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Strengthening Geospatial Literacy Through High School–University Collaboration: A Multi-Site Tiered Desktop–Cloud GIS Model

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ABSTRACT

Geospatial literacy is increasingly important for students' ability to interpret spatial information and solve data-based problems. However, many Indonesian schools still face constraints in teacher readiness, technological infrastructure, and contextualized learning materials. This study investigates how structured high school–university collaboration can strengthen geospatial literacy through a collaboration-management model and a tiered desktop–cloud GIS learning pathway. It used a qualitative multi-site instrumental case study with embedded quantitative descriptive indicators, including a program-suitability survey and pre/post rubric-based competency scores. Data were collected through interviews, observations, focus group discussions, questionnaires, and document analysis across three collaboration sites in Jakarta–Depok, Yogyakarta, and Bandung. Five interrelated components shaped implementation: collaborative governance, a tiered competency-based curriculum, open, shared geospatial infrastructure (QGIS, Google Earth Engine, and OpenStreetMap), sustained teacher professional development, and authentic project-based learning. Program suitability was high overall (84.6% Agree/Strongly Agree), students produced 45 GIS-based projects, and 89% of participants completed the required artifacts for their assigned tier. Mean rubric scores improved from pre to post in spatial analysis (45–82), GIS software proficiency (38–79), geospatial problem-solving (42–78), and data interpretation (51–85). Improvements are reported as absolute, normalized, and relative gains, with caution that relative gain may overstate change when baseline scores are low. The findings provide a reusable collaboration and implementation model for expanding desktop–cloud GIS learning in secondary education; the quantitative indicators triangulate the qualitative evidence and should not be interpreted as causal effects.

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1. Introduction

Geospatial literacy—the capacity to read, interpret, analyze, and communicate spatial information—has become a core competency for 21st-century learners as societies increasingly rely on geospatial data for decision-making in areas such as disaster risk reduction, climate resilience, public health, and sustainable planning. In parallel, Geographic Information Systems (GIS) have shifted from optional classroom tools to foundational technologies for spatial analysis in the digital economy; recent work underscores that the ability to work with geospatial information is increasingly prerequisite for meaningful participation in digitally mediated society (Olatoye & Nkwenti, 2024; Roy et al., 2024).

Consistent with this shift, educational research shows that integrating GIS into secondary schooling can strengthen students' spatial reasoning, statistical interpretation, and confidence in engaging with spatial patterns (Rizou & Klonari, 2022). Indonesian evidence likewise reports gains in conceptual understanding and analytical reasoning when GIS learning is implemented with appropriate instructional design (Manakane et al., 2023). Yet these benefits are not automatic: limited infrastructure, uneven teacher expertise, and the scarcity of contextualized learning materials routinely constrain implementation, and these constraints are amplified in blended or remote settings where teacher readiness and technical support are decisive (Tosun, 2024).

These constraints are particularly consequential in Indonesia, where the country's archipelagic geography and ongoing national spatial-data initiatives increase the need for geospatially capable

human resources. Policy directions such as the One Map Policy have elevated expectations for geospatial data use and literacy across sectors (Kementerian Koordinator Bidang Perekonomian Republik Indonesia, 2023). However, GIS integration in schools remains uneven and vulnerable to discontinuity because infrastructure and professional support vary widely, and access to locally relevant datasets and learning resources is often limited (Fleischmann et al., 2020; Humble, 2023).

Recent Indonesian evidence indicates that teacher readiness and facilitating conditions remain uneven. For example, a national survey of geography teachers reported that overall digital readiness was adequate, but routine technology utilization and infrastructure support varied substantially, prompting recommendations for needs-based training and strengthened infrastructure (Ware & Putri, 2025). In vocational geography contexts, teachers' acceptance of GIS has likewise been shaped by external support and facilitating conditions rather than perceived ease of use alone (Bakri et al., 2020).

High school–university collaboration is often presented as a practical way to reduce GIS implementation gaps through knowledge transfer, shared facilities, co-developed modules, and mentoring (Olatoye & Fru, 2025). However, prior collaboration studies have more often emphasized program benefits than the management structures and implementation routines needed to sustain such work across sites.

In this study, we use the term learner autonomy (rather than "independent generation") to describe students' increasing capacity to make consequential decisions in GIS-supported inquiry—including selecting a locally relevant problem, identifying and documenting data sources, planning and executing an analysis workflow, and communicating map-based evidence with progressively reduced scaffolding. Autonomy-related practices were evidenced primarily through qualitative accounts (interviews/FGDs), observation notes, and artifact documentation (workflow logs, reflective notes, and peer-review records). The rubric-based assessment (Methods) operationalizes geospatial competence (i.e., assessable performance in GIS-enabled tasks) rather than autonomy as a standalone quantitative construct.

Despite growing interest in GIS-supported learning, prior studies commonly report outcomes from single-site implementations or describe instructional activities without specifying the management structures needed to sustain cross-institutional collaboration. The novelty of this study lies in (a) articulating and evidencing a geospatial literacy management model for high school–university partnership, and (b) linking that management architecture to a tiered desktop–cloud GIS learning pathway with rubric-based evidence of student competence and autonomy across multiple regions.

Across the GIS-in-schools literature, many studies focus on single-site interventions, tool-specific learning activities, or short-term training effects, while providing limited detail on the governance routines, sustainability mechanisms, and cross-institutional implementation packages required to maintain collaboration at scale. As a result, readers often cannot reproduce how partnerships are organized (e.g., decision rights, accountability routines, and resource-sharing arrangements) or how these structures link to assessable learning evidence across sites.

Accordingly, this multi-site study analyzes collaborative geospatial literacy programs implemented in Jakarta–Depok, Yogyakarta, and Bandung to address three research questions: (1) What constitutes an effective geospatial literacy management model within high school–university collaboration? (2) What key components are required to implement and sustain such collaborative programs? and (3) How do students' geospatial competence indicators and autonomy-related practices (as evidenced in artifacts and participant accounts) evolve within the collaboration program? The study's objective is to derive a coherent, scalable model and implementation package that can inform policy, curriculum design, and institutional practice in Indonesian secondary education.

2. Method

This section describes the research design and paradigm, study sites and participants, data generation procedures, and the qualitative and quantitative analysis steps used in this multi-site case study.

2.1. Research Design

This study employed a qualitative approach using an instrumental case study design to gain an in-depth understanding of high school–university collaboration in strengthening geospatial literacy (Kekeya, 2021). This design was selected because it enables comprehensive exploration of the complexity of collaborative programs, their implementation dynamics, and their educational implications within natural settings. In addition to the qualitative case evidence, the study embedded quantitative measures (a 5-point program-suitability survey and a pre/post rubric-based competency assessment) to triangulate perceived program suitability with performance evidence.

Paradigm and integration strategy. The study is situated in an interpretivist case-study paradigm, aiming to explain how collaboration was organized and enacted within naturalistic school settings. Quantitative components were embedded as descriptive indicators within the broader qualitative case design (embedded mixed-methods), used to triangulate perceptions and artifact-based performance evidence rather than to estimate causal effects.

The research was conducted across three regions in Indonesia that have implemented collaborative programs in geospatial literacy, Jakarta and Depok (collaboration between SMA Negeri 8 Jakarta and Universitas Indonesia), Yogyakarta (collaboration between SMA Negeri 1 Yogyakarta and Universitas Gadjah Mada), and Bandung (collaboration between SMA Negeri 3 Bandung and Institut Teknologi Bandung). Site context. All participating schools were public senior high schools (SMA Negeri) located in large urban or peri-urban areas, each with an established partnership with a nearby university. Programs had been running for at least two years prior to data generation. Across sites, access to devices, internet stability, and dedicated GIS lab time varied; collaboration mitigated these constraints through shared modules, rotating lab access, and scheduled university-facility sessions for higher-compute tasks.

The study spanned 12 months, from January to December 2025. Participants were selected through purposive sampling based on the following criteria: (1) programs had been running for at least two years, (2) complete program documentation was available, and (3) willingness to participate in the study. Across the three sites (total), the sample included nine school principals and program coordinators, twelve supervising lecturers and researchers, eighteen geography and ICT teachers, sixty student participants (twenty per location), and six alumni who continued their studies in related fields. Student participants were drawn across Grades X–XII to represent the three curriculum tiers (Foundational–Advanced). Because students were enrolled in different tiers during the 12-month study window, completion rates in the Results refer to completion of the required artifacts for the tier in which students participated during the study year (not completion of all three tiers by every student).

2.2. Data and analysis procedures

Data collection was conducted through methodological triangulation (Schlunegger et al., 2024). First, semi-structured interviews were carried out with all participant categories to explore program implementation, emerging challenges, and perceived outcomes. Second, participatory observations were conducted during GIS learning activities, workshops, project mentoring sessions, and other collaborative events, which were documented through field notes and photo/video records. Third, document analysis was performed on program curricula, learning modules, student GIS projects, activity reports, and statistical data. Finally, focus group discussions were held with student participants to gain deeper insights into their learning experiences and perceptions.

Data generation detail, Semi-structured interviews were conducted with each participant category (n = 63; ~35–70 minutes per interview). Participatory observations covered GIS lessons, workshops, mentoring clinics, and university-lab sessions (n = 30; approximately 90 observation hours). Focus group discussions were conducted with students at each site (n = 6; 6–8 participants; ~75–90 minutes). Document analysis included program curricula/modules, MoUs and meeting minutes, activity reports, student artifacts (maps, workflow logs, reports), and assessment records (n = 168).

Data analysis followed thematic analysis procedures, including: (1) familiarization through repeated reading of transcripts, (2) initial coding to identify meaning units, (3) grouping codes into themes, (4) reviewing and refining themes, (5) defining and naming themes, and (6) producing the analytical report.Analytic detail. Coding combined inductive open coding (to surface site-specific implementation practices) with a structured cross-case framework to organize themes around governance, curriculum

progression, infrastructure, capacity building, and authentic PjBL routines. A codebook was iteratively refined through analytic memoing, and themes were reviewed against raw transcripts, field notes, and documents to ensure internal coherence and cross-site plausibility. Coding was conducted by three members of the author team; a subset of transcripts was double-coded to check consistency, and disagreements were resolved through discussion and memo-based justification.

Cross-case synthesis proceeded in two stages. First, within-case analyses were conducted for each collaboration site (Jakarta–Depok, Yogyakarta, and Bandung) to identify site-specific implementation routines, enabling conditions, and evidence of student learning products. Second, patterns were compared across cases to derive shared themes and a consolidated five-component management framework. The embedded quantitative indicators (survey agreement levels and rubric-based pre/post scores) were analyzed descriptively and used to triangulate—rather than to claim causal attribution—the qualitative accounts and artifact evidence.

Within-case memos were first produced for each site (context, routines, constraints, and outputs). Sites were then compared using a matrix to identify convergent mechanisms (shared routines) and site-specific adaptations. The five-component management framework was derived by retaining elements that were (a) evidenced across at least two sites, (b) linked to documented implementation routines, and (c) connected to the production of tier-aligned artifacts.

To enhance trustworthiness (credibility, transferability, dependability, and confirmability), the study applied: (1) triangulation across sources, methods, and researchers; (2) member checking by verifying key interpretations with participants; (3) peer debriefing with geography education experts; and (4) an audit trail documenting sampling decisions, instrument versions, coding steps, and analytic memos throughout the research process.

2.3. Program intervention and assessment instruments

Intervention structure. Across sites, the collaboration implemented a three-tier curriculum (Foundational—Grade X; Intermediate—Grade XI; Advanced—Grade XII) delivered through blended sessions (school-based lessons, university-lab visits, and mentoring clinics). Each tier culminated in an assessed artifact (map layout and workflow documentation at the Foundational tier; an intermediate analysis project using geoprocessing tools at the Intermediate tier; and an advanced, locally grounded capstone project at the Advanced tier) with increasing emphasis on student autonomy and peer review. This tiered and mentored structure is consistent with evidence that sustained, partnership-based GIS learning designs can support skill development through routinized practice opportunities rather than one-off exposure (McKenzie et al., 2022), and with research showing that students' GIS learning involves distinct interaction strategies that benefit from structured scaffolding and progression (Berendsen et al., 2023). Blended delivery is also increasingly documented as a viable approach for maintaining continuity of GIS learning while extending access to digital resources and specialist facilities (Bedair et al., 2022).

Program dosage. Across sites, the Foundational tier comprised approximately 12 sessions (~24 hours), the Intermediate tier 14 sessions (~28 hours), and the Advanced tier 16 sessions (~32 hours). Delivery was blended, combining school-based sessions with scheduled university-lab visits for higher-compute activities; mentoring clinics occurred approximately biweekly (every two weeks) and supported project development and peer review. Where dosage differed by site, adaptations were made to fit school timetables and infrastructure constraints.

Geospatial tool stack and data quality. The baseline stack used open and widely available platforms: QGIS for desktop GIS, OpenStreetMap as a volunteered geographic information source for local features, and Google Earth Engine for cloud-based remote-sensing and large-scale raster analysis (Tamiminia et al., 2020). Because OSM coverage and quality can vary by context, "high-quality geospatial data" in this study refers to datasets with documented provenance, scale/resolution, metadata (including CRS), internal consistency (topology/attribute sanity checks), and a license that permits educational use—criteria aligned with empirical work demonstrating systematic variability in OSM completeness/accuracy patterns at scale (Zhou et al., 2022). Sites contextualized projects using locally relevant datasets while maintaining these minimum quality criteria.

Access and data governance. Students accessed Google Earth Engine via individual Google accounts with access managed through a university-administered shared Cloud Project (no paid billing) and

Google Groups, and project data were stored using a structured shared Google Drive repository (site → cohort → project) mirrored to a university server with weekly backups. All datasets used in student projects were documented for provenance, CRS, and licensing/attribution (including OSM and remote-sensing sources). Projects avoided sensitive personal geodata; when location data could identify individuals or schools, records were aggregated or anonymized in line with school ethics guidance.

Rubric-based competency assessment. To quantify change in geospatial competence, student performance was assessed pre- and post-program using a rubric aligned to four dimensions: (1) spatial analysis (e.g., selecting and justifying an analytical operation), (2) GIS software proficiency (e.g., layer management, symbology, geoprocessing execution), (3) geospatial problem-solving (e.g., problem framing, method selection, validation), and (4) data interpretation (e.g., reading outputs, articulating uncertainty, and drawing evidence-based conclusions). Artifacts were scored on a 0–100 scale derived from rubric criteria. This approach is supported by recent synthesis evidence that rubric-based assessment can yield positive, measurable effects on performance-related outcomes and learning regulation when criteria are explicit and consistently applied (Panadero et al., 2023). To improve scoring dependability, a subset of artifacts was double-scored by trained raters and discrepancies were resolved through adjudication—procedures consistent with validity-oriented scoring guidance emphasizing consistency and reliability checks in rater-mediated assessments (Elosua, 2022).

Rubric development and scoring quality. Rubric indicators were drafted from the GIS-in-education assessment literature and aligned to the tiered artifact requirements. The rubric was reviewed by five geography/GIS education experts and piloted on 15 artifacts to refine descriptors and scoring anchors. Raters received structured training using exemplar artifacts. A subset of artifacts (approximately 25%) was double-scored, and inter-rater reliability was computed using ICC (two-way random effects, absolute agreement) (value = 0.86). Discrepancies were resolved through adjudication and rubric-anchor reference.

Computation of improvement. The manuscript reports three complementary indicators of change in rubric scores: (1) absolute gain (post − pre), (2) normalized gain ((post − pre) / (100 − pre)) × 100, and (3) relative gain ((post − pre) / pre) × 100. Relative gain is included for continuity with prior program reporting but can inflate change when baseline scores are low; therefore, interpretations prioritize absolute and normalized gains. All values are reported alongside the underlying pre/post mean scores and the aggregation rule (per student, then averaged across sites).

3. Results and Discussion

3.1. Results

Cross-case findings across the three high school–university collaboration sites yielded a comprehensive geospatial literacy management framework comprising five interrelated components: (1) collaborative governance, (2) a tiered competency-based integrated curriculum, (3) infrastructure and technology support, (4) sustainable capacity-building programs, and (5) a learning ecosystem beyond the classroom. Across sites, program documents and participant accounts described a governance structure comprising a joint Steering Committee, an Operational Coordination Team, specialized Working Groups, and an Advisory Board involving geospatial industry practitioners and government representatives. The curriculum was organized into three progressive levels: Foundational (Grade X), Intermediate (Grade XI), and Advanced (Grade XII). Data indicate that 89% of students successfully completed the required artifacts for their assigned tier during the study year, suggesting strong feasibility and adherence of this progression model. Table 1 summarizes how each management component was operationalized across sites to support implementation and sustainability.

Table 1. Operationalization of the five management components in the collaboration program.

Component	Operationalization in this program
Governance	Steering & operational teams; MoU; schedule; role clarity; accountability routines
Tiered curriculum	Foundational → Intermediate → Advanced; rubric-aligned artifacts; gradual release of scaffolding

Component	Operationalization in this program
Shared infrastructure	QGIS + OSM + optional GEE; baseline device/internet requirements; data governance and QA/QC
Teacher capacity building	Co-planning; mentoring clinics; observation/feedback cycles; shared modules and rubrics
Authentic PjBL ecosystem	Local problems; peer review; public-facing map products; reflection on uncertainty/limitations

Tier completion criteria, required artifacts, and assessment foci are summarized in Table 2. In brief, the Foundational tier emphasizes map literacy, basic CRS understanding, and reproducible workflows in QGIS. The Intermediate tier emphasizes applied geoprocessing, basic validation, and interpretation of outputs. The Advanced tier emphasizes problem framing, multi-source integration, justification of analytical choices, and audience-oriented communication of uncertainty and limitations.

Table 2. Tier completion criteria and assessment artifacts

Tier (Grade)	Core competencies (examples)	Primary tools	Required artifact	Assessment focus (rubric indicators)
Foundational (X)	Map literacy; CRS basics; vector data handling; basic symbology and layout	QGIS; local/open basemaps	Map layout + workflow log (data sources, CRS, steps)	Cartographic conventions; correct CRS; clean attributes; reproducible steps
Intermediate (XI)	Geoprocessing (buffer/overlay/join); basic validation; simple spatial statistics	QGIS; OSM layers	Mini-project analysis map + short methods note	Appropriate method selection; correct processing; basic QA/QC; interpretation
Advanced (XII)	Problem framing; multi-source data integration; model justification; communication to audience	QGIS + optional GEE; OSM; open RS data	Capstone project (map + report + presentation)	End-to-end reasoning; uncertainty/limitations; evidence-based conclusions; autonomy

To evaluate program suitability, questionnaire data were collected from teachers and students participating in the initiative. Table 3 presents the distribution of responses across five categories: Strongly Agree (SS), Agree (S), Neutral (N), Disagree (TS), and Strongly Disagree (STS).

Table 3. Distribution of Questionnaire Responses on Program Suitability

Response Category	Frequency (n)	Percent (%)
Strongly Agree (SS)	91	37.9
Agree (S)	112	46.7
Neutral (N)	36	15.0
Disagree (TS)	1	0.4
Strongly Disagree (STS)	0	0.0
Total	240	100.00

Source: Research Data, 2025

Note: Table 3 reports aggregated Likert ratings across the program-suitability scale. The ratings combine responses from students (n = 45) and teachers (n = 15) across four survey items (k = 4), producing n = 240 rating selections. Because the table presents aggregated ratings, it should be interpreted as an overall indication of perceived suitability rather than as subgroup-specific evidence for students and teachers separately.

The data reveal strong positive perceptions regarding the program's suitability. A combined 84.6% of responses (SS and S) expressed agreement with program components, while only 0.4% indicated disagreement and none expressed strong disagreement. These findings indicate positive overall

perceptions of the collaborative program's design and implementation at the aggregate level. This pattern aligns with previous research suggesting that systematically designed collaborative programs that are responsive to participant needs tend to receive strong support from educational stakeholders (Griffiths et al., 2020). Research by Le et al. (2018) likewise indicates that direct involvement in collaborative learning design can increase ownership and acceptance of the program. Therefore, the findings suggest that successful implementation depends not only on technical feasibility but also on alignment with the expectations and needs of educational users.

Table 4. Improvement in Geospatial Competency Components

Competency Component	**Pre-Program (%)**	**Post-Program (%)**	**Relative Gain (%)**	Absolute Gain (points)	Normalized Gain (%)
Spatial Analysis Skills	45	82	82	37	67
GIS Software Proficiency	38	79	108	41	66
Geospatial Problem-Solving	42	78	86	36	62
Data Interpretation	51	85	67	34	69

Source: Research Data, 2025

Note: Relative gain (%) represents ((post − pre) / pre) × 100. Absolute gain represents (post − pre) points. Normalized gain (%) represents ((post − pre) / (100 − pre)) × 100. All values are rounded to the nearest whole number.

Table 4 shows notable improvement across all geospatial competency dimensions following program implementation. In absolute terms, scores increased by 37 points in spatial analysis, 41 points in GIS software proficiency, 36 points in geospatial problem-solving, and 34 points in data interpretation. Normalized gains ranged from 62% to 69%, indicating moderate-to-substantial improvement across dimensions. Relative gain values are reported for transparency, but they should be interpreted cautiously because lower baseline scores can inflate percentage change.

Collaboration also enhanced student access to technological infrastructure through GIS laboratories in high schools supported by universities, provision of software licenses or open-source alternatives, access to high-quality geospatial data, online learning platforms, and periodic use of university facilities. The adoption of open-source tools such as QGIS, Google Earth Engine, and OpenStreetMap proved effective in addressing cost constraints while promoting principles of open science (Rosas-Chavoya et al., 2022).

Technical implementation notes. To support replication and day-to-day feasibility, the partners documented a baseline technical setup for schools: a 64-bit operating system, at least 8 GB RAM, and stable internet connectivity for cloud tasks (Google Earth Engine access and dataset retrieval), while university laboratories were scheduled for sessions requiring higher computing capacity. For OpenStreetMap activities, students were oriented to basic data ethics (avoiding sensitive personal information), attribution and licensing, and simple quality-assurance checks (e.g., cross-checking features against recent imagery and local knowledge).

Throughout the academic year, student participants completed 45 GIS-based research projects addressing local geographic issues, including flood risk mapping, urban green space analysis, school accessibility studies, and agricultural land-use planning. These authentic learning experiences enabled students to apply geospatial concepts to real-world problems.

Representative project vignettes illustrate how geospatial competence was enacted in authentic tasks. (1) Flood risk mapping projects typically combined elevation/slope layers and land-use information with local drainage observations to produce exposure maps and prioritized mitigation zones using overlay and reclassification workflows in QGIS. (2) Urban green space analyses frequently used satellite-derived vegetation proxies in Google Earth Engine to compare neighborhoods and to relate green cover patterns to built-up intensity, followed by cartographic communication in QGIS. (3) School accessibility studies often extracted road networks and points of interest from OpenStreetMap to estimate relative travel impedance and to visualize service gaps, paired with a short interpretive report that justified assumptions and noted limitations.

The cross-site results—high program suitability, strong progression through the tiered curriculum, substantial gains across geospatial competencies, and the completion of 45 authentic projects—indicate that the collaboration operated as a coherent system rather than a collection of isolated activities. Accordingly, this Discussion addresses the three research questions while drawing on three complementary lenses: (1) constructivism/cognitive apprenticeship to explain scaffolded mastery and gradual release of responsibility; (2) project-based learning to interpret the role of authentic, locality-relevant inquiry; and (3) TPACK to explain how teachers integrated tools, content, and pedagogy through sustained mentoring.

3.2. Discussion

Across Jakarta–Depok, Yogyakarta, and Bandung, the cross-case evidence points to three linked patterns. First, the collaboration functioned as a coherent implementation system comprising five interlocking components collaborative governance, a tiered competency-based curriculum, open/shared infrastructure, sustained teacher capacity building, and authentic project-based learning—experienced by participants as feasible and suitable. Second, implementation depended on these components operating in concert: standardizing on open and cloud platforms (QGIS–OSM with optional GEE) and shared facilities reduced access constraints, while locality-relevant projects anchored learning in meaningful inquiry. Third, the embedded quantitative indicators and artifact portfolio suggest within-program improvements in students' geospatial competence and autonomy-related practices; these indicators triangulate the qualitative accounts and should not be interpreted as causal effects.

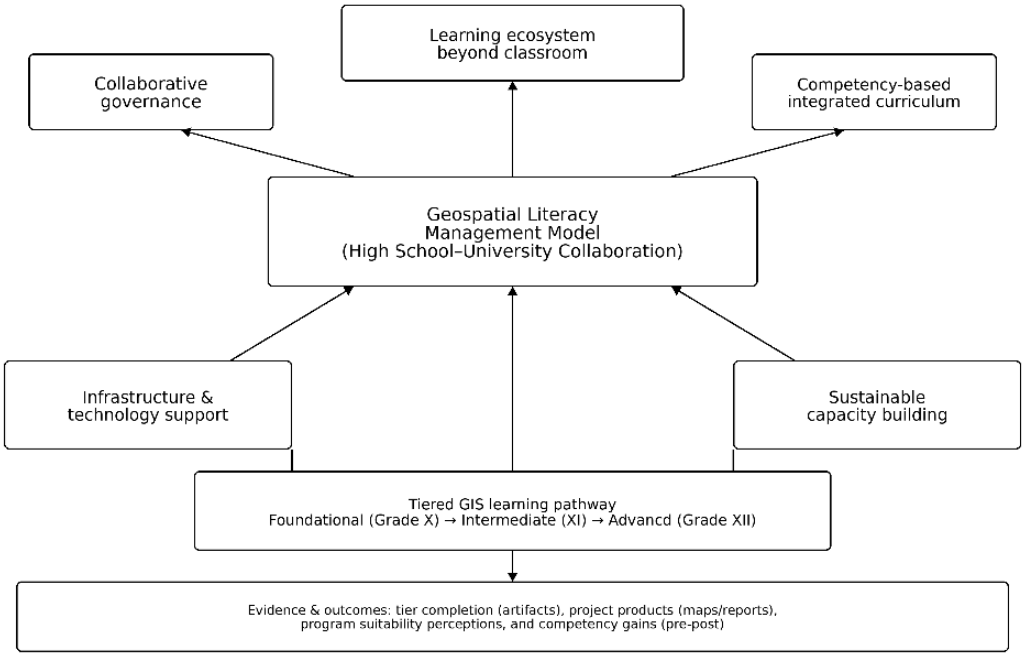

Figure 1. Visual synthesis linking the five-component geospatial literacy management model, the tiered GIS learning pathway, and the evidence/outcomes used to interpret findings

3.2.1. What constitutes an effective geospatial literacy management model through high school–university collaboration?

Findings across Jakarta–Depok, Yogyakarta, and Bandung indicate that an effective high school–university collaboration is sustained not by the presence of GIS tools alone, but by an implementation architecture that reduces friction in day-to-day school practice. In this study, architecture crystallized into five interdependent components—collaborative governance; a tiered, competency-based curriculum; open and shared technology/infrastructure support; sustained teacher capacity building; and an authentic learning ecosystem beyond the classroom—that operated as a tightly coupled system rather than parallel silos. This configuration directly addresses recurrent barriers reported in the recent literature: teachers may be willing to innovate, but durable uptake depends on structured supports that

protect teacher agency, provide practical resources, and embed new tools into existing instructional realities. For example, evidence from a story-mapping GIS initiative shows that teacher agency and autonomy are pivotal for turning training into classroom enactment, especially when teachers can adapt resources to their local contexts and are supported by credible partnerships (Brown et al., 2024). In a complementary line of work, GIS-integrated teaching has been shown to improve learners' motivation outcomes under appropriate instructional conditions, reinforcing the idea that implementation success hinges on the fit between pedagogical design and school constraints (Bikar et al., 2022). Read through this lens, the strong feasibility signal in the suitability survey (84.6% Agree/Strongly Agree; Table 3) is best interpreted as evidence of implementation fit: participants experienced the model as enabling rather than burdensome.

Beyond feasibility, the model also clarifies what counts as robust geospatial literacy development in secondary settings. The tiered curriculum sequences complexity and makes progression visible through artifacts, while the governance–infrastructure–capacity bundle stabilizes quality so that outcomes do not depend on a small number of "champion" teachers. This emphasis is consistent with recent teacher-focused scholarship in which educators value not only technical operation of geomedia but, crucially, students' critical interpretation of location-based information; teachers also express concerns when students' critical literacy lags behind their technical production (Pellikka et al., 2024). By embedding interpretation, uncertainty, and evidence-based communication into tier completion (Table 2) and project reporting, the present model operationalizes that priority in a way that is assessable and instructionally tractable.

Finally, the coherence among these five components helps explain why implementation was stable across three sites and why outcomes were consistent. Recent quasi-experimental evidence indicates that GIS-based teaching can improve students' learning outcomes, but effects are not necessarily uniform—underscoring the importance of structured scaffolding, clear tasks, and sustained supports rather than "tool exposure" alone (Yang et al., 2024). The novelty of the present contribution is therefore not a single pedagogical technique, but the system-level integration of governance, curriculum progression, open/shared access, professional learning, and authentic inquiry into one management model that can be implemented across diverse school contexts while still generating traceable evidence through artifacts (Table 2), perceived feasibility (Table 3), and competency gains (Table 4).

3.2.2. What are the key components for implementing collaborative programs to strengthen geospatial literacy?

Across the three sites, standardizing the learning environment on QGIS, OpenStreetMap (OSM), and Google Earth Engine (GEE) functioned as a practical equity mechanism: it reduced the extent to which students' opportunities to practice analysis depended on school budgets, licensing availability, or local computing capacity. This is consistent with evidence that GIS-supported instruction can improve student learning, yet the magnitude of improvement is contingent on whether the learning environment provides stable access and adequate scaffolding rather than sporadic exposure (Yang et al., 2024). In this sense, adopting an open-source stack is not merely a technical preference; it is an implementation choice aligned with the broader democratization logic of open geospatial ecosystems, where accessible tooling supports reproducibility and wider participation (Graser et al., 2025). Empirically, the educational value of GIS becomes most visible when students engage in structured inquiry with spatial data: a recent study in *Transactions in GIS* reported that inquiry-based learning supported by GIS positively affected students' academic achievement, attitudes, and geography literacy, indicating that GIS becomes instructionally potent when embedded within inquiry routines rather than treated as an add-on activity (Hursen & Beyoğlu, 2025). In parallel, classroom-oriented work on GEE demonstrates how cloud processing can make remote-sensing analysis feasible for secondary learners by shifting computational burdens away from local hardware, enabling students to focus on interpreting patterns and communicating evidence (Dema & Sivitskis, 2025). In our program, periodic access to university laboratories further strengthened this feasibility by providing predictable moments of high-capability practice and troubleshooting support, which—when paired with stable tool standardization—helps prevent implementation drop-off during technically demanding tasks and sustains continuity of student practice (Kriel & van der Merwe, 2025).

The 45 student projects anchored learning in place-based issues (e.g., flood exposure, green space equity, accessibility, land-use pressures), and this authenticity matters because it provides a credible

pathway from procedural GIS skills to evidence-based argumentation. Recent findings show that GIS learning becomes more meaningful when learners connect analysis outputs to real places and stakeholder contexts: a place-based GIS intervention documented positive student and community learning experiences as learners engaged in locally grounded problem-solving and communicated results beyond the classroom (Soucy et al., 2024). From a motivational standpoint, this design logic aligns with contemporary SDT evidence that students' autonomous motivation and engagement are reliably stronger in environments that support agency and meaningful participation (Bureau et al., 2022; Mammadov & Schroeder, 2023). Importantly, GIS-integrated geography instruction has also been shown to raise student motivation outcomes under appropriate instructional conditions; for example, a controlled study reported significantly higher intrinsic motivation under GIS-integrated teaching compared to conventional approaches among underachieving students (Bikar et al., 2022).

These studies help interpret why locality-relevant projects in our program were associated with sustained participation: authenticity does not only "contextualize" content; it supplies the conditions for internalization—students can see the purpose of analysis, evaluate evidence against real constraints, and experience competence through visible products and feedback loops. Critically, the present findings suggest that infrastructure and authenticity are not independent levers but mutually reinforcing. Prior quasi-experimental evidence indicates that GIS can improve learning outcomes, but not uniformly, implying that variability is often a function of implementation conditions and learning design rather than tool presence alone (Yang et al., 2024). In our model, open/cloud access and shared facilities made advanced workflows feasible; authentic projects supplied the pedagogical "reason to analyze"; and recurring inquiry routines stabilized students' opportunities to practice, interpret, and communicate results—an integration that is consistent with documented benefits of GIS-supported inquiry for achievement and geography literacy (Hursen & Beyoğlu, 2025) and with SDT meta-analytic findings on autonomy-supportive learning environments and adaptive student outcomes. Therefore, the most defensible interpretation is configurational: reliable improvements across sites were driven by the interaction of enabling access (open/cloud + shared facilities) and meaningful use (authentic, local inquiry), rather than by any single element in isolation (Yang et al., 2024; Hursen & Beyoğlu, 2025).

3.2.3. How does high school–university collaboration relate to geospatial competence and student autonomy?

The embedded rubric evidence suggests sizeable within-program improvements across multiple competency dimensions: GIS software proficiency, geospatial problem-solving, spatial analysis, and data interpretation (Table 4). Because the design is not experimental and relative gains can inflate change when baseline scores are low, interpretations emphasize absolute and normalized gains and treat the quantitative results as triangulation rather than attribution.

Equally important, the collaboration appeared to support autonomy-related practices and motivation. Students made consequential choices about research questions, datasets, analytical pathways, cartographic communication, and stakeholder audiences. Such practices align with project-based learning and are supported by Self-Determination Theory: autonomy through choice and ownership; competence via visible progression across tiers and artifacts; and relatedness through mentor guidance and peer collaboration. Participant reports of increased interest in geospatial sciences suggest internalized motivation, suggesting that learners began to see GIS as a language for civic reasoning and problem-solving rather than merely a technical requirement (Tosun, 2024; Muenks & Peterson, 2020). The positive aggregate ratings in Table 3 further indicate that the collaboration was generally experienced as enabling rather than burdensome, although the table does not permit subgroup-specific claims.

Cross-site consistency strengthens the plausibility of the interpretation. Despite different institutional histories and local geographies, the same mechanisms—tiered scaffolding, open/cloud tools, mentored professional learning, and authentic projects—were associated with comparable patterns of results. This suggests that collaboration may have acted as a compensatory infrastructure, reducing disparities typically associated with resource gaps and uneven teacher preparation. In implementation terms, the program balanced core components (the non-negotiables that support coherence) with adaptable peripheries (local datasets, project themes, timelines), a design known to support portability and scale in education reforms (Schlunegger et al., 2024; Kekeya, 2021).

While the design does not isolate the marginal effect of each component, the convergence of survey approval, competency deltas, and authentic portfolios supports a configurational explanation: the bundle—governance, curriculum, infrastructure, teacher learning, and authentic tasks—best explains the observed patterns (Vogel et al., 2022; Calzati & Loenen, 2023; Schlunegger et al., 2024).

The findings across all three research questions show that the collaboration was associated with measurable improvements in geospatial competence and with broader shifts in teacher practice, student autonomy-related practices, and the overall learning ecosystem. The consistency of these patterns across diverse school contexts indicates that the model functions as a coherent, scalable approach rather than a site-specific intervention, and that its strength lies in the interplay among governance, curriculum progression, technological access, sustained professional learning, and authentic inquiry. These insights reinforce the argument that high school–university partnerships can serve as a structural response to long-standing barriers in geospatial education, enabling secondary schools to access resources, expertise, and pedagogical models that would otherwise be difficult to sustain alone. Having established how the collaborative model operates, why it works, and what outcomes it suggests, the following conclusion synthesizes these implications and outlines their significance for policy, practice, and future research.

4. Conclusion

Drawing on a multi-site instrumental case study across Jakarta–Depok, Yogyakarta, and Bandung, this study specifies a geospatial literacy management model for high school–university collaboration built on five interlocking components: governance routines, tiered curriculum progression, shared open/cloud infrastructure, sustained teacher capacity building, and an ecosystem of authentic inquiry through project-based learning. Within the 12-month study window, the collaboration achieved high perceived suitability, generated a portfolio of 45 GIS-based projects, and showed within-program improvements in rubric-scored competence indicators. Qualitative evidence also suggested the emergence of autonomy-related practices in student inquiry. For practice and policy, the model implies that scaling GIS learning in secondary schools requires not only tools but also formalized coordination (MoUs, decision routines), stable access arrangements (open tools + shared facilities), and recurring teacher support cycles tied to tier-aligned artifacts and assessment criteria. Methodologically, the embedded quantitative indicators are descriptive and intended for triangulation; future research should test the model using stronger comparative designs and report fuller measurement properties (e.g., reliability, dispersion, and subgroup patterns).

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Data availability. The data used in this study is not publicly available and contains information of a restricted nature. Therefore, it cannot be shared publicly to maintain confidentiality and research ethics agreed upon during the data collection process.

AI Use Declaration. The author used AI in the initial stages of developing the outline for this article, with an estimated contribution of approximately 10–15% of the overall writing process. The author has reviewed, revised, and edited all AI-assisted output and takes full responsibility for the content and any potential errors contained in this article.

References

Bakri, A., Sugiarti, Y., & Wahyudin, D. (2020). Readiness of Indonesian TVET teachers in receiving GIS technology using TAM 2. *INVOTEC*, 16(2), 104–120. https://doi.org/10.17509/invotec.v16i2.28477

Bedair, S., Sayed, S. A., & AlMetwaly, W. M. (2022). Enhancing hybrid learning using open source GIS-based maps archiving system. *The Egyptian Journal of Remote Sensing and Space Sciences, 25*(3), 779–793. https://doi.org/10.1016/j.ejrs.2022.07.003

Berendsen, M. E., Hodza, P., & Hamerlinck, J. D. (2023). Researching student interaction with GIS software while learning spatial concepts: Toward a standard measure of GIS interaction. *Journal of Geography, 122*(4), 81–92. https://doi.org/10.1080/00221341.2023.2220328

Bikar, S. S., Rathakrishnan, B., Rabe, Z., Mahat, H., Sharif, S., & Talin, R. (2022). The impact of geography information system integrated teaching on underachieving students' intrinsic motivation. *International Research in Geographical and Environmental Education, 31*(4), 304–319. https://doi.org/10.1080/10382046.2021.2001983

Brown, S., Küçük, Z. D., Rickard, A., Lonergan, J., Abernethy, R., McNerney, L., McNerney, E., Foley, R., Behan, A., Byrne, A., Essel, B., Ffrench, J., Faull, J., & Cahalane, C. (2024). The role of teacher agency in using GIS to teach sustainability: An evaluation of a lower secondary school story mapping GIS initiative in Ireland. *International Research in Geographical and Environmental Education, 33*(1), 56–71. https://doi.org/10.1080/10382046.2023.2214044

Bureau, J. S., Howard, J. L., Chong, J. X. Y., & Guay, F. (2022). Pathways to student motivation: A meta-analysis of antecedents of autonomous and controlled motivations. *Review of Educational Research*. https://doi.org/10.3102/00346543211042426

Calzati, S., & Loenen, B. Van. (2023). An ethics assessment list for geoinformation ecosystems : revisiting the integrated geospatial information framework of the United Nations. *International Journal of Digital Earth ISSN:*, *16*(1), 1418–1438. https://doi.org/10.1080/17538947.2023.2200041

Dema, T., & Sivitskis, A. J. (2025). Using Google Earth Engine to teach burn severity mapping of wildfires across Bhutan. *The Geography Teacher, 22*(2), 74–82. https://doi.org/10.1080/19338341.2025.2487456

Elosua, P. (2022). Validity evidences for scoring procedures of a writing assessment task: A case study on consistency, reliability, unidimensionality and prediction accuracy. *Assessing Writing, 54*, 100669. https://doi.org/10.1016/j.asw.2022.100669

Fleischmann, E. M., Westhuizen, C. P. Van Der, Africa, S., & Campus, P. (2020). The educational research landscape on GIS integration and challenges – globally and in South Africa. *Journal of Geography Education in Africa (JoGEA)*, *3*, 63–80. https://doi.org/10.46622/jogea.v3i.2549

Graser, A., Sutton, T., & Bernasocchi, M. (2025). The QGIS project: Spatial without compromise. *Patterns*, 6(7), 101265. https://doi.org/10.1016/j.patter.2025.101265

Griffiths, Amy-Jane, Alsip, James, Hart, Shelley R, Round, Rachel L, & Brady, John. (2020). Together We Can Do So Much: A Systematic Review and Conceptual Framework of Collaboration in Schools. *Canadian Journal of School Psychology*, *36*(1), 59–85. https://doi.org/10.1177/0829573520915368

Handoyo, B., et.al. (2024). Effect of The Spatial Based Learning Using Quantum Geographic Information System on Students' Critical Thinking Skills. *Journal of Social Studies Education Research*, *15*(5), 328–379. https://jsser.org/index.php/jsser/article/view/5789

Humble, N. (2023). Future paths for GIS in K-12 education: A review of possibilities and constraints. *European Journal of Geography*, 14(3), 79–88. https://doi.org/10.48088/ejg.n.hum.14.3.079.088

Hursen, C., & Beyoğlu, D. (2025). The impact of inquiry-based learning activities supported by geographical information systems on the academic achievement, attitudes, and geography literacy of students. *Transactions in GIS, 29*(6), e70122. https://doi.org/10.1111/tgis.70122

Kekeya, J. (2021). Qualitative case study research design: The commonalities and differences between collective, intrinsic and instrumental case studies. *Contemporary PNG Studies*, *36*, 28–37. https://doi.org/10.3316/informit.356219476950585

Kementerian Koordinator Bidang Perekonomian Republik Indonesia. (2023, March 20). *Implementasi Kebijakan Satu Peta mengakselerasi pertumbuhan nasional dan tangani ketimpangan wilayah*. Kementerian Ekonomi RI. https://www.ekon.go.id/publikasi/detail/5043/implementasi-kebijakan-satu-peta-mengakselerasi-pertumbuhan-nasional-dan-tangani-ketimpangan-wilayah (Accessed 2026-02-27).

Kohler, K. (2021). Strategic Foresight : Knowledge , Tools , and Methods for the Future for the Future. *CSS Risk and Resilience Reports*. https://doi.org/10.3929/ethz-b-000505468

Kriel, C., & van der Merwe, C. D. (2025). Teaching Geographic Information Systems in South African Geography classrooms, using problem-based learning. *South African Geographical Journal, 107*(4), 586–602. https://doi.org/10.1080/03736245.2025.2472665

Le, H., Janssen, J., & Wubbels, T. (2018). Collaborative learning practices : teacher and student perceived obstacles to effective student collaboration. *Cambridge Journal of Education*, *48*(1), 103–122. https://doi.org/10.1080/0305764X.2016.1259389

Mammadov, S., & Schroeder, K. (2023). A meta-analytic review of the relationships between autonomy support and positive learning outcomes. *Contemporary Educational Psychology, 75*, 102235. https://doi.org/10.1016/j.cedpsych.2023.102235

Manakane, S. E., Latue, P. C., & Rakuasa, H. (2023). Integrating Geospatial Technology in Learning : An Innovation to Improve Understanding of Geography Concepts. *Sinergi International Journal of Education*, *1*(2), 55–69. https://doi.org/10.61194/education.v1i2.70

McKenzie, P., Cook, S., & Roulston, S. (2022). Learners as teachers—Teachers as learners: A collaborative approach to develop skills in GIS education. *The Geography Teacher, 19*(1), 4–11. : https://doi.org/10.1080/19338341.2021.1982748

Muenks, K., & Peterson, E. G. (2020). Parents' Beliefs about High School Students' Spatial Abilities: Gender Differences and Associations with Parent Encouragement to Pursue a STEM Career and Students' STEM Career Intentions. *Sex Roles*, *82*(9), 570–583. https://doi.org/10.1007/s11199-019-01072-6

Olatoye, T. A., & Fru, R. N. (2025). The Power of Geospatial Intelligence : GIS-Enhanced Curriculum for Sustainable Planning and Socio- Economic Transformation in Northern Cape , South Africa. *E-Journal of Humanities, Arts and Social Sciences (EHASS)*, *6*(13), 41–54. https://doi.org/10.38159/ehass.20256133

Olatoye, T. A., & Nkwenti, R. (2024). A Review towards Enhancing Geospatial Technologies in South African Rural Education. *Journal of Culture and Values in Education*, *7*(4), 190–210. https://doi.org/10.46303/jcve.2024.48

Panadero, E., Jonsson, A., Pinedo, L., & Fernández-Castilla, B. (2023). Effects of rubrics on academic performance, self-regulated learning, and self-efficacy: A meta-analytic review. *Educational Psychology Review, 35*, Article 113. https://doi.org/10.1007/s10648-023-09823-4

Pellikka, A., Nylèn, T., Hirvensalo, V. J., Hynynen, L. S., Lutovac, S., & Muukkonen, P. (2024). Understanding teachers' perceptions of geomedia: Concerns about students' critical literacy. *Teaching and Teacher Education, 144*, 104607. https://doi.org/10.1016/j.tate.2024.104607

Rizou, O., & Klonari, A. (2022). Investigating the Impact and Effectiveness of an ICT-based Teaching Scenario on Secondary School Students ' Geospatial and Statistical Literacy : A Case Study from Greece. *European Journal of Geography*, *13*(3), 50–69. https://doi.org/10.48088/ejg.o.riz.13.3.050.069

Rosas-Chavoya, M., Gallardo-Salazar, J. L., López-Serrano, P. M., Alcántara-Concepción, P. C., & León-Miranda, A. K. (2022). QGIS a constantly growing free and open-source geospatial software contributing to scientific development. *Cuadernos de Investigación Geográfica*, 48(1), 197–213. https://doi.org/10.18172/cig.5143

Roy, P. P., Abdullah, M. S., & Siddique, I. M. (2024). Machine learning empowered geographic information systems: Advancing spatial analysis and decision making. *World Journal of Advanced Research and Reviews*, 22(1), 1387–1397. https://doi.org/10.30574/wjarr.2024.22.1.1200

Schlunegger, M. C., Zumstein-shaha, M., & Palm, R. (2024). Methodologic and Data-Analysis Triangulation in Case Studies : A Scoping Review. *Sage Journals*, *46*(8), 611–622. https://doi.org/10.1177/01939459241263011

Soucy, A. R., Rahimzadeh-Bajgiran, P., De Urioste-Stone, S., Eitel, K., Jansujwicz, J., & Brownlee, M. (2024). Impact of a place-based educational approach on student and community members' experiences and learning within a post-secondary GIS course. *Journal of Geoscience Education*. https://doi.org/10.1080/10899995.2024.2379194

Tamiminia, H., Salehi, B., Mahdianpari, M., Quackenbush, L., Adeli, S., & Brisco, B. (2020). Google Earth Engine for geo-big data applications: A meta-analysis and systematic review. *ISPRS Journal of Photogrammetry and Remote Sensing, 164*, 152–170. https://doi.org/10.1016/j.isprsjprs.2020.04.001

Tosun, A. (2024). Improving Spatial Thinking Skills of Gifted Students Through Social Studies Course: An Instructional Module. *Education and Science*, *49*(220), 17–58. https://doi.org/10.15390/EB.2024.12724

Vogel, R., Matsuo, C., & Herbert, B. (2022). Cross-sector partnerships : Mapping the field and advancing an institutional approach. *IJMR*, *12*, 394–414. https://doi.org/10.1111/ijmr.12283

Waleed, M., Mubeen, M., Ahmad, A., & Habib. (2022). Evaluating the efficiency of coarser to finer resolution multispectral satellites in mapping paddy rice fields using GEE implementation. *Scientific Reports*, *12*(1), 1–15. https://doi.org/10.1038/s41598-022-17454-y

Ware, Y., & Putri, H. E. (2025). Transformation of geography education in the digital era: Evaluation of geography teacher readiness through Outcome-Based Education (OBE) approach. GeoEco, 11(2), 575–592. https://doi.org/10.20961/ge.v11i2.96827

Yang, D., Wang, C., & Qian, L. (2024). Does the use of GIS in geographical education yield better learning outcomes? Evidence from a quasi-experimental study on air pollution teaching. *Transactions in GIS, 28*(2), 433–454. https://doi.org/10.1111/tgis.13142

Zhou, Q., Wang, S., & Liu, Y. (2022). Exploring the accuracy and completeness patterns of global land-cover/land-use data in OpenStreetMap. *Applied Geography, 145*, 102742. doi: https://doi.org/10.1016/j.apgeog.2022.102742