



## Beyond Technocentrism: A Tripartite Framework for Humanizing AI Integrated Scientific Modeling in Climate-Related Geography Education

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### ABSTRACT

*This study aims to explore how critically designed digital content can foster spatial-social reasoning and critical thinking in Geography education within AI-integrated learning environments. Using a systematic literature review method based on a modified PRISMA protocol, 35 peer-reviewed studies (2000–2024) were selected from Scopus, SINTA, and Google Scholar databases. The analysis employed thematic coding and critical interpretive synthesis to examine four pedagogical dimensions: digital interactivity, spatial-social reasoning, AI personalization, and critical-reflective pedagogy. Findings reveal that digital content can act as an epistemological scaffold through three core functions: as a cognitive tool for spatial inquiry, a medium for ethical deliberation, and a dialogic platform for collaborative knowledge-building. Quantitative gains were observed in spatial literacy (32–47%), ethical awareness, and metacognitive regulation when digital tools were integrated within authentic and justice-oriented learning contexts. The study highlights the value of a tripartite pedagogical framework that bridges connectivism and Freirean critical pedagogy, particularly in Global South education. It also underscores the urgency of embedding AI ethics and critical digital pedagogy in teacher training and curriculum reform. These findings suggest that transformative learning outcomes are achievable when technology is positioned not merely as a*

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*delivery tool, but as a dialectical medium for democratic, contextual, and ethical education.*

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## INTRODUCTION

In the era of the Fourth Industrial Revolution, the epistemological foundations of education are undergoing a profound transformation. The rapid advancement of digital ecosystems, artificial intelligence (AI), and big data technologies is not only redefining workforce demands but also reshaping how knowledge is constructed, accessed, and applied. According to the *Future of Jobs Report* by the World Economic Forum (2023), 44% of essential job-related skills are projected to shift by 2027, with an increasing emphasis on analytical thinking, digital literacy, and AI integration. These developments signal an urgent need for educational paradigms to evolve beyond rote memorization and didactic instruction toward frameworks that prioritize critical thinking, collaboration, and technological fluency.

Geography and Social Studies education sit at the heart of this transformation. As disciplines inherently concerned with the analysis of space, place, environment, and social dynamics, they are uniquely positioned to cultivate students' abilities in spatial reasoning, systemic analysis, and ethical reflection. Issues such as climate change, urbanization, global inequality, and digital surveillance demand not only technical comprehension but also a deep understanding of socio-spatial relationships and justice-oriented inquiry. However, current pedagogical practices—particularly in the Global South, including Indonesia—often fall short of this imperative. Instructional methods remain predominantly teacher-centered, reliant on static texts, and lacking meaningful integration of digital content (Mardapi et al., 2020; Sumarmi & Bachtiar, 2022). National-level data from the Ministry of Education's Research and Development Agency (Puslitjak Kemendikbudristek, 2022) reveal that only 27% of Geography and Social Studies educators incorporate digital tools in transformative ways.

Yet, the affordances of digital content offer powerful possibilities to revitalize these disciplines. Interactive geovisualizations, AI-driven simulations, real-time dashboards, and spatial modeling tools allow learners to explore complex phenomena through experiential and inquiry-based learning. These tools can serve as *cognitive partners* in modeling urban inequality, *reflective platforms* for ethical deliberation on environmental or migration issues, and *dialogic spaces* that empower both teachers and students to co-construct knowledge critically. Bodzin (2011) and Sumarmi & Bachtiar (2022) emphasize how digital media can enhance spatial literacy by enabling students to manipulate variables, visualize causal relationships, and simulate geospatial scenarios. However, the mere presence of technology does not guarantee pedagogical transformation. As Selwyn (2019) warns, a technocratic orientation that views digital tools as neutral delivery mechanisms risks depersonalizing education and reducing it to mechanistic skills training, stripped of humanistic and emancipatory dimensions.

To engage critically with these tensions, this study adopts a theoretical lens that synthesizes digital constructivism (Vygotsky, 1978; Siemens, 2005) and critical pedagogy (Freire, 1970). Constructivist learning theories posit that knowledge is actively constructed through experience and social interaction. In digital contexts, this idea expands into connectivism, where learning occurs across distributed networks of people, tools, and digital systems (Siemens, 2005). Meanwhile, Freirean critical pedagogy conceptualizes education as a liberatory act—grounded in dialogue, reflection, and social transformation. Within this perspective, technology is not an end in itself but a means to challenge dominant ideologies, democratize knowledge production, and foster critical consciousness.

Despite the individual strengths of these paradigms, their application in digital education often remains siloed. Connectivism provides a robust framework for understanding distributed cognition and digital fluency, yet it tends to under-theorize the socio-political dimensions of AI-mediated learning. On the other hand, Freire's pedagogy emphasizes ethical deliberation and social justice but offers limited guidance on how emerging technologies might scaffold spatial reasoning and collaborative inquiry. Bridging these frameworks, this study argues for a critical digital pedagogy model—one that positions technology as a dialectical tool for fostering spatially literate and socially conscious citizens. This research, therefore, interrogates a central question: How can critically designed digital content

support the development of students' spatial-social reasoning and critical consciousness in the age of artificial intelligence?

Rather than treating digital tools merely as repositories of information or as efficient delivery systems, this study proposes a tripartite pedagogical framework that repositions digital content as a dynamic educational agent. First, digital content serves as a cognitive scaffold for spatial inquiry, enabling the modeling of climate-induced migration or patterns of urban expansion. Second, it functions as a reflective medium for ethical deliberation, allowing learners to critically analyze AI-generated predictions through a justice-oriented lens. Third, it acts as a dialogic platform for the co-construction of knowledge between educators and learners. By synthesizing insights from 35 seminal studies published between 2000 and 2024, this research contributes a robust conceptual framework for reimagining Geography and Social Studies education in ways that are contextual, humanizing, and critically engaged. In doing so, it addresses the urgent need for educational systems, particularly in the Global South, not only to prepare learners for economic participation in the digital age, but also to cultivate democratic citizenship and ethical leadership in an increasingly complex and interconnected world.

## METHOD

This study employs a systematic literature review (SLR) with qualitative content analysis to develop a theoretical-conceptual framework, guided by a modified PRISMA protocol for conceptual inquiry (Snyder, 2019). The literature search spanned Scopus, Google Scholar, and SINTA databases (2000–2024), using the query string ("*digital content*" OR "*edtech*" OR "*AI education*") AND ("*critical thinking*" OR "*spatial literacy*") AND ("*geography education*" OR "*social studies*") to identify 520 initial documents. Through double-blind screening by two independent researchers ( $\kappa = 0.88$  interrater reliability), 35 high-quality sources were selected based on four inclusion criteria: focus on Geography/Social Studies education, examination of digital/AI integration, pedagogical analysis of spatial literacy/critical thinking, and publication in reputable journals (Scopus Q1-Q3 or SINTA 1-2). Document quality was rigorously evaluated using Selwyn's (2019) critical framework assessing pedagogical depth, epistemological clarity, and socio-spatial relevance.

Thematic coding extracted core pedagogical dimensions—digital interactivity, spatial-social reasoning, and AI personalization—while contrasting theoretical approaches (digital constructivism: Siemens, 2005; critical pedagogy: Freire, 1970). A critical interpretive synthesis (Sandelowski & Barroso, 2007) integrated empirical findings and theoretical perspectives to construct the conceptual framework. Validation involved three triangulation strategies: expert review by Geography Education professors, negative case analysis of contradictory literature, and causal logic diagrams to test systemic coherence. The principal limitation concerns geographical bias (68% Global North sources), necessitating contextual adaptation for Global South implementation (Sumarmi & Bachtiar, 2022; Snyder, 2019).

## RESULTS AND DISCUSSIONS

### Results of Literature Synthesis

Based on the screening results of the query ("*digital content*" OR "*edtech*" OR "*AI education*") AND ("*critical thinking*" OR "*spatial literacy*") AND ("*geography education*" OR "*social studies*"), a total of 35 documents met the inclusion criteria. These selected studies were analyzed and categorized into four key thematic domains.

### Characteristics of Selected Literature (n = 35)

A systematic understanding of the contribution of each literature is obtained through an analysis of the main thematic focus of the selected studies. Each study is classified based on the dominant

characteristics raised, allowing the identification of research directions and theoretical and practical contributions of each theme. A summary of the classification results is presented in Table 1.

**Table 1.** Classification of Thematic Focus and Examples of Key Studies from Selected Literature

Thematic Focus	Number of Studies	Key Study Examples
Digital Interactivity	15 studies	Bodzin (2011), Liu & Lee (2020), Chen & Looi (2019)
Spatial-Social Reasoning	12 studies	Gersmehl & Gersmehl (2006), Sumarmi & Bachtiar (2022), Brown et al. (2021)
AI Personalization	5 studies	Luckin et al. (2016), Chen et al. (2021), Wang & Bower (2020)
Critical Pedagogy	3 studies	Freire (1970), Santos-Reis et al. (2022), Kim (2020)

### Key Findings per Domain

Four key findings emerged from the literature synthesis based on the identified thematic domains. The Digital Interactivity domain highlights the use of GIS, AR/VR simulations, and real-time dashboards, which have been shown to enhance spatial literacy by up to 47% (Bodzin, 2011) and significantly improve causal reasoning skills compared to traditional methods (Liu & Lee, 2020). In the Spatial-Social Reasoning domain, many studies are situated in authentic contexts such as urbanization, inequality, and climate change. The integration of spatial and social data was found to increase ethical awareness by 65% (Sumarmi & Bachtiar, 2022) and deepen students' systemic understanding (Gersmehl & Gersmehl, 2006).

The AI Personalization domain reports positive outcomes through adaptive feedback systems, AI tutors, and data-driven simulations; however, concerns about algorithmic bias and cognitive homogenization persist, with over 80% of studies emphasizing the need for algorithmic transparency (Chen et al., 2021). Although limited in number, studies in the Critical Pedagogy domain demonstrate the impact of reflective dialogue and the deconstruction of digital content. When combined with immersive experiences such as VR, critical pedagogy has shown to enhance ethical reasoning (Santos-Reis et al., 2022; Kim, 2020).

### Geographical and Methodological Distribution

Analysis of the geographical distribution and methodological approaches of the reviewed literature provides an overview of the regional trends of the studies and the diversity in the use of methods. These findings are important for understanding the epistemological context behind these studies, as well as potential biases or gaps in representation between the Global North and the Global South. A summary of the geographical and methodological distribution is presented in Table 2.

**Table 2.** Geographic and Methodological Distribution of Synthesized Studies

Aspect	Statistics
Studies from Global North	24 studies (68%)
Studies from Global South	8 studies (23%), including 4 from Indonesia
Quantitative Methods	18 studies (51%)
Qualitative Methods	12 studies (34%)
Mixed Methods	5 studies (14%)

### Identified Research Gaps

The review revealed three key research gaps. First, a clear geographical bias exists, as only 12% of the studies investigated educational contexts in Southeast Asia, highlighting a lack of representation from this important and diverse region. Second, in relation to AI and ethics, 90% of AI-related studies primarily focus on cognitive outcomes, while largely neglecting the social implications of AI integration in education (Selwyn, 2019). Third, there is a lack of longitudinal data, with very few studies tracking

the long-term impact of digital content on learners' critical awareness, which limits understanding of sustained learning effects over time.

### Implications for Future Research

Addressing these gaps calls for more focused research efforts. Future studies should prioritize AI ethics in Global South contexts, such as examining how algorithmic bias shapes spatial inequality representations in countries like Indonesia. Additionally, scholars are encouraged to develop a contextualized framework of critical digital pedagogy by integrating Freirean thought (1970) with digital constructivism (Siemens, 2005), to better respond to both ethical and cognitive dimensions in technology-enhanced learning environments.

### Five Key Representative Studies

Five representative studies were selected based on thematic relevance, methodological rigor, and citation impact, reflecting the diversity of approaches in the literature analyzed. These five studies illustrate the integration of digital content, artificial intelligence, and critical pedagogy in the context of geography and social studies education. Table 3 presents a summary of the title, main focus, and key findings of each study.

**Table 3.** Summary of Five Representative Studies in Digital and Critical Geography Education

No	Study	Title	Focus	Key Finding / Note
1	Sumarmi & Bachtiar (2022)	Digital Geography in Indonesian Context	Enhancing spatial literacy through GIS based on local issues (SINTA 1)	+41% improvement in socio-spatial analysis
2	Santos-Reis et al. (2022)	VR for Social Justice Education	Favela-based urban simulation combined with critical pedagogy (Scopus Q1)	2.5× increase in ethical reflection with guided dialogue
3	Chen et al. (2021)	Adaptive Learning Systems in STEM	Meta-analysis of AI systems for spatial literacy (Scopus Q1)	Personalization is effective when paired with critical questioning
4	Gersmehl & Gersmehl (2006)	Spatial Reasoning in Geography Education	Using "mental maps" to understand complex systems	Cited over 420 times in Scopus
5	Selwyn (2019)	Should Robots Replace Teachers?	Critique of technocratic approaches to AI in education	Technology should diversify paths of understanding, not standardize them.

### Literature Review Summary

A total of 35 relevant studies were identified from an initial pool of 520 documents using the query string: ("digital content" OR "edtech" OR "AI education") AND ("critical thinking" OR "spatial literacy") AND ("geography education" OR "social studies"). These studies were analyzed thematically to reveal key patterns, technologies used, and pedagogical implications, particularly in the context of spatial literacy and critical thinking within geography or social studies education.

Most of the selected studies emphasized the role of digital interactivity in enhancing students' spatial reasoning. Interactive tools such as Geographic Information Systems (GIS), Augmented Reality (AR), and Virtual Reality (VR) were commonly utilized. For instance, GIS applications significantly improved spatial literacy by 41% through dynamic visualization (Bodzin, 2011), while interactive mapping tools enhanced causal reasoning abilities 2.3 times more effectively than traditional methods (Liu & Lee, 2020). Local studies from Indonesia also demonstrated strong outcomes; Sumarmi

&Bachtiar (2022) reported a 47% improvement in students' socio-spatial analysis after engaging with digital geography simulations grounded in real-world urban issues.

In parallel, the incorporation of Artificial Intelligence (AI) personalization systems—such as adaptive learning platforms and AI tutors—was shown to support learners' self-regulation and engagement (Chen et al., 2021; Luckin et al., 2016). However, these benefits were often tempered by ethical concerns. Selwyn (2019), for instance, warned that algorithmic personalization could unintentionally standardize thought patterns and marginalize diverse ways of knowing. Notably, 80% of studies discussing AI stressed the urgency of algorithmic transparency and ethical safeguards, especially in culturally diverse contexts.

The theme of critical pedagogy appeared in a smaller subset of studies but brought significant conceptual depth. Freire's (1970) foundational work was frequently cited, highlighting the need for liberatory, rather than technocratic, approaches to education technology. Applied examples included VR simulations on urban inequality combined with reflective dialogue, which significantly increased ethical awareness among learners (Santos-Reis et al., 2022). Others focused on the deconstruction of bias within digital geospatial content, advocating for critical geographic media literacy (Kim, 2020). The following Table 4 highlights a sample of twelve key studies that reflect the diversity and thematic focus of the selected literature.

**Table 4.** Summary of Key Literature (n = 12 of 35)

No	Author(s) & Year	Title (Abbreviated)	Key Finding	Source & Indexing
1	Bodzin (2011)	Integrating GIS in Geography Education	GIS enhanced spatial literacy by 41% through dynamic visualization	<i>Journal of Geography</i> (Scopus Q2)
2	Sumarmi & Bachtiar (2022)	Digital Geography in Indonesian Context	Local simulations improved socio-spatial analysis by +47%	<i>Jurnal Pendidikan Geografi</i> (SINTA 1)
3	Liu & Lee (2020)	Interactive Maps for Spatial Reasoning	Interactive maps improved causal reasoning by 2.3×	<i>IRGEE</i> (Scopus Q1)
4	Santos-Reis et al. (2022)	VR for Social Justice Education	VR + critical dialogue increased ethical reflection by 2.5×	<i>Computers &amp; Education</i> (Scopus Q1)
5	Gersmehl & Gersmehl (2006)	Spatial Reasoning in Geography	"Mental maps" supported complex system analysis	<i>Geographical Review</i> (Scopus Q1)
6	Chen et al. (2021)	Adaptive Learning Systems in STEM	AI personalization effective when integrated with critical inquiry	<i>Educational Tech R&amp;D</i> (Scopus Q1)
7	Selwyn (2019)	Should Robots Replace Teachers?	Warned of cognitive reduction in uncritical AI-based learning	<i>Polity Press</i> (Book)
8	Kim (2020)	Critical Geographic Media Literacy	Deconstructing media bias improved social awareness	<i>Journal of Geography Education</i> (Q2)
9	Luckin et al. (2016)	AI in Education: Challenges & Opportunities	Adaptive systems support self-regulation but need transparency	<i>IJAIED</i> (Scopus Q1)
10	Brown et al. (2021)	Collaborative VR for Spatial Reasoning	VR collaboration enhanced socio-spatial problem-solving	<i>BJET</i> (Scopus Q1)
11	Freire (1970)	Pedagogy of the Oppressed	Advocated for education as liberation, not domination	<i>Continuum</i> (Book)

No	Author(s) & Year	Title (Abbreviated)	Key Finding	Source & Indexing
12	Wang & Bower (2020)	AI Tutor Personalization	AI tutors increased engagement, yet lacked ethical scaffolding	<i>IEEE TLT</i> (Scopus Q1)

### Distribution and Research Gaps

Geographically, 68% of studies were conducted in Global North contexts, while only 23% originated from the Global South with four studies based in Indonesia. Methodologically, the studies were predominantly quantitative (51%), followed by qualitative (34%) and mixed methods (14%). Despite growing interest in AI applications, only 14% of the reviewed studies critically addressed ethical dimensions of AI, and 90% overlooked the socio-cultural implications of deploying such technologies in non-Western settings. Most articles were sourced from Scopus-indexed journals (68%), with others from Google Scholar (20%) and SINTA (12%). The publication trend peaked between 2020 and 2023, suggesting a recent surge in interest around digital and AI-based innovations in geography and social studies education.

### Thematic Synthesis: Digital Content as Epistemological Scaffold

The analysis of 35 peer-reviewed studies reveals four interrelated dimensions through which digital content supports critical spatial and social reasoning in Geography and Social Studies education. The first dimension, digital interactivity as a cognitive catalyst, highlights how interactive geovisualizations, such as GIS platforms, AR/VR simulations, and real-time dashboards, serve as transformative tools that move beyond static, textbook-based instruction. Studies by Bodzin (2011) and Liu & Lee (2020) demonstrate that enabling students to manipulate variables in urban sprawl simulations or climate models enhances their grasp of cause-effect relationships, leading to a 32–47% improvement in spatial literacy. This supports Siemens' (2005) connectivist theory, in which digital tools act as cognitive partners in knowledge construction.

The second dimension, spatial-social reasoning through authentic contexts, is emphasized in works by Gersmehl & Gersmehl (2006) and Banks (2008), who argue that the pedagogical potential of digital content is maximized when embedded in real-world socio-spatial issues. For example, AI-generated migration maps and inequality dashboards used in Indonesian classrooms (Sumarmi & Bachtiar, 2022) enabled students to better understand abstract concepts like displacement and urban injustice, while also fostering ethical awareness and contextual reasoning.

The third dimension involves AI personalization for metacognitive growth. Adaptive learning systems that tailor geospatial problem-solving tasks to individual student ability levels show considerable promise for supporting metacognitive development. Luckin et al. (2016) found that ethically designed AI tutors enhanced learners' self-regulation, particularly when task complexity was adjusted in real-time. Nevertheless, Selwyn (2019) cautions that uncritical application of personalization risks reducing education to algorithmic optimization, thereby neglecting deeper pedagogical goals.

Finally, the fourth dimension, critical-reflective pedagogy as a counterbalance, draws on Freirean principles to resist the technocratic drift of digital education. In the study by Santos-Reis et al. (2022), students engaged in VR simulations of urban poverty exhibited significantly deeper ethical reflection when prompted by teacher-guided questioning for instance, "Whose voices are absent in this simulation?" Such practices help prevent digital tools from becoming instruments of "banking education" (Freire, 1970), ensuring they cultivate critical consciousness rather than passive consumption.

### Conceptual Integration: A Critical Digital Pedagogy Framework

Synthesizing these findings, a tripartite framework is proposed (see Fig. 1), wherein digital content functions as: 1) Cognitive Scaffold – supporting spatial inquiry through dynamic modeling, 2) Reflective Medium – enabling ethical deliberation, 3) Dialogic Platform – facilitating collaborative meaning-making between teachers and learners.

This integrated model bridges Siemens' (2005) theory of networked learning with Freire's (1970) concept of critical consciousness. It also addresses Selwyn's (2019) concern about the instrumentalization of AI by demonstrating how technology can serve both analytical and ethical dimensions. A compelling example is found in Indonesian classrooms where AI-generated flood-risk maps were used to provoke student-led debates on housing policy equity (Sumarmi & Bachtiar, 2022), showcasing the framework's capacity to transform spatial learning into democratic engagement.

## CONCLUSION AND SUGGESTION

This study highlights the critical role of thoughtfully designed digital content in enhancing spatial-social reasoning and critical consciousness within Geography and Social Studies education. Based on a systematic review of 35 peer-reviewed studies, four key pedagogical dimensions were identified: digital interactivity, spatial-social reasoning, AI personalization, and critical-reflective pedagogy. These dimensions show that digital tools—when applied beyond technocentric paradigms—can act as cognitive scaffolds, ethical platforms, and dialogic spaces for deeper learning. Substantial improvements were recorded in spatial literacy (32–47%), metacognitive development, and ethical reflection, especially when digital tools were integrated with authentic, justice-oriented pedagogy. However, current research remains limited by the dominance of Global North perspectives, the narrow focus of AI use on cognitive outcomes, and the lack of longitudinal investigations into transformative learning.

Future advancements in this field require stronger emphasis on AI ethics within Global South contexts, particularly by investigating how algorithmic systems influence spatial inequality representations in local educational settings. Development of a critical digital pedagogy—rooted in Freirean principles and enhanced through digital constructivist strategies—must become central in teacher preparation programs. Stronger research designs, especially those involving long-term and mixed-method approaches, are necessary to evaluate the sustained impact of digital learning tools on students' critical awareness. Meaningful curriculum and policy reform should position digital content as a transformative medium—one that advances democratic learning, fosters ethical inquiry, and supports inclusive knowledge-building in AI-mediated educational environments.

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