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Engaging Students in Learning Geography as a Multidisciplinary Subject Through GeoAI

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Abstract

Geography, a field that intertwines Earth's physical landscapes with human societies, demands innovative teaching methods to captivate K-12 students. Geospatial Artificial Intelligence (GeoAI), blending artificial intelligence with geospatial data, provides a dynamic tool to enhance geography education. This paper investigates how GeoAI, including advancements in generative AI, fosters interactive and real-world learning experiences to engage students in geography as a multidisciplinary subject. It outlines GeoAI's historical evolution, educational applications, engagement strategies, and integration challenges and opportunities in K-12 settings, supported by case studies and visual aids (GeoAI Research Group, 2025).

Keywords

GeoAI, Generative AI, Geography education, Interactive learning, Data-driven inquiry, Multidisciplinary projects

1. Introduction

Geography bridges physical and social sciences, exploring Earth's environments and human interactions. Yet, traditional K-12 geography education often fails to engage students, appearing abstract or disconnected from daily life. Innovative tools are needed to make geography relevant and multidisciplinary. Geospatial Artificial Intelligence (GeoAI), which merges AI with geospatial data, enables students to analyze real-world data and explore global issues interactively, transforming geography education (Janowicz et al., 2020; GeoAI Research Group, 2025). This paper examines GeoAI's role in engaging K-12 students, tracing its history, exploring its educational applications, including generative AI, and addressing strategies, challenges, and opportunities for classroom integration (GeoAI Research Group, 2025).

2. History and Development of GeoAI

GeoAI integrates AI with geographic information science (GIS) to tackle spatial challenges. Its roots date back to the 1980s and 1990s, when researchers developed AI-based expert systems for spatial decisionmaking (Couclelis, 1986) and early machine learning for geographic data analysis (Openshaw, 1992). These efforts established the foundation for computational spatial analysis.

The 2010s brought significant advancements, fueled by big data, high-performance computing, and deep learning (Janowicz et al., 2020). High-resolution data from satellite imagery, GPS, and volunteered geographic information (VGI) enhanced GeoAI applications. Key milestones include:

2. History and Development of GeoAI

GeoAI combines artificial intelligence (AI) with geographic information science (GIS) to solve problems related to maps and places. It started in the 1980s and 1990s and has grown into a powerful tool for understanding the world. Below are the key steps in its development, explained in simple terms:

- **Early AI in GIS**: In the 1980s, researchers created simple computer programs called rule-based systems to help solve geographic problems. These programs used "if-then" rules, like "if an area has lots of rain, then it's good for farming." For example, they could help decide where to build a new road or park by following preset rules (Couclelis, 1986). This was like teaching a computer to think like a geographer, making it easier to plan cities or protect nature.
- **Machine Learning Applications**: In the 1990s, computers got smarter with machine learning, a type of AI that learns from data without strict rules. These systems could look at satellite images and figure out what's on the ground, like forests, cities, or farmland. They also helped fill in missing map data, such as estimating rainfall in areas without weather stations. For instance, a machine learning program could identify farmland from photos, helping farmers plan better (Openshaw, 1992).
- **Deep Learning Advancements**: By the 2010s, deep learning made GeoAI even more powerful. Deep learning is like teaching a computer to think like a human brain, recognizing complex patterns in pictures or data. It can spot buildings or roads in satellite images or predict things like flood risks in a city. For example, students could use deep learning to study how a town might grow in the future, making geography lessons exciting (Janowicz et al., 2020).
- **Social Sensing and VGI**: Also in the 2010s, GeoAI started using data from smartphones and social media, called volunteered geographic information (VGI). This data shows how people move or what they say about places. For example, GeoAI can track how crowded a city is by analyzing phone locations or study public reactions to a storm by reading social media posts. This helps students understand how people interact with their environment, like mapping traffic in their town (Janowicz et al., 2020).
- **Formalization of GeoAI**: By the late 2010s, GeoAI became its own field, like a school club that gets officially recognized. Researchers formed groups and started journals, such as the International Journal of Geographical Information Science, to share ideas about GeoAI. This growth made it easier to use GeoAI in schools, helping students explore maps and data in new ways, like creating projects about their local area (Janowicz et al., 2020).

GeoAI now helps with city planning, tracking climate change, and more. In education, it makes learning interactive and connects geography to other subjects, with generative AI creating personalized lessons (Huang et al., 2025).

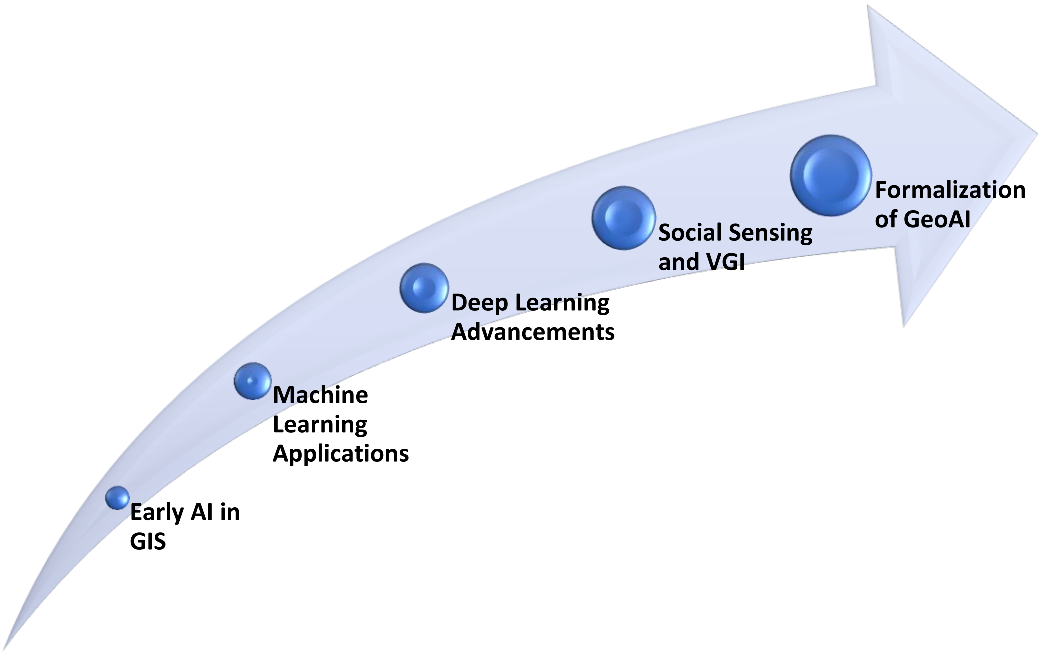

Figure 1: Timeline of GeoAI Development

Description: A visual timeline depicting GeoAI's evolution from the 1980s to 2025, highlighting early AI in GIS (1980s), machine learning (1990s), deep learning and VGI (2010s), and generative AI in education (2020s).
Source: Adapted from Janowicz et al. (2020) and Huang et al. (2025).

3. GeoAI in Education

GeoAI transforms geography education by introducing K-12 students to advanced technologies and real-world applications. It supports engaging learning experiences through:

- **Interactive Mapping**: GeoAI tools, like ArcGIS, let students create and explore maps that show real-world patterns, such as how climate change affects coastlines with rising sea levels or melting ice caps. These colorful, interactive maps make it easier for students to see and understand geographic changes, turning abstract ideas into clear visuals that spark curiosity (Esri, 2023).
- **Data-Driven Inquiry**: GeoAI helps students work with real data, like weather patterns or population growth, to answer questions about the world. For example, students can study rainfall data to predict flood risks or explore city population data to understand growth trends. This hands-on approach builds skills in analyzing information and thinking critically about what the data means (Beyoğlu & Hürsen, 2023).
- **Simulations**: GeoAI creates virtual models of processes like how cities grow or how rivers change over time. For instance, students can use GeoAI to simulate a city expanding or a forest shrinking due to deforestation, making these ideas feel real and easier to grasp. These interactive models help

students see geography in action, connecting classroom lessons to the real world (National Geographic Society, 2025).

- **Virtual Field Trips**: GeoAI platforms, like Google Earth, let students visit faraway places like rainforests, deserts, or bustling cities without leaving the classroom. For example, they can explore the Amazon rainforest or ancient ruins in Rome, learning about different environments and cultures. These virtual trips make geography exciting by connecting students to diverse places around the globe (National Geographic Society, 2025).
- **Multidisciplinary Projects**: GeoAI brings together geography with other subjects like computer science and history. For example, students might use GeoAI to map pollution in their town, combining science to study environmental impacts, coding to analyze data, and social studies to explore how communities are affected. These projects show students how geography connects to other fields to solve real problems, like cleaning up rivers or planning sustainable cities (Esri, 2023).

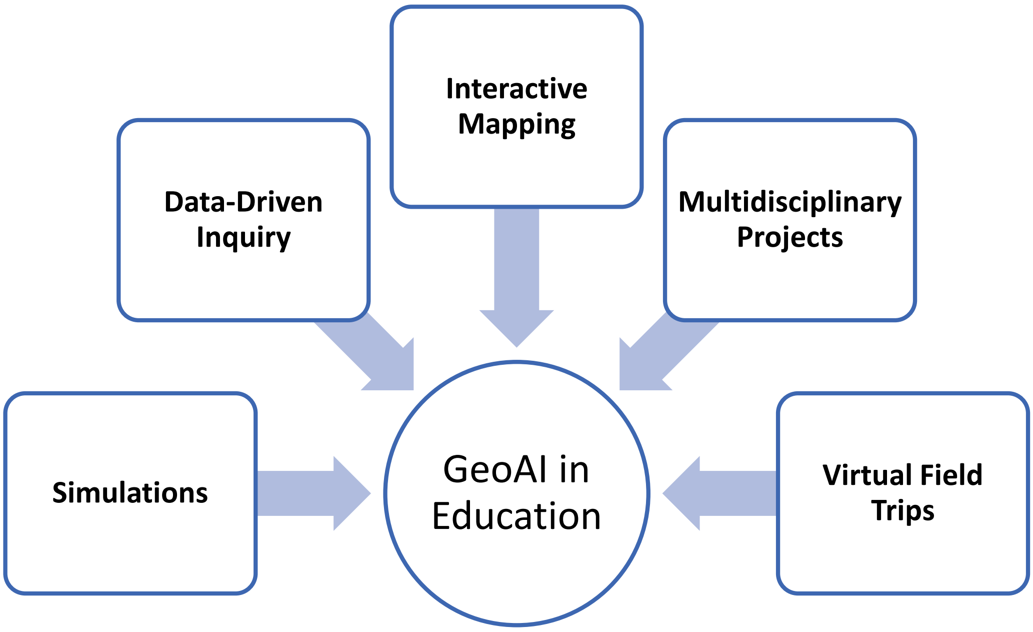

Figure 2: GeoAI Applications in K-12 Geography Education

Description: A diagram illustrating how GeoAI applications (e.g., mapping, simulations, field trips) connect to multidisciplinary outcomes like data literacy and interdisciplinary learning. Source: Adapted from Esri (2023) and National Geographic Society (2025).

3.1 Generative AI in Geography Education

Generative AI, a subset of AI that creates content such as text, images, or simulations, offers transformative potential for geography education by tailoring learning experiences to student needs and fostering creativity (Huang et al., 2025). Its applications include:

- **Personalizing Curriculum**: Generative AI can produce customized geographic content, such as interactive quizzes on local ecosystems or tailored case studies on urban development, aligning with students' interests and skill levels. For example, AI can generate region-specific climate change scenarios to make lessons relevant (Huang et al., 2025).

- **Enhancing Pedagogy**: By shifting from traditional lectures to interactive learning, generative AI enables students to engage with dynamic tools, such as AI-generated maps or simulations of geographic phenomena like erosion or population growth, fostering active learning (Puentedura, 2006).
- **Improving Assessment**: Adaptive evaluation systems powered by generative AI provide real-time feedback, adjusting question difficulty based on student responses. For instance, AI can create quizzes that adapt to a student's understanding of spatial patterns, ensuring personalized learning paths (Huang et al., 2025).
- **Augmenting Fieldwork**: Generative AI supports real-time data analysis during virtual or physical fieldwork, such as processing satellite imagery to identify land use changes. It also facilitates global collaboration by generating shared virtual environments where students from different regions analyse global issues like deforestation (Huang et al., 2025).
- **Fostering Creativity**: AI can generate hypothetical geographic scenarios, such as predicting future urban sprawl or simulating alternative climate outcomes, encouraging students to think creatively and propose solutions to real-world problems (Huang et al., 2025).
- **Ethical Considerations**: Educators must ensure generative AI outputs are accurate and free from biases, such as skewed demographic data in AI-generated maps, and teach students to critically evaluate AI content (Huang et al., 2025).

These applications align with the SAMR model, moving from substitution (e.g., replacing paper maps with digital ones) to redefinition (e.g., creating dynamic, AI-driven simulations) to transform educational tasks (Puentedura, 2006). The increasing adoption of geospatial technologies like GIS and Google Earth in K-12 education further supports GeoAI integration, with research showing a rise in related publications since the 2000s (Beyoğlu & Hürsen, 2023).

Table 1: GeoAI Tools and Platforms for K-12 Geography Education

Tool/Platform	**Description**	**Educational Benefits**	**Source**
ArcGIS StoryMaps	Tool for creating interactive geographic narratives	Enhances storytelling and visualization skills	Esri (2023)
Google Earth	Virtual globe for exploring geographic data	Boosts spatial thinking and awareness	Beyoğlu & Hürsen (2023)
National Geographic Explorer Classroom	Connects students with GeoAI-using explorers	Inspires real-world and career exploration	National Geographic Society (2025)
ChatGPT	Generative AI for revision and lesson planning	Personalizes learning and aids teachers	Logue (2023); Kenyon (2023)

Caption: Summary of GeoAI tools for K-12 geography education, detailing benefits and sources. Source: Compiled from Esri (2023), Beyoğlu & Hürsen (2023), National Geographic Society (2025), Logue (2023), and Kenyon (2023).

4. Engaging Students with GeoAI

To engage students, educators should design accessible, interactive learning experiences:

- **Project-Based Learning**: Students use GeoAI to address real-world issues, like mapping flood risks, integrating geography with environmental science (Esri, 2023).
- **Gamification**: Educational games with GeoAI, such as map-based challenges, make learning fun (National Geographic Society, 2025).
- **Collaborative Learning**: Group projects on GeoAI tasks, like analysing migration patterns, foster teamwork (Esri, 2023).
- **Real-World Applications**: Linking projects to current events, like climate change, enhances relevance (Beyoğlu & Hürsen, 2023).
- **Interdisciplinary Integration**: GeoAI connects geography with science and social studies, promoting holistic learning (Esri, 2023).

5. Case Studies and Examples

While GeoAI in K-12 education is emerging, examples from higher education and recent K-12 applications offer insights.

5.1 Higher Education and Professional Training

- **University of Florida's GEO:AI Certificate**: This program offers hands-on computing labs where students apply GeoAI to tasks such as image classification and spatial interpolation. For example, students use GeoAI to map urban heat islands, analyzing satellite imagery to identify areas with high temperatures in cities, which can be adapted for K-12 projects, such as mapping local parks or school grounds (University of Florida, 2022). These activities introduce students to advanced geospatial analysis while connecting geography with environmental science and urban planning.
- **Stanford University's GeoAI Workshops**: Stanford's workshops train educators and students in GeoAI applications for environmental monitoring, such as tracking coastal erosion using AI-analyzed satellite data. These workshops emphasize interdisciplinary projects that combine geography with data science, offering models for K-12 activities like monitoring local environmental changes (Stanford University, 2024).
- **Esri's Educational Resources**: Esri's ArcGIS StoryMaps enable students to create interactive geographic narratives that blend text, maps, and multimedia. For instance, college students have used StoryMaps to document historical migration patterns, a concept adaptable for K-12 classrooms where students could create narratives about local community changes, integrating geography with history and social studies (Esri, 2023).

- **National Geographic's Explorer Classroom**: This program connects students with explorers using GeoAI for real-world research, such as monitoring deforestation in the Amazon. Through virtual sessions, students learn how GeoAI processes satellite imagery to track environmental changes, inspiring them to explore geography-related careers and apply similar techniques to study local ecosystems (National Geographic Society, 2025).

5.2 Generative AI in Practice

- **Google Earth for Spatial Thinking**: Google Earth enhances students' geographic awareness by allowing them to explore global landscapes and analyze spatial patterns, such as urban sprawl in metropolitan areas. For example, middle school students can use Google Earth to study land use changes in their city, comparing historical and current imagery to understand urban development, which fosters critical thinking and spatial reasoning skills (Patterson, 2018; cited in Beyoğlu & Hürsen, 2023).
- **ChatGPT for Revision**: Teachers have utilized ChatGPT to create personalized revision materials, such as interactive quizzes on topics like climate zones or population dynamics. These tools adapt to students' knowledge levels, providing tailored questions and explanations to reinforce learning, making revision engaging and effective (Logue, 2023).
- **AI for Model Answers**: Generative AI has been used to produce model answers for A-Level geography topics, such as Changing Places, helping students understand the structure and depth required for high-quality responses. For instance, AI-generated answers on urban regeneration provide clear examples of analytical writing, guiding students in their exam preparation (Harding, 2023).
- **Adaptive Teaching with AI**: AI tools support adaptive teaching by tailoring instruction to individual student needs. For example, AI can generate customized lesson plans on topics like plate tectonics, adjusting content complexity based on student performance, which enhances engagement and understanding (Downs & Campbell, 2023).
- **Lesson Planning Assistance**: ChatGPT assists teachers in creating innovative lesson plans, such as activities exploring global trade routes using GeoAI tools. This saves time and introduces creative approaches, like integrating economic geography with data analysis, to make lessons more engaging (Kenyon, 2023).
- **Educational Resources**: AI tools generate diverse resources, such as quizzes, voiceovers for instructional videos, and interactive maps. For example, teachers use AI to create multimedia presentations

6. Challenges and Opportunities

Integrating GeoAI into K-12 geography education presents significant challenges and opportunities, requiring careful planning to maximize its educational impact.

6.1 Challenges

- **Teacher Training**: Many educators lack familiarity with GeoAI tools, necessitating comprehensive professional development to build confidence and competence (Beyoğlu &

Hürsen, 2023). Without training, teachers may struggle to integrate GeoAI effectively, limiting its impact.

- **Access to Technology**: The digital divide poses a barrier, with many schools lacking high-speed internet, modern devices, or software licenses needed for GeoAI applications (Beyoğlu & Hürsen, 2023). This is particularly acute in under-resourced or rural schools.
- **Curriculum Development**: Creating age-appropriate GeoAI curricula requires significant time, expertise, and resources, which many schools lack (Esri, 2023). Curricula must balance technical complexity with accessibility for young learners.
- **Over-Reliance on AI**: Excessive dependence on AI risks diminishing teachers' roles, potentially leading to a loss of pedagogical depth or unrealistic expectations for covering complex topics quickly (Hickman & Ghosh, 2023).
- **Ethical Considerations**: Data privacy, algorithmic bias, and the accuracy of AI-generated content are critical concerns. For example, biased AI outputs could misrepresent geographic data, misleading students (Huang et al., 2025).
- **Tool Complexity**: GeoAI tools, designed for professional use, may be too complex for K-12 students, requiring simplified interfaces or teacher mediation (Beyoğlu & Hürsen, 2023).
- **Teacher Resistance**: Some educators may resist adopting GeoAI due to unfamiliarity, fear of technology replacing their roles, or skepticism about its educational value (Hickman & Ghosh, 2023).

6.2 Opportunities

- **Enhanced Learning Experiences**: GeoAI creates interactive, immersive learning environments, such as virtual field trips or real-time data visualizations, that engage students beyond traditional textbooks (Esri, 2023). For instance, students can explore global ecosystems interactively, increasing motivation.
- **Career Preparation**: Early exposure to GeoAI equips students with skills for careers in geospatial technology, urban planning, and environmental science, aligning with growing industry demands (National Geographic Society, 2025).
- **Interdisciplinary Learning**: GeoAI fosters connections between geography, computer science, and social studies, promoting a holistic understanding of global issues like climate change or urbanization (Beyoğlu & Hürsen, 2023).
- **Global Citizenship**: By analysing real-world geographic data, GeoAI helps students understand global challenges, fostering empathy and responsibility as global citizens (National Geographic Society, 2025).
- **21st-Century Skills**: GeoAI projects develop critical skills like problem-solving, data analysis, and digital literacy, essential for future academic and professional success (Esri, 2023).

Table 2: Challenges and Solutions for Integrating GeoAI in K-12 Classrooms

Challenge	**Description**	**Solution**	**Source**
Teacher Training	Limited familiarity with GeoAI tools	Offer professional development workshops	Beyoğlu & Hürsen (2023)
Access to Technology	Insufficient school infrastructure	Invest in internet, devices, and community partnerships	Beyoğlu & Hürsen (2023)
Curriculum Development	Need for age-appropriate curricula	Collaborate with experts to design curricula	Esri (2023)
Over-Reliance on AI	Risk of reducing teacher roles	Balance AI with teacher-led instruction	Hickman & Ghosh (2023)
Ethical Considerations	Data privacy and AI bias concerns	Implement ethical guidelines and transparency	Huang et al. (2025)
Tool Complexity	GeoAI tools too complex for K-12 students	Develop simplified interfaces for young learners	Beyoğlu & Hürsen (2023)
Teacher Resistance	Reluctance to adopt new technologies	Provide incentives and support for adoption	Hickman & Ghosh (2023)

Caption: Comparison of challenges and solutions for GeoAI integration in K-12 education. Source: Compiled from Beyoğlu & Hürsen (2023), Esri (2023), Hickman & Ghosh (2023), and Huang et al. (2025).

7. Conclusion

GeoAI transforms K-12 geography education by enabling interactive, data-driven learning. Its evolution from early GIS applications to a field incorporating generative AI highlights its educational potential (Janowicz et al., 2020; Huang et al., 2025). Despite challenges like training, access, and ethical concerns, GeoAI fosters engaging, multidisciplinary learning. Educators, policymakers, and technology providers must:

- Offer professional development for GeoAI tools.
- Ensure equitable technology access.
- Develop age-appropriate curricula.

By leveraging GeoAI, educators can inspire students to explore geography with curiosity and creativity, preparing them for global challenges (Esri, 2023; National Geographic Society, 2025; GeoAI Research Group, 2025).

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