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Utilization of Kepler.gl in the Development of a Digital Geography Learning Module on Population Density

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Abstract: Digital learning modules and geospatial visualization have largely been developed separately in geography education, and interactive maps are often embedded as illustrations rather than used as evidence for learning tasks. This study developed a Kepler.gl-integrated digital geography learning module on population density for Grade XI students and evaluated its feasibility and practicality. The ADDIE model was employed. Learning needs were identified through a questionnaire completed by 36 students and an interview with a geography teacher. The module was validated by a content expert and a media expert and then implemented with 111 students in four classes and two geography teachers at a public senior high school in Malang Regency, Indonesia. Data were collected using validation sheets and four-point response questionnaires and were analyzed descriptively. In the module, Kepler.gl maps of district-level population density for 2020, 2023, and a 2025 projection serve as the data source for worksheet tasks in which students classify, compare, and explain density patterns. The module obtained feasibility scores of 95.24% from the content expert and 91.67% from the media expert, and practicality scores of 92.13% from students and 87.50% from teachers, all in the highest category. The module was usable on computers and smartphones, although map loading depended on internet stability and students needed brief orientation. These results indicate expert-rated feasibility and user-perceived practicality. The module's contribution to students' understanding and spatial thinking was not examined and remains a topic for further research.

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Introduction

Digital technology has shifted education toward more flexible, interactive, and learner-centered processes, and learning resources have moved from printed materials toward digital materials that combine several forms of information in one environment (Bond et al., 2020). Digital learning modules are one such resource. They organize objectives, content, activities, assessment, and feedback into a structured sequence and can integrate text, images, video, and interactive media (Hamid et al., 2021; Islamiati et al., 2024). These characteristics are relevant to geography, which examines location, spatial distribution, and human environment relationships that learners need to interpret through maps, imagery, graphs, and regional data (Jiang, 2022; Kholoshyn et al., 2025).

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Population density is a geography topic that particularly depends on spatial representation. It reflects relationships among people, space, and the environment and is linked to urbanization, land-use change, infrastructure provision, and environmental carrying capacity (Sitiningrum, 2024). Indonesia's density exceeds 150 people/km², whereas Java exceeds 1,200 people/km² (Statistik, 2024). Senior high school textbooks present this topic through text, tables, graphs, and maps (Handoyo, 2021), but these representations are static and give learners few opportunities to explore how population data relate to places. At the study school, lessons on density relied mainly on textbooks and lectures and focused on calculation, although projectors, internet access, and smartphones were available.

Previous studies that address this problem fall into three groups. Studies of digital modules and e-modules describe benefits for the organization, flexibility, and multimedia richness of instruction (Nuralita et al., 2025; Razi, 2024), but maps in these products usually appear as illustrations, and tasks rarely ask learners to draw evidence from spatial data. Studies of GIS and WebGIS show that geospatial technologies can support the identification of spatial patterns and relationships (Favier & van der Schee, 2012; Kerski, 2023; Panjaitan et al., 2024). Systematic reviews, however, report barriers such as software complexity, training needs, and weak curricular alignment, which keep GIS use in separate, tool-centred sessions (Bernhäuserová et al., 2025; Schulze, 2021). Narrative web maps such as StoryMaps contextualize content through a pre-authored storyline rather than learner-driven exploration (Cyvin et al., 2022). Kepler.gl, an open-source, browser-based platform that renders spatial data as interactive choropleth, three-dimensional, and temporal visualizations without programming, has been used mainly for research and data communication (Lin et al., 2024; Mericskay, 2023), and its instructional use in school geography has rarely been documented.

These strands have developed largely in parallel. Embedding a map in a module does not by itself change how students learn. What matters is whether the map serves as the evidence base for tasks that ask students to observe, compare, explain, and respond to spatial patterns (Jo & Bednarz, 2014). This study addresses that gap with a module in which Kepler.gl visualizations are the primary data source for a sequence of worksheet (LKPD) tasks. Three features distinguish the design. Each learning objective is linked to a spatial representation and a corresponding task, the visualizations operate at two scales the districts of Greater Malang and the regencies/cities of East Java and three time points, and the maps are combined with satellite imagery, field photographs, and temporal graphs in a browser-based environment that runs on smartphones without installation. The study aimed to (1) develop the module using the ADDIE model, (2) evaluate its feasibility based on expert judgment, and (3) evaluate its practicality based on student and teacher responses. The module's influence on learning outcomes was outside the scope of this study.

Research Method

This research and development study followed the ADDIE model, namely Analyze, Design, Development, Implementation, and Evaluation (Branch & Varank, 2009). ADDIE was chosen because it makes explicit how the output of each stage informs the next and

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allows formative evaluation throughout development (Spatioti et al., 2022). Qualitative data from needs analysis, interviews, validator comments, observation, and user feedback guided revisions, whereas rating-scale data were used to determine feasibility and practicality. Table 1 summarizes each stage.

Table 1. Procedures, Data Sources, and Outputs of Each ADDIE Stage

Stage	Activities and participants	Instruments and data	Output and use in the next stage
Analyze	Analysis of the Phase F Geography Learning Outcomes and the Grade XI textbook. Needs questionnaire (36 students). Interview with one geography teacher (12 February 2026). Observation of facilities	Document analysis, needs questionnaire, interview guide, observation notes	Three needs that defined the product specifications
Design	Twelve-screen storyboard. Mapping of each learning objective to content, representation, task, and evidence (Table 3). Selection of case areas and datasets (BPS, SIPSN). Drafting of instruments	Storyboard, alignment matrix, draft instruments	Blueprint for building the module and instruments for data collection
Development	Module built in Google Sites with embedded *Kepler.gl* maps and an LKPD in the Discussion Room. Validation by one content expert and one media expert (April 2026). Revision	Content and media validation sheets with comment fields	Feasibility scores (Table 4) and 12 revisions completed before implementation
Implementation	Trial with 111 students in four intact classes and two teachers, 26–30 April 2026, one 2 × 45-minute session per class	Student and teacher questionnaires, observation notes, oral feedback	Practicality scores (Table 5) and records of usage conditions
Evaluation	Formative checks after each stage and summative analysis of feasibility and practicality	All data above	Final module and suggestions documented for the next development cycle

Source: Researchers (2026)

Table 1 presents the systematic procedures used to develop the GeoDensity digital learning module based on the ADDIE model, consisting of five stages: Analyze, Design, Development, Implementation, and Evaluation. During the analysis stage, students' learning needs were identified through questionnaires, teacher interviews, document analysis, and classroom facility observations. The findings informed the design of a twelve-screen storyboard, including learning objectives, content, spatial representations, and student activities. The module was subsequently developed using Google Sites with embedded Kepler.gl visualizations and worksheets (LKPD), followed by content and media expert

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validation. The implementation stage involved 111 students and two geography teachers, while the evaluation stage focused on assessing the product's feasibility and practicality. Overall, the table illustrates the systematic relationship between development activities, data sources, research instruments, and outputs at each stage of the ADDIE process.

The study was conducted at SMA Negeri 1 Gondanglegi, a public senior high school in Malang Regency, East Java. In the analysis stage, 36 Grade XI students completed the needs questionnaire and one geography teacher was interviewed. Two lecturers from the Geography Education Study Program, Universitas Negeri Malang, served as validators, namely a content expert in population density and a media expert in education with expertise in instructional media development. Implementation involved four intact Grade XI classes, XI-5, XI-6, XI-7, and XI-9, with 111 students, and two geography teachers. The classes were selected purposively because the students had completed the chapter on Environment and Population and the classes were made available by the school. The results therefore reflect authentic conditions in one school rather than a representative sample.

The instruments are listed in Table 2. All rating instruments used a four-point scale from 1 (strongly disagree) to 4 (strongly agree) so that respondents would state a definite judgment (Sugiyono, 2022). Indicators were adapted from established frameworks to the module's characteristics, particularly its Kepler.gl visualization. Validation sheets also contained fields for weaknesses, suggestions, and a usage recommendation. Construct validity was addressed by deriving indicators from these frameworks. The internal consistency of the student questionnaire was estimated with Cronbach's alpha ($\alpha = 0.94$). Inter-rater reliability could not be estimated because each validation sheet was completed by one expert.

Table 2. Research Instruments

Instrument	Respondents	Aspects (number of items)
Needs questionnaire and interview guide	36 students, 1 teacher	Learning preferences, learning resources and media, use of spatial media, difficulties, expected materials
Content validation sheet	1 content expert	Coverage (5), accuracy (5), currency and contextual relevance (3), spatial visualization (4), skills and learning activities (4)
Media validation sheet	1 media expert	Presentation technique (4), display and design (5), module characteristics (5), language and readability (3), *Kepler.gl* visualization (4)
Student questionnaire	111 students	Ease of use (7), content design (9), usefulness (4)
Teacher questionnaire	2 teachers	Ease of use, learning interactivity, module usefulness, spatial visualization, language and readability (4 each)

Source: Researchers (2026)

Table 2 summarizes the research instruments employed to collect data throughout the development and evaluation of the digital learning module. These instruments included student needs questionnaires, teacher interview guides, content validation sheets, media

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validation sheets, student response questionnaires, and teacher response questionnaires. Each instrument addressed different assessment dimensions, ranging from learning needs and content accuracy to media design, ease of use, and perceived usefulness. The use of multiple instruments enabled the researchers to obtain information from different perspectives, including experts and intended users. Furthermore, the student questionnaire demonstrated a Cronbach's Alpha coefficient of 0.94, indicating high internal consistency. Overall, the table provides an overview of the instruments used to support the systematic collection of data during the product development and evaluation processes.

Qualitative data were reduced, displayed, and interpreted, and validator and user comments were grouped by module component and translated into revision decisions. Quantitative data were analyzed with table 3 and 4

$$P = \frac{\sum X}{N} x\ 100\%$$

Where:
P = Assessment Percentage
∑X = Total Score Obtained
N = Maximum Score

The feasibility percentage was subsequently converted into the feasibility categories presented in Table 3

Table 3. Feasibility Categories of the *Kepler.gl*-Integrated Digital Learning Module

Percentage	Feasibility Criteria
81–100%	Very Feasible
61–80%	Feasible
41–60%	Fairly Feasible
21–40%	Unfeasible
0-20%	Very Unfeasible

Source : (Arnab et al., 2022)

The practicality level of the module was determined based on the results of the teacher and student response questionnaires after implementation, using the criteria presented in Table 4.

Table 4. Practicality Criteria for the Digital Geography Learning Module Integrated with *Kepler.gl*

Percentage	Practicality Criteria
85–100%	Very Practical
70-85%	Practical
50-70%	Fairly Practical
1-50%	Less Practical

Source : (Arnab et al., 2022)

Table 4 presents the criteria used to determine the practicality of the digital geography learning module based on student and teacher responses following implementation. The practicality levels are classified into four categories: very practical (85–100%), practical (70–

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85%), fairly practical (50–70%), and less practical (1–50%). These criteria provide a basis for interpreting users' perceptions of the module's ease of use, learning interactivity, content design, and usefulness in geography instruction. Unlike the feasibility criteria in Table 3, which focus on expert evaluations, this classification emphasizes the experiences and perceptions of students and teachers as the intended users. Consequently, the table provides a reference for determining whether the developed module can be practically used in the geography learning environment.

Result and Discussion

Analysis Stage

The Phase F Geography Learning Outcomes of the Kurikulum Merdeka require students to analyze and communicate geographical phenomena using geographic data, maps, and technology, and for population density students are expected to relate population data to regional conditions. The Grade XI textbook presents the topic systematically, but its maps and graphs are static complements to the text (Handoyo, 2021). In the needs questionnaire (n = 36, multiple responses allowed), 72.2% of students reported visual and kinesthetic preferences and 44.4% an auditory preference. Students preferred observing images, videos, or maps (69.4%) and hands-on exploration (61.1%), yet learning was dominated by teacher explanation (75.0%) and textbooks (69.4%). Printed maps (38.9%) and atlases (25.0%) were the main spatial media, Google Maps (13.9%) and other digital maps (5.6%) were rarely used, and 33.3% of students had never used maps in geography lessons. Students described density as difficult because it was presented as statistics and text. The teacher confirmed that lessons focused on definitions and calculation and asked for clear materials with worksheet-like activities linking data to regions. Three needs followed from these data, namely tasks that use geographic data and maps, interactive rather than static representations, and local content accessible on smartphones.

Design Stage

The storyboard (Figure 1) sequences the home page, objectives, instructions, content on concept and calculation, classification, factors, impacts, and mitigation, the Kepler.gl visualization, the Discussion Room containing the LKPD, a glossary, and references. Each learning objective was then mapped to its content, representation, task, and evidence of learning (Table 5). The tasks move from reading and calculating, to classifying and comparing, to explaining and proposing, following the progression from spatial concepts through representations to spatial reasoning described by Jo and Hong-Dwyer (2024).

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Figure 1. Storyboard of the *Kepler.gl*-Integrated Digital Geography Learning Module

Figure 1 illustrates the storyboard of the GeoDensity digital learning module, which was developed as an initial design framework before its implementation using Google Sites. The storyboard consists of twelve screens covering the homepage, learning outcomes and objectives, user instructions, population density concepts, calculations, classifications, influencing factors, impacts, mitigation strategies, Kepler.gl visualizations, the discussion room and LKPD, glossary, and references. Each component is organized to provide a systematic learning sequence that guides students through the instructional content progressively. The design also demonstrates how learning materials, spatial visualizations, and student activities are integrated into a single digital learning environment. Therefore, the storyboard serves as a development blueprint while illustrating the module's content organization, navigation structure, and overall instructional design.

Table 5. Alignment of Learning Objectives, Spatial Representations, Student Tasks, and Evidence of Learning

Learning objective	Spatial representation	Student task (LKPD)	Evidence
1. Explain and calculate population density	*Kepler.gl* tooltip values for districts of Greater Malang	Read district values from the map, check them with the arithmetic, agrarian, economic, or physiographic formula, and explain their meaning	Calculations and explanations
2. Identify density classifications	Choropleth classes, satellite imagery of clustered and dispersed settlements, field photographs with Google Maps links	Classify districts and relate each class to the settlement pattern visible in the imagery	Classification with justification

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Learning objective	Spatial representation	Student task (LKPD)	Evidence
3. Analyze factors	3D bars contrasting the Malang city core with rural southern districts	Compare high- and low-density districts and explain differences using accessibility, economic activity, and terrain	Comparative explanation in the Discussion Room
4. Examine impacts	Bars for 2020, 2023, and 2025 projection, temporal graph, East Java data including waste generation (SIPSN)	In groups, analyze density change and density–waste relationships in an assigned East Java region	Group analysis supported by data
5. Propose mitigation efforts	All representations above	Propose region-specific responses and respond to other groups' proposals	Proposals and peer responses

Table 5 illustrates the alignment between learning objectives, spatial representations, student activities in the worksheets (LKPD), and the expected evidence of learning. Five main learning objectives are addressed: explaining and calculating population density, identifying density classifications, analyzing factors influencing population density, examining its impacts, and proposing mitigation strategies. Each objective is associated with relevant spatial representations, including interactive Kepler.gl maps, satellite imagery, temporal graphs, and three-dimensional visualizations. Students are subsequently guided to retrieve data, perform calculations, compare geographical areas, analyze changes, and formulate solutions based on regional characteristics. This table demonstrates that geospatial technology is not merely used as a medium for presenting information but also functions as a source of evidence that supports students' analytical activities and spatial reasoning.

Development Stage

The module, named GeoDensity, was built in Google Sites and runs in a web browser on computers and smartphones. District and regency/city population data were obtained from BPS and waste-generation data from the National Waste Management Information System (SIPSN). The data were processed into Kepler.gl maps embedded in the content pages and in the LKPD. Kepler.gl performs three instructional functions (Figure 2). As a data source, it lets students retrieve density values by hovering over districts instead of receiving them from the text. As a tool for comparison, its choropleth fill and three-dimensional bars make the contrast between the urban core of Malang City and the low-density southern districts visible and show where density changes over time. As a bridge to concepts, it prompts students to explain observed patterns with the factors and impacts in the content and to check them against imagery and photographs. Short instructions above the map explain landscape orientation, zooming, and hovering to reduce the technical load of exploration.

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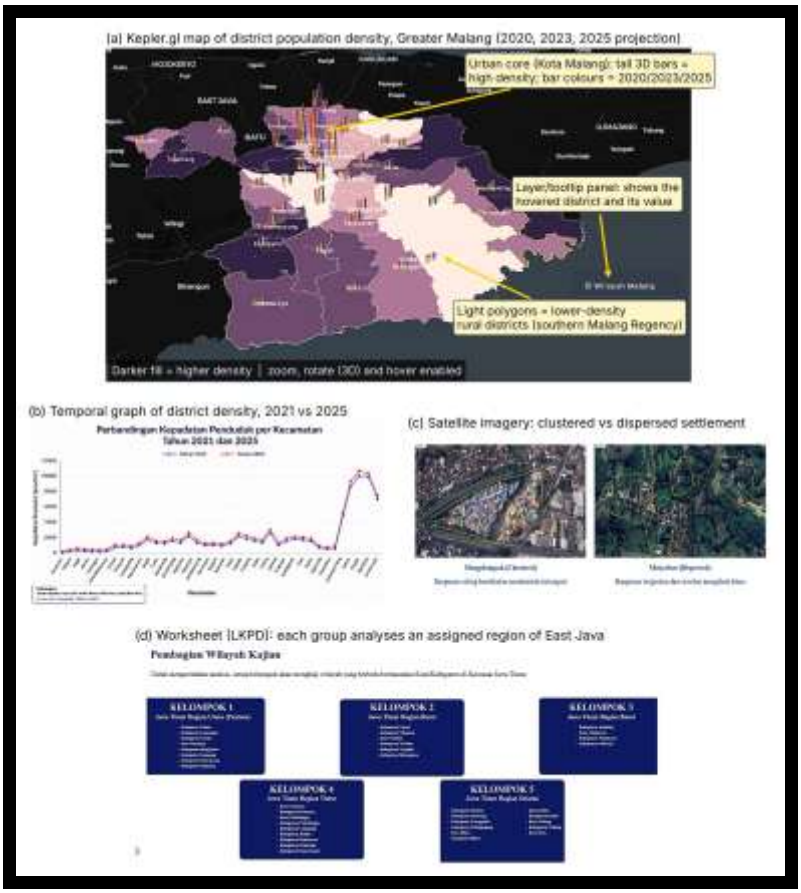


Figure 2. Spatial Representations Used in the Worksheet Tasks: (a) *Kepler.gl* Interactive Map, (b) Temporal Graph, (c) Satellite Imagery of Settlement Patterns, (d) Assignment of East Java Regions to Student Groups

Figure 2 presents the different spatial representations used as information sources for the worksheet activities, including the Kepler.gl interactive map, temporal graph, satellite imagery of settlement patterns, and assignment of East Java regions to student groups. The interactive map enables students to identify population density distribution across different geographical areas, while the temporal graph helps them examine changes in population density from 2020 and 2023 to the 2025 projection. Satellite imagery provides visual information about settlement characteristics, whereas regional assignments support group-based geographical analysis. The combination of these representations encourages students to observe, compare, and interpret geographical phenomena using available spatial data. Consequently, this figure demonstrates how geospatial visualization is integrated into learning activities as an information source that supports students' geographical analysis and interpretation.

Table 6. Results of Content and Media Expert Validation

Validator	Aspect	Items	Score / maximum	Percentage (%)
Content expert	Coverage	5	20 / 20	100.00
	Accuracy	5	19 / 20	95.00

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Validator	Aspect	Items	Score / maximum	Percentage (%)
	Currency and contextual relevance	3	10 / 12	83.33
	Spatial visualization	4	15 / 16	93.75
	Skills and learning activities	4	16 / 16	100.00
	Total (very feasible)	**21**	**80 / 84**	**95.24**
Media expert	Presentation technique	4	14 / 16	87.50
	Display and design	5	17 / 20	85.00
	Module characteristics	5	20 / 20	100.00
	Language and readability	3	11 / 12	91.67
	Kepler.gl spatial visualization	4	15 / 16	93.75
	Total (very feasible)	**21**	**77 / 84**	**91.67**

Both validators rated the module as very feasible and recommended its use with minor revision (Table 6). The aspect scores are more informative than the totals. The lowest content score concerned currency and contextual relevance (83.33%), and the lowest media score concerned display and design (85.00%). These are the features on which the module's rationale depends, which suggests that a geovisualization platform does not by itself make content contextual or legible. Both qualities had to be designed through revision, consistent with evidence that visual design shapes how learners engage with materials (Tomita, 2022). Spatial visualization received 93.75% from both experts. These scores reflect expert judgment of product quality and do not describe students' learning.

All 12 recommendations were implemented before the trial. The content expert asked for Google Maps links and satellite imagery, the four density classifications with formulas, expert definitions and references, clearer sub-topics, impacts and solutions organized by environmental and spatial aspects, and temporal graphs in the LKPD. The media expert asked for larger fonts, a home-page background showing actual density conditions, consistent margins, concept highlights and summaries, better text–background contrast, and harmonized images. Four of the six content recommendations concerned spatial contextualization. This suggests that, from the expert's perspective, an interactive map alone did not anchor abstract density data in recognizable places, and that complementary representations at the scale of actual settlements were needed, as research on multimodal geography learning also emphasizes (Ericson & Häikiö, 2025; Yamauchi et al., 2025)

Implementation Stage

Each class took part in one 90-minute session consisting of an introduction, a projector demonstration of the module and basic Kepler.gl operations, independent and group exploration of the content and LKPD with the teacher as facilitator, completion of the student questionnaire through Google Forms, oral feedback, and closure. Two classes worked in the computer laboratory. The other two used their own smartphones with mobile data or a researcher-provided hotspot because a power outage closed the laboratory. The teachers completed their questionnaire on 30 April 2026. Table 7 reports the results.

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Table 7. Practicality Results Based on Student and Teacher Responses

Respondents	Aspect	Items	Score / maximum	Percentage (%)
Students (n = 111)	Ease of use	7	2,871 / 3,108	92.37
	Content design	9	3,668 / 3,996	91.79
	Usefulness	4	1,642 / 1,776	92.45
	Overall (very practical)	**20**	**8,181 / 8,880**	**92.13**
Teachers (n = 2)	Ease of use	4	28 / 32	87.50
	Learning interactivity	4	27 / 32	84.38
	Module usefulness	4	29 / 32	90.63
	Spatial visualization	4	28 / 32	87.50
	Language and readability	4	28 / 32	87.50
	Overall (very practical)	**20**	**140 / 160**	**87.50**

Table 7 presents the practicality assessment results based on responses from 111 students and two teachers following the implementation of the digital learning module. The overall student response reached 92.13%, with usefulness receiving the highest score of 92.45%, followed by ease of use at 92.37% and content design at 91.79%. Meanwhile, the overall teacher response reached 87.50%, with module usefulness obtaining the highest score of 90.63%, while learning interactivity received the lowest score of 84.38%. Both results were classified as very practical according to the established criteria. These findings indicate that students and teachers perceived the module as easy to use and beneficial for geography learning. Nevertheless, the relatively lower score for learning interactivity suggests opportunities for further improvement through the integration of educational quizzes, games, and more varied learning activities.



Figure 3. Documentation of the implementation of the *Kepler.gl*-integrated digital learning module

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A product is practical when its intended users can use it as intended without major difficulties (Nieveen, 1999). Both groups rated the module as very practical. All student aspects exceeded 91%, whereas teachers gave the highest score to usefulness (90.63%) and the lowest to learning interactivity (84.38%). The lower interactivity rating deserves attention because interactivity is a central claim of geovisualization-based learning. Within a single session that also included orientation and questionnaire completion, much of the activity probably remained individual map exploration rather than sustained discussion, which is consistent with students' requests for quizzes, games, and more varied activities. The high student ratings were also collected right after a first encounter with a new medium, so novelty and acquiescent responding may have raised them.

Observation and feedback added four points not captured by the scores. The module remained usable when two classes moved from computers to smartphones. All features worked on every device type, but *Kepler.gl* maps loaded more slowly on smartphones with unstable connections, and most difficulties occurred when students first opened the link. The teachers acted mainly as facilitators while students explored the maps, discussed findings, and helped one another. Finally, the teachers suggested only larger fonts in some sections, and students asked for interactive quizzes, animated videos, and educational games rather than changes to the content or maps

Contribution, Implications, and Limitations

The main contribution lies in the instructional design rather than the technology. Earlier digital modules mostly organized content, multimedia, and assessment with maps as illustrations (Hamid et al., 2021; Nuralita et al., 2025), and classroom GIS often required separate software and training (Bernhäuserová et al., 2022). This module takes an intermediate position in which spatial data sit inside the learning sequence and every objective is tied to a task that draws on a spatial representation. This responds to the observation that geospatial tools support inquiry when tasks are structured to guide learners from observation toward explanation (Purwanto et al., 2025; Zain et al., 2025). Unlike StoryMaps, whose narrative is authored in advance, the Kepler.gl maps leave pattern-finding to students. Because Kepler.gl runs in a browser without installation and remained usable on smartphones during a power outage, it may lower some of the barriers reported for school GIS (Sari et al., 2025), although orientation and connectivity still require planning (Koessoy et al., 2025).

Theoretically, the design draws on two principles. Contextual geography learning is supported when concepts are encountered in places learners know (Cahyanti et al., 2023; Puastuti & Sinthiya, 2021), and spatial reasoning is described as a progression from spatial concepts through representations to reasoning about patterns. The use of the students' own region and the task sequence were intended to reflect these principles. The present data show that experts judged the module suitable for this purpose and that users found it practical. They do not show changes in students' understanding or spatial thinking, which were not measured. Any such contribution should be treated as a possibility suggested by the design and by earlier studies that requires testing (Meechandee & Meekaew, 2025).

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Several limitations apply. The trial involved one school and four purposively selected classes, each validation sheet was completed by one expert, and practicality relied on self-reports collected after a single session. The module depends on a stable internet connection, users needed initial orientation to the interface, and the content is limited to population density.

Conslusion

This study developed a Kepler.gl-integrated digital geography learning module on population density through the ADDIE model. In the module, interactive maps of district and regency/city population data serve as the evidence base for worksheet tasks aligned with each learning objective and are supported by satellite imagery, field photographs, and temporal graphs. Content and media experts rated the module as very feasible, and students and teachers rated it as very practical. The module was usable on computers and smartphones, although its use depended on internet stability and brief initial orientation. These results establish feasibility and practicality only. The module's possible contribution to students' understanding and spatial thinking was not examined. The study offers an instructional design in which geospatial visualization is aligned with objectives, tasks, and assessment rather than added as supplementary medias.

Recomendation

Teachers using the module should allow time for orientation to Kepler.gl, check devices and connectivity in advance, and prepare offline alternatives such as exported maps and data tables. Future studies could examine whether and how the module relates to students' spatial thinking and interpretation of population phenomena through experimental or quasi-experimental designs with comparison groups, involve several schools and larger expert panels, combine the module with inquiry-oriented models such as problem-based or project-based learning, and extend the design to topics such as urbanization, land-use change, and disaster mitigation.

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