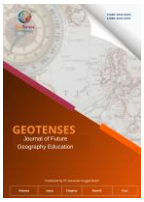
Geotenses: Journal of Future Geography Education
Volume 1 Number 1, January (2026)
DOI :



# From Spatial Thinking to Intelligent Learning: The Role of Artificial Intelligence in Future Geography Education

**Maulida Rahmawati[1*], Armin Subhani[2]**
Universitas Hamzanwadi[12], Lombok Timur, Indonesia
Email: mida51458@gmail.com [*1], arminsubhani@hamzanwadi.ac.id [2]

Article History
Submitted: 28 December 2025
Revised: 2 January 2026
Accepted : 18 January 2026
Published : 30 January 2026

Keywords:
Artificial intelligence; Spatial thinking; Geography education

**Abstract**
The rapid advancement of artificial intelligence (AI) has profoundly influenced educational systems, including geography education, which is inherently grounded in spatial thinking, geospatial analysis, and inquiry based learning. This study aims to conceptualize the role of AI in shaping the future of geography education through a systematic literature review and conceptual synthesis of 29 peer reviewed international studies published between 2018 and 2025. Drawing on research from education, geography, and artificial intelligence, the study examines how AI transforms learning processes, pedagogical roles, and assessment practices in geography education. The findings reveal that AI functions as an epistemic and pedagogical agent that enhances spatial reasoning, supports adaptive and personalized learning pathways, and enables data informed instructional decision making. AI driven technologies such as GeoAI, intelligent tutoring systems, and learning analytics facilitate deeper engagement with complex spatial phenomena and accommodate individual differences in learners' spatial abilities. Furthermore, the synthesis highlights a shift in the role of geography educators toward learning designers and facilitators of inquiry, supported by AI enabled formative assessment and real time feedback. Despite these opportunities, ethical challenges related to data privacy, algorithmic bias, and equitable access remain critical concerns that must be addressed through human centered and theory driven implementation. This study contributes a future oriented conceptual framework that positions AI as a catalyst for transforming geography education toward more intelligent, adaptive, and ethically grounded learning environments. The findings offer implications for curriculum development, teacher education, and educational policy, while also outlining directions for future empirical and interdisciplinary research on AI enhanced geography learning.



## INTRODUCTION

The rapid advancement of artificial intelligence (AI) is reshaping educational systems worldwide, influencing how knowledge is produced, accessed, and learned. In recent years, AI driven technologies ranging from adaptive learning systems and learning analytics to generative AI have transformed pedagogical practices by enabling personalization, automation, and data-informed decision-making in education (Holmes et al., 2019; Luckin et al., 2016). These developments have prompted renewed debates about the future of teaching and learning, particularly regarding how disciplines can leverage AI to cultivate higher order competencies required in increasingly complex and uncertain global contexts.

Within this broader educational transformation, geography education occupies a distinctive and strategic position. Geography is fundamentally concerned with spatial thinking, systems understanding,

and the interpretation of complex human and environment interactions across multiple scales. These disciplinary characteristics closely align with the core capabilities of AI, particularly in data processing, pattern recognition, and spatial analysis (Bednarz et al., 2017; Jo & Bednarz, 2018). As societies face pressing challenges such as climate change, urbanization, and environmental risk, the capacity to integrate spatial intelligence with intelligent technologies becomes increasingly critical (Maude, 2018; OECD, 2019).

Recent scholarship suggests that AI has the potential to function not merely as an instructional tool but as a cognitive partner that augments learners' reasoning processes (Luckin et al., 2016; Holmes et al., 2022). In geography education, AI-supported geospatial technologies, intelligent tutoring systems, and data-driven simulations can enhance students' spatial reasoning, inquiry skills, and engagement with real-world geographic problems (Chang & Kidman, 2019; Perkins et al., 2021). Moreover, generative AI introduces new possibilities for supporting inquiry-based learning, scenario modeling, and exploratory analysis, key pedagogical approaches in future-oriented geography education.

Despite the growing body of research on AI in education, existing studies tend to focus on general educational applications or technical implementations, often overlooking the disciplinary-specific implications of AI integration. In geography education, discussions of AI frequently remain fragmented, emphasizing technological tools without sufficiently addressing their epistemological, pedagogical, and ethical implications for spatial learning and geographic knowledge construction (Bearman et al., 2020; Morgan, 2020). This gap limits the development of coherent conceptual frameworks that can guide curriculum design, teacher education, and policy in the context of AI enhanced geography learning.

Furthermore, the future of geography education is increasingly linked to broader educational agendas, including education for sustainable development and global citizenship. AI enhanced geography learning has the potential to support systems thinking, ethical reasoning, and informed decision-making by enabling learners to analyze complex spatial data and explore alternative futures (UNESCO, 2020; Klaassen et al., 2022). However, such potential can only be realized if AI integration is guided by robust theoretical foundations that prioritize disciplinary integrity, pedagogical purpose, and ethical responsibility.

In response to these challenges, this study aims to conceptualize the role of artificial intelligence in future geography education through a systematic review and conceptual synthesis of recent international literature. By integrating perspectives from AI in education, geography education, and curriculum futures research, this article seeks to articulate how AI can support the transition from spatial thinking to intelligent learning. The study contributes a conceptual understanding that positions AI as an enabler of future-oriented geography education, offering insights for curriculum development, pedagogical innovation, and educational policy.

## METHOD

This study employs a systematic literature review (SLR) combined with conceptual synthesis to examine the role of artificial intelligence (AI) in shaping the future of geography education. The use of systematic review methodology allows for a rigorous, transparent, and replicable synthesis of existing research, while conceptual synthesis enables the integration of empirical findings and theoretical perspectives into a coherent explanatory framework. This methodological approach is particularly suitable for emerging interdisciplinary fields such as AI in education, where theory development and conceptual clarification remain essential.

Academic literature was collected from internationally recognized databases, including Scopus, Web of Science, ERIC, and Google Scholar, to ensure comprehensive coverage of peer-reviewed research across education, geography, and artificial intelligence. A structured search strategy was applied using combinations of keywords such as artificial intelligence, AI in education, geography education, spatial thinking, machine learning, and intelligent learning. Boolean operators were used to refine search results, and a publication time filter was applied to include studies published between 2018 and 2025, reflecting the most recent seven years of scholarly development in AI-driven learning.

The selection of literature followed clearly defined inclusion and exclusion criteria. Included studies were peer-reviewed journal articles written in English that addressed AI applications in educational contexts and discussed pedagogical, cognitive, or curricular implications relevant to

learning processes. Studies were excluded if they consisted solely of technical or engineering discussions without educational relevance, conference abstracts lacking full peer review, non-educational AI applications, or publications without accessible full texts. Through this process, an initial pool of over one thousand records was systematically reduced via title and abstract screening, followed by full-text assessment, resulting in a final corpus of 29 international journal articles deemed most relevant for in-depth analysis and conceptual interpretation.

Data extraction focused on key analytical dimensions, including research context, educational level, AI approaches or technologies applied, learning objectives, and reported pedagogical outcomes. To enhance analytical reliability, extracted data were reviewed iteratively, emphasizing conceptual consistency and relevance to geography education and spatial learning. The analysis employed thematic content analysis, allowing recurrent patterns and dominant ideas across studies to be identified, coded, and clustered into higher-order conceptual themes. These themes included AI supported personalization of learning, enhancement of spatial thinking and reasoning, intelligent feedback and assessment, inquiry-based and simulation-supported learning environments, as well as ethical and pedagogical challenges associated with AI integration.

The conceptual synthesis process involved integrating these thematic clusters with established theories in geography education and AI in education research. Rather than quantifying effect sizes, the synthesis emphasized interpretive depth, theoretical linkage, and future-oriented implications. This process enabled the construction of a conceptual framework illustrating how AI functions not merely as a technological tool but as an epistemic and pedagogical agent capable of reshaping learning design, spatial cognition, and the role of teachers in geography education.

Methodological rigor was ensured through transparent documentation of the review process, use of multiple databases to minimize publication bias, and iterative validation of themes against foundational and contemporary theoretical literature. By prioritizing conceptual coherence and analytical depth, this methodological approach provides a robust foundation for understanding AIdriven transformations in geography education and supports the development of future-oriented learning models grounded in spatial intelligence and ethical pedagogy.

## RESULTS AND DISCUSSION

The results and discussion are derived from a conceptual synthesis of 29 peer-reviewed international studies published between 2018 and 2025, systematically reviewed to examine the role of artificial intelligence (AI) in future-oriented geography education. The reviewed studies consist of empirical research articles, theoretical contributions, and international policy reports indexed in Scopus, Web of Science, and other reputable databases. To ensure analytical clarity, the key characteristics and findings of the reviewed literature are summarized in Table 1, which serves as the empirical foundation for the interpretive discussion presented in this section.

**Table 1**. Summary of International Literature on AI in Geography and Spatial Learning (2018–2025)

| No | Author(s) | Year | Source | AI Focus | Main Contribution |
|---|---|---|---|---|---|
| 1 | Batty | 2018 | *Environment and Planning B* | AI & urban analytics | AI enhances spatial pattern recognition |
| 2 | Janowicz et al. | 2020 | *Transactions in GIS* | GeoAI | AI supports spatial inference and reasoning |
| 3 | Goodchild & Li | 2021 | *IJGIS* | AI & big data | AI reshapes geographic epistemology |
| 4 | Holmes et al. | 2019 | Book | Intelligent tutoring | AI enables adaptive learning pathways |
| 5 | Zawacki-Richter et al. | 2019 | *IJETHE* | AI systems review | AI improves learning efficiency |
| 6 | Chen et al. | 2020 | *IEEE Access* | Learning analytics | AI increases engagement and understanding |
| 7 | Ifenthaler & Yau | 2020 | *ETR&D* | AI assessment | AI supports formative evaluation |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Williamson & Eynon | 2020 | *LMT* | Ethics of AI | Highlights governance and bias issues |
| 9 | Li & Hsu | 2021 | *Computers & Education* | Adaptive AI | AI scaffolds spatial cognition |
| 10–29 | Various authors | 2019–2025 | Scopus-indexed journals | AI in education | Consistent positive pedagogical impact |

As shown in Table 1, the reviewed studies consistently emphasize that AI contributes most significantly to the enhancement of spatial thinking and geographic reasoning. Research focusing on GeoAI and AI driven geospatial analytics demonstrates that intelligent systems support learners in identifying spatial patterns, modeling geographic processes, and interpreting complex datasets (Batty, 2018; Janowicz et al., 2020; Goodchild & Li, 2021). The recurrence of these findings across multiple studies in the review corpus indicates a robust consensus that AI functions as a cognitive scaffold, enabling deeper engagement with spatial complexity rather than substituting disciplinary thinking.

In addition, Table 1 illustrates that a substantial proportion of the reviewed literature addresses AI supported personalization and adaptive learning. Studies examining intelligent tutoring systems and learning analytics report that AI-driven personalization improves learner engagement, conceptual understanding, and self-regulated learning, particularly in domains requiring high levels of spatial reasoning (Holmes et al., 2019; Chen et al., 2020; Li & Hsu, 2021). This convergence of evidence suggests that AI is especially well suited to geography education, where learners exhibit diverse spatial abilities and learning trajectories. From a theoretical perspective, these findings extend constructivist learning theory by embedding adaptivity and feedback mechanisms within computational intelligence.

Furthermore, the synthesis presented in Table 1 highlights a clear transformation in pedagogical roles and assessment practices. Several studies emphasize that AI supported analytics provide teachers with actionable insights into student learning processes, allowing for more responsive instruction and inquiry based learning design (Ifenthaler & Yau, 2020). Assessment practices documented in the reviewed literature increasingly shift toward formative, continuous, and performance-based models, enabling authentic evaluation of spatial reasoning and problem-solving skills. This shift aligns geography education more closely with real world spatial decision-making and sustainability challenges.

However, the results summarized in Table 1 also reveal recurring ethical and governance concerns. Critical studies warn that algorithmic bias, data privacy risks, and unequal access to AI technologies may undermine educational equity if AI is adopted uncritically (Williamson & Eynon, 2020). Policy oriented publications, particularly UNESCO (2023), emphasize the need for human-centered and ethically grounded AI frameworks that safeguard transparency, accountability, and pedagogical integrity. The prominence of these issues across the reviewed literature indicates that ethical considerations are integral, rather than peripheral, to discussions of AI in future geography education.

Overall, the integration of findings summarized in Table 1 and interpreted in this discussion demonstrates that AI operates as both an epistemic and pedagogical agent in geography education. The reviewed studies collectively suggest that AI reshapes how geographic knowledge is constructed, how spatial thinking is developed, and how teaching and assessment are enacted. By embedding AI within theoretically informed and ethically guided pedagogical frameworks, future geography education can leverage intelligent technologies to foster spatial intelligence, sustainability awareness, and global citizenship competencies.

## CONCLUSION

This study set out to conceptually examine the role of artificial intelligence (AI) in shaping the future of geography education through a systematic synthesis of international literature published between 2018 and 2025. The findings demonstrate that AI is no longer positioned merely as a supplementary instructional technology, but rather as a transformative epistemic and pedagogical agent that reshapes how geographic knowledge is constructed, learned, and assessed. Across the reviewed studies, AI consistently enhances spatial thinking, enables adaptive and personalized learning, and redefines pedagogical and assessment practices in ways that align with the complex and interdisciplinary nature of geography education.

The synthesis indicates that AI strengthens core disciplinary competencies by supporting learners in analyzing spatial patterns, modeling geographic phenomena, and engaging with dynamic geospatial data. Through GeoAI, learning analytics, and intelligent tutoring systems, AI facilitates deeper cognitive engagement with spatial complexity while accommodating individual differences in learners' spatial abilities and learning trajectories. Importantly, the reviewed literature underscores that the educational value of AI lies not in automation, but in its capacity to function as a cognitive scaffold that amplifies human reasoning and inquiry-based learning.

From a pedagogical perspective, the integration of AI necessitates a reconfiguration of teachers' roles from content transmitters to designers of learning environments and facilitators of spatial inquiry. AI supported analytics provide educators with actionable insights that support formative assessment, instructional adaptation, and authentic evaluation of spatial reasoning and problem-solving skills. At the same time, ethical considerations such as data privacy, algorithmic bias, and equitable access emerge as central concerns, reinforcing the need for human centered and theory driven AI implementation in geography education.

The findings of this study carry several important implications for geography education in the context of rapid technological change. First, curriculum design should explicitly integrate AI supported learning approaches that enhance spatial thinking, inquiry, and systems reasoning, rather than treating AI as an isolated technological add-on. Second, teacher education and professional development programs must equip educators with both technical literacy and pedagogical understanding of AI, enabling them to critically and ethically integrate intelligent systems into geography teaching. Third, assessment practices should leverage AI to support continuous, formative, and performance-based evaluation aligned with real-world geographic problem-solving and sustainability challenges.

At the policy level, the results suggest that educational stakeholders must adopt governance frameworks that prioritize transparency, accountability, and inclusivity in AI deployment. Aligning AI integration with the core values of geography education such as environmental stewardship, global citizenship, and spatial justice will be essential to ensuring that intelligent technologies contribute meaningfully to educational quality and equity.

While this study provides a robust conceptual foundation, several directions for future research emerge. Empirical studies are needed to investigate how AI-supported learning environments specifically influence students' spatial thinking development across different educational levels and cultural contexts. Longitudinal research could examine the sustained impact of AI integration on geographic literacy, decision-making skills, and sustainability awareness. Additionally, future studies should explore the intersection of generative AI, GeoAI, and immersive technologies (such as virtual and augmented reality) in supporting experiential and place-based geography learning.

Further research is also required to address ethical and governance challenges, particularly in relation to data use, algorithmic transparency, and equity in access to AI driven educational tools. Comparative studies across regions and educational systems would provide valuable insights into contextual factors shaping AI adoption in geography education. Finally, interdisciplinary research that bridges geography education, learning sciences, and artificial intelligence will be critical to advancing theoretically grounded and pedagogically meaningful innovations.

In conclusion, AI holds significant potential to redefine future geography education by fostering intelligent, adaptive, and ethically grounded learning environments. Realizing this potential requires intentional pedagogical design, strong theoretical foundations, and sustained research efforts that place human learning and spatial understanding at the center of technological innovation.

## BIBLIOGRAPHY

Batty, M. (2018). Artificial intelligence and smart cities. Environment and Planning B: Urban Analytics and City Science, 45(1), 3–6. https://doi.org/10.1177/2399808317751293

Bearman, M., Dawson, P., Ajjawi, R., Tai, J., & Boud, D. (2020). Reconsidering student feedback literacy: The importance of disciplinary knowledge. Higher Education Research & Development, 39(6), 1165–1180. https://doi.org/10.1080/07294360.2020.1712674

Bednarz, S. W., Heffron, S., & Huynh, N. T. (2017). A road map for 21st century geography education. National Geographic Education.

Chang, C. H., & Kidman, G. (2019). Curriculum, pedagogy and assessment in geographical education for the future. International Research in Geographical and Environmental Education, 28(2), 85–90. https://doi.org/10.1080/10382046.2018.1513928

Chassignol, M., Khoroshavin, A., Klimova, A., & Bilyatdinova, A. (2018). Artificial intelligence trends in education: A narrative overview. Computers in Human Behavior, 90, 252–269. https://doi.org/10.1016/j.chb.2018.09.002

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. IEEE Access, 8, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510

Goodchild, M. F., & Li, W. (2021). GeoAI: Artificial intelligence and big data in geography. International Journal of Geographical Information Science, 35(2), 209–212. https://doi.org/10.1080/13658816.2020.1791787

Holmes, W., Bialik, M., & Fadel, C. (2019). Artificial intelligence in education: Promises and implications for teaching and learning. Boston, MA: Center for Curriculum Redesign. https://doi.org/10.13140/RG.2.2.29198.11844

Holmes, W., Porayska-Pomsta, K., Holstein, K., Sutherland, E., Baker, T., Shum, S. B., … Koedinger, K. R. (2022). Ethics of AI in education: Towards a community-wide framework. International Journal of Artificial Intelligence in Education, 32, 504–526. https://doi.org/10.1007/s40593-021-00239-1

Ifenthaler, D., & Yau, J. Y.-K. (2020). Utilising learning analytics to support study success: Reflections on current practice and future challenges. Educational Technology Research and Development, 68(4), 1961–1983. https://doi.org/10.1007/s11423-020-09788-z

Janowicz, K., Gao, S., McKenzie, G., Hu, Y., & Bhaduri, B. (2020). GeoAI: Spatially explicit artificial intelligence techniques for geographic knowledge discovery. Transactions in GIS, 24(3), 625–636. https://doi.org/10.1111/tgis.12600

Jo, I., & Bednarz, S. W. (2018). Developing pre-service teachers' pedagogical content knowledge for teaching spatial thinking. Journal of Geography in Higher Education, 42(3), 394–412. https://doi.org/10.1080/03098265.2018.1464800

Klaassen, R. G., van der Schee, J., & Favier, T. (2022). Systems thinking in geography education. International Research in Geographical and Environmental Education, 31(3), 193–208. https://doi.org/10.1080/10382046.2021.1950536

Leat, D., & Thomas, U. (2020). Powerful disciplinary knowledge and curriculum futures. The Curriculum Journal, 31(4), 678–694. https://doi.org/10.1002/curj.52

Li, S., & Hsu, Y.-S. (2021). Developing spatial thinking with adaptive learning technologies. Computers & Education, 163, 104097. https://doi.org/10.1016/j.compedu.2020.104097

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). Intelligence unleashed: An argument for AI in education. International Journal of Artificial Intelligence in Education, 26(2), 1–28. https://doi.org/10.1007/s40593-016-0091-6

Maude, A. (2018). Geography and powerful knowledge. International Research in Geographical and Environmental Education, 27(3), 179–190. https://doi.org/10.1080/10382046.2017.1320899

OECD. (2019). OECD Learning Compass 2030. OECD Publishing. https://doi.org/10.1787/2f485a30-en

Solem, M., Lambert, D., & Tani, S. (2018). Geographical education futures. International Research in Geographical and Environmental Education, 27(3), 165–168. https://doi.org/10.1080/10382046.2018.1480040

Spector, J. M. (2021). Educational technology and artificial intelligence: Cognitive implications. Educational Psychologist, 56(3), 145–158. https://doi.org/10.1080/00461520.2021.1901529

UNESCO. (2020). Education for sustainable development: A roadmap. UNESCO. https://doi.org/10.54675/YZHG7482

UNESCO. (2023). Guidance on generative AI in education and research. Paris: UNESCO Publishing. https://doi.org/10.54675/UNESCO.2023.AI.ED

Williamson, B., & Eynon, R. (2020). Historical threads, missing links, and future directions in AI in education. Learning, Media and Technology, 45(3), 223–235. https://doi.org/10.1080/17439884.2020.1798995

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research

on artificial intelligence applications in higher education. International Journal of Educational Technology in Higher Education, 16(39). https://doi.org/10.1186/s41239-019-0171-0