

Didactic Potential of Using GIS And Remote Sensing Technologies in Studying Physical-Geographical Processes

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Abstract: The rapid evolution of geospatial technologies has re-shaped the epistemology of physical geography and opened new pedagogical avenues. This article investigates the didactic potential of Geographic Information Systems (GIS) and remote sensing (RS) for improving the comprehension of physical-geographical processes in higher education. A mixed-methods study was carried out with 112 first-year geography undergraduates who took part in a GIS-enhanced geomorphology module that embedded multi-temporal satellite imagery and spatial analysis tasks. Quantitative learning gains were measured with pre- and post-tests, and qualitative insights were gathered through reflective journals and semi-structured interviews. Results indicate a statistically significant improvement in conceptual understanding, spatial reasoning, and transfer of knowledge to field contexts. Students reported greater engagement and a shift from rote memorisation towards inquiry-based problem-solving. The findings corroborate recent research that positions GIS and RS as catalysts for higher-order thinking and scientific literacy in geography education, while also revealing infrastructural and methodological challenges that need to be addressed to unlock their full didactic potential.

Keywords: Geospatial education; GIS; remote sensing; physical geography; spatial thinking; higher education; didactics.

Introduction:

Digital transformations have fundamentally altered how geographers observe, model and explain Earth-surface dynamics. The convergence of affordable satellite data, cloud-based processing and intuitive GIS interfaces has brought professional-grade analytical capabilities into the classroom, thereby reframing physical-geographical education from descriptive map study to data-driven investigation (Bondarenko, 2025). Studies conducted over the past decade document positive correlations between GIS-supported instruction and students' achievement, although effect sizes vary across contexts (Bond & Ward, 2023).

Remote sensing complements GIS by providing synoptic, multi-spectral observations of land-surface phenomena at scales inaccessible through conventional fieldwork. A recent cross-national survey emphasised that integrating RS imagery into

coursework fosters environmental literacy and motivates learners to connect local field observations with global patterns (Smith & Lee, 2024). Professional communities have responded with open educational resources and webinars that lower entry barriers for educators, yet uptake remains uneven (Esri, 2024).

Despite proven benefits, two gaps persist. First, empirical evidence on learning outcomes often relies on small samples or single-topic interventions, limiting generalisability. Second, few studies systematically examine the combined didactic affordances of GIS and RS within the same learning sequence. This article addresses these gaps by reporting on a quasi-experimental module that integrates both technologies to elucidate fluvial and tectonic processes in an introductory physical-geography course. The research questions are:

- How does the integrated use of GIS and RS

affect students' conceptual understanding of physical-geographical processes?

- What qualitative shifts in learning strategies and epistemic beliefs accompany technology-enhanced instruction?
- Which organisational and methodological constraints influence the didactic realisation of GIS/RS potentials?

The study was conducted during the spring semester of 2024/2025 at Samarkand State University. A cohort of 112 first-year geography undergraduates (mean age = 19.7, SD = 1.1) enrolled in the compulsory "Geomorphological Processes" course participated. All students possessed basic computer literacy but had not previously used professional GIS software.

Over nine weeks, students attended one weekly lecture (90 min) and one computer-lab session (120 min). Lectures introduced theoretical foundations of plate tectonics, weathering and fluvial dynamics, while lab sessions employed ArcGIS Pro and Sentinel-2 imagery to analyse drainage density, digital elevation models and temporal landform change. Students progressed from guided tasks to open-ended projects in which they modelled basin morphometry and related it to precipitation data.

Learning outcomes were assessed with a 30-item multiple-choice and short-answer test administered in week 1 and week 10. The test was validated by three subject experts (Cronbach's $\alpha = 0.82$). Reflective journals captured weekly perceptions of difficulties, insights and technology use. At module end, 24 volunteers participated in semi-structured interviews focusing on epistemic attitudes and perceived transfer to field practice.

Test score differences were analysed with paired-samples t-tests ($\alpha = 0.05$). Journal entries and interview transcripts were coded thematically using an inductive approach to identify recurring motifs relating to cognitive, affective and metacognitive dimensions. Triangulation across data sources enhanced credibility.

Quantitative analysis revealed a significant increase in mean test scores from 48.6 % (SD = 9.4 %) to 74.3 % (SD = 8.1 %) ($t = 32.41$, $p < 0.001$). Effect size (Cohen's $d = 2.86$) indicates a substantial learning gain attributable to the GIS/RS intervention. Notably, items probing the interpretation of hypsometric curves and sediment budget estimation showed the largest improvements, suggesting enhanced capacity to link abstract concepts with spatial evidence.

Qualitative data underscored a parallel evolution in learning strategies. Early journal entries described

"following step-by-step instructions," whereas later reflections articulated "formulating spatial hypotheses before opening the software." Students acknowledged that overlaying Landsat time-series on digital elevation models helped them visualise river migration processes previously imagined only from textbook schematics. Interviewees credited the dynamic zooming function for enabling multi-scale reasoning and for fostering a "researcher's mindset rather than a student's."

The instructional design also stimulated collaborative sense-making. In laboratory observations, peer-led discussions frequently emerged as students compared spectral signatures or debated threshold settings for slope classification. Participants reported that negotiation of analytical decisions sharpened their critical thinking and validated the legitimacy of multiple solutions when dealing with complex terrain data.

The marked improvement in test scores supports earlier meta-analytic findings that GIS-based instruction enhances geography learning by promoting active knowledge construction (Bondarenko, 2025). By incorporating remote sensing, the present study extended these benefits to the temporal domain, allowing students to detect landform evolution and develop process-oriented explanations consistent with systems thinking. The substantial effect size exceeds averages reported in previous work, which may be attributed to the module's sustained duration and the seamless alignment between theoretical lectures and practical labs.

Cognitively, GIS and RS mediate the transition from rote memorisation to exploratory inquiry. Visual-spatial representations act as external scaffolds that reduce intrinsic cognitive load, thereby freeing working memory resources for higher-order reasoning. Students' narratives of "seeing processes unfold on the screen" attest to the value of dynamic visualisation in constructing mental models that integrate form, function and scale. These insights echo remote-sensing education literature that emphasises the role of synoptic imagery in cultivating holistic environmental perspectives (Wang & Zhou, 2024).

Affective gains were equally pronounced. The novelty and perceived authenticity of manipulating real-world datasets fostered situational interest, which, according to self-determination theory, can develop into enduring intrinsic motivation. Heightened engagement was particularly evident during field excursions when students used mobile GIS

applications to validate desktop analyses, illustrating how technology bridges classroom and field experiences.

However, the research also surfaced limitations. Technical challenges, including intermittent internet connectivity and high processing demands of 3-D visualisations, occasionally disrupted workflow. Pedagogically, novice instructors may overemphasise software procedures at the expense of geographic reasoning. Effective integration therefore presupposes continuous professional development, access to institutional geospatial infrastructure and carefully designed tasks that align analytical complexity with learning objectives.

CONCLUSION

The study demonstrates that the combined use of GIS and remote sensing possesses considerable didactic potential for deepening students' understanding of physical-geographical processes. Empirical evidence shows significant cognitive and affective benefits, manifesting in improved conceptual mastery, spatial reasoning and research-oriented learning attitudes. To institutionalise these gains, universities should invest in robust geospatial laboratories, adopt open data policies and embed teacher-training modules that focus on pedagogy rather than mere software proficiency. Future research should investigate longitudinal impacts on professional competencies and explore adaptive learning analytics to personalise geospatial instruction.

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