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INTEGRATING DIGITAL MAPPING TECHNOLOGIES INTO GEOGRAPHICAL SKILLS EDUCATION: A SYSTEMATIC REVIEW, INDICATIVE META-ANALYTIC SYNTHESIS, AND INTEGRATIVE THEORETICAL FRAMEWORK

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ABSTRACT

Digital mapping technologies—geographic information systems (GIS), web-GIS, virtual globes, remote sensing, story maps, and emerging augmented-reality and GeoAI tools—are increasingly promoted as vehicles for developing geographical skills. However, the evidence remains dispersed across geography education, the geosciences, and educational technology; previous reviews have focused almost exclusively on GIS, and no synthesis has both mapped this landscape and quantified the learning effect. This study aims to (i) characterise the research landscape of the field, (ii) estimate the indicative learning effect of mapping-technology instruction on spatial and geographical-skill outcomes, and (iii) develop an integrative theoretical framework explaining how digital mapping technologies mediate geographical-skill development. Following PRISMA 2020 guidelines, 492 records identified from Scopus and Google Scholar were deduplicated into 470 unique works; 427 studies were included in the thematic and bibliometric synthesis, and 16 intervention studies involving 1,708 learners were pooled using a random-effects model with Hedges' g. The results show that output grew steadily after 2013 and peaked in 2019–2020; GIS/web-GIS dominated the technology base (≈48%) and spatial thinking the outcome space (≈27%). The indicative pooled effect was moderate and statistically significant, $g = 0.51$, 95% CI [0.41, 0.62], with low heterogeneity ($I^2 = 11\%$); controlled studies showed $g = 0.47$ and single-group pre/post studies $g = 0.57$. It is concluded that digital mapping technologies reliably support geographical-skill development, particularly when embedded in inquiry-based, problem-based, and scaffolded pedagogical designs, and the proposed Digital Geo-Mediated Learning framework offers a testable model for future research.

Keywords: *geographical skills; geospatial technology; meta analysis synthesis; spatial thinking; systematic review*

INTRODUCTION

Maps are important media for identifying, understanding, and analyzing changes occurring across space on the Earth's surface. They visualize geospatial data and thereby enable users to interpret spatial relationships more effectively (Kraak & Ormeling, 2020). The use of maps has expanded rapidly, and map production is no longer confined to geographers but is also undertaken by scholars and practitioners in economics, politics, sociology, and cultural studies. The development of cartography has a long history, extending from prehistoric and ancient mapping practices to modern, digital, and three-dimensional cartography. This evolution reflects not only improvements in technical accuracy but also broader changes in how humans understand space, power, and knowledge (Branch, 2011; Farman, 2010). This trajectory matters for education because each cartographic transition—from static paper sheets to interactive digital environments—has redefined not only how spatial information is produced but also what learners must be able to do with it, shifting the pedagogical emphasis from passive map reading toward interactive spatial analysis and map making (Kraak & Ormeling, 2020).

Within geography education, maps are not merely illustrative aids but constitutive tools of disciplinary reasoning: geography studies spatial phenomena on the Earth's surface through geospatial data, and the map is the principal representational form through which such data are analysed and communicated (Kraak & Ormeling, 2020). Map reading, analysis, and interpretation are accordingly positioned in curriculum standards and in the spatial-thinking literature as core learning outcomes of geography instruction, because they operationalise the concepts of space, tools of representation, and processes of reasoning that define spatial thinking (R. S. Bednarz & Lee, 2011; Council, 2006). Advances in digital technology have extended these demands, as learners now encounter and produce maps not only in printed form but also in interactive digital environments (Kerski, 2015). The shift carries an educational promise: if learners can interrogate spatial data directly, they should develop the higher-order geographical skills that paper maps only gesture toward—reading pattern and process together, reasoning across scales, and connecting human and physical systems. National and disciplinary bodies have institutionalised this expectation, from the spatial-thinking agenda of the National Research Council (2006) to the geocapabilities programme advanced by geography educators internationally (Lambert et al., 2008).

Four interrelated constructs anchor this study, and their selection follows a deliberate conceptual logic. Spatial thinking is the most fundamental: a cognitive amalgam of concepts of space, tools of representation, and processes of reasoning (Council, 2006), whose components have been identified empirically (R. S. Bednarz & Lee, 2011). Spatial literacy denotes the functional dimension of that cognition—the capacity to use spatial representations such as maps and geovisualisations competently and critically in everyday and academic contexts. Geographical (geospatial) skills are the discipline-specific operationalisation of both, encompassing the abilities to acquire, organise, analyse, and communicate geographic information that professional and school geography demand (Solem et al., 2008). Geocapabilities, finally, is the broadest construct, framing these skills within a capabilities approach as contributions to learners' human potential and access to powerful disciplinary knowledge (Lambert et al., 2008; Tian et al., 2025). The four concepts thus form a nested progression—from general cognition (spatial thinking), through functional competence (spatial literacy) and disciplinary application (geographical skills), to educational purpose (geocapabilities)—and digital mapping technologies potentially intervene at every level of this progression (Bearman et al., 2016; Walkington et al., 2019). This progression is used throughout the review to organise the outcome constructs.

The empirical literature that grew around this promise is, however, fragmented. Studies appear in geography-education journals, the geosciences, educational-technology outlets, and even library and information science, each with its own vocabulary—"spatial thinking," "spatial literacy," "geographic skills," "geocapabilities," "relational thinking." Technologies range from desktop GIS and web-GIS to virtual globes such as Google Earth, remote sensing, ArcGIS StoryMaps, GPS-based fieldwork, and, more recently, augmented reality and GeoAI. More importantly, existing syntheses leave substantive questions unanswered. Previous reviews have concentrated almost exclusively on GIS: (Bernhäuserová et al., 2022) systematically reviewed only the barriers to GIS implementation in education, and

(Konstantakatos & Galani, 2022) evaluated only how GIS use in geographical and environmental education has been assessed; neither covered story maps, immersive technologies, or GeoAI, and neither quantified learning effects. On the quantitative side, the landmark meta-analysis of (Uttal et al., 2013) established that spatial skills are trainable, but it addressed spatial training in general, was not specific to mapping technologies or geography education, and predates web-GIS, story maps, and GeoAI. Consequently, three things remain unknown: (1) the overall landscape of the field across all mapping technologies and skill constructs, (2) the magnitude of the learning effect of mapping-technology instruction specifically on geographical skills, and (3) a theoretical account of the mechanism linking technology to skill development. This dispersion, together with these unanswered questions, makes it difficult to answer two practical questions that teachers and curriculum designers repeatedly ask: does mapping-technology instruction actually improve geographical skills, and if so, by how much and under what conditions?

This article addresses those questions through a combined bibliometric–systematic review and meta-analysis of 470 unique works spanning 1990–2025 and then uses the synthesis to build an integrative theoretical framework. We pursue three objectives, expressed as research questions:

RQ1 (Landscape). How has research on digital mapping technologies for geographical-skills education developed over time, and what are its dominant venues, technologies, skill targets, and educational levels?

RQ2 (Effect). What is the pooled effect of mapping-technology instruction on spatial-thinking and geographic-skill outcomes, and how does it vary by study design?

RQ3 (Theory). How can the accumulated findings be consolidated into a coherent theoretical framework that explains how mapping technologies develop geographical skills?

By integrating a descriptive map of the field with a quantitative estimate of its central effect and a theoretical model, the review aims to be useful to researchers seeking gaps, to teacher educators seeking warrant, and to designers seeking principles.

MATERIALS AND METHODS

This study employed a systematic review design supported by bibliometric mapping, thematic synthesis, and an indicative meta-analytic synthesis. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses to ensure transparency in identification, screening, eligibility assessment, and reporting with PRISMA 2020 guidelines (Page et al., 2021). The design is best characterised as a mixed-methods review in which the components are combined sequentially rather than treated as separate studies: the PRISMA-governed systematic review provides the transparent evidence base; bibliometric mapping and thematic synthesis answer the descriptive landscape question (RQ1); the indicative meta-analytic synthesis answers the effect question (RQ2); and the integrative framework consolidates both strands to answer the theoretical question (RQ3). Each component is therefore necessary because each research question requires a different analytical lens applied to the same corpus.

1. Information sources and search

Bibliographic records were collected from Scopus and Google Scholar in May 2025. These two databases were selected to combine curated indexing coverage with broader scholarly retrieval, particularly for education-related and regionally published studies that may not be fully represented in Scopus. The search covered publications from 1990 to 2025. The year 1990 was chosen as the lower bound because it marks the beginning of the diffusion of desktop GIS beyond specialist laboratories and the earliest sustained discussion of GIS and digital mapping in school and university geography; this bound therefore captures the entire digital-mapping era of geography education while excluding the pre-digital cartographic-training literature that falls outside the scope of this review.

The search strategy combined three groups of keywords: geographical-skill constructs, digital mapping technologies, and educational contexts. The main search terms included:

“spatial thinking” OR “spatial literacy” OR “geographical skills” OR “geographic skills” OR “geospatial skills” OR “map skills” OR “geocapabilities” OR “relational thinking” OR “systems thinking”

AND

"GIS" OR "geographic information system" OR "web-GIS" OR "geospatial technology" OR "digital map" OR "online map" OR "virtual globe" OR "Google Earth" OR "remote sensing" OR "story maps" OR "augmented reality" OR "GeoAI"

AND

"education" OR "teaching" OR "learning" OR "students" OR "curriculum" OR "instruction" OR "geography education"

The search was conducted through three overlapping strands: (1) geographical and spatial skills; (2) geospatial information and technology in education; and (3) instructional models integrating geography learning and geospatial technologies.

2. Eligibility criteria

Studies were included if they met the following criteria:

a. The study addressed the use of digital or analogue mapping technologies in an educational setting.
b. The study focused on the development of geographical skills, spatial thinking, spatial literacy, map skills, geospatial skills, relational thinking, systems thinking, or geocapabilities.
c. The study was situated in formal or informal education, including primary, secondary, higher education, or teacher education.
d. The study provided bibliographic, conceptual, empirical, or intervention-based evidence relevant to geography education or geospatial learning.

Studies were excluded if they:

a. Focused solely on technical GIS Science, remote sensing, spatial modelling, machine learning, or geospatial computation without an educational component.
b. Discussed mapping technologies only as data-processing tools without reference to learning, instruction, curriculum, or skill development.
c. Were duplicates across databases.
d. Not sufficiently related to geographical-skills education based on title, keywords, or abstract screening.

With respect to publication type, eligible records comprised peer-reviewed journal articles, review articles, conference papers, book chapters, and scholarly books; theses, editorials, and

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unpublished reports were excluded. Only publications written in English were included, given the international vocabulary of the field and the indexing coverage of the two databases. No restriction was placed on access model: open-access and subscription-based publications were equally eligible, since access model has no bearing on the substantive relevance of a study.

3. Study selection

A total of 492 records were initially identified. After duplicate removal using normalized titles and bibliographic metadata, 470 unique records remained (see **Figure 1**). These records were screened based on titles, keywords, and abstracts. Forty-three records were excluded because they focused on purely technical or non-educational geospatial applications. As a result, 427 studies were retained for thematic and bibliometric synthesis.

For the meta-analytic synthesis, the 427 education-related studies were further screened to identify empirical intervention studies that measured spatial-thinking or geographical-skill outcomes before and after mapping-technology instruction. Sixteen studies involving 1,708 learners reported sufficient quantitative or design-related information to estimate standardized learning effects.

4. Data extraction and bibliometric coding

Data extraction was conducted using a structured coding sheet. For each included record, the following information was extracted: author, year, title, source, keywords, abstract, citation count, technology type, educational level, geographical-skill construct, and study design. The technology taxonomy included GIS/web-GIS, virtual globes, remote sensing, digital cartography, story maps, GPS/mobile field tools, augmented or virtual reality, geogames, and GeoAI/big-data applications. The skill taxonomy included spatial thinking, spatial literacy, geographical or geospatial skills, map skills, spatial ability, geocapabilities, relational thinking, and systems thinking. Because many studies addressed more than one technology or skill construct, multiple coding was allowed. Record management, deduplication, and coding were performed in Microsoft Excel; descriptive bibliometric analyses and visualisations were generated in R (version 4.3); and the meta-analytic synthesis—the random-effects model, heterogeneity statistics, forest and funnel plots, and Egger's regression—was computed using the metafor package in R.

For the meta-analytic subset, additional information was extracted, including sample size, intervention type, comparison condition, outcome measure, research design, and reported statistics. Where available, means, standard deviations, t-values, F-values, p-values, or pre/post change statistics were used to estimate standardized mean differences.

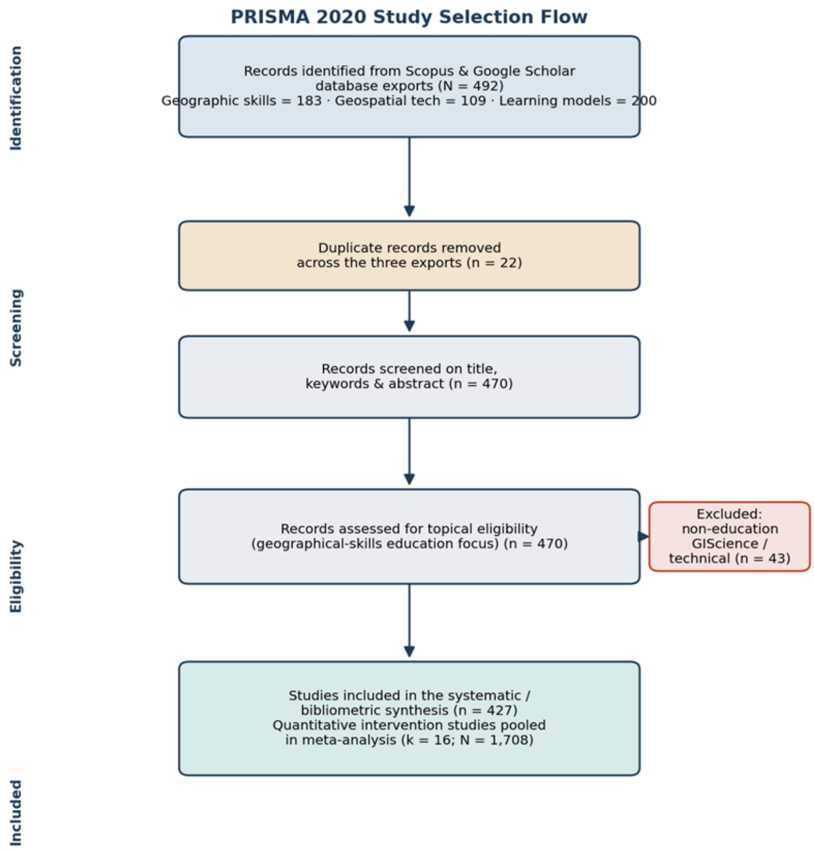

Figure 1. PRISMA 2020 flow of study identification, screening, eligibility, and inclusion.

Source: Authors' elaboration following the PRISMA 2020 statement (Page et al., 2021)

5. Meta-analytic procedure

The standardized mean difference was calculated as Hedges' g to adjust for small-sample bias. Random-effects models were used because the included studies varied in educational level, intervention design, technology type, instructional duration, and outcome measurement. Heterogeneity was assessed using Cochran's Q, I^2, τ^2, and a 95% prediction interval.

Study design was examined as an a-priori moderator by comparing controlled intervention studies with single-group pre/post studies. Funnel-plot asymmetry and Egger's regression were used to explore potential small-study effects, although these results were interpreted cautiously because the number of studies was modest.

Because not all studies reported complete statistical information in their abstracts or available bibliographic records, the pooled effect should be interpreted as an indicative estimate rather than a definitive causal parameter. The meta-analytic synthesis is therefore intended to provide a preliminary quantitative overview of the direction and approximate magnitude of learning effects, while highlighting the need for future full-text meta-analysis with formal risk-of-bias assessment.

6. Risk of Bias Considerations

Risk-of-bias considerations were used to contextualize the interpretation of the intervention studies included in the meta-analytic synthesis. Because the studies varied in design and because several were quasi-experimental or single group pre/post interventions, the assessment focused on five domains: selection bias, baseline comparability, measurement validity, attrition or incomplete outcome data, and selective reporting.

Controlled studies were considered to provide stronger causal evidence than single-group pre/post designs because they included a comparison condition. However, many controlled studies in educational settings did not use random assignment and were therefore classified as having "some concerns" rather than "low risk." Single group pre/post studies were interpreted more cautiously because observed gains may reflect maturation, testing effects, teacher effects, or other contextual influences rather than the intervention alone. The risk-of-bias assessment was not used to exclude studies from the synthesis, but it informed the interpretation of the pooled effect. Consequently, the meta-analytic result is presented as an indicative estimate of the learning effect rather than as definitive causal evidence.

RESULTS AND DISCUSSION

1. Results: the research landscape (RQ1)

The field is young but rapidly maturing. Annual output was negligible through the 1990s, accelerated sharply from 2013, and peaked in 2019–2020 (52 works in 2020), with a robust flow continuing to 2025 (**Figure 2**). The inflection around 2013 coincides with the diffusion of free web-GIS (notably ArcGIS Online), the maturation of virtual globes in classrooms, and renewed disciplinary calls—exemplified by Bednarz and Kerski's (2013) road map—for embedding spatial thinking across geography education, building on earlier standards-linked geospatial initiatives (S. W. Bednarz & Whisenant, 2000). Although the search window covered 1990–2025, the earliest record that met the eligibility criteria was published in 1997; **Figure 2** therefore displays the observed 1997–2025 period rather than the full search window.

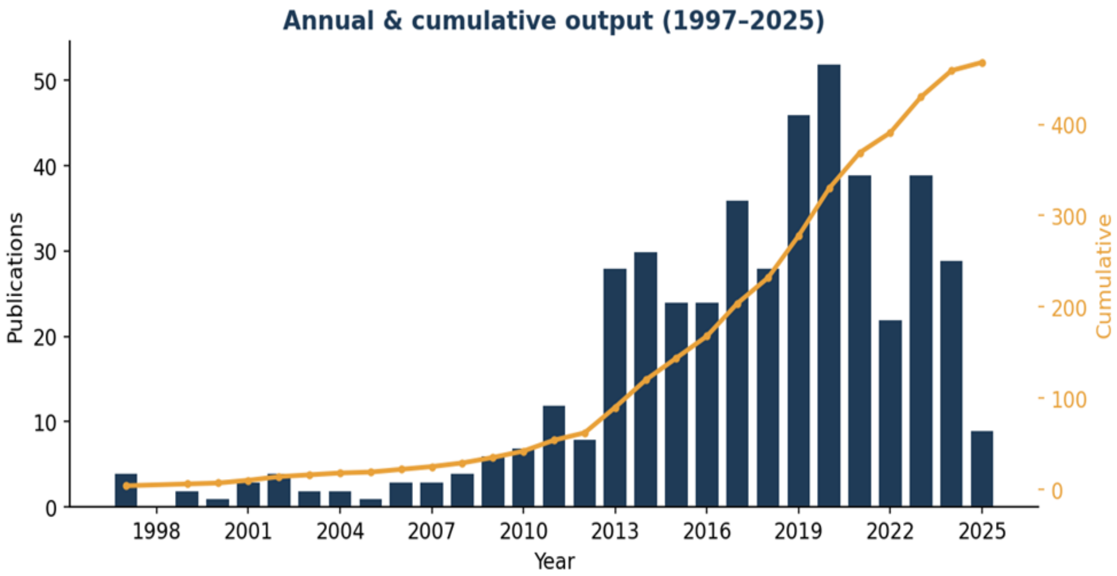

Figure 2. Annual and cumulative scholarly output on mapping technologies in geographical-skills education, 1997–2025.

Source: Authors' analysis of Scopus and Google Scholar data, 2026

Output is concentrated in a small set of disciplinary outlets. The Journal of Geography is the field's hub by a wide margin, followed by the Journal of Geography in Higher Education and a cluster of geoscience-education, environmental-education, and GIScience venues. The presence of the Journal of Map and Geography Libraries signals an active strand of work on spatial literacy in academic libraries. **Table 1** lists the leading venues.

Table 1. Leading publication venues among the 470 unique works.

Source title	Works	Share
Journal of Geography	59	12.6%
Journal of Geography in Higher Education	20	4.3%
Journal of Map and Geography Libraries	13	2.8%
Journal of Geoscience Education	11	2.3%
International Research in Geographical & Environmental Education	10	2.1%
IOP Conf. Series: Earth and Environmental Science	10	2.1%
Review of International Geographical Education (RIGEO)	8	1.7%
European Journal of Geography	6	1.3%

Source: Authors' analysis of Scopus and Google Scholar data, 2026

The technology base is dominated by GIS and web-GIS, which appear in roughly 226 works—close to half the corpus—followed at a distance by GeoAI/big-data framings, remote sensing, and digital cartography. Immersive technologies (AR/VR), virtual globes, mobile/field tools, story maps, and geogames form a smaller but growing periphery. On the outcome side, spatial thinking is the overwhelmingly dominant target (126 works), with spatial literacy and the explicitly disciplinary "geographic skills" construct forming a second tier. Geocapabilities and relational/systems thinking, although theoretically prominent, are rarely operationalised empirically (**Figure 3**).

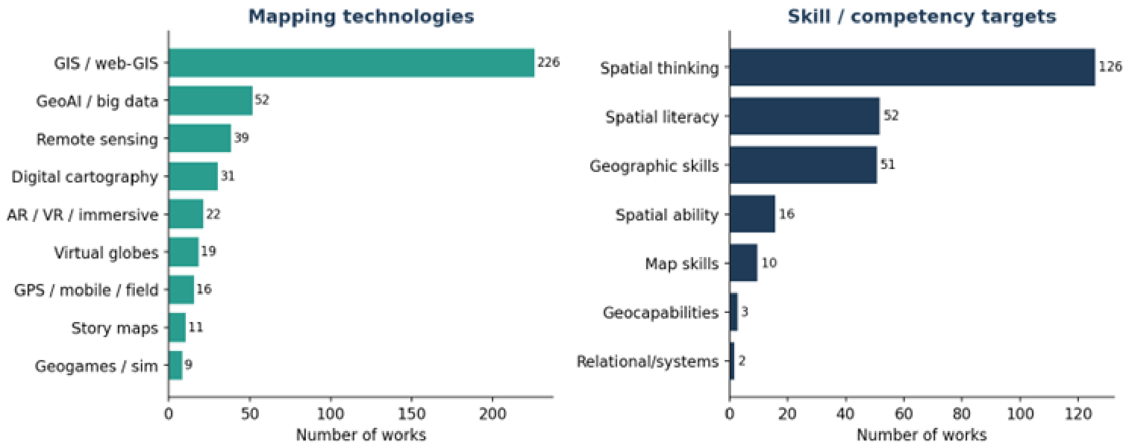

Figure 3. Distribution of mapping technologies (left) and targeted skill/competency constructs (right) across the corpus. Works may appear in more than one category.

Source: Authors' analysis of Scopus and Google Scholar data, 2026

Cross-tabulating the schemes shows that GIS/web-GIS is the workhorse for cultivating spatial thinking, while virtual globes and remote sensing are more often tied to content learning and map-reading skills, and story maps are associated almost exclusively with geocapabilities and communication. By educational level, higher education is the most studied setting (≈85 works), followed by secondary (≈52), primary (≈42), and teacher education (≈35)—a distribution that leaves the formative primary years comparatively under-researched.

The most-cited education-relevant works combine reference texts (Kraak & Ormeling, 2020) influential conceptual statements meta-analysis on the malleability of spatial skills and a research agenda for geospatial technologies and learning (Baker, 2015; Uttal et al., 2013), and design-oriented studies on GIS learning material (Ridha et al., 2020) . Their co-occurrence signals a field bridging cognitive-science evidence that spatial skills are trainable with discipline-specific arguments for why geography should do the training (**Table 2**).

Table 2. Selected foundational and most-cited education-relevant works.

First author (year)	Cites	Contribution
Kraak & Ormeling (2020)	~1,490	Reference text on cartographic visualisation of geospatial data
Ridha et al. (2020)	~1,200	Designing GIS learning material grounded in spatial thinking
Uttal et al. (2013)	~435	Meta-analytic evidence that spatial skills are malleable and trainable
Bednarz & Kerski (2013)	~300	Road map for 21st-century geography-education research
Favier & van der Schee (2014)	~70	Quasi-experimental gains in relational thinking from geospatial tech

Source: Authors' analysis of Scopus and Google Scholar data, 2026

2. Results: meta-analysis of learning effects (RQ2)

Sixteen intervention studies (N = 1,708 learners), spanning middle school to teacher education and a range of technologies from desktop and web-GIS to Google Earth, orienteering apps, and giant traveling maps, met the criteria for quantitative synthesis (Bodzin, 2011; Collins, 2018; Favier & Schee, 2014; Fleming & Mitchell, 2017; Hadi et al., 2021; Kim et al., 2012; Kulo & Bodzin, 2013; Lee & Bednarz, 2009; Metoyer & Bednarz, 2017; Perugini & Bodzin, 2020; Romadlon et al., 2021; Tosun & Gökçe, 2024; Wijayanto et al., 2023; Yani et al., 2018; YİĞİT & KARATEKİN, 2021). The random-effects pooled effect of mapping-technology instruction on spatial-thinking and geographic-skill outcomes was moderate and clearly significant, g = 0.51, 95% CI [0.41, 0.62], z = 9.7, $p < .001$ (**Figure 4**).

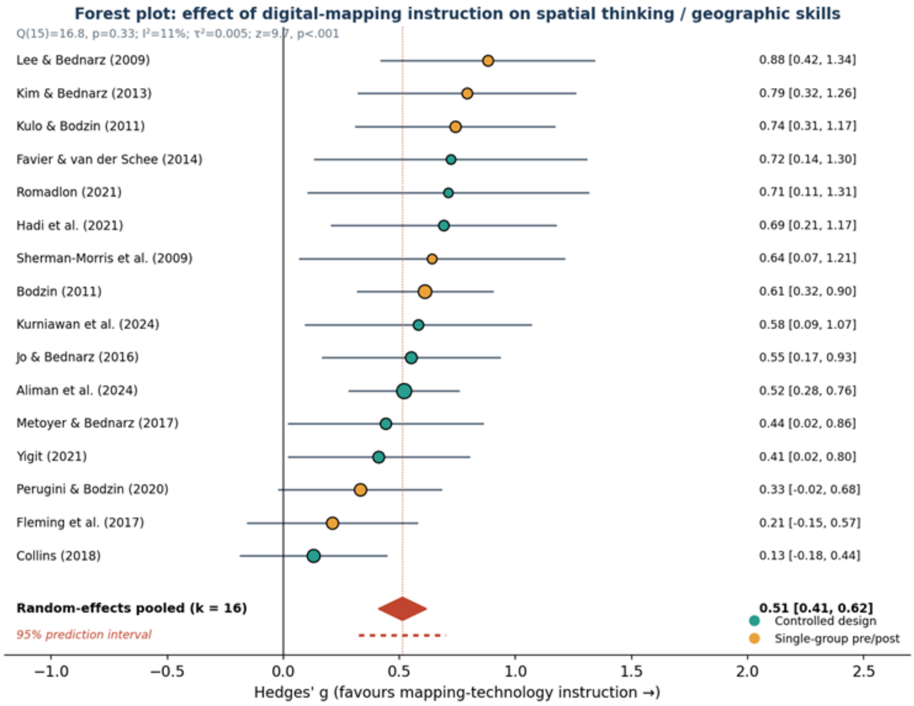

Figure 4. Forest plot of standardised effects (Hedges' g) of digital-mapping instruction on spatial-thinking / geographic-skill outcomes.

Source: Authors' meta-analytic computation using the metafor package in R, 2026

Heterogeneity was low, Q(15) = 16.8, p = .33, I^2 = 11%, τ^2 = 0.005, indicating that the studies estimate a fairly consistent underlying effect. Critically, the 95% prediction interval, [0.33, 0.70], lies entirely above zero: in a new comparable setting the expected effect would still be positive and at least small-to-moderate. This consistency is notable in an educational literature where heterogeneity is usually substantial, and it strengthens confidence that the benefit is real rather than an artefact of a few favourable studies. This result should be interpreted cautiously. Although the pooled effect suggests a consistent positive association between mapping-technology instruction and geographical-skill development, the included studies varied in design quality, instructional duration, measurement instruments, and reporting completeness. Therefore, the result is best understood as an indicative estimate of the likely magnitude of learning gains rather than as a definitive causal effect.

a. Moderator analysis: study design

Single group pre/post studies yielded a somewhat larger pooled effect (g = 0.57, 95% CI [0.39, 0.75], k = 7) than controlled designs (g = 0.47, 95% CI [0.35, 0.60], k = 9), consistent with the expectation that the absence of counterfactual inflates apparent gains. However, the difference was not statistically significant (z = 0.83, p = .41), and—reassuringly—the controlled studies, which provide the stronger causal warrant, still showed a robust moderate effect. The near-null outliers were instructive: (Collins, 2018) comparison of digital versus paper maps (g = 0.13) and Fleming and Mitchell's (2017) giant-traveling-map study (g = 0.21) suggest that swapping the medium without changing the cognitive demands of the task yields little, a point we return to in the framework.

Table 3. Random-effects pooled effects overall and by study design.

Subgroup	k	g [95% CI]	I^2	Interpretation
All studies	16	0.51 [0.41, 0.62]	11%	Moderate, significant
Controlled (quasi/true-exp.)	9	0.47 [0.35, 0.60]	0%	Moderate, robust
Single group pre/post	7	0.57 [0.39, 0.75]	32%	Moderate–large, more varied

Source: Authors' meta-analytic computation using the metafor package in R, 2026

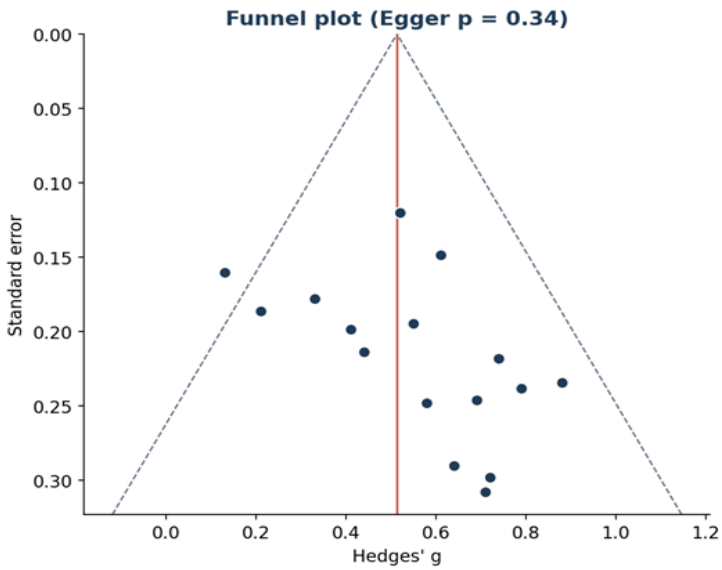

Figure 5. Funnel plot of effect size against standard error with pseudo-95% confidence contours.

Source: Authors' meta-analytic computation using the metafor package in R, 2026

b. Small-study effects

The funnel plot was reasonably symmetric and Egger's regression was non-significant (p = .34), giving no strong statistical signal of publication or small-study bias (**Figure 5**). This should be read cautiously given the modest number of studies and the abstract-derived effect sizes, but it does not suggest that the pooled estimate is materially inflated by selective reporting.

3. Result: Toward an integrative theoretical framework (RQ3)

The descriptive and quantitative results converge on a single message: the technology matters, but it matters because of what it lets learners and teachers do, not by mere exposure. To make that mechanism explicit we propose the Digital Geo-Mediated Learning (DGML) framework (**Figure 6**), which integrates four bodies of work surfaced by the review—the technology taxonomy, the cognitive science of spatial skill, the pedagogy of inquiry and authentic problem-solving, and the geocapabilities tradition—into one explanatory model.

The framework has five interacting components:

a. Mapping technologies are the affordance layer—GIS, web-GIS, virtual globes, remote sensing, story maps, AR/VR, and GeoAI—each offering distinct capacities for representation, query, overlay, and visualisation. They are inputs, not causes.
b. Pedagogical mediation is the central mechanism. The review shows that effects are largest where technology is embedded in inquiry, problem-based, and authentic tasks with explicit scaffolding and teacher technological–pedagogical–content knowledge (TPACK), and smallest where the tool merely substitutes for paper. The GIS-course studies report moderate-to-large gains while pure media swaps do not (Favier & Van Der Schee, 2014; Jo et al., 2016).
c. Cognitive processes spatial encoding, mental visualisation, and representational competence are the proximal route through which mediated activity changes skill. Evidence that spatial skills

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are malleable supplies the cognitive warrant for the whole enterprise (Uttal et al., 2013).

d. Geographical-skill outcomes form the dependent layer: spatial thinking and spatial literacy, extending to relational and systems thinking and, at the disciplinary apex, geocapabilities and geographical imagination (Tian et al., 2025)

e. Learner attributes—prior spatial ability, gender, motivation, and self-efficacy moderate every path, and a feedback / skill-transfer loop returns developed skill to the learner, raising readiness for more demanding tasks. All of this sits within an enabling context of curriculum and standards, infrastructure and access, teacher professional development, and the assessment of spatial outcomes the conditions (Huh & Jo, 2023) and others identify as making or breaking implementation.

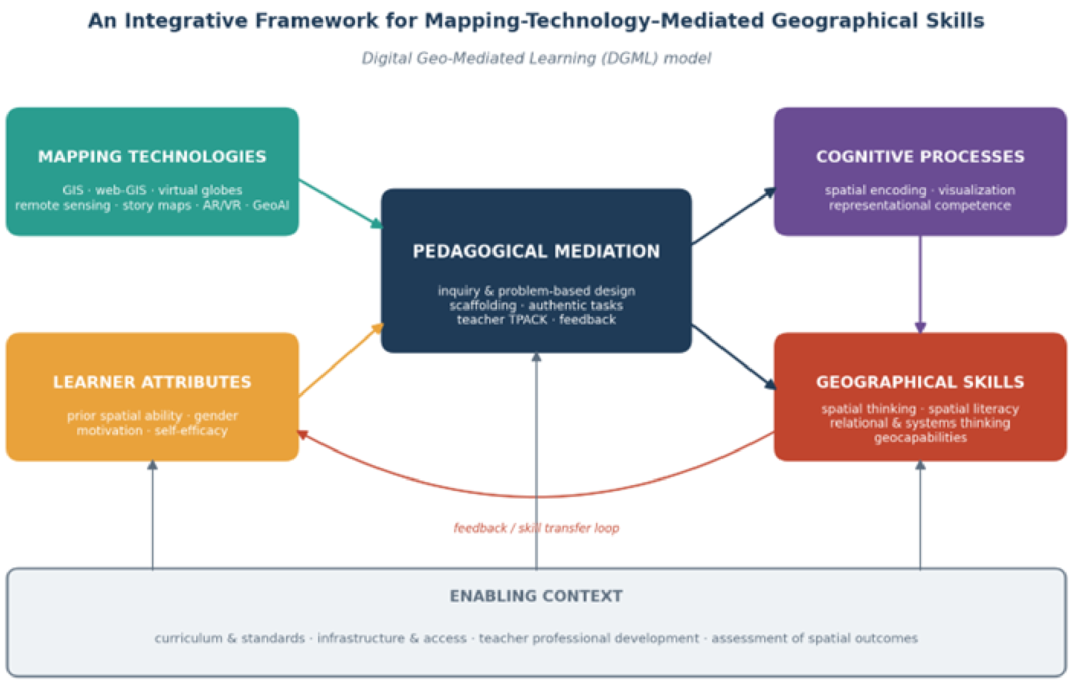

Figure 6. The Digital Geo-Mediated Learning (DGML) framework: mapping technologies act on geographical-skill outcomes through pedagogical mediation, cognitive processing, and learner attributes, within an enabling context, closed by a skill-transfer feedback loop.

Source: Authors' construction based on the review synthesis, 2026

The DGML framework thus reframes the field's guiding question. The productive question is not "does GIS work?" but "under what pedagogical mediation, for which learners, and in what enabling context does a given mapping technology develop a specified geographical skill?" The moderate, consistent meta-analytic effect is precisely what this model predicts: a reliable benefit whose ceiling is set by pedagogy rather than by the tool.

4. Discussion

Three findings stand out. First, the field has consolidated around GIS-family technologies and the spatial-thinking construct, with a clear empirical centre of gravity in the Journal of Geography and allied venues. Second, mapping-technology instruction produces a moderate and remarkably consistent improvement in geographical skills (g = 0.51), with a prediction interval that remains positive an unusually stable result for educational interventions. Third, the magnitude is governed by pedagogy: controlled studies retain a robust effect, but interventions that change only the medium and not the task approach zero.

Beyond these headline findings, four patterns deserve interpretation rather than restatement. First, the moderator analysis indicates that study design shapes the apparent effect: single-group pre/post designs produced a larger estimate (g = 0.57) than controlled designs (g = 0.47), a gap consistent with maturation and testing effects inflating uncontrolled gains; that the controlled estimate remains moderate and precise is therefore the more meaningful result, and the near-null media-swap studies (Collins, 2018; Fleming & Mitchell, 2017) sharpen the interpretation—the benefit is produced by the cognitive demands of the task, not by the digital medium itself. Second, the dominance of GIS/web-GIS (≈48% of the corpus) reflects both the institutional embedding of GIS in curricula and software ecosystems and a path-dependence in research: instruments, teacher training, and journal traditions built around GIS make GIS studies easier to conduct and publish (Bearman et al., 2016; Esteves & Rocha, 2015; González & ..., 2020). The corollary is an evidence imbalance—story maps, geogames, virtual globes, immersive AR/VR, and GeoAI are pedagogically promising (Adanali, 2021; Schultz & DeMers, 2020; Tian et al.,

2025) but empirically thin, so the pooled effect generalises most safely to GIS-family interventions. Third, geocapabilities and relational/systems thinking are invoked far more often than they are measured. This is partly a measurement problem—capabilities are long-run, value-laden outcomes that resist pre/post testing—and partly a design problem, because few interventions last long enough to plausibly move them (Favier & Van Der Schee, 2014; Tian et al., 2025); until validated instruments exist, the field risks claiming capability outcomes on spatial-thinking evidence. Fourth, primary education lags behind other levels (≈42 works) despite evidence that even young children can use spatial representations productively (Kim et al., 2012); the lag plausibly reflects curriculum structures that defer formal geography, teachers' limited geospatial preparation (Sherman-Morris et al., 2009; Wijayanto et al., 2023), and the desktop-era complexity of earlier tools—an obstacle that tablet-based apps and simplified web maps have since lowered (Favier & Schutjens, 2025).

These results align the geography-education literature with the broader cognitive-science finding that spatial skills are trainable (Uttal et al., 2013) and give empirical teeth to the geocapabilities argument by showing that the skills it prizes do respond to designed instruction. They also caution against techno-optimism: acquiring software is not acquiring skill. For practice, the implication is to invest in task design—for example, problem-solving, project-based, experiment-based, and model-based designs (Aliman et al., 2024; Kurniawan et al., 2024; Schubert, 2021) and in teacher TPACK at least as much as in tools, and to extend attention to the under-studied primary years, to learner diversity including gifted learners (Lakin et al., 2024), and to immersive and GeoAI technologies whose evidence base remains thin.

CONCLUSIONS

Drawing on 470 publications spanning thirty-five years, this study provides grounds for measured optimism regarding the integration of digital mapping technologies into geographical-skills education. The evidence indicates that digital mapping produces a moderate improvement in spatial and geographical skills, particularly when the technology is embedded within welldesigned, inquiry-oriented pedagogy rather than treated merely as a technical tool. The proposed Digital Geo-Mediated Learning framework consolidates these findings into a testable conceptual model that foregrounds the interaction among pedagogical mediation, cognitive processing, learner attributes, technological affordances, and enabling learning contexts.

Nevertheless, these conclusions should be interpreted in light of several limitations. The synthesis was based primarily on bibliographic exports rather than complete full-text articles. Consequently, the meta-analytic effect sizes were derived from quantitative outcomes and research-design information available in abstracts. Where studies reported only the direction and statistical significance of an effect, a consistent magnitude was assigned.

The technology and geographical-skill classifications were also generated through keyword and abstract matching, which may have resulted in the misclassification of studies employing uncommon or discipline-specific terminology. In addition, the three bibliographic exports were drawn mainly from Scopus and Google Scholar and were dominated by English-language publications. As a result, regional studies and scholarship published in other languages may be underrepresented.

The intervention literature was further characterised by relatively short implementation periods and proximal post-tests. Although the findings demonstrate immediate improvements in spatial and geographical skills, the durability of these gains and their transfer to unfamiliar geographical problems, everyday spatial decision-making, and authentic environmental contexts remain largely untested. The bibliometric analysis was also descriptive. Advanced network-based techniques, including co-citation analysis, keyword co-occurrence mapping, thematic clustering, and collaboration-network analysis, were not undertaken. Moreover, the geographical distribution of publications by author affiliation could not be examined because affiliation metadata were incomplete, particularly in the Google Scholar exports.

These limitations define a clear research agenda for the next decade. Future research should employ longer interventions, delayed post-tests, and transfer measures; expand investigations at the primary-school level; examine immersive technologies and GeoAI-supported learning; undertake full-text meta-analyses accompanied by systematic risk-of-bias appraisal; and incorporate co-citation, co-word, thematic, collaboration, and geographical-distribution analyses.

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