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Mathematical Critical Thinking and Learning Experiences of Junior High School Students: A Preliminary Needs Assessment for FJIMEC–GeoGebra–Scratch Model Development

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Abstract

Despite decades of curriculum reform, persistent gaps in Indonesian mathematics education remain. Students are taught mathematics formally, yet consistently fail to demonstrate higher-order reasoning abilities. Both national and international assessments confirm that mathematical critical thinking skills encompassing the ability to evaluate arguments, investigate claims, and draw logical conclusions remain a critical weakness, particularly at the junior high school level. This situation is further compounded by the minimal use of digital technologies such as GeoGebra and Scratch in everyday classroom instruction. This study conducted a preliminary investigation into the mathematical critical thinking abilities and mathematics learning experiences of Grade VIII students in Cirebon Regency (West Java) and Pamekasan Regency (East Java), serving as the empirical foundation for the development of the FJIMEC (Focusing, Justifying, Investigating, Messaging, Evaluating, Concluding) instructional model integrated with GeoGebra and Scratch. Using a convergent parallel mixed-methods design, the study involved 128 students and four mathematics teachers. The critical thinking test results were concerning: mean scores of 41.2 for Cirebon and 39.8 for Pamekasan, with 84.4% of students falling in the low category. The weakest indicators were Evaluating and Concluding. The Mann-Whitney U test revealed no significant between-region difference ($p = 0.412$), indicating a systemic deficit. Questionnaire analysis revealed low technology utilization ($M = 2.43/5.00$) and high mathematics anxiety. These findings provide preliminary empirical support for developing a FJIMEC–GeoGebra–Scratch instructional model.

Keywords: Mathematical critical thinking; GeoGebra; FJIMEC model; Mathematics learning experience

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INTRODUCTION

Mathematics is one of the central pillars of educational curricula worldwide; however, increasing instructional time in mathematics does not automatically produce students capable of thinking critically in mathematical terms. Mathematical critical thinking ability encompassing the capacity to interpret, analyze, evaluate, infer, explain, and self-regulate in the thinking process constitutes a foundational competency that every student urgently needs in order to navigate the complex challenges of 21st-century life (Sutama et al., 2022; Wang & Abdullah, 2024). In Indonesia, the gap between the demands of critical thinking competency and the reality of student achievement has reached a substantial level. Indonesia ranked 68th out of 80 participating countries in the Programme for International Student Assessment (PISA) 2022, with a mean mathematics score of 366, 106 points below the OECD average (472), with only approximately 1% of students reaching Levels 5–6 that require complex mathematical reasoning (OECD, 2023). At the national level, the 2022 National Assessment (Asesmen Nasional/AN) reported that the majority of junior high school students still fall in the "requires special intervention" numeracy category, directly reflecting students' low mathematical critical thinking skills. This confirms that mathematical critical thinking is not merely an additional goal, but a fundamental need that must be systematically addressed in instructional design.

Numerous recent studies have examined efforts to improve mathematical critical thinking ability from various perspectives. From a pedagogical standpoint, research indicates that the greatest weaknesses among junior high school students lie in evaluation and inference the ability to assess the validity of arguments and draw sound conclusions while interpretation tends to be relatively more manageable (Wulandari et al., 2025; Duru & Obasi, 2023). Students are generally better able to identify information from a problem, but experience significant difficulty when asked to independently prove, evaluate, or draw conclusions (Alfayez et al., 2022; Tursynkulova et al., 2023). This deficit pattern is cross-regional and has been documented across various regions of Indonesia (Nurhikmayati et al., 2024; Siahaan et al., 2023). From a technological perspective, GeoGebra—an open-source dynamic mathematics software that enables visual exploration of geometry, algebra, and calculus concepts has been empirically demonstrated to improve the mathematical critical thinking ability and mathematical communication skills of junior high school students (Yohannes & Chen, 2024; Gurmu et al., 2024; Hadi et al., 2024). Likewise, Scratch the block-based programming platform developed by MIT Media Lab has been shown to develop computational thinking that supports systematic reasoning and has been demonstrated to reduce mathematics anxiety through a creative, product-based learning approach (Ye et al., 2023; Fang et al., 2023; Fang et al., 2024; Pérez-Jorge & Martínez-Murciano, 2022). Meta-analytic reviews further confirm that dynamic mathematics software-assisted approaches significantly enhance the higher-order thinking skills of secondary school students (Ji et al., 2024).

Although research on mathematical critical thinking and the use of GeoGebra and Scratch continues to grow, several gaps remain unaddressed. First, most existing studies examine each technology or each critical thinking indicator in isolation, without the benefit of an instructional model featuring explicit one-to-one correspondence between each learning syntax and a specific critical thinking indicator. Second, despite the global growth in GeoGebra use in mathematics education, its implementation within structured instructional models specifically designed to enhance critical thinking at the Indonesian junior high school level remains highly limited and uneven (Siswanto et al., 2024; Yohannes & Chen, 2023). Third, to the authors' knowledge, limited studies have explicitly integrated GeoGebra and Scratch within a structured instructional model targeting mathematical critical thinking indicators at the Indonesian junior high school level. Fourth, there is a lack of adequate empirical grounding in the form of actual data on students' critical thinking ability and mathematics learning experiences to serve as the basis for developing contextually relevant and well-targeted innovative instructional models.

The novelty of this study can be understood across three layers. First, empirical novelty: mapping Grade VIII students' mathematical critical thinking and learning experiences across two Indonesian regions provides a cross-regional empirical profile that is currently lacking in the literature. Second, conceptual novelty: the FJIMEC syntax proposes an explicit one-to-one correspondence between each instructional phase and a specific critical thinking indicator, offering a structured framework that is not found in prior models. Third, developmental relevance: the use of needs-assessment data as the empirical basis for instructional model design ensures that the model is contextually grounded rather than theoretically assumed.

To address these gaps, this study was designed in two phases: the first phase is a comprehensive preliminary study (preliminary study), and the second phase is the development of the FJIMEC (Focusing–Justifying–Investigating–Messaging–Evaluating–Concluding) instructional model integrated with GeoGebra and Scratch. This article reports the findings of the first phase, conducted in Cirebon Regency (West Java) and Pamekasan Regency (East Java), with four specific objectives: (1) to map the mathematical critical thinking profile of Grade VIII students based on the six FJIMEC indicators; (2) to analyze students' learning experiences, attitudes, and engagement in mathematics; (3) to identify learning problems and needs from the teachers' perspective; and (4) to formulate a robust empirical foundation for the development of the FJIMEC model integrated with GeoGebra and Scratch.

This study makes a dual contribution to the advancement of knowledge and mathematics education practice. Theoretically, it fills a gap in the literature by providing a comprehensive, empirically grounded portrait of the mathematical critical thinking profiles of Indonesian junior high school students across regions, while simultaneously formulating the conceptual framework of the FJIMEC model with its explicit correspondence between learning syntax and critical thinking indicators. Practically, the findings of this preliminary study serve as a solid foundation for developing the FJIMEC–GeoGebra–Scratch instructional model: an innovative model that explicitly targets all six critical thinking indicators, supported by GeoGebra's dynamic visualizations and Scratch's computational expression, and designed for effective implementation under infrastructure constraints by leveraging the mobile devices already owned by students.

METHOD

Research Design

This study employed a convergent parallel mixed-methods design (Creswell & Plano Clark, 2018), in which quantitative data from the Mathematical Critical Thinking Test (MCTT) and the Mathematics Learning Experience Questionnaire (MLEQ), along with qualitative interview data, were collected simultaneously within a single research period, analyzed separately using their respective procedures, and then integrated at the interpretation stage to produce a more comprehensive understanding than would be achieved through either approach alone. The research paradigm is pragmatic, acknowledging the complementary validity of both quantitative and qualitative perspectives in explaining complex, multidimensional educational phenomena.

This study constitutes the Analysis phase within a broader Research & Development (R&D) sequence employing the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation). The Analysis phase (preliminary study) reported in this article functions as a comprehensive needs assessment, ensuring that the FJIMEC model to be developed is grounded not in assumptions, but in solid empirical data reflecting actual field conditions.

Research Location and Time

The study was conducted at four public junior high schools (SMP Negeri) distributed across two regencies: Cirebon Regency, West Java (two schools) and Pamekasan Regency, East Java (two schools). The selection of two regencies located on different islands and in different provinces was based on the following considerations: (a) geographical variation, as the two regencies represent different provincial and socio-cultural contexts (West Java and East Java); (b) differences in demographic and infrastructural characteristics, with Cirebon representing a semi-urban coastal setting and Pamekasan representing a semi-rural island context; (c) comparable curriculum implementation, as all four schools follow the national curriculum and had completed the topic of Linear Equations prior to data collection; and (d) adequate researcher access at both locations. The selection of 64 students per region was considered sufficient for a preliminary needs-assessment study, while acknowledging that this sample size does not support broad generalization. Data collection was carried out from March to April 2026, during the even semester of the 2025/2026 academic year.

Participants

Participants consisted of 128 Grade VIII junior high school students (64 in Cirebon, 64 in Pamekasan) and four mathematics teachers (one per class). Students were selected using purposive sampling based on the following criteria: (a) actively enrolled Grade VIII students who had studied the topic of Linear Equations; and (b) willingness to participate voluntarily. Prior to data collection, institutional research permission was obtained from each school, and informed consent was secured from teachers and school principals. Student assent was obtained verbally, with parents/guardians notified through school administration. Student participation was entirely voluntary, and all data were treated confidentially with identifiers replaced by codes. The distribution of participants is presented in Table 1.

Table 1. Distribution of Research Participants

No	School	Class	Students (n)	Teachers	Regency
1	SMPN [A]	VIII-A	32	1	Cirebon, West Java
2	SMPN [B]	VIII-B	32	1	Cirebon, West Java
3	SMPN [C]	VIII-A	32	1	Pamekasan, East Java
4	SMPN [D]	VIII-B	32	1	Pamekasan, East Java
	Total	4 classes	128	4	2 regencies

Research Instruments

Three main instruments were used in this study. The first instrument was the Mathematical Critical Thinking Test (MCTT). The MCTT comprised 6 descriptive items on the topic of Linear Equations for Grade VIII, with each item exclusively measuring one FJIMEC indicator: Item 1, Focusing (identifying and focusing on key information from a contextual problem); Item 2, Justifying (providing logical justification for a mathematical claim); Item 3, Investigating (investigating and verifying whether a set of points forms a straight line); Item 4, Messaging (communicating the entire mathematical process comprehensively and in a structured manner the term 'Messaging' is used here as an acronym component of FJIMEC and refers specifically to mathematical communication as defined in the critical thinking literature); Item 5, Evaluating (evaluating the validity of two opposing arguments about the relationship between two lines); and Item 6, Concluding (formulating a conclusion about the relationship between two lines based on gradient analysis). Each item was scored using an analytic rubric on a 0–4 scale, yielding a total score range of 0–24, which was then converted to a 0–100 scale. Content validity was established through expert judgment by three mathematics education lecturers using content validity ratio (CVR) criteria; item-level CVR values ranged from 0.67 to 1.00, with a mean CVR of 0.83 (valid category). Items were reviewed and refined based on expert feedback prior to data collection. The test was administered under supervised conditions, and open-ended responses were scored by two raters using an analytic rubric; inter-rater reliability was ensured through initial calibration and discussion of scoring discrepancies. Reliability: $\alpha = 0.78$ (reliable). It should be acknowledged that each critical thinking indicator is represented by only one item, which is a limitation of the instrument; therefore, indicator-level scores should be interpreted with appropriate caution.

The second instrument was the Mathematics Learning Experience Questionnaire (MLEQ), employing a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) with 20 items measuring five dimensions: Dimension I, Interest and Attitudes toward Mathematics (items 1–5); Dimension II, Quality of Teacher Instruction (items 6–10); Dimension III, Comprehension and Content Mastery (items 11–15); Dimension IV, Technology Utilization and Independent Learning (items 16–17); and Dimension V, Assessment and Feedback (items 18–20). Construct validity was assessed through exploratory factor analysis (EFA); the Kaiser-Meyer-Olkin (KMO) value was 0.81 and Bartlett's test of sphericity was significant ($p < .001$), indicating sampling adequacy. Items were retained using a factor loading threshold of ≥ 0.40 with principal axis factoring and Varimax rotation. Reliability for the overall scale was $\alpha = 0.82$ (highly reliable); subscale reliability ranged from 0.71 to 0.84. The negatively worded

Item 3 (mathematics anxiety) was reverse-coded prior to computing dimension means. It is acknowledged that Dimension IV contains only two items, which limits its psychometric robustness; scores for this dimension should therefore be interpreted with caution. The third instrument was a Semi-Structured Interview Guide for Teachers. Interviews were conducted individually (30–45 minutes per session), audio-recorded with participants' consent, and subsequently transcribed verbatim. The interview guide covered five themes: (1) instructional methods and models used; (2) perceptions of student difficulties; (3) use of digital technology; (4) understanding of critical thinking; and (5) barriers and expectations regarding instructional innovation. Thematic coding was conducted by two researchers; coding discrepancies were resolved through discussion until consensus was reached. Member checking was performed by sharing a summary of themes with participants for verification.

Data Analysis Technique

Data from the MCTT and MLEQ were analyzed using descriptive statistics (mean, standard deviation, frequency distribution) and inferential analysis. Because the data did not meet the assumption of normality based on the Kolmogorov-Smirnov test ($p < .05$), between-region comparisons were performed using the non-parametric Mann-Whitney U test. In addition to p-values, effect sizes (rank-biserial correlation, r) and medians with interquartile ranges (IQR) are reported to enable interpretation of the practical significance of group differences. MLEQ scores were categorized according to the following ranges: Very Low (1.00–1.79), Low (1.80–2.59), Moderate (2.60–3.39), High (3.40–4.19), and Very High (4.20–5.00). Interview data were analyzed using Braun & Clarke’s (2006) thematic analysis through six stages: data familiarization, initial code generation (open coding), theme searching (axial coding), theme review, theme definition and naming (selective coding), and report writing. Data triangulation was conducted by comparing findings from all three instruments to confirm the consistency and credibility of the conclusions.

RESULTS AND DISCUSSION

Mathematical Critical Thinking Test (MCTT) Results

Analysis of the MCTT data from 128 students yielded descriptive statistics as presented in Table 2. The resulting picture consistently reflects critical thinking ability that falls substantially below the minimum proficiency threshold across all six FJIMEC indicators.

Table 2. Descriptive Statistics of MCTT Scores per FJIMEC Indicator

No	FJIMEC Indicator	M Cirebon	SD	M Pamekasan	SD	M Combined	Cat.	p (U)
1	F – Focusing	52.3	10.2	50.8	11.4	51.6	Low	.618
2	J – Justifying	43.7	12.8	42.1	13.5	42.9	Low	.524
3	I – Investigating	38.9	14.1	36.4	15.0	37.7	Low	.387
4	M – Messaging	44.5	11.9	41.9	12.7	43.2	Low	.461
5	E – Evaluating	32.6	13.6	31.2	14.2	31.9	Very Low	.573
6	C – Concluding	34.8	12.3	37.2	13.1	36.0	Very Low	.432
	Overall Mean	41.2	12.5	39.8	13.3	40.5	Low	.412

Note: M = Mean (scale 0–100); SD = Standard Deviation; Cat. = Category; VL = Very Low; p (U) = Mann-Whitney U significance value (two-tailed, $\alpha = .05$). Category: Very Low < 35; Low 35–59; Moderate 60–74; High 75–84; Very High ≥ 85. n = 64 per region.

Table 3. Distribution of Students’ Critical Thinking Ability Categories (n = 128)

Category	Range	f Cirebon	% Cirebon	f Pamekasan	% Pamekasan	% Combined
Very High	≥ 85	0	0.0	0	0.0	0.0
High	75–84	3	4.7	2	3.1	3.9
Moderate	60–74	8	12.5	7	10.9	11.7
Low	35–59	34	53.1	35	54.7	53.9
Very Low	< 35	19	29.7	20	31.3	30.5
Total	—	64	100.0	64	100.0	100.0

Because the data were non-normally distributed, median and interquartile range (IQR) values and effect sizes (rank-biserial correlation) are reported alongside means and standard deviations in supplementary material; the Mann-Whitney U results include U statistics and z values in addition to p-values. Tables 2 and 3 together reveal several noteworthy patterns. First, 84.4% of students (108 out of 128) fell in the Low or Very Low category, and not a single student reached the Very High category. Second, there is a structured pattern of score decline from the Focusing indicator ($M = 51.6$) toward the Evaluating ($M = 31.9$) and Concluding ($M = 36.0$) indicators a pattern suggesting that the higher the cognitive level demanded, the greater the deficit experienced by students. Third, the Mann-Whitney U test yielded $p = .412$ ($p > .05$) for the overall mean comparison, confirming no significant difference between the critical thinking abilities of students in Cirebon and Pamekasan.

Mathematics Learning Experience Questionnaire (MLEQ) Results

Analysis of the MLEQ data from 128 students yielded a profile of mathematics learning experiences as presented in Tables 4 and 5.

Table 4. Descriptive Statistics of MLEQ by Dimension

No	MLEQ Dimension	M Cirebon	SD	M Pamekasan	SD	M Overall	Category
I	- Interest & Attitudes toward Mathematics	2.64	0.71	2.58	0.74	2.61	Moderate
II	- Quality of Teacher Instruction	3.12	0.65	3.08	0.68	3.10	Moderate
III	- Comprehension & Content Mastery	2.87	0.69	2.79	0.72	2.83	Moderate
IV	- Technology Utilization & Independent Learning	2.41	0.82	2.45	0.79	2.43	Low
V	- Assessment & Feedback	3.05	0.61	2.98	0.66	3.02	Moderate
	Overall Mean	2.82	0.70	2.78	0.72	2.80	Moderate

Note: M = Mean (scale 1–5); SD = Standard Deviation. Category: Low (1.80–2.59), Moderate (2.60–3.39), High (3.40–4.19).

Table 5. MLEQ Items with the Most Critical Scores

Item	Statement	M Cirebon	M Pamekasan	Remarks
16	- The use of technology in mathematics learning at school is adequate	2.31	2.35	Lowest
3	- I feel anxious or afraid before mathematics lessons/exams	3.82	3.91	Highest (negative)
17	- I regularly study mathematics independently outside of school hours	2.52	2.48	Very low
7	- I am actively engaged and participating during mathematics lessons	2.58	2.54	Low
1	- I enjoy mathematics lessons	2.71	2.65	Low
10	- My teacher uses a variety of different instructional methods	2.84	2.76	Low

Item 3 is negatively worded (unfavourable): a high score indicates elevated mathematics anxiety.

Table 4 shows that of the five MLEQ dimensions, only Dimension IV (Technology Utilization & Independent Learning) fell in the Low category ($M = 2.43$), while the remaining four dimensions hovered at the lower boundary of the Moderate category. Table 5 details the most critical items: the lowest score was recorded for item 16, concerning the adequacy of technology ($M = 2.31$ in Cirebon; 2.35 in Pamekasan), while the highest score carrying a negative meaning was recorded for item 3, concerning mathematics anxiety ($M = 3.82$ in

Cirebon; 3.91 in Pamekasan), indicating that the majority of students experienced substantial mathematics anxiety prior to their mathematics lessons.

Teacher Interview Results: Thematic Analysis

Thematic analysis of interview data from four teachers yielded five central themes that collectively paint a picture of mathematics learning conditions across the four schools. Table 6 presents a summary of the themes, representative evidence, and their implications for the development of the FJIMEC model.

Table 6. Central Themes from Teacher Interviews, Evidence, and Implications

No	Central Theme	Representative Evidence	Implications for FJIMEC
T1	Dominance of Conventional Methods	- 4/4 teachers use lecture and routine drill exercises as primary methods; unstructured group discussion; no critical reasoning-based learning scenarios have ever been implemented	- The FJIMEC model must provide highly operational, ready-to-use lesson plans and student worksheets so that teachers do not need to redesign from scratch
T2	Absence of Digital Technology	- Not a single teacher has ever used GeoGebra or Scratch in instruction; 2 teachers occasionally use PowerPoint; 1 teacher uses YouTube videos; limited computers are cited as the primary barrier	- Integration of GeoGebra (offline/mobile version) and Scratch (tablet version) must be designed mobile-first to run on students' smartphones without desktop computers
T3	Student Difficulties in Higher-Order Reasoning	- All teachers agree that students experience serious difficulties with HOTS items, particularly those requiring explicit reasoning, argument evaluation, and drawing conclusions; students rely heavily on memorization of formulas and procedures	- The Justifying, Evaluating, and Concluding syntaxes need the greatest scaffolding allocation in the FJIMEC design, with activities graded from highly guided to independent
T4	Limited Teacher Critical Thinking Literacy	- 3 out of 4 teachers are familiar with the term critical thinking from training, but do not lack concrete strategies to develop it in everyday instruction; 1 teacher admits to never having explicitly trained critical thinking	- The FJIMEC model must be accompanied by a detailed teacher guide containing the operational definition of each critical thinking indicator, sample prompting questions per syntax, and formative assessment rubrics
T5	Barriers and Expectations	- Barriers: limited IT facilities, packed timetable, high administrative burden; Expectations: all teachers expressed enthusiasm for a new, practical, engaging model that can be implemented with minimal facilities	- The FJIMEC design must consider time efficiency (completable within 2×40 minutes) and minimize infrastructure requirements by leveraging smartphones already owned by students

Source: Thematic analysis of teacher interviews, March–April 2026.

Discussion

A Pervasive Critical Thinking Deficit: Findings and Interpretations

A mean MCTT score of 40.5 out of 100, with 84.4% of students classified in the low to very low category, is not merely a statistical figure; it is an indication of a substantial gap demanding a targeted pedagogical response. This score falls far below the minimum proficiency threshold (score of 60) on the topic of Linear Equations, which is not mathematically complex for Grade VIII junior high school students. This finding suggests that the critical thinking deficit is not primarily caused by content complexity, but by a lack of learning experiences that explicitly and systematically train the components of critical thinking.

The pattern of declining scores from Focusing (51.6) to Evaluating (31.9) and Concluding (36.0) is not random; it is highly structured and carries significant pedagogical meaning. This pattern precisely delineates the upper boundary of cognitive ability developed through conventional instruction: students are trained to identify information from problems a skill frequently practiced in lecture-based learning but are not trained to evaluate arguments and formulate valid conclusions, skills that require exploratory, dialogic, and reflective thinking experiences. This finding aligns with systematic reviews concluding that weaknesses in evaluation and inference represent a consistent pattern in critical thinking research in Indonesian mathematics education (Suryawan et al., 2023; Wulandari et al., 2025; Duru & Obasi, 2023). It also corroborates findings from multiple studies demonstrating that students globally are more proficient in concrete and procedural aspects of critical thinking than in those demanding abstract and reflective reasoning (Dolapcioglu & Doğanay, 2022; Monteleone et al., 2023; Wang & Abdullah, 2024).

The absence of a significant between-region difference ($p = .412$) is an important finding that warrants careful interpretation. It refutes any interpretation suggesting that this problem is merely local or context-specific. Rather, it suggests that similar patterns may be present across different regional contexts; however, broader generalization requires larger and more representative studies. This finding indicates that the mathematical critical thinking deficit observed in this study is not merely a local or context-specific phenomenon within the sampled schools. The same pattern has been documented across various regions of Indonesia, confirming that the problem is cross-regional and systemic (Nurhikmayati et al., 2024; Siahaan et al., 2023). Research at the university level confirms the same, with critical thinking deficits in evaluation and inference remaining unresolved even after students enter higher education (Putri et al., 2025; Wang & Abdullah, 2024; Witarsa & Muhammad S, 2023).

Mathematics Anxiety: An Observed Affective Tendency Requiring Further Investigation

The high score on the negatively worded anxiety item ($M = 3.82$ for Cirebon; $M = 3.91$ for Pamekasan) was the highest score among all 20 MLEQ items. This suggests that students may experience discomfort or fear related to mathematics learning. However, because anxiety was not measured using a dedicated validated mathematics anxiety scale but only through a single questionnaire item, this interpretation should be considered preliminary and indicative rather than conclusive. Mathematics anxiety directly impairs working memory capacity the most essential cognitive resource for critical thinking processes as confirmed by multiple recent studies (Caviola et al., 2022; Cuder et al., 2023). As a consequence, anxious students are not only reluctant to attempt difficult problems, but are also neurologically hindered in their capacity for evaluative and inferential thinking.

The causal relationship between mathematics anxiety and low critical thinking skills forms a mutually reinforcing cycle: high anxiety leads to task avoidance → task avoidance results in insufficient critical thinking practice → insufficient practice produces low competence → low competence exacerbates anxiety. The FJIMEC–GeoGebra–Scratch model is designed to address these affective concerns through two potential pathways: GeoGebra may provide visual representations that transform abstract concepts into something more concrete and manipulable, potentially reducing the uncertainty associated with mathematics tasks; while Scratch may provide a playful, creative, and product-based learning context that shifts focus from performance to expression. Prior research has suggested that such approaches may be associated with reduced mathematics discomfort (Pérez-Jorge & Martínez-Murciano, 2022), although the extent to which the proposed model achieves these effects must be empirically verified in future intervention studies.

The Technology Gap: An Underutilized Learning Opportunity

MLEQ Dimension IV (Technology Utilization, M = 2.43) recorded the lowest score of any dimension, and item 16 concerning the adequacy of technology (M = 2.31–2.35) produced the lowest score in the entire instrument. This stands in sharp contrast to the availability of digital technology that could be leveraged: GeoGebra is freely available in both online and offline versions for desktop and mobile; Scratch is accessible via browser or tablet without requiring special installation. The gap between technology availability and its use in the classroom is not primarily an infrastructure problem though computer limitations do exist but rather a pedagogical one: teachers lack a model for integrating these technologies meaningfully into the instructional flow.

This is further reinforced by teacher interviews (Theme T2), which revealed that not a single teacher had ever used GeoGebra or Scratch. This finding is consistent with recent literature showing that, despite the continued global growth in GeoGebra use in mathematics education, its implementation within structured instructional models at Indonesian junior high schools remains highly limited and uneven (Siswanto et al., 2024; Yohannes & Chen, 2023; Gurmu et al., 2024). The direct design implication is that the FJIMEC model must be built assuming teachers have no prior experience with GeoGebra or Scratch. The implementation guide must include step-by-step tutorials for both platforms, with mobile-friendly versions to accommodate schools without computer laboratories.

Convergent Implications for the FJIMEC–GeoGebra–Scratch Model Design

Triangulation across three data sources the MCTT, MLEQ, and teacher interviews reveals a consistent convergence of findings, as summarized in the joint display (Table 7): (1) students consistently demonstrate a weak critical thinking profile on higher-order indicators (Evaluating, Concluding); (2) learning experiences are dominated by passive methods that do not utilize technology; (3) the anxiety item suggests students may experience discomfort in mathematics, creating an affective dimension that instructional design should acknowledge; and (4) teachers are willing but lack operational models and tools. This convergence across four layers of problems provides a strong empirical rationale for the development of the FJIMEC model.

Table 7. Joint Display: Convergence of MCTT, MLEQ, and Teacher Interview Findings

Problem Area	MCTT Evidence	MLEQ Evidence	Teacher Interview Evidence	Interpretation
- Higher-order reasoning (Evaluating, Concluding)	- Lowest scores: E=31.9, C=36.0 (Very Low)	- Low active engagement (M=2.56); low enjoyment (M=2.68)	- All teachers: students struggle with HOTS; no critical reasoning activities implemented	- Students lack structured reasoning practice; need for scaffolded argument evaluation tasks
- Technology use in learning	- N/A (not directly assessed)	- Lowest dimension: Technology (M=2.43, Low); tech adequacy item M=2.33	- No teacher has used GeoGebra or Scratch; computer availability cited as barrier	- Model must be mobile-first; needs built-in teacher tutorial for GeoGebra/Scratch

Problem Area	MCTT Evidence	MLEQ Evidence	Teacher Interview Evidence	Interpretation
- Mathematics discomfort / affective barrier	- Consistent decline from F to E/C suggests avoidance pattern	- High score on anxiety item (M=3.87, single item only)	- Teachers note reluctance and avoidance; prefer memorization	- Model design should incorporate low-threat, creative activities (preliminary suggestion, requires empirical testing)
- Teacher capacity and readiness	- N/A	- Low instructional variety (M=2.80); passive methods dominant	- 3/4 teachers familiar with critical thinking term but lack implementation strategies	- Detailed teacher guide with rubrics and sample prompts required

Source: Integrated analysis from MCTT, MLEQ, and teacher interviews, 2026.

The design logic connecting findings to model features is presented systematically: each FJIMEC syntax directly responds to one or more findings from this preliminary study. The Focusing syntax addresses identified weaknesses in information identification, which can be further enhanced through GeoGebra visualizations. The Justifying and Evaluating syntaxes the two that correspond with the weakest indicators address argumentative reasoning deficits through structured discussion activities and the evaluation of Scratch programs. The Investigating syntax addresses mathematical verification weaknesses through dynamic GeoGebra exploration. The Messaging syntax addresses mathematical communication weaknesses through Scratch project creation. The Concluding syntax addresses conclusion-drawing weaknesses through GeoGebra-based generalization visualization. Multiple international studies have demonstrated the effectiveness of GeoGebra-assisted instructional models in enhancing the higher-order thinking skills of junior high school students (Ji et al., 2024; Gurmu et al., 2024; Yohannes & Chen, 2023). GeoGebra within problem-based learning has been shown to significantly improve junior high school students' mathematical communication compared to conventional instruction a finding that directly supports the GeoGebra component of FJIMEC (Hadi et al., 2024; Negara et al., 2022; Ode Samura & Darhim, 2023).

Theoretically, this integration aligns with the Technology-Pedagogy-Content Knowledge (TPACK) framework, in which mathematical content knowledge, pedagogical knowledge embedded in the FJIMEC syntax, and technological knowledge of GeoGebra-Scratch are cohesively integrated—as demonstrated by numerous recent studies on technology integration in mathematics education (Kartal & Çınar, 2022; Jiménez Sierra et al., 2023; Marbán et al., 2025). Each FJIMEC phase has a distinct yet synergistic TPACK design, yielding a richer learning experience than the use of any individual component in isolation. This empirical grounding is further reinforced by research showing that active, exploration- and inquiry-based learning approaches which structurally resemble FJIMEC in their emphasis on active student engagement significantly improve critical thinking ability and higher-order thinking skills (Antonio & Prudente, 2024; Arifin et al., 2025; Zhang & Ma, 2023).

Limitations

This study has several limitations that should be acknowledged. First, the sample consisted of 128 students and four teachers from four purposively selected public junior high schools in two regencies; the findings therefore cannot be generalized to the broader Indonesian student population without further investigation using larger, more representative samples. Second, each FJIMEC critical thinking indicator was assessed by only one test item, which limits the reliability of indicator-level conclusions and calls for caution in their interpretation. Third, mathematics anxiety was operationalized through a single questionnaire item rather than a validated anxiety scale, meaning that anxiety-related findings are exploratory and descriptive in nature. Fourth, the qualitative component involved only four teachers, which restricts the depth and transferability of the interview findings. Fifth, this study does not test the effectiveness of the FJIMEC–GeoGebra–Scratch model; the findings serve only as a needs-assessment foundation, and the model's impact on learning outcomes must be evaluated in future design and intervention studies.

CONCLUSION

This preliminary study has systematically uncovered, mapped, and explained three interrelated problems in mathematics learning among Grade VIII junior high school students in Cirebon and Pamekasan Regencies, which collectively establish a robust empirical foundation for the development of the FJIMEC–GeoGebra–Scratch instructional model. The first problem is a pervasive and systemic critical thinking deficit. A mean MCTT score of 40.5/100, with 84.4% of students falling in the low–very low category, and the most significant weaknesses in the Evaluating ($M = 31.9$) and Concluding ($M = 36.0$) indicators, confirms the scale of this deficit. The absence of significant between-region differences ($p = .412$) suggests that similar patterns may occur across different school contexts within the sampled regions; however, broader generalization to the national level requires larger and more representative studies. The second problem is a classroom ecosystem constrained by anxiety and passivity. High levels of mathematics anxiety ($M = 3.87$ on the anxiety item), low active engagement ($M = 2.56$), and minimal technology utilization ($M = 2.43$) combine to create a learning environment that is not conducive to the development of critical thinking.

Mathematics anxiety, in particular, must be regarded as a primary affective barrier to be addressed, not merely a side effect in instructional model design. The third problem is a gap in teacher capacity. Although all teachers demonstrated willingness and enthusiasm for innovation, they lack the operational models, tools, and guides needed to explicitly develop critical thinking and to meaningfully integrate digital technology into instruction. These three problems collectively indicate a clear need for an instructional model that explicitly supports students' mathematical critical thinking, reduces anxiety, and integrates accessible digital tools. The FJIMEC model integrated with GeoGebra and Scratch represents a promising response to these needs, explicitly targeting all six critical thinking indicators through structured syntaxes, supported by GeoGebra's dynamic visualizations and Scratch's computational expression, and designed for implementation under infrastructure constraints through a mobile-first, offline-capable approach. However, the effectiveness of the proposed FJIMEC–GeoGebra–Scratch model must be examined in future validation and intervention studies. Future research will encompass: (1) development of FJIMEC instructional prototypes (lesson plans, student worksheets, GeoGebra applets, Scratch projects, critical thinking assessment rubrics, and a teacher guide); (2) expert validation by mathematics education and educational technology specialists; (3) a small-scale trial in a single class; and (4) a quasi-experimental field trial to causally evaluate the model's effectiveness in improving the mathematical critical thinking ability of junior high school students.

RECOMMENDATION

Recommendations for future research should be directed toward the empirical testing of the FJIMEC–GeoGebra–Scratch model, rather than being limited to a needs assessment study. The initial stage may focus on developing comprehensive instructional prototypes, including the instructional syntax, teaching modules, student worksheets, GeoGebra applets, Scratch projects, critical thinking rubrics, and teacher guides. These prototypes should be validated by experts in mathematics education, educational technology, assessment, and school practitioners to ensure content relevance, ease of implementation, and technological feasibility.

Subsequently, a limited trial should be conducted in one or two classes to examine the usability of the model, students' responses, time constraints, teacher readiness, and the stability of mobile device use. The main study is recommended to employ a quasi-experimental design involving a control group, pretest-posttest procedures, and an analysis of the model's effects on each FJIMEC indicator, particularly Evaluating and Concluding, which were identified as the main areas of weakness. The test instrument should also be strengthened by including more than one item for each indicator in order to improve its reliability.

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AUTHOR CONTRIBUTIONS STATEMENT

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Yumiati	✓			✓	✓						✓	✓		✓
Endang Wahyuningrum	✓		✓		✓	✓	✓			✓	✓		✓	
Sudirman	✓	✓		✓		✓			✓			✓	✓	
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Hasan Basri	✓	✓			✓	✓		✓	✓	✓		✓		

CONFLICT OF INTEREST STATEMENT
The authors declare no conflict of interest.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy considerations of research participants.

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