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Procedural Logic Gaps in Mitigation Mapping: Content Analysis of QGIS-Based Essay Responses

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Abstract

Theoretical knowledge about disasters does not always correspond to technical ability in mapping risks. Lombok Island has high tectonic complexity because it is flanked by the Sunda Subduction Zone in the south and the Flores Back-Arc Thrust in the north, which requires precise spatial data-based mitigation strategies. This study aims to reconstruct students' mental models in integrating geospatial technology and disaster content through content analysis of essay answers. The novelty of this study lies in revealing the 'procedural logic gap' that is often overlooked in menu-driven practical assessments. The method used is descriptive-qualitative with a content analysis approach on 35 students of the Physics Study Program who have taken the Mapping course. The analysis framework adopts the Geospatial Technology Competency Model (GTCM) and the SOLO Taxonomy. Research results reveal a sharp cognitive polarization, where the majority of respondents (60%) are at the Pre-structural and Uni-structural levels. Key findings indicate the phenomenon of "Disconnected Cognition"; students understand the conceptual aspects of tectonics (Tier 3 GTCM), yet fail to construct a systematic QGIS workflow (Tier 4 GTCM), which is reflected in fragmented procedure descriptions. The inability to integrate this operational logic causes mitigation map outputs to become merely "visual decorations" without optimal function as a decision-making tool. This study recommends a repositioning of the GIS curriculum to emphasize strengthening system logic rather than merely imitating software procedures.

Keywords: Disaster mitigation mapping; Geospatial technology competency; Procedural logic gap; QGIS; Spatial thinking; SOLO taxonomy

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INTRODUCTION

Indonesia has a high disaster risk due to its geological and geographical location (Rachman et al., 2025). Geologically, Indonesia is located at the convergence of four major tectonic plates: the Eurasian, Indo-Australian, Philippine, and Pacific plates, making the country prone to earthquakes, tsunamis, and volcanic eruptions (Hutchings & Mooney, 2021; Pambudi & Ulfa, 2024). Geographically, Indonesia's location in the tropics and at the convergence of two oceans and two continents (Venelia et al., 2021) makes it vulnerable to landslides, flash floods, floods, extreme weather, extreme waves, erosion, and droughts, which can also trigger forest and land fires (BNPB, 2025). According to BNPB 2025, provinces in Indonesia have a disaster risk index for events such as floods, earthquakes, tsunamis, volcanic eruptions, forest and land fires, landslides, extreme waves and erosion, droughts, and extreme weather (Faradiba et al., 2025; Wibowo et al., 2024).

The 2024 World Risk Report (WRR) states that Indonesia ranks second out of 193 countries with the highest disaster risk in the world. This situation is closely related to its geographical and geological characteristics, which make it vulnerable to hydrometeorological and geological disasters (Pambudi & Ulfa, 2024; Fuady et al., 2021). In addition, factors such as social, economic, physical, and environmental vulnerability, as well as capacity in disaster management, also play a role in increasing disaster risk in Indonesia. One area in Indonesia that is vulnerable to geological disasters is the island of Lombok (Priyono et al., 2021). This occurs because Lombok Island is located in the Eastern Sunda Arc and is an area with a high level of seismicity (Supendi et al., 2020), which is influenced by a complex regional tectonic configuration. Geodynamically, this location is effectively situated between two dominant earthquake-generating (seismogenic) sources (Ridwan et al., 2021; Anwar et al., 2022): (1) The Sunda Subduction Zone in the south, which represents the collision zone between the Indo-Australian and Eurasian Plates and has the potential to trigger megathrust events (Hasanah et al., 2024), and (2) the Bali-Flores Back-Arc Thrust Fault in the north, which indicates intra-arc compressional deformation (Yang et al., 2020). This dual convergence makes Lombok a region vulnerable to destructive earthquakes originating from these shallow northern mechanisms and potential subduction activity in the south (Minardi et al., 2021).

The high tectonic complexity on Lombok Island specifically demands precise mitigation strategies, one of which is disaster risk mapping that serves as a fundamental instrument in the preparedness phase (Prasetyo et al., 2024). Mapping is not merely a presentation of spatial visuals, but a process of integrating multisectoral data that allows policymakers to accurately identify vulnerability zones (Pambudi & Ulfa, 2024). In this context, the use of Geographic Information System (GIS) software such as QGIS becomes crucial due to its open-source nature and extensive geoprocessing analysis capabilities for modeling the impacts of earthquakes and tsunamis (Sabarudin & Rasyid, 2023). However, the effectiveness of GIS technology in disaster mitigation highly depends on the user's spatial thinking ability (Hadi et al., 2021; Wahyuningtyas et al., 2020). Spatial thinking is a set of cognitive skills that includes understanding of spatial structures, spatial transformation operations, and cognitive representation of geographical phenomena (NRC, 2006). In the creation of mitigation maps, spatial thinking acts as a mental navigation that guides a person to determine a logical workflow, from selecting the appropriate coordinate projection to determining a valid overlay method (Ahmed et al., 2021; Nazirurrahman et al., 2025).

Success in producing accurate mitigation maps depends not only on the availability of software but also on meeting user competency standards. In this regard, the Geospatial Technology Competency Model (GTCM) provides a comprehensive framework that divides geospatial competencies into several hierarchical levels (Jakson & Kerski, 2023). This model asserts that proficiency in GIS software (Tier 4: Design and Control Skills) must be based on a strong foundation of academic knowledge (Tier 3: Academic Competencies), which includes geography, mathematics, and critical thinking skills (Olha V & Bondarenko, 2025). In the context of creating mitigation maps, the most crucial competencies often lie at the intersection of Technical Knowledge (using tools in QGIS) and Content Knowledge (disaster risk analysis). Users who only have technical-level competencies without being supported by academic competencies such as an understanding of coordinates, map projections, and the logic of spatial analysis will be trapped in the phenomenon of 'black-box mapping.' Where the map-making process is carried out without a deep understanding of the parameters used, thus potentially causing fatal misinterpretation of tectonic data for public safety.

One of the major challenges in geospatial education today is that often, individuals are able to operate software mechanically (based on tutorials), but fail to understand the underlying procedural logic (Vega, 2022). The inability to explain the steps of map creation or to interpret tectonic maps in writing indicates a cognitive gap. Without a strong foundation in spatial thinking, technical procedures in QGIS risk becoming mere digital routines that are prone to logical errors, which in the end can result in invalid mitigation map outputs. The phenomenon of 'mechanization' in GIS operation aligns with concerns about the low fulfillment of standards in the Geospatial Technology Competency Model (GTCM). Within the GTCM framework, technical competence at Tier 4 (software mastery) should be rooted in Tier 3, which includes academic competencies such as critical thinking and analytical skills Spatial. When users are only fixated on the sequence of menu clicks without understanding the functional essence of each tool, such as the difference in logic between clip and intersect or the significance of coordinate system projection, what occurs is a dissonance between technical skills and scientific reasoning.

This gap often goes undetected if evaluations are only conducted through testing the final map results or direct practice observations that are tutorial-like imitations. Therefore, an evaluation instrument is needed that can deeply dissect the user's 'thought process' or mental model. Procedural essay tests offer advantages in revealing procedural knowledge, which is an individual's ability to reconstruct technical steps into a logical narrative that reflects a comprehensive understanding of concepts. Through written explanations, researchers can identify where the respondent's logic breaks down, either in administrative stages in QGIS or in risk reasoning regarding complex tectonic phenomena. Previous studies have extensively evaluated the effectiveness of QGIS training.

The research conducted by (Amri et al., 2017) examined the implementation of disaster risk reduction education for children in Indonesia. The research was revisited by (Amri et al., 2022) on the Integration Path of Disaster Risk Reduction Education in Schools: Insights from the Evaluation of SPAB in Indonesia. Research conducted by (Tahmidaten and Wawan, 2019) focused on the Implementation of Disaster Education in Indonesia (A Literature Study on the Problems and Solutions). Research conducted by (Leiwakabessy and Liora, 2024) explored the Socialization of the Use of Geophysical Science in Natural Disaster Mitigation and Environmental Awareness Development among Junior High School Students. Research conducted by (Madona, 2021) examined individual preparedness for earthquakes in the educational and training centers of the Meteorology, Climatology, and Geophysics Agency. Research was conducted by (Syamsuddin et al., 2025) on Earthquake and Tsunami Disaster Risk Mapping and Mitigation Strategies in Torok Aik Belek Village: A Community-Based Approach. Research was conducted by (Susilo et al., 2022) on Natural Disaster Mitigation using geophysical methods.

Research was conducted by (Permatasari et al., 2022) on the development and evaluation of a web GIS application to support volcanic hazard mitigation in the southern part of Mount Merapi, Sleman Regency, Yogyakarta Province, Indonesia. Research was conducted by (Rofiah et al., 2021) on Key Elements of Disaster Mitigation Education in Inclusive School Environments in the Indonesian context. Research was conducted by (Pradipta et al., 2023) on Enhancing Community Disaster Education for Disaster Mitigation. Research by (Saamion, 2021) on Mitigation Education in Reducing the Impact of Disasters in Padang City. Research by (Ariyanto et al., 2019) on landslide zones using the geoelectric method for disaster mitigation in Pamekasan. Research conducted by (Hasan et al., 2022) on Landslide Area Identification Using the Geoelectric Resistivity Method as a Disaster Mitigation Strategy. Research by (Hayatuzzahra et al., 2024) Regarding Preliminary Research for the Identification of Disturbances as Disaster Mitigation Efforts in Sumbawa Besar Using Geophysical and Geological Methods. From previous research until now, disaster mitigation education still needs to be carried out from various aspects and fields. Although many studies on disaster mitigation education have been conducted, a comprehensive literature review shows a gap where no research has systematically examined the in-depth analysis of the procedural logic behind creating such mitigation maps. This study aims to fill that gap by evaluating respondents' essay answers to map the extent to which geospatial competence and spatial thinking ability are integrated in facing disaster risk challenges, especially in areas with unique geological characteristics such as Lombok Island.

This study aims to reconstruct the mental models of respondents in integrating geospatial technology and disaster content through content analysis of essay responses. The novelty of this research lies in revealing the 'procedural logic gap' that has often been overlooked in menu-driven practical assessments. The main focus is directed at deconstructing the technical steps of creating administrative maps in QGIS as well as evaluating the depth of respondents' spatial reasoning in interpreting regional tectonic risks in Lombok Island. The results of this study are expected to provide theoretical contributions to the development of GIS learning strategies that emphasize strengthening system logic rather than merely imitating software procedures.

METHOD

Research Design

This study used a descriptive-qualitative design with a content analysis approach (Krippendorff, 2018). This design was chosen because of its relevance in dissecting cognitive phenomena and procedural logic conveyed in the form of texts such as students' essay answers. Unlike conventional GIS practicum evaluations, which are performative in nature, this study was designed to deconstruct respondents' thought processes (mental models) in integrating QGIS technical skills and spatial disaster mitigation analysis. The analytical framework in this study adopts the principles of the Geospatial Technology Competency Model (GTCM) to map the hierarchy of competencies (Jackson & Kerski, 2023), as well as the use of taxonomy to evaluate the depth of reasoning and quality of respondents' learning outcomes (Biggs & Collis, 1982). Data were processed through a systematic codification process to identify patterns of gaps between ideal procedures (QGIS operational standards) and the the actual procedures constructed by the respondents in accordance with the principles of spatial thinking in the geospatial curriculum (National Academies Press, 2006).

Population and Sample

The subjects of this study were determined through purposive sampling techniques, involving students of the Physics Study Program, Faculty of Mathematics and Natural Sciences, from the 2021, 2022, and 2023 cohorts. A total of 35 students were selected as respondents with the main inclusion criterion being that they had taken and completed the Mapping course. The selection of varied cohorts aimed to obtain a comprehensive picture of procedural logic retention and disaster mitigation understanding at different levels of academic depth.

Data Analysis Techniques

The data obtained from respondents' essay answers were analyzed using qualitative content analysis techniques with a flow model adapted from Krippendorff (2018). The analysis process was carried out through four main stages to ensure the objectivity and depth of the findings:

Unitizing dan Data Reduction

In the early stage, all of the respondents' essay answers were divided into the smallest units of information (text fragments) that represent QGIS procedural steps and disaster mitigation logic. Data that were not relevant to the research objectives were reduced to focus the analysis on cognitive and technical aspects.

Coding dan Categorizing (Proses Pengodean)

The researchers conducted coding of text fragments based on the Geospatial Technology Competency Model (GTCM) framework. Respondent answers were classified into three main categories:

- Logical-Sequential: Answers that show a sequential and logical procedural flow.
- Partial-Fragmented: Answers that mention tools but fail to organize a systematic workflow.

- Misconception: Answers that show a critical error in basic concepts (such as coordinate systems or data types).

Gap Analysis (Analisis Kesenjangan)

This stage is the core of the research, where the researcher compares the Ideal Procedure (based on QGIS operational standards and tectonic mitigation theory) with the Actual Procedure written by the respondents. The gaps found are then interpreted to reveal cognitive distortions or spatial thinking obstacles experienced by students.

Inferencing dan Verifying

The final stage involves drawing conclusions inductively. The findings of pattern gaps are then compared with Spatial Thinking theory to provide a theoretical explanation for why such logical errors occur. To ensure the validity of the data, investigator triangulation is conducted by involving a GIS expert to review the results of the essay answer coding.

To measure the depth of respondents' procedural logic, essay answers are classified into four levels of understanding: Strategic-Systematic, Procedural-Mechanical, Fragmented-Partial, and Misconception. The determination of these categories is based on the completeness of GIS workflow elements such as data entry, geoprocessing, and layouting (National Academies Press, 2006), as well as the accuracy of disaster mitigation reasoning based on the provided tectonic maps. The categorization process is carried out collaboratively through peer-debriefing to minimize researcher subjectivity (Krippendorff, 2018). The analytic rubric criteria use an adaptation of the SOLO Taxonomy (Structure of Observed Learning Outcome). The quality of respondents' essay answers is evaluated using this framework to map the development of respondents' understanding structure (Biggs & Collis, 1982). The evaluation stages start from the Uni-structural level (understanding only one aspect of the procedure), Multi-structural (understanding many aspects separately/mechanically), up to Relational level (able to integrate QGIS procedures with mitigation analysis logically). This approach allows researchers to identify specific points where procedural logic gaps occur at each stage of map creation according to geospatial competency standards (Jackson & Kerski, 2023).

Table 1. Categories of comprehension

Score Category	SOLO Taxonomy Level	Characteristics of Essay Answers (Procedural Logic)	Its relation to GTCM (GIS Competency)
Very Good / Good	Relational	Respondents are able to connect the QGIS workflow comprehensively (Input – Process - Output) and relate tectonic data to mitigation steps.	Mastering Tier 4 (Technical) and Tier 3 (Academic) in an integrated manner.
Average	Multi-structural	Respondents mentioned many technical steps (e.g., Buffer, Overlay, Clip), but the order was random or they did not know the reason for using those tools.	Mastering Tier 4 mechanically (mimicking tutorials), but weak in system logic.
Poor	Uni-structural	The answer only focuses on one aspect (for example: only mentioning the name of the software or only mentioning the name of the disaster) without a workflow.	Has only reached the tool-based introduction stage, does not yet have procedural competence.
Very Poor	Pre-structural	The answers are irrelevant, misconceptions, or unable to interpret tectonic map symbols at all.	Experiencing cognitive barriers at Tier 3 (Basic Geospatial Literacy).

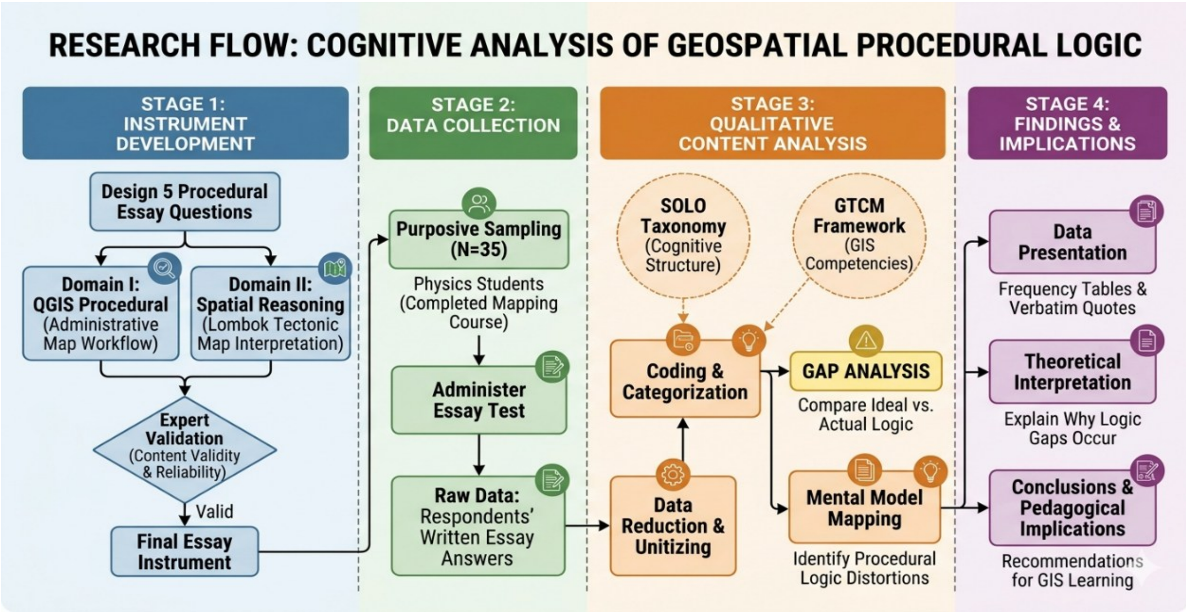

Figure 1. Research Flow

RESULTS AND DISCUSSION

Analysis of geophysical mapping competence based on QGIS for disaster mitigation shows a very diverse distribution of cognitive abilities among 35 respondents. Based on validity (0.948) and reliability (0.704) tests, the essay test instrument used proved to be consistent in measuring the five main indicators of geospatial competence. Overall, the research results reveal a cognitive polarization, where there is a wide gap between respondents with adequate technical literacy and respondents experiencing fundamental interpretation failures. This polarization is reflected in the dominance of respondents in the Very Poor (34%) and Poor (26%) categories, which, when dissected using the SOLO Taxonomy framework, indicates that the majority of students are still at the Pre-structural and Uni-structural levels (Biggs & Collis, 1982). Respondents at this level tend to fail in integrating various geophysical variables into a systematic QGIS workflow, so that mitigation mapping is only understood as a fragmented technical procedure, rather than as a unified operational logic. This competency imbalance also confirms the presence of barriers at Tier 3 (Academic Competencies) in the GTCM model, where weaknesses in basic geospatial literacy are directly proportional to students' low ability to develop data-driven mitigation recommendations (Jackson & Kerski, 2023). This phenomenon indicates that even though students have access to QGIS software (Baigereyev et al., 2024), without a strong foundation in procedural logic, the resulting maps will not achieve optimal function as a decision-making tool in sustainable disaster mitigation.

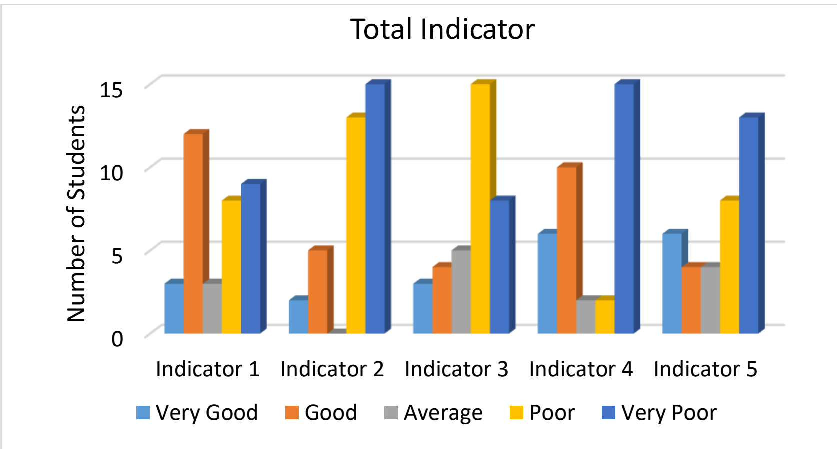

Figure 2. Analysis Results of Indicators 1 to 5

Indicator 1 is a cognitive threshold that determines the success of subsequent spatial analysis. Based on Figure 2, 31% of respondents (n=11) successfully fell into the Very Good and Good categories. Success in this group indicates a solid mastery of Tier 3 (Academic Competencies), where students are able to decode geophysical symbols in Figure 4 (Tectonic Map) into relevant geological information. This is demonstrated by their ability to accurately identify subduction zones and faults as sources of disaster risk (Hutchings & Mooney, 2021; Supendi et al., 2020). However, this conceptual success does not always correlate directly with procedural ability. This phenomenon is clearly seen in sample responses from respondents who, in theory, could explain the tectonic mechanism in Figure 4 but experienced cognitive degradation when asked to reconstruct the workflow for creating an administrative map in Figure 3 (Question No. 4).

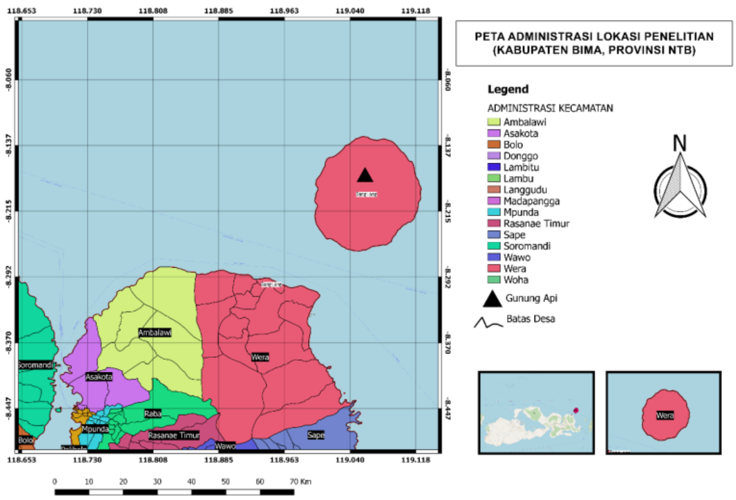

Figure 3. Administrative Map on question number 4

Although the majority of respondents fall into the low category, there is a small group (31% in Indicator 1) that is able to reach the Very Good and Good categories. Analysis of the sample responses from respondents in this category (as presented in the Student Answer Figures) reveals cognitive characteristics at the Relational level in the SOLO Taxonomy. In question number 2, respondents were able to decode Figure 4 (Tectonic Map of Nusa Tenggara) very systematically. Unlike the Very Poor group, who only see the map as a static visual, these respondents were able to connect the tectonic components:

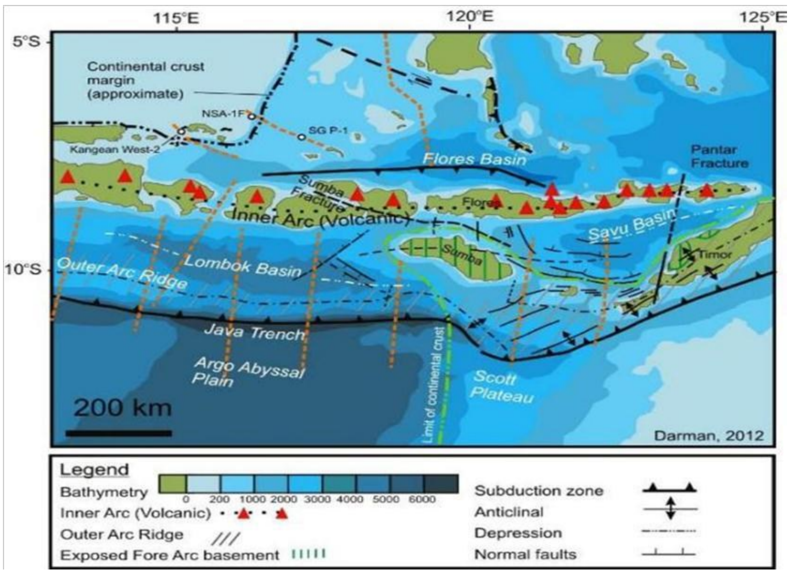

Figure 4. Tectonic Map of NTB in Question Number 2

“The potential disaster that may occur is an earthquake, considering the number of active volcanoes and the presence of faults that pass through it”

Respondents not only mentioned the type of disaster, but also provided arguments based on geophysical features (faults and volcanoes). This demonstrates mastery of Tier 3 (Academic Competencies) in GTCM, where basic geophysical literacy has been transformed into a risk analysis tool. The most noticeable distinction between the Good group and the other groups lies in the answer to question number 4 regarding the QGIS workflow. While the lower group experienced "logical fragmentation," these respondents were able to reconstruct the workflow completely:

“First is the preparation of shapefile (SHP) data... input into one of the software... QGIS... use the add vector feature... use the Symbology feature... next the map is equipped with elements such as a legend, scale...”

This respondent reached the Relational level because they are able to connect each stage chronologically and functionally (Input - Process - Output). The respondent understands that administrative data from BIG must be processed through the Symbology feature to produce meaningful information before entering the Layouting stage. The clarity of this flow proves that procedural logic has been strongly established, so that the use of software is no longer merely a tutorial imitation but a manifestation of system understanding (National Academies Press, 2006). The good technical ability in the previous indicators has a linear impact on the quality of mitigation recommendations in question number 5. The respondent is able to propose concrete actions:

"Ban on building in red zones prone to landslides; Relocation of residents in riverbank areas..."

In line with the goal of sustainable mitigation, this respondent indicates that maps are not merely an "end product," but rather a basis for decision-making. The characteristics of this answer meet Tier 4 (Technical Skills) standards integrated with disaster sociological awareness. The gap found in 34% of students in the Very Poor category (Figure 2) indicates that they lose the logical chain possessed by the sample respondent.

The frequency distribution in Figure 2 shows a significant cognitive polarization phenomenon in geophysical mapping competence. Although the test instrument has high reliability (0.704), respondents' achievements are dominated by the Very Poor (34%) and Poor (26%) categories. To dissect the root of this problem, an in-depth analysis was conducted by comparing two respondent answers representing the Relational cognitive level (Skilled Group) and Uni-structural level (Weak Group). Indicators 1 and 2 measure students' ability to perform decoding on Figure 4 (Tectonic Map). At this stage, most respondents (including the weak group) actually have quite good academic knowledge (Tier 3 GTCM).

“The main disaster potential in the area on the map is a major earthquake that can trigger a tsunami, because this region is located directly above the active subduction zone between the Indo-Australian Plate and the Eurasian Plate...”

This ability shows that students conceptually understand the causal relationship between plate tectonics and disaster risk. According to the SOLO Taxonomy, respondents have reached the Relational level in the aspect of declarative knowledge. They not only memorize terms but are able to connect geophysical features (subduction zones) with their functional consequences (earthquakes/tsunamis). However, the crucial finding in this study is that this conceptual proficiency is superficial and does not automatically transform into procedural proficiency. The real cognitive failure occurs in the indicators of QGIS technology mastery. This is where the procedural logic gap lies that drastically separates the two groups of respondents. In the majority group (Very Poor), a phenomenon called "Disconnected Cognition" was found. This is evident in the sample answers of respondents who are only able to explain the initial stages without the ability to continue the procedure:

"Looking for map data in SHP format... Then take the data of the district boundary part ar... Village boundary ar... Which is called in QGIS... Then, right"

The phrase "Then right" that hangs is empirical evidence that respondents have lost control over the digital workflow. Although they are familiar with the tools (tool-based), they do not have a mental "roadmap" to process the data. According to the GTCM Tier 4 (Technical Skills) framework, these respondents only have imitation skills (copying initial tutorials) without system logic independence. Gaps in the technical-procedural aspect directly affect the quality of mitigation outputs. Respondents who experience a break in logic on Indicator 4 tend to produce mitigation recommendations that are normative-generic (memorized), rather than based on spatial data. Skilled respondents can suggest "Relocation of residents in riverbank areas" based on risk map analysis results. Meanwhile, weak respondents can only mention a list of mitigation terms without knowing how the maps they created support those decisions. The inability to integrate QGIS-processed results into concrete action plan shows that without strong procedural logic, geophysical mapping will only become a 'visual decoration' and fail to function as a decision-making instrument in disaster mitigation (Syamsuddin et al., 2025; Nazirurrahman et al., 2025).

This research proves that the main obstacle for students does not lie in ignorance of disaster theory, but in the fragmentation of operational logic within the GIS environment. The dominance of the Very Poor category (Figure 2) confirms that the current GIS learning model is still too focused on software feature introduction (tool-oriented) and neglects strengthening systematic thinking construction (logic-oriented).

CONCLUSION

This study concludes that there is a sharp cognitive polarization in QGIS-based geophysical mapping competence among students. Although conceptually students are able to reach the Relational level in understanding tectonic phenomena (Tier 3 GTCM), that ability does not transform linearly into digital procedural skills. The majority of respondents (60%) are still stuck at the Pre-structural and Uni-structural levels in the SOLO Taxonomy, which is characterized by fragmented operational logic when managing spatial data. The key findings of this study reveal the phenomenon of 'Disconnected Cognition,' where students understand data input but fail to construct the processing workflow up to the presentation of mitigation information. This proves that the main barrier in GIS learning is not the lack of knowledge of disaster theory, but the absence of systematic procedural logic. As a result, the maps produced tend to become mere 'visual decorations' without a valid risk analysis foundation for sustainable mitigation decision-making. Therefore, a repositioning of the mapping learning curriculum is needed, shifting from merely introducing software features (tool-oriented) towards strengthening systematic thinking construction (logic-oriented). The integration of innovative learning models, such as STEM-Disaster assisted by Artificial Intelligence (AI), is recommended as a strategic solution to bridge the gap between academic knowledge and students' technical-procedural skills.

RECOMMENDATION

Findings regarding this procedural logic gap imply the need for a transformation in the learning model. The integration of a STEM (Science, Technology, Engineering, and Mathematics) approach assisted by Artificial Intelligence (AI) through a Project-Based Learning (PjBL) model is seen as a strategic solution to reconstruct students' mental models, so that earthquake literacy is no longer theoretical, but rather applicable and procedural.

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AUTHOR CONTRIBUTIONS STATEMENT

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Eko Hariyono	✓	✓	✓	✓			✓	✓		✓	✓			
Binar Kurnia Prahani	✓	✓	✓	✓			✓	✓		✓	✓			
Muhammad Satriawan	✓	✓	✓	✓			✓	✓		✓	✓			
Parizal Hidayatullah	✓		✓	✓	✓		✓	✓	✓	✓	✓			

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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