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TOWARDS AI-DRIVEN GEOSPATIAL EDUCATION: A CURRICULUM REFORM FRAMEWORK FOR GEOMATICS PROGRAMS IN TRANSITION ECONOMIES.

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ABSTRACT: Geomatics Education in transition economies faces a dual challenge: maintaining foundational skills in Surveying and Mapping while integrating disruptive technologies such as artificial intelligence (AI), machine learning, and smart geospatial systems. As global industries increasingly rely on AI-driven geospatial intelligence for urban planning, environmental monitoring, disaster management, and sustainable development, geomatics programs must undergo curriculum reform to remain relevant and effective. This paper proposes a curriculum reform framework that embeds AI literacy, geospatial data science, and interdisciplinary collaboration into traditional geomatics education. The framework rests on three pillars: integrating AI tools and methods into core courses, encouraging partnerships between academia, industry, and government to ensure applied relevance, and cultivating ethical and critical thinking to address data governance and societal impacts. Utilizing a qualitative research design built upon the Context, Descriptor, and Coherence (CDC) curriculum development model and a thematic analysis of international initiatives, the framework demonstrates how transition economies can leapfrog developmental barriers and produce graduates capable of harnessing AI-driven geospatial systems for evidence-based decision-making. By situating geomatics education within the broader context of digital transformation, the study positions these programs as catalysts for innovation, resilience, and sustainable growth. Graduates trained under this model are prepared to meet the challenges of a rapidly evolving geospatial landscape while upholding ethical standards and contributing to socially inclusive, sustainable development.

Keywords: Geomatics Education; AI-Driven Curriculum; GeoAI; Transition Economies; Sustainable Development; Triple Helix Model; Digital Leapfrogging; Ethical Geospatial Governance

INTRODUCTION

The field of geospatial science is increasingly integrating traditional surveying methods with advanced computational tools, particularly artificial intelligence (AI) and machine learning. As these technologies become more widely applied in areas such as urban planning, environmental management, and disaster response, geomatics education must adapt to remain relevant (Kamel Boulos et al., 2019; Li & Hsu, 2022; Song et al., 2023). For geomatics programs in transition economies, countries shifting toward market-based systems or expanding their industrial capacity, this creates a distinct challenge. These programs must preserve strong foundations in core areas such as geodesy and mapping while incorporating emerging digital tools and intelligent geospatial systems (Janowicz et al., 2020). Achieving this balance is essential for developing the skills required to support innovation and sustainable development.

At the same time, the geospatial industry is undergoing a transformation comparable to the earlier shift from paper-based cartography to digital Geographic Information Systems (GIS). Driven largely by the increasing use of AI in geospatial analysis, this shift is reshaping how spatial data is collected, processed, and applied in decision-making (Retscher, 2025). More importantly, it is expanding access to geospatial tools and redefining professional roles within the field (Mai et al., 2025). Advances in natural language AI and large language models (LLMs) now enable users to pose complex spatial queries in everyday language, reducing reliance on highly specialized technical skills and repositioning GIS professionals as analysts and decision-support experts (Kang et al., 2024). This transformation is not only technological but also functional, affecting how key tasks are performed across the traditional geomatics workflow toward AI-driven advancements.

In addition, AI and machine learning are addressing long-standing limitations of traditional GIS, particularly in processing large, real-time datasets and modelling complex environmental systems (Kamel Boulos et al., 2019; Song et al., 2023). These technologies integrate diverse data sources, including satellite imagery, drone data, and crowdsourced information, to identify patterns and generate actionable insights. In areas such as disaster management, the integration of GIS with AI-driven predictive models supports real-time monitoring and early warning systems for hazards such as floods and landslides (Diehr et al., 2025; van Geenhuizen & Nejabat, 2023).

However, these advances also introduce new challenges. There is an increasing need for professionals who can ensure data quality, interpret model outputs, and address ethical concerns associated with automated spatial decision-making (Guillen-Aguinaga et al., 2025; Wen & Li, 2023). Despite these emerging demands, many geomatics curricula, particularly in transition economies, have been slow to incorporate AI-driven competencies in a structured and context-specific manner (Yoo, 2026). While existing studies examine GeoAI applications and technological innovation, there is limited work that integrates these developments into a coherent framework for curriculum reform within such contexts. This gap highlights the need for a systematic approach to curriculum transformation. Accordingly, this study proposes a framework for integrating AI-driven geospatial competencies into geomatics education, with particular emphasis on the institutional and developmental realities of transition economies. To address this gap and provide an actionable pathway for institutional modernization, this study establishes clear benchmarks for educational adaptation. Specifically, the formal research objectives of this paper are to:

1. Identify and categorize the core computational and data science competencies required to transition from traditional GIS to AI-driven geospatial workflows within transition economies.
2. Develop a conceptually coherent curriculum reform framework based on a three-phase structured design (Context, Descriptor, Coherence) and the Triple Helix model of innovation.
3. Evaluate international curriculum initiatives to validate practical mitigation strategies for overcoming financial, human capital, and institutional barriers to GeoAI integration.

LITERATURE REVIEW

GeoAI combines artificial intelligence, particularly machine learning and deep learning, with geospatial data to enable advanced spatial analysis. It enables geographic knowledge discovery without relying entirely on predefined models, allowing systems to learn patterns directly from data (Pierdicca & Paolanti, 2022; Song et al., 2023). As a result, tasks such as land-use classification, object detection from 3D point clouds, and semantic segmentation can be automated, improving both efficiency and accuracy in geospatial analysis.

In practical terms, GeoAI has been applied in areas such as disaster management, where it supports the processing of large volumes of real-time data for early warning systems. Integrating GIS with AI-based predictive models addresses limitations in speed, scale, and data complexity (Wang et al., 2024). Applications also extend to urban studies, environmental monitoring, health geography, and cartography (Li & Hsu, 2022; Liu & Biljecki, 2022; Song et al., 2023). However, while these studies demonstrate the analytical potential of GeoAI, they often focus on technical performance rather than the implications for education and professional training. In addition, concerns related to data privacy, algorithmic bias, and transparency have prompted increasing attention to interpretable and ethically responsible models (Janowicz et al., 2020).

Alongside these technological developments, the institutional context of innovation remains critical. The Triple Helix (TH) model explains how interactions between academia, industry, and government shape innovation systems (Etzkowitz, 2018). In more developed economies, this relationship has evolved into a relatively balanced and flexible structure, with universities playing a central role in linking knowledge production to practical application. However, in many transition economies, these interactions remain uneven, with strong government control and limited collaboration between universities and industry constraining innovation (Etzkowitz, 2003; Etzkowitz & Leydesdorff, 1995). This weak integration contributes to the persistent gap between research and real-world application, often referred to as the “valley of death” (Landoni & Muradzada, 2024). While the Triple Helix model provides a useful framework for understanding these dynamics, its application to curriculum design and educational reform remains underexplored.

In parallel, the concept of educational leapfrogging offers a lens for understanding how transition economies can respond more rapidly to technological change (Lee, 2017). Rather than following traditional development pathways, institutions can adopt advanced digital tools such as virtual laboratories, online learning platforms, and competency-based training systems (Pak et al., 2020). The COVID-19 pandemic accelerated this shift, highlighting the importance of digital resilience and adaptability in higher education systems (Afolabi & Olajuyigbe, 2022; Ossiannilsson, 2022). However, the effectiveness of such approaches is uneven and often constrained by infrastructure limitations and institutional capacity.

More broadly, strengthening digital and educational resilience is essential to building adaptable learning systems that can respond to future disruptions. It also supports wider development goals, including sustainability and inclusive education. While existing studies show that digital innovation can help institutions in transition economies overcome structural limitations (Adamu et al., 2025; Chatzinikolaou, 2025; Mai et al., 2025), there remains limited integration of these insights into a coherent framework for curriculum reform that combines technological, institutional, and ethical dimensions.

Ultimately, a critical synthesis of these three distinct streams of literature reveals a clear path forward for curriculum architecture. While GeoAI establishes the raw computational competencies and automated spatial analysis workflows required by modern graduates, its deployment cannot happen in an institutional vacuum. The persistent structural fragmentation and the university-industry "valley of death" identified in transition economy applications of the Triple Helix model demonstrate that updating technical course content alone is insufficient; curriculum reform must be structurally coupled with industry needs and government policy. Furthermore, because accelerated educational leapfrogging and rapid AI adoption inherently introduce severe data privacy vulnerabilities, systemic biases, and infrastructural inequalities, these changes cannot be purely functional. They must be anchored by clear ethical frameworks. By drawing these threads together, this paper argues that an effective geomatics curriculum overhaul requires a triadic integration of technical, structural, and ethical dimensions, a theoretical alignment that directly shapes the three-pillar framework operationalized through the methodology that follows.

METHODOLOGY

This study adopts a qualitative research design to develop a curriculum reform framework for geomatics education in transition economies. The design process is guided by an adaptation of the "CDC" (Context, Descriptor, Coherence) model originally conceptualized by Rata (2021). While Rata's foundational work focuses on knowledge-rich curriculum theory—emphasizing the structure of specialized knowledge—this study operationalizes those theoretical tenets into a pragmatic, three-phase curriculum design methodology. By translating Rata's epistemological framework into structural design phases, the CDC model ensures that the technical depth of the curriculum is structurally anchored and contextually relevant (Fig 1). The first phase, Context, focuses on defining the guiding principles and parameters for the framework. This involves identifying key challenges facing geomatics programs in transition economies and establishing design principles that prioritise depth of learning, flexibility, and adaptability to different regional contexts (Pierre Gouëdard et al., 2020).

The second phase, Descriptor generation, involves identifying the core competencies required for AI-driven geospatial education. This is achieved through thematic analysis of existing geomatics curricula and relevant industry standards, including international professional frameworks such as those developed by the International Federation of Surveyors (FIG) and the United States Geospatial Intelligence Foundation (USGIF) (Rata, 2021). The analysis focuses on emerging skill areas such as AI literacy, geospatial data science, and interdisciplinary problem-solving.

The third phase, Coherence, ensures that the identified competencies are logically structured and aligned with broader innovation systems. In this study, alignment is achieved using the Triple Helix framework, which links academic training with industry needs and government priorities. This step is important for ensuring that the proposed curriculum is not only academically sound but also institutionally relevant and sustainable (Kolmos et al., 2016). To support the framework development, the study also draws on selected case studies from regions such as Nepal, Armenia, and Southeast Asia. These examples provide practical insights into how curriculum reforms have been implemented in similar contexts and help to validate the applicability of the proposed frameworks.

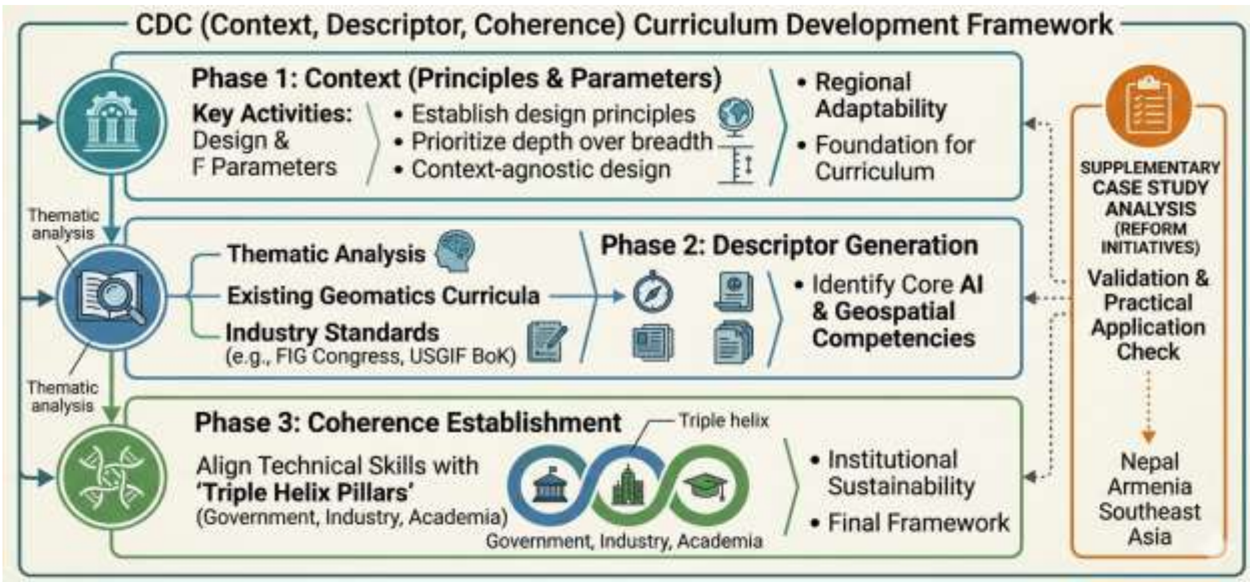

Figure 1: *CDC Framework Methodology*

(Adapted from Rata, E. (2021). What is a knowledge-rich curriculum? *The New Zealand Annual Review of Education*, 26, p. 30)

To validate the framework's practical utility, four national initiatives were purposively selected as case studies: Nepal, Armenia, Malaysia, and India. The selection was governed by three specific criteria to ensure both representativeness and transferability across diverse institutional environments:

i. Economic and Sectoral Alignment: All four nations represent transition or expanding economies undergoing rapid digital transformation, where traditional geomatics structures are being forced to adapt to disruptive tech clusters.
ii. Varied Structural Governance: The cases reflect diverse institutional models within the Triple Helix spectrum, ranging from highly centralized, state-led initiatives (e.g., Malaysia's e-Cadastre systems) to collaborative, committee-driven academic overhauls (e.g., Nepal's BE Geomatic Engineering curriculum revisions).
iii. Demonstrated GeoAI Deployment: Each chosen country possesses documented, peer-reviewed empirical evidence of applied GeoAI or smart city frameworks (such as the convolutional neural network mapping initiatives in Yerevan, Armenia), providing a concrete baseline for linking educational competencies to actual industrial outputs.

ANALYSIS AND DISCUSSION

Pillar 1: Technical Integration and GeoAI Literacy

The first pillar focuses on integrating AI literacy into the core geomatics curriculum. Rather than treating artificial intelligence as a separate or optional component, it should be embedded within foundational courses such as geodesy, photogrammetry, remote sensing, and GIS (Mojžíšek et al., 2025). This approach reflects the increasing importance of data-driven methods in geospatial analysis and the need for graduates who can operate across both traditional and computational domains.

Table 1: Evolution of Geomatics Tasks from Traditional to AI-Driven Approaches

Geomatics Task	Traditional Methodology	AI-Driven Advancement	Primary Benefit
Data Collection	Manual surveying, fixed-line systems	UAVs, satellite swarms, IoT sensors	Faster data acquisition and real-time updates
Data Processing	Manual digitization, rule-based coding	Deep learning, automated extraction	Improved scalability and reduced errors
Spatial Analysis	Query-based, static overlays	Predictive modeling, GeoAI	Enhanced forecasting and pattern detection
Visualization	2D/3D static maps	Digital twins, AR/VR, dynamic simulation	More interactive and immersive insights
User Interaction	Expert-only software interfaces	Natural language processing (NLP)	Increased accessibility for non-experts

Sources: (Diehr et al., 2025; Landoni & Muradzada, 2024; Pierdicca & Paolanti, 2022)

This integration requires moving beyond a purely software-based training approach toward a stronger emphasis on geospatial data science. In practice, students must develop programming skills, particularly in Python, alongside familiarity with key libraries such as GeoPandas for spatial data handling and TensorFlow or PyTorch for machine learning applications. The growing scale and complexity of geospatial data also necessitate exposure to cloud computing environments and MLOps practices, which support the deployment and management of models in real-world settings (Chimbunde & Moreeng, 2024).

Evidence from applied case studies highlights the relevance of these competencies. For example, research conducted in Yerevan, Armenia, shows that Convolutional Neural Networks (CNNs) can achieve accuracy levels of up to 92.4% in urban land-use mapping, significantly improving upon traditional classification methods (Mkhitaryan et al., 2025). Such applications demonstrate the practical value of AI-driven techniques in enhancing decision-making, particularly within transition economies. To support this shift, specific technical competencies should be prioritised within the curriculum, as summarised in Table 2. While foundational knowledge remains essential, there is increasing emphasis on the ability to work with automated systems, large datasets, and predictive models (Rahman, 2026). These competencies are critical for preparing graduates to meet the evolving demands of the geospatial industry. This technical integration forms the foundation upon which institutional collaboration and ethical governance, discussed in the subsequent pillars, can be effectively operationalized.

Table 2: Core Competencies for GeoAI-Driven Geomatics Education

Skill Category	Core Competencies	Future Professional Requirement
Programming	Python, R, SQL	Ability to develop data-driven geospatial workflows
Machine Learning	Supervised/unsupervised learning, CNNs	Training and validating GeoAI models
Data Management	Cloud platforms, big data frameworks, MLOps	Managing large-scale spatiotemporal datasets
Spatial Science	GIS, GNSS, geodesy, photogrammetry	Integrating foundational knowledge with AI tools
Advanced Analysis	Pattern recognition, predictive modelling	Extracting actionable insights from complex datasets

Pillar 2: Structural Collaboration and the Triple Helix Model

The second pillar focuses on strengthening collaboration between academia, industry, and government as a foundation for sustainable curriculum reform. This is grounded in the Triple Helix model, which emphasizes how innovation emerges through interactions between universities (knowledge creation), industry (application and commercialization), and government (policy and regulation) (Chatzinikolaou, 2025; van Geenhuizen & Nejabat, 2023). In the context of geomatics education in transition economies, such collaboration is essential for aligning academic training with real-world needs.

A key challenge in these contexts is the persistent gap between academic research and industry application, often described as the "valley of death", which is the vulnerable transitional phase where high-potential academic research fails to secure the commercial funding or industry partnership necessary to develop into practical, real-world applications (van Geenhuizen & Nejabat, 2023). Addressing this gap requires more structured and sustained engagement across sectors. In practice, this includes initiatives such as student internships, collaborative research projects, and curriculum co-design involving industry stakeholders (Liu et al., 2018). These approaches help ensure that graduates develop relevant skills while enabling industry to benefit from emerging research and talent.

Government also plays a critical role by providing policy direction and targeted funding aligned with national priorities, such as smart city development, digital land administration, and disaster risk management (Etzkowitz, 2018; Guillen-Aguinaga et al., 2025). In addition, hybrid structures such as innovation hubs and science parks can facilitate collaboration by creating shared spaces for experimentation and knowledge exchange.

Evidence from transition contexts illustrates the effectiveness of such partnerships when they are deliberately structured. In Nepal, curriculum revision processes involve benchmarking against regional standards and consultation with joint committees of academic and industry representatives (Kolmos et al., 2016). Similarly, in Malaysia and India, public–private partnerships, particularly in initiatives such as e-Cadastre systems and smart city programmes, have contributed to the modernization of geospatial practices while influencing training and professional standards (Azmi & Zin, 2011; Mudde et al., 2024). These examples demonstrate that coordinated collaboration can act as a catalyst for both educational and sectoral transformation. Overall, the Triple Helix model provides a practical framework for embedding curriculum reform within a broader innovation system, ensuring its relevance, sustainability, and long-term impact in rapidly evolving technological environments.

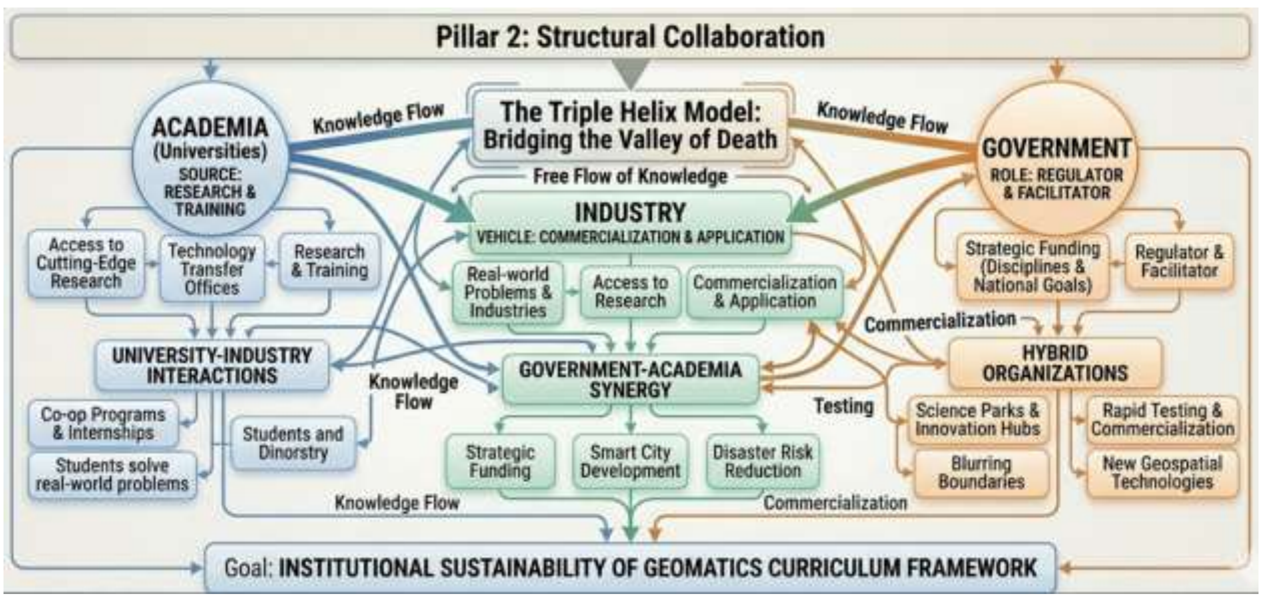

Figure 2: Curriculum Framework for Pillar 2: Structural Collaboration and the Triple Helix Model (Adapted from "Innovation Governance: From the 'Endless Frontier' to the Triple Helix," by Etzkowitz, H. (2018) *Knowledge and Space*, 12, p. 295).

Pillar 3: Ethical Governance and GeoEthics

The third pillar addresses the societal and ethical dimensions of geospatial technology, emphasizing responsible data governance and critical thinking. As AI systems become more autonomous and pervasive, geomatics professionals face increasing risks related to data privacy, algorithmic bias, and surveillance (Specht & Kent, 2024). Preparing students to navigate these challenges is essential to ensure that geospatial technologies are applied in a responsible and equitable manner.

Curriculum components under this pillar must systematically address the social dimensions of automated mapping, beginning with geo-privacy and confidentiality. Within this domain, students must learn to implement advanced techniques such as anonymization, differential privacy, and data minimization to robustly protect individual identities within expanding spatiotemporal datasets. This technical safeguard must be conceptually paired with training in bias mitigation, which highlights how historical and social inequalities can easily become embedded in foundational geospatial datasets, ultimately leading to discriminatory outcomes in infrastructure planning and public resource allocation. Furthermore, to ensure transparency and explainability, the curriculum must train future graduates to build interpretable GeoAI models and equip them to communicate complex automated model outputs clearly to non-expert users and public stakeholders. Finally, these core responsibilities require a firm grounding in legal and regulatory literacy, ensuring that students are deeply familiar with both global and localized data protection frameworks, such as the GDPR and the EU AI Act, and can fluidly navigate their direct operational implications for ongoing geospatial research and professional practice.

This pillar is reinforced by international frameworks that guide ethical AI deployment. UNESCO's Recommendation on the Ethics of Artificial Intelligence provides a normative foundation, while initiatives such as the Locus Charter emphasize principles including minimal data collection and the protection of vulnerable groups (UNESCO, 2021). Integrating these standards into geomatics education can foster a culture of ethical responsibility and accountability. Overall, ethical governance and Geo-Ethics are not peripheral considerations but core requirements of modern geomatics education, equipping graduates to balance technological capability with social responsibility.

Strategies for Curriculum Reform and Implementation

Implementing comprehensive curriculum reform in transition economies requires a multi-stage, policy-driven approach that addresses both technical and structural barriers. Successful reform involves not only updating course content but also aligning institutional processes, stakeholder priorities, and industry expectations. A practical example of such a process can be seen in the revision of the Bachelor of Engineering (BE) program in Geomatics in Nepal (Oli & Jaishi, 2026). This case illustrated a systematic approach to curriculum transformation through stakeholder engagement and evidence-based planning.

The reform process begins with benchmarking, which involves collecting information on emerging geospatial technologies, such as UAVs, digital twins, and AI-driven tools, and examining the curricula of neighboring countries to ensure both regional and global relevance (Oli & Jaishi, 2026). This step helps establish a foundation for a curriculum that balances traditional geomatics competencies with modern computational and analytical skills. Next, drafting involves subject matter experts preparing a preliminary curriculum that integrates these emerging technologies, alongside revised learning outcomes, practical exercises, and interdisciplinary modules (Tseng et al., 2020). This stage emphasizes the need to blend core technical skills with AI literacy, data science, and hands-on experience with modern instruments.

The peer review stage provides critical quality control. The draft curriculum is evaluated by an expert committee, typically comprising deans, department heads, and industry representatives. Feedback at this stage ensures that the proposed curriculum meets professional standards, aligns with industry expectations, and addresses societal and ethical considerations (Oli & Jaishi, 2026). Finally, institutional approval formalizes the process. The revised curriculum is submitted to the University Senate or equivalent governing body for final endorsement, after which it is implemented for new student cohorts. This staged process ensured that reform is both deliberate and sustainable, providing a model that other transition economies can adapt to modernize their geomatics education programs effectively.

Overcoming Barriers to Implementation

Transitioning to an AI-driven geomatics curriculum presents several challenges, particularly in contexts where financial resources are limited and institutional structures are heavily influenced by legacy practices. One of the most significant hurdles is financial investment. High-performance computing infrastructure, specialized software licenses, and ongoing system maintenance can impose substantial costs that are often difficult for universities in transition economies to absorb (UNGGIM, 2020). Another challenge lies in human capital. Globally, there is a shortage of professionals who possess expertise in both geospatial science and AI, making it difficult to recruit qualified instructors capable of delivering the new curriculum. Institutional and bureaucratic factors can also impede reform, particularly in systems where hierarchical "statist" models and centralized decision-making dominate (Azmi & Zin, 2011). To address these challenges, programs can implement targeted mitigation strategies (Guillen-Aguinaga et al., 2025; Mojžíšek et al., 2025; UNGGIM, 2020).

To successfully mitigate these institutional hurdles, programs can adopt a multi-faceted approach centered on open platforms, scalable resource architecture, and aggressive faculty upskilling. First, the strategic adoption of open-source tools and platforms, such as QGIS, Python, and OpenStreetMap, can significantly alleviate crushing software licensing costs, foster highly collaborative learning environments, and stimulate grassroots technical innovation. This is effectively supplemented by cloud-based education systems, where structured partnerships with prominent cloud service providers supply students with massively scalable computing resources without demanding substantial, upfront institutional investments in localized high-performance hardware. Underlying these technical adjustments is the critical necessity for continuous professional development, which uses structured faculty upskilling programs, targeted international fellowships, and intensive training workshops to ensure that instructional staff remain highly proficient in both emerging AI applications and foundational geospatial methodologies. Table 3 summarizes the main barriers and their corresponding mitigation strategies:

Table 3: Challenges and Mitigation Strategies for AI-Driven Curriculum Reform

Readiness Dimension	Challenge in Transition Economies	Mitigation Strategy
Financial	High cost of technology and infrastructure	Open-source software, cloud-based labs
Human Capital	Shortage of AI-Geospatial experts	Faculty upskilling, international fellowships
Institutional	Statist models, bureaucratic inertia	Decentralization, Triple Helix pilot programs
Technical	Fragmentation of data systems	National Spatial Data Infrastructures (NSDI)
Cultural	Resistance to automated decision-making	Ethical training, transparency frameworks

The Role of GeoAI in Smart Urbanism and Sustainability

The practical impact of the proposed curriculum reform is most evident in applications related to smart cities and sustainable land management. In urban contexts such as Yerevan, the integration of AI with GIS helps overcome challenges associated with governance fragmentation and institutional inertia by providing timely, location-specific, and actionable insights (Wang et al., 2024). Advanced spatial analysis, when combined with AI techniques enables policymakers to identify critical environmental risk drivers, including land surface temperature variations, vegetation health, and urban heat islands (Tim et al., 2020).

In this framework, land use functions both as a driver and an outcome of sustainability outcomes. Unmanaged or poorly planned urban expansion can increase resource inefficiency, exacerbate environmental degradation, and heighten vulnerability to climate-related hazards (Mkhitaryan et al., 2025). By training geomatics students to model land-use change, forecast degradation, and simulate alternative planning scenarios, transition economies can enhance resilience and advance Sustainable Development Goal 11 (Sustainable Cities and Communities). The framework further emphasizes that the combination of machine learning, geospatial technologies, and qualitative institutional diagnostics is crucial for guiding smart city planning (Mudde et al., 2024). Graduates equipped with these skills are better positioned to support evidence-based decision-making, optimize urban resource allocation, and promote environmentally sustainable urban growth.

Educational Leapfrogging: Acceleration and Resilience

Educational leapfrogging refers to the strategic adoption of innovations to accelerate learning outcomes and address global inequalities. In the context of geomatics, this involves integrating next-generation teaching tools such as gamification, virtual reality laboratories, and competency-based, self-paced online modules. These approaches help bridge the “geospatial digital divide” by providing high-quality, interactive learning experiences that align with the expectations of digital-native students (Landoni & Muradzada, 2024). However, the process of leapfrogging requires careful planning. While bypassing traditional stages can accelerate progress, it may also introduce challenges, including heightened cybersecurity risks and the marginalization of learners with limited digital literacy. To be effective, leapfrogging strategies must be inclusive and supported by robust regulatory frameworks. Ultimately, the success of educational leapfrogging depends as much on institutional culture, faculty readiness, and organizational adaptability as it does on technological adoption (Azmi & Zin, 2011; Hanif et al., 2026).

Conclusion

The shift toward AI-driven geospatial education represents a necessary evolution for geomatics programs in transition economies. The proposed curriculum framework positions these programs as catalysts for innovation by integrating technical AI competencies with institutional collaboration and ethical governance. In this context, the role of the geomatics professional is evolving from a traditional data collector to an intelligent conductor of spatial information systems. This transformation extends beyond the adoption of AI as a tool for efficiency; it requires structural changes in curriculum design, infrastructure, human capacity, and regulatory frameworks.

Graduates must be equipped not only with technical proficiency but also with the ability to navigate complex, "wicked" geospatial challenges and contribute to evidence-based decision-making in dynamic environments. Grounding education in the principles of the Triple Helix model, alongside robust ethical frameworks, ensures that future professionals can operate responsibly, collaboratively, and effectively.

Integrating AI into geomatics does not replace the surveyor's role but redefines it. The ongoing paradigm shift toward GeoAI integration is reshaping the industry, creating opportunities for professionals who can combine human judgment with automated systems. Those who embrace continuous learning, interdisciplinary collaboration, and ethical responsibility will be best positioned to harness the full potential of geospatial intelligence. Ultimately, the success of curriculum reform depends on sustained commitment across academia, industry, and government to ensure that the benefits of digital transformation are both inclusive and sustainable.

While this framework provides a conceptually coherent pathway for curriculum reform, its design carries certain limitations that must be acknowledged. First, because the framework relies primarily on qualitative conceptual modeling and purposive desk-based international case evaluations, it lacks immediate longitudinal empirical data regarding actual graduate performance and employer feedback post-implementation. Second, the structural implementation of the Triple Helix alignment remains highly dependent on regional policy flexibilities, meaning that rigid bureaucratic inertia or hyper-centralized political contexts may experience varying degrees of friction not fully captured by this generalized model. To address these boundaries, future research should focus on conducting empirical, longitudinal tracking of pilot geomatics programs that adopt these AI-driven modules. Additionally, future studies would benefit from establishing localized quantitative metrics to evaluate the exact computing infrastructure costs and human capital training hours required across different tiers of transition economies, thereby offering a more granular, operational blueprint for academic administrators globally.

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