. Specifically, elevated negative asymmetry values are evident in dimensions I (−1.607), III (−2.065), IV (−1.160) and V (−1.136), suggesting a pronounced aggregation of scores at the upper end of the scale. Conversely, the kurtosis values are elevated in multiple dimensions, notably I (3.794) and III (3.027), indicating leptokurtic distributions with a conspicuous accumulation around the mean.

This pattern, far from necessarily being interpreted as a setback in learning, can be interpreted as a process of cognitive and metacognitive readjustment, in which students move from initial simplified perceptions to more critical and prudent interpretations after facing spatially more complex tasks. The combination of marked asymmetries and high kurtosis, in conjunction with the formal normality tests conducted (see Table 2 and Figure 1), substantiated the

utilisation of non-parametric statistical tests for the analysis of pretest-posttest design alterations (Wilcoxon) and for the comparison of independent groups (Mann-Whitney U).

Table 2. Descriptive statistics and normality tests for the dimensions assessed in the post-test

Dimension	N	M ±SD	Asymmetry	Kurtosis
I	95	1,49±0,4	-1,607	3,794
II	95	0,73±0,44	0,537	0,292
III	95	1,75±0,55	-2,065	3,027
IV	95	1,7±0,34	-1,160	0,564
V	95	1,37±0,33	-1,136	1,870
Total	95	1,49±0,4	-1,333	1,891

Source: Own elaboration

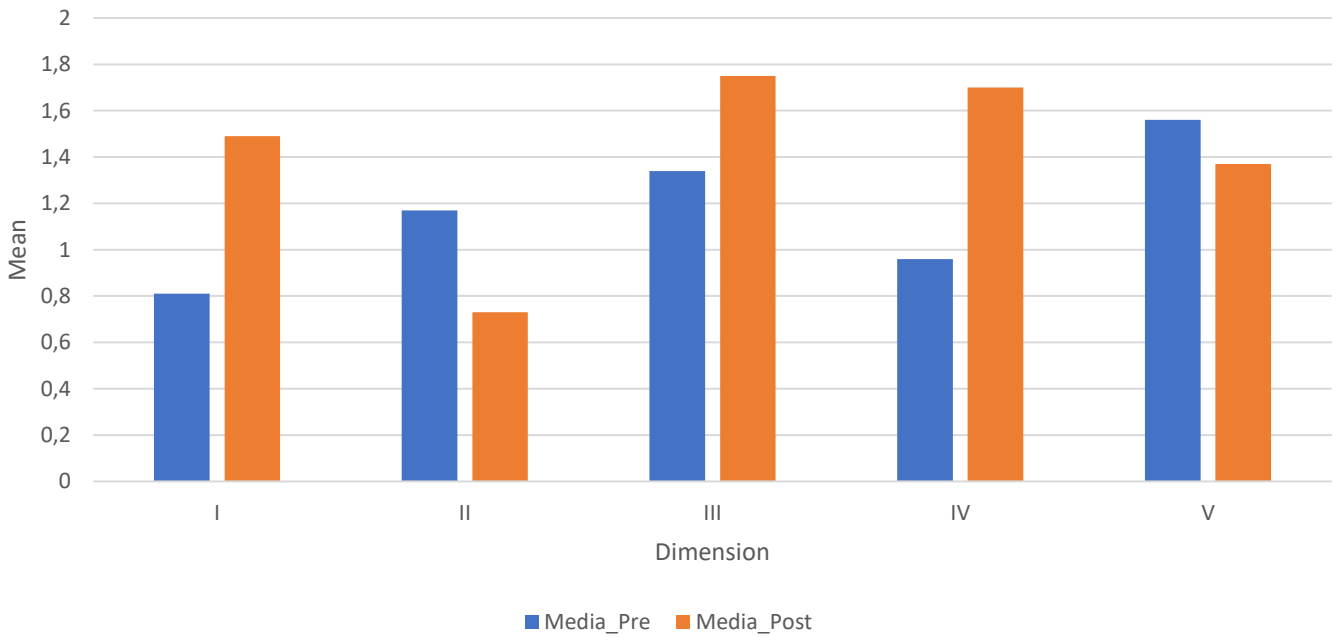

Figure 1. Performance variation: Pre-test versus Post-test by dimensions

After the confirmation of the absence of normality in the distribution of scores, the changes between the pre-test and post-test were analysed using the non-parametric Wilcoxon signed-rank test. The findings indicate statistically significant alterations across all the evaluated dimensions ($p < .001$ in all instances), suggesting that the intervention engendered substantial enhancements in the skills analysed.

However, a detailed analysis of the data reveals that these changes do not follow a uniform pattern but rather respond to the specific nature of each skill. The mean scores for the dimensions of conceptual understanding of depopulation (I), quantitative skills and indicator management (III), and digital skills and use of GIS (IV) increased clearly and significantly ($r = 0.769$, $r = 0.445$ and $r = 0.717$, respectively). These increases were accompanied by medium or high Hake gains ($g = 0.57$, $g = 0.62$ and $g = 0.71$). The findings of this study suggest not only statistical significance but also a substantial degree of learning that has been achieved.

Conversely, the dimensions of spatial thinking and cartographic analysis (II) and attitudinal and metacognitive dimension (V) exhibited a decline in the mean score, although these alterations were equally substantial ($r = 0.528$ and r

= 0.404). This pattern, far from being interpreted as a setback, should be understood as a process of cognitive and metacognitive readjustment, in which students move from simplified initial perceptions to more critical, prudent and complex interpretations after the intervention.

The integration of statistical significance (Wilcoxon), effect size (r) and normalised gain (Hake) allows us to affirm that the intervention produced a differential impact, but one that was consistent with the nature of each competency dimension, highlighting the potential of GIS-based approaches for developing conceptual, quantitative and digital competences, while suggesting that higher-order geographical thinking may require longer intervention periods and more explicit reflective strategies..

The results of this study are summarised in Table 3 and Figure 2, which presents the overall impact of the intervention by dimension.

Table 3. Impact of the intervention by dimension: pre-test–post-test changes, effect sizes, and normalised gain

Dimension	Competence assessed	N	Pretest M (DT)	Post-test M (DT)	Test	Statistician	p	Effect size	Hake's gain (g)
I	Conceptual understanding of depopulation	95	0,81 (0,39)	1,49 (0,40)	Wilcoxon	Z = −7,496	< .001	r = 0,769	**0,57**
II	Spatial thinking and cartographic analysis	95	1,17 (0,46)	0,73 (0,44)	Wilcoxon	Z = −5,150	< .001	r = 0,528	**−0,53**
III	Quantitative competence and indicator management	95	1,34 (0,71)	1,75 (0,55)	Wilcoxon	Z = −4,335	< .001	r = 0,445	**0,62**
IV	Digital competence and use of ICT/GIS	95	0,96 (0,66)	1,70 (0,34)	Wilcoxon	Z = −6,988	< .001	r = 0,717	**0,71**
V	Attitudinal and metacognitive dimension	95	1,56 (0,25)	1,37 (0,34)	Wilcoxon	Z = −3,936	< .001	r = 0,404	**−0,43**

Source: Own elaboration

4.1. Overall results

The mean score increased from 5.84 (SD = 1.40) in the pretest to 7.04 (SD = 1.15) in the posttest (N = 95), with a t (94) = 6.964, p < .001, and an effect size d = 0.71, indicating a moderately high impact of the intervention on general geographical competence. Hake's gain was 0.29, indicating a noticeable improvement but still far from the maximum learning potential.

4.2. Results by dimension

To provide a more detailed assessment of the intervention's effects, the results were analyzed across the five dimensions evaluated. Significant differences were observed between the pretest and posttest scores, although the magnitude and direction of the changes varied among dimensions:

- Conceptual understanding of depopulation: the mean increased from 0.81 (SD = 0.39) to 1.49 (SD = 0.40). The Wilcoxon test yielded Z = −7.496, p < .001, with an effect size r = 0.769. Hake's gain (g = 0.57) is at a medium level, indicating a clear improvement in conceptual understanding of the phenomenon.
- Spatial thinking and cartographic analysis: the mean decreased from 1.17 (SD = 0.46) to 0.73 (SD = 0.44), with Z = −5.150, p < .001 and r = 0.528. Hake's gain was negative (g = −0.53), suggesting difficulties in transferring learning to more complex cartographic tasks and possible alignment problems between the intervention and the assessment in this dimension.
- Quantitative competence and indicator management: the average rose from 1.34 (SD = 0.71) to 1.75 (SD = 0.55), with Z = −4.335, p < .001, r = 0.445. Hake's gain reached g = 0.62, considered high average, indicating that working with official data and calculating demographic indicators was particularly effective.

- Digital competence and use of GIT/GIS: the average increased from 0.96 (SD = 0.66) to 1.70 (SD = 0.34), with Z = −6.988, p < .001 and r = 0.717. Hake's gain was g = 0.71, in the high range; this reinforces the idea that the integration of Story Maps and spatial data infrastructures into university teaching significantly enhances the digital geographic competence of future teachers.
- Attitudinal and metacognitive dimension: the mean decreased from 1.56 (SD = 0.25) to 1.37 (SD = 0.34), with Z = −3.936, p < .001 and r = 0.404. Hake's gain was negative (g = −0.43), which may be due both to the characteristics of the items used—focused on very demanding explicit positions—and to the need for more time for reflective work.

4.3. Variables

The findings of the present study, as indicated by the results of the covariance and regression analyses, demonstrate that the primary predictor of posttest scores in each dimension is the baseline level. The results further demonstrate that gender, rural origin and previous background in geography/social sciences have limited and non-systematic effects. A preliminary investigation revealed that students from rural backgrounds exhibited modest initial advantages in terms of conceptual understanding and sensitivity to the problem. However, these initial advantages did not result in significant disparities in academic gains.

The non-parametric Mann–Whitney U test was employed to detect potential differences between males and females in post-test scores and gains in each dimension. No statistically significant differences were observed in any of the contrasts (p > .05). The effect sizes were negligible (r < .12), indicating that the learning produced by the intervention was equivalent in both groups (Table 4).

Table 4. Gender differences in posttest dimensions and in earnings (Δ)

Type	Dimension	Man M (DT)	Rank prom. M	Woman W (DT)	Rank prom. W	U	Z	p	r
Posttest	I	1,51 (0,31)	45,84	1,47 (0,44)	49,10	939,0	−0,554	.579	0,06
	II	0,80 (0,52)	50,16	0,70 (0,40)	46,90	939,0	−0,583	.560	0,06
	III	1,71 (0,59)	45,86	1,77 (0,54)	49,09	939,5	−0,772	.440	0,08
	IV	1,74 (0,30)	49,63	1,68 (0,36)	47,17	956,0	−0,442	.659	0,05
	V	1,32 (0,40)	45,13	1,40 (0,29)	49,46	916,0	−0,725	.468	0,07
Earnings (Δ)	I	0,47 (0,65)	43,59	0,78 (0,48)	50,24	867,0	−1.110	0.267	0.11
	II	−0,42 (0,64)	50,89	-0,45 (0,61)	46,53	915,5	−0.736	0.461	0.08
	III	0,31 (0,83)	46,00	0,46 (0,81)	49,02	944,0	−0.520	0.603	0.05
	IV	0,90 (0,71)	52,30	0,67 (0,68)	45,82	870,5	−1.096	0.273	0.11
	V	−0,08 (0,32)	44,84	-0,25 (0,42)	49,60	907,0	−0.796	0.426	0.08

Note: r=|Z|/95 || r = effect size, calculated as Z/√N. The magnitude of the effect is interpreted according to Cohen's criteria: small (≈ 0.10), medium (≈ 0.30) and large (≥ 0.50).

Subsequent to the analysis by gender, the rurality-urbanity variable was analysed in order to identify differences in the origin of the students (see Table 5).

In accordance with the data presented (Table 5), no statistically significant disparities were identified in any of the post-test dimensions or in the gains obtained (p > .05). The effect sizes were negligible (r ≤ .12), indicating that the impact of the intervention was equivalent irrespective of the students' territorial origin. It is noteworthy that, although the effect is not significant in the ranges where rurality appears to be greater (I and III), the intervention is clearly inclusive and does not depend on origin.

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Table 5. Differences by origin (urban or rural) in the dimensions of the posttest and in earnings (Δ)

Type	Dimension	Rank prom. Urbano	Rank prom. Rural	U	Z	p	r
Posttest	**I**	48,44	44,96	461,5	−0.417	0.677	0.04
	II	47,87	48,92	487,0	−0.132	0.895	0.01
	III	48,41	45,17	464,0	−0.545	0.585	0.06
	IV	47,58	50,92	463,0	−0.423	0.672	0.04
	V	46,77	56,50	396,0	−1.144	0.253	0.12
Earnings (Δ)	**I**	46,70	57,00	390.0	−1.210	0.226	0.12
	II	48,23	46,38	478.5	−0.221	0.825	0.02
	III	47,74	49,79	476.5	−0.249	0.804	0.03
	IV	47,82	49,25	483.0	−0.170	0.865	0.02
	V	47,67	50,25	471.0	−0.303	0.762	0.03

Note: r=|Z|/95 || r = effect size, calculated as Z/√N. The magnitude of the effect is interpreted according to Cohen's criteria: small (≈ 0.10), medium (≈ 0.30) and large (≥ 0.50)

The final element analysed was the educational stage at which the participants had last studied geography content related to depopulation, or in upper secondary school (Tables 6 and 7). A thorough examination of this variable reveal that there are no statistically significant differences observed in the post-test scores or the gains achieved in any of the dimensions evaluated ($p > .05$). The effect sizes were found to be low or trivial ($r \leq .17$), indicating that the impact of the intervention was independent of the students' previous educational stage.

Table 6. Differences by educational stage (secondary education or sixth form) in the dimensions of the post-test and in earnings (Δ)

Type	Dimension	Rank prom. Secondary school	Rank prom. baccalaureate	U	Z	p	r
Posttest	**I**	51,34	43,21	905,0	−1.443	0.149	0.15
	II	46,99	49,45	1035,5	−0.459	0.646	0.05
	III	50,71	44,12	940,5	−1.641	0.101	0.17
	IV	50,37	44,60	959,5	−1.081	0.280	0.11
	V	48,35	47,50	1072,5	−0.148	0.883	0.02
Earnings (Δ)	**I**	50,66	44,18	943.0	−1.127	0.260	0.12
	II	49,27	46,18	1021.0	−0.543	0.587	0.06
	III	51,33	43,22	905.5	−1.457	0.145	0.15
	IV	50,26	44,76	965.5	−0.968	0.333	0.10
	V	47,71	48,41	1076.0	−0.121	0.904	0.01

Note: r corresponds to the effect size of the Mann–Whitney U contrast, calculated as Z/√N and interpreted according to Cohen's criteria (small ≈ 0.10; medium ≈ 0.30; large ≥ 0.50).

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Table 7. Independence of learning by dimensions with respect to the student profile

Dimension	Sex		Rurality		Educational stage	
	p	r	p	r	p	r
I. Conceptual understanding	0.579	0.06	0.677	0.04	0.149	0.15
II. Spatial thinking	0.560	0.06	0.895	0.01	0.646	0.05
III. Quantitative competence	0.440	0.08	0.585	0.06	0.101	0.17
IV. Digital competence GIT	0.659	0.05	0.672	0.04	0.280	0.11
V. Attitudinal and metacognitive dimension	0.468	0.07	0.253	0.12	0.883	0.02

Note: r = |Z| / √N. All effect sizes are trivial (r < .20).

This finding (Figure 2) indicates that the impact of the intervention has been pervasive, demonstrating the comprehensive and robust nature of the teaching proposal.

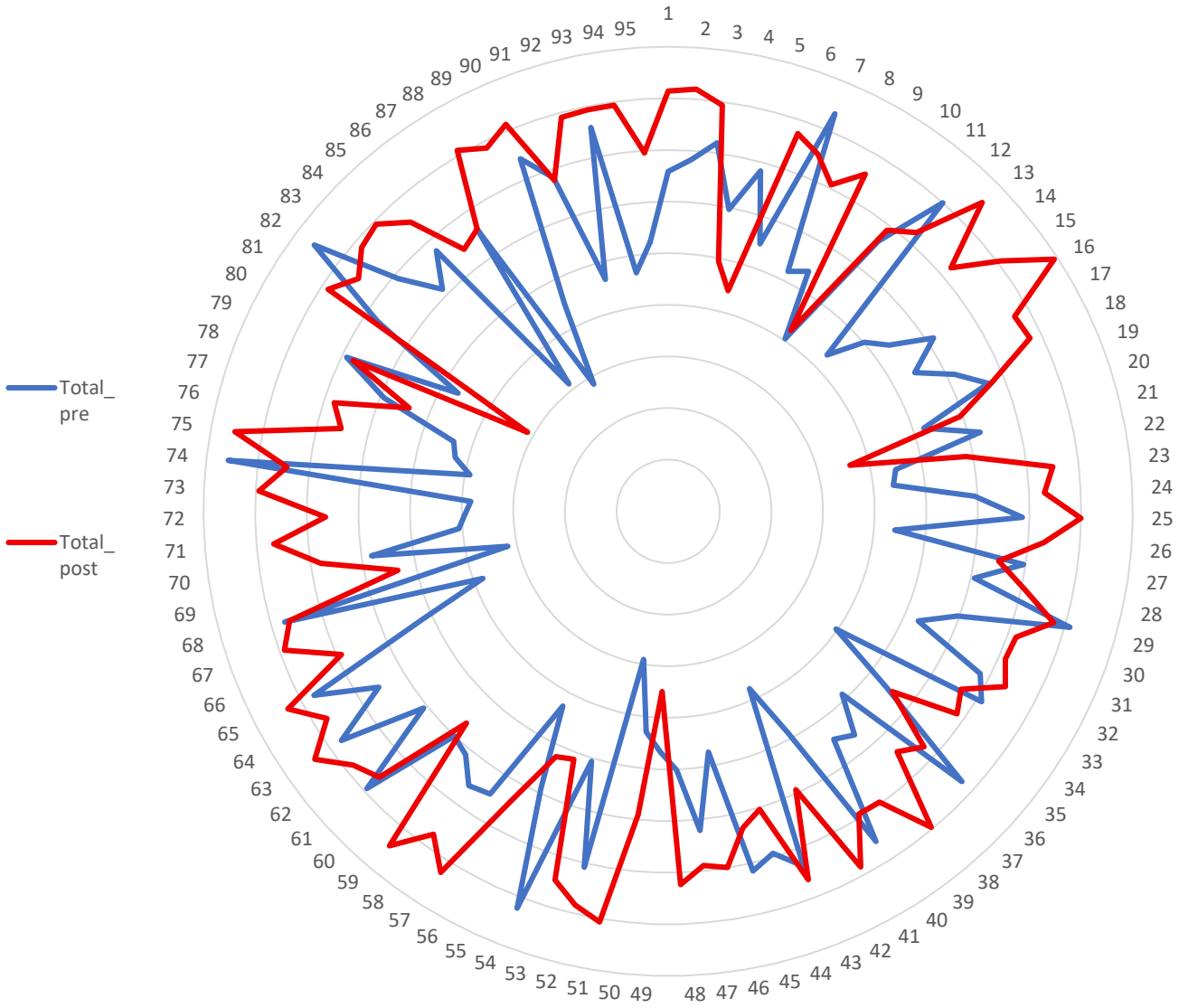

Figure 2. Individual outcome of the educational intervention

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5. Discussion

This study examined the impact of a GIS-based intervention on the development of geographical competences among pre-service teachers, with particular attention to the opportunities and limitations of using rural depopulation as a context for geographical learning. The discussion is organised around the three research questions that guided the study.

The findings of this study should be interpreted in light of previous research on the educational use of geotechnologies in geography education. A growing body of literature has shown that GIS-based interventions tend to produce significant improvements in procedural and technical skills, particularly in digital competence and data handling (De Miguel, 2016; Kerski, 2015; Pamuk, 2023). However, the development of higher-order cognitive skills, such as spatial reasoning and metacognition, remains more complex and typically requires longer instructional periods and explicit reflective strategies (Brooks, 2018; Donadelli, 2017; Gryl & Jekel, 2012).

The findings substantiate the hypothesis that a geographically situated teaching intervention, predicated on the analysis of depopulation and the pedagogical utilisation of GIS, can significantly enhance specific geographical aptitudes in prospective educators. It is evident that the most significant gains are concentrated in the digital, quantitative and conceptual dimensions. This finding is consistent with previous studies that highlight the effectiveness of GIS-based instruction in enhancing digital and quantitative competences (De Miguel, 2016; Kerski, 2015; Pamuk, 2023).

A more detailed examination of the intervention design helps to explain the differentiated impact observed across competence dimensions. The strong improvements in digital and quantitative competences can be directly linked to the phases involving the use of GIS, Story Maps, and the analysis of official statistical data, where students actively engaged in data handling and spatial visualisation tasks. Similarly, the gains in conceptual understanding appear to be associated with the initial sessions focused on theoretical instruction and critical reading of scientific literature.

In contrast, the more limited development of spatial thinking and metacognition may be related to the relatively short duration of the intervention and the reduced number of sessions explicitly devoted to reflective and higher-order reasoning processes. Although the final phase included the design of teaching proposals and metacognitive reflection, these activities may not have been sufficient to produce measurable short-term improvements in these dimensions.

Nevertheless, one of the most significant contributions of the study is precisely in the non-uniform nature of the results. The dimensions associated with deep spatial thinking and metacognition do not demonstrate immediate enhancements following the intervention, and in some cases, posttest scores even exhibit a decline. This finding does not invalidate the proposal; rather, it calls into question overly instrumental approaches to the use of GIS in geography teaching. Furthermore, it suggests a potential for broad applicability across different student profiles, although this interpretation should be treated with caution given that the study did not directly assess implementation in diverse educational contexts. Therefore, the implications of these findings for educational practice should be considered as exploratory rather than conclusive.

From an interpretative perspective, these results can be understood as a process of cognitive and metacognitive readjustment. Following the engagement with tasks of a more complex nature, encompassing multiple scales, and founded upon authentic data, students have been observed to relinquish their preliminary, simplistic interpretations, opting instead for a more circumspect and critical stance. This phenomenon has been described in the literature as a temporary effect associated with increased cognitive demands in higher-order thinking processes (Brooks, 2018; Donadelli, 2017;).

In relation to the research questions, the results allow us to answer RQ1 in the affirmative, as they demonstrate that a contextualised intervention based on real territorial problems favours the development of integrated geographical competences in future teachers. These findings: digital competence ($g = 0.71$) and quantitative ($g = 0.62$) are consistent with previous research highlighting the effectiveness of GIS-based instruction in enhancing students' digital and quantitative competencies (Kerski, 2015; De Miguel, 2016; Pamuk, 2023). With regard to RQ2, the study demonstrates that technical-procedural skills are more sensitive to short-term geotechnological methodologies, while deep spatial thinking and metacognition demonstrate a slower and non-linear evolution. The decrease observed in spatial thinking ($g = –0.53$) should not be interpreted as a regression in learning. Instead, it may reflect a process of cognitive restructuring, as students engage with more complex spatial tasks and move beyond simplified interpretations. This interpretation is supported by previous studies indicating that higher-order spatial thinking requires longer instructional periods and explicit scaffolding to develop effectively (Donadelli, 2017; Gryl & Jekel, 2012).Finally, in relation to RQ3, the cross-cutting nature of the impact – independent of gender, rural origin, or previous educational background – reinforces the

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inclusive potential of the proposal and its applicability in diverse educational contexts. This finding metacognitive dimension (g = –0.43) is also consistent with previous research suggesting that metacognitive and attitudinal competencies develop more slowly and require sustained reflective practices over time (Brooks, 2018; Pamuk, 2023).

From an educational perspective, the results of the study prompt a re-evaluation of the design of interventions in university geography education. In particular, they emphasise the necessity to extend the duration of training experiences, incorporate explicit activities involving spatial reasoning and critical analysis of territorial conflicts, and complement quantitative instruments with qualitative methodologies that allow for a deeper understanding of metacognitive and attitudinal processes.

Overall, the findings of this study reinforce the distinction identified in the literature between short-term acquisition of technical skills and the long-term development of deep geographical thinking. While GIS-based interventions are highly effective in fostering digital and quantitative competencies, their impact on spatial reasoning and metacognitive awareness appears to depend on longer-term pedagogical designs and more explicit reflective strategies, as highlighted in previous research (Brooks, 2018; Gryl & Jekel, 2012; Pamuk, 2023).

6. Conclusions

The findings of this study suggest that a geographically contextualised geography education intervention, supported by the pedagogical use of GIS and grounded in the analysis of a real socio-spatial problem such as rural depopulation, may contribute to the development of key competences in initial teacher education. In particular, the results indicate improvements in digital, quantitative, and conceptual domains, which appear to be associated with the handling of spatial data and the interpretation of territorial processes.

At the same time, results indicate more limited or delayed effects in higher-order competences, such as spatial reasoning and metacognition. These dimensions do not appear to respond immediately to short-term interventions and may require longer instructional periods, targeted pedagogical strategies, and sustained opportunities for critical reflection. In this respect, the results offer cautious support for questioning techno-deterministic assumptions and underline the importance of integrating GIS within pedagogical frameworks explicitly oriented towards deep geographical thinking.

These interpretations should be considered considering several limitations. The absence of a control group restricts the possibility of establishing causal relationships, while the relatively short duration of the intervention constrains the assessment of more complex cognitive processes. In addition, the use of structured instruments may not fully capture the evolution of territorial attitudes and values. Furthermore, the study does not directly assess professional teaching competences—such as lesson planning, instructional design, or classroom implementation—which limits the extent to which the findings can be extrapolated to actual teaching practice.

The findings suggest that GIS-based interventions are particularly effective for strengthening conceptual, quantitative and digital competences in initial teacher education. However, the development of higher-order geographical thinking and metacognitive awareness appears to require longer intervention periods and more explicit reflective strategies. Rural depopulation proved to be a particularly valuable learning context because it connected geographical concepts and skills with a real and territorially relevant challenge. Future research should explore longer-term interventions and alternative pedagogical approaches to support the development of advanced spatial thinking.

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pedagogies. Contributions address key transformations shaping contemporary geography, including deglobalisation, multipolar world orders, postcolonial critique, contested knowledge and places, and the integration of artificial intelligence in educational practice and research. The Special Issue is edited by **Dr Neli Heidari**, University of Bremen, Germany, **Dr Uwe Krause**, Fontys University of Applied Sciences, The Netherlands & Ege University Izmir, Türkiye, **Dr Susan Caldis**, Macquarie University, Australia, **Prof. Tine Beneker**, Utrecht University, The Netherlands, and **Dr Alexandros Bartzokas-Tsiompras**, National Technical University of Athens, Greece, & Associate Editor of the European Journal of Geography.

Contribution to the Special Issue Topics: This study contributes to the Special Issue by examining how GIS-based learning can support powerful geography education in times of territorial transition. Through the analysis of rural depopulation, it explores the development of spatial thinking, digital competence, and critical geographical understanding among pre-service teachers, highlighting both the potential and limitations of geotechnologies for addressing complex socio-spatial challenges.

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