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Teachers' Readiness for STEAM and Differentiated Teaching: Its Connection to Students' Critical Thinking in Mathematics

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Abstract: Global assessments such as PISA 2022 and TIMSS 2019 reveal that Indonesian students' mathematical literacy and critical thinking remain below international benchmarks. This study aims to examine the relationship between teachers' readiness for STEAM and differentiated instruction and students' critical thinking in mathematics. Using a descriptive–exploratory design as the baseline phase of a research and development project, data were collected from 30 mathematics teachers and 40 eighth-grade students through interviews, classroom observations, and a diagnostic critical-thinking test based on framework. The results show that only 10 % of teachers implemented STEAM and 16.7 % applied differentiation, while students achieved a mean score of 1.85 (out of 4), with the weakest performance in evaluation and inference. The novelty of this study lies in its empirical linkage between teacher readiness and student cognitive outcomes within a developing-country context. Practically, the findings imply the need for professional development and contextualized STEAM-based modules with built-in differentiation. This study contributes baseline evidence for designing and validating a differentiated STEAM mathematics module to enhance students' higher-order thinking.

Keywords: Critical Thinking, Differentiated Teaching, Mathematics Education, Teachers' Readiness

A. Introduction

In the era of rapid technological development and global competitiveness, education systems worldwide face increasing pressure to equip students with the competencies required in the twenty-first century. Among these competencies, critical thinking has emerged as a central pillar for developing independent, creative, and adaptive learners capable of addressing complex real-world problems. International frameworks, such as the Partnership for 21st Century Learning (2021), emphasize critical thinking, collaboration, creativity, and digital literacy as fundamental skills for modern learners. However, large-scale assessments reveal that Indonesian students continue to face significant challenges in developing higher-order thinking skills, particularly in mathematics, signaling a persistent gap between global expectations and national performance.

The Programme for International Student Assessment (PISA) 2022 ranked Indonesia 73rd out of 81 participating countries, with a mathematics literacy score far below the OECD average. Similarly, the TIMSS 2019 results indicate that more than 78% of Indonesian students are limited to low-level cognitive tasks, with less than 5% able to solve problems requiring high-level reasoning. These findings collectively indicate that Indonesian students' mathematical literacy and critical thinking skills remain limited. Such persistent underperformance may be closely linked to instructional practices that prioritize procedural fluency and rote memorization rather than reasoning, inquiry, and sustained engagement with cognitively demanding tasks.

At the classroom level, mathematics teaching in many Indonesian schools tends to emphasize algorithmic procedures and formula memorization. Teachers often rely on textbook-driven instruction, focusing on the transmission of knowledge rather than fostering deep conceptual understanding. Consequently, students are seldom provided with opportunities to question, analyze, and evaluate mathematical ideas critically. These pedagogical patterns hinder the development of analytical reasoning, evaluative judgment, and inferential skills—three key components of critical thinking as defined by Facione (1990). In the context of mathematics learning, these skills are essential for enabling students to make logical connections, evaluate mathematical arguments, and draw warranted conclusions.

The lack of critical thinking development in mathematics classrooms is further compounded by teachers' limited understanding and readiness to implement innovative teaching approaches such as STEAM (Science, Technology, Engineering, Arts, and Mathematics). The STEAM approach encourages interdisciplinary learning that integrates science, technology, engineering, arts, and mathematics to create meaningful, project-based learning experiences. By bridging abstract mathematical concepts with real-life contexts, STEAM fosters creativity, problem-solving, and critical inquiry. Numerous studies highlight its potential to promote higher-order thinking; however, its success depends heavily on teachers' pedagogical competence, integrative design skills, and willingness to move beyond traditional instructional routines.

In parallel, differentiated instruction provides a complementary pedagogical framework that acknowledges variations in students' readiness, interests, and learning profiles. More explicit alignment between the two approaches is critical: differentiation functions as a necessary amplifier for STEAM's effectiveness because it ensures that interdisciplinary, inquiry-based tasks are accessible to learners with diverse prior knowledge. When differentiation strategies—such as tiered tasks, flexible grouping, and formative readiness assessments—are embedded within

STEAM activities, every student can engage meaningfully with the reasoning, modeling, and evaluative processes required for critical thinking development. Without differentiation, STEAM tasks risk benefiting only higher proficiency learners while leaving others behind.

Preliminary studies in Indonesia confirm that many teachers remain unfamiliar with the conceptual foundations and practical application of both STEAM and differentiation. Observations across schools reveal that only a small proportion of teachers attempt to integrate STEAM principles in ways that respond to students' varied readiness levels. Most educators still employ uniform instructional materials, rarely adjusting task complexity or learning supports. This situation suggests that the shift from traditional, teacher-centered practices to innovative, student-centered approaches remains far from being realized, and that the implementation of STEAM without systematic differentiation may not sufficiently elevate students' critical-thinking performance.

Moreover, the low level of students' critical thinking skills observed in diagnostic assessments particularly in analysis, evaluation, and inference—reinforces the need for instructional reform that integrates both STEAM and differentiation. Students may demonstrate basic interpretation and explanation, yet they struggle to evaluate arguments, detect reasoning errors, or construct inferences from incomplete information. Existing studies similarly report that while students can restate mathematical procedures, they often lack opportunities to engage in the inferential and evaluative reasoning required in STEAM-centered tasks. Strengthening these dimensions necessitates instructional designs that deliberately scaffold diverse learners through progressively complex, inquiry-driven problem contexts.

Despite the growing literature on STEAM and critical thinking, few studies have explicitly investigated the interaction between teacher readiness and student cognitive outcomes. There is a paucity of empirical studies that simultaneously examine (a) teachers' readiness for the dual pedagogical innovations of STEAM and differentiation, and (b) the direct association of this readiness with specific dimensions of students' critical thinking in mathematics, particularly within resource-constrained educational systems. This gap is critical because teacher readiness is the determinant of whether such innovations can be implemented with fidelity and produce measurable improvements in students' higher-order reasoning.

Given these challenges, this study aims to present preliminary findings on teachers' readiness for implementing STEAM and differentiated instruction alongside students' critical thinking skills in mathematics. By identifying baseline conditions, the study provides empirical grounding for the forthcoming development of a differentiated STEAM-based mathematics module. Ultimately, the contribution of this study lies in situating the readiness–outcome relationship within a developing-country context, where resource limitations, pedagogical constraints, and uneven professional development opportunities shape the feasibility and effectiveness of STEAM-based innovation.

Few studies have explored the empirical relationship between teachers' readiness for STEAM-based and differentiated teaching and students' critical thinking performance in mathematics. Most existing research either focuses on evaluating the effectiveness of STEAM implementation or investigates teachers' perceptions in isolation, while the role of differentiated instruction as a necessary amplifier that ensures STEAM tasks reach learners with diverse readiness levels—receives insufficient explicit linkage in applied studies. However, there is a paucity of empirical studies that simultaneously examine (a) teachers' readiness for the dual pedagogical innovations of STEAM and differentiation, and (b) the direct association of this readiness with specific dimensions of students' critical thinking in mathematics, particularly in resource-constrained educational systems. This lack of empirical linkage represents a crucial research gap that warrants exploration and motivates the present preliminary R&D phase.

Figure 2. Conceptual Framework of the Study

The framework illustrates that teachers' readiness for STEAM shapes the quality of differentiated instructional practices implemented in heterogeneous classrooms. Differentiation functions as a critical amplifier that enables STEAM activities to accommodate variation in students' prior knowledge, readiness levels, and learning preferences, thereby maximizing the potential impact of STEAM on mathematical critical thinking. Within this framework, the relationship between teacher readiness, differentiation, and student outcomes is mediated by teachers' instructional design skills, their pedagogical beliefs, and the broader classroom environment. This conceptual link underscores that STEAM alone may be insufficient without the parallel capacity of teachers to adapt tasks, supports, and learning pathways to diverse learner needs. However, despite the importance of this interaction, there remains a paucity of empirical studies that simultaneously examine teachers' readiness for the dual pedagogical innovations of STEAM and differentiation, as well as the direct association of this readiness with specific dimensions of students' critical thinking in mathematics, particularly in resource-constrained educational systems.

B. Methods

This study employed a descriptive–exploratory design as the initial stage of a larger research and development (R&D) project following the model of Borg and Gall (2013). Descriptive–exploratory studies are appropriate for establishing a clear understanding of baseline conditions prior to developing instructional interventions (Creswell, 2014). In this preliminary phase, the research focused on identifying teachers' readiness to implement STEAM and differentiated instruction—both conceptually and in classroom practice—as well as documenting students' mathematical critical-thinking performance. Differentiated instruction is treated in this study following Tomlinson's (2014) framework, while STEAM is positioned as an interdisciplinary pedagogical approach integrating science, technology, engineering, arts, and mathematics (Yakman & Lee, 2012).

Data were collected from September to November 2024 in 24 public and private junior high schools in Enrekang Regency. Purposive sampling was used to ensure representation across teacher experience levels, school characteristics, and student readiness, which is commonly recommended in exploratory educational research where contextual variation is relevant (Cohen, Manion, & Morrison, 2018). Table 1 summarizes the characteristics of the participating teachers and students.

Table 1. Participant Characteristics

Group	N	Gender (M/F)	School Type	Urban/Rural	Experience / Ability
Mathematics Teachers	30	12 / 18	17 public / 13 private	14 / 16	1–5 yrs (27%); 6–15 yrs (43%); >15 yrs (30%)
Grade VIII Students	40	18 / 22	24 public / 16 private	19 / 21	Mixed readiness levels

Semi-structured interviews with teachers explored their conceptual understanding of STEAM, familiarity with differentiated instruction, assessment practices, and challenges in enacting student-centered pedagogies. Classroom observations were carried out using structured checklists designed to capture instructional patterns, integration of cross-disciplinary elements, and the extent to which teachers differentiated content, process, or product during instruction. These procedures enabled triangulation of teacher-reported readiness with their actual classroom practices.

Data were gathered using three complementary instruments: semi-structured teacher interviews, structured classroom observations, and a diagnostic test of students' critical-thinking ability. Semi-structured interviews allow in-depth exploration of teacher beliefs and practices while maintaining comparability across respondents (Kvale & Brinkmann, 2015). Interview questions investigated teachers' conceptual understanding of STEAM (Yakman & Lee, 2012), their familiarity with differentiated instruction (Tomlinson, 2014), and the challenges they encountered in implementing student-centered pedagogy.

Classroom observations were conducted using structured checklists adapted from validated observation frameworks used in mathematics and STEM studies (Danielson, 2013; Sun & Zhang, 2022). The observation indicators documented instructional strategies, integration of interdisciplinary elements, use of learning media, student engagement, and the presence of differentiation in content, process, or product. Observational data were used to triangulate interview responses, consistent with Yin's (2018) recommendation for strengthening credibility through multi-source evidence.

Students' critical-thinking skills were assessed with a diagnostic test developed based on the six indicators proposed by Facione (1990): interpretation, analysis, evaluation, inference, explanation, and self-regulation. The use of indicator-aligned open-ended items is consistent with best practices in assessing higher-order thinking in mathematics (Brookhart, 2010). To provide clarity regarding the instrument, examples of test items include:

1) *Analysis:* "A store sells Package A (3 notebooks, 2 pencils, Rp18,000) and Package B (2 notebooks, 4 pencils, Rp16,000). Determine the possible unit price of a notebook and a pencil based on this information."
2) *Evaluation:* "Review the following steps for calculating the area of a triangle. Evaluate whether the reasoning is correct and justify your conclusion."
3) *Inference:* "A survey indicates that 60% of students understand fractions. If five students are selected randomly, what is the probability that at least three understand the concept? Provide justification."

Student responses were scored using a four-point analytic rubric aligned with Facione's descriptors. Two independent raters evaluated all responses, and inter-rater agreement reached a high reliability level (Cohen's $\kappa = 0.87$), which exceeds the recommended threshold for qualitative scoring (McHugh, 2012). All instruments underwent expert validation by mathematics education specialists to ensure content appropriateness, clarity, and alignment with constructs measured.

The data collection process followed three sequential stages recommended in R&D preliminary studies (Borg & Gall, 2013): (a) preparation through instrument design, validation, and pilot testing; (b) implementation through interviews, observations, and diagnostic testing; and (c) consolidation through transcription, scoring, coding, and data integration. Teacher interviews each lasted 30–45 minutes, classroom observations followed standardized protocols, and diagnostic testing was administered under controlled conditions to minimize measurement error.

Quantitative data were analyzed descriptively using means and percentage distributions for each Facione indicator, categorized into performance levels consistent with Brookhart's (2010) recommendations for interpreting critical-thinking outcomes. To strengthen the statistical rigor, a Pearson correlation analysis was conducted to examine the relationship between teacher readiness scores—aggregated from interview and observation data—and students' average critical-thinking scores at the classroom level. Pearson correlation is an appropriate inferential test for linear relationships in normally distributed educational data (Cohen et al., 2018). Results indicated a moderate positive correlation ($r = .41$, $p = .028$), suggesting that higher teacher readiness may be associated with better student reasoning outcomes.

Qualitative data from interviews and observations were analyzed using Miles, Huberman, and Saldaña's (2014) interactive model of data reduction, data display, and conclusion drawing. Emerging themes were organized into categories reflecting teachers' knowledge, pedagogical practice, and attitudes toward STEAM and differentiated instruction. Integrating qualitative and quantitative findings through triangulation (Yin, 2018) provided deeper insight into how teacher readiness aligns with students' higher-order thinking.

To ensure trustworthiness, the study implemented expert validation of instruments, inter-rater reliability checks, member checking with teachers, and triangulation across data sources. All procedures adhered to ethical standards for educational research (BERA, 2018). Ethical approval was obtained from the Enrekang District Education Office (Letter No. 02/Eth/2025), and informed consent was collected from all participants prior to data collection.

C. Results and Discussion

The preliminary data collected from 40 Grade VIII students revealed a consistently low level of critical-thinking proficiency across Facione's (1990) six indicators. As shown in the diagnostic results, students achieved mean scores of 2.20 for interpretation, 2.00 for explanation, and only 1.85 overall falling within the "low" category, with the lowest score in self-regulation (1.30). These patterns indicate that students are able to restate information to a limited extent but struggle substantially with deeper analytical and evaluative reasoning. Low inferential and evaluative skills suggest an instructional environment where learners are seldom engaged in open-ended exploration or argumentative reasoning conditions typically required to stimulate critical thinking (Brookfield, 2012; Schoenfeld, 1992).

The teacher data further illuminate the mechanisms underlying these student outcomes. Among the 30 participating mathematics teachers, only 10% had ever implemented STEAM-based learning, while 66.7% reported that their schools lacked STEAM modules, and 60% had no access to differentiated instructional materials. Additionally, 40% of teachers did not understand the concept of STEAM at all, and only 7% demonstrated strong mastery and systematic implementation. A similar pattern was found for differentiated instruction: only 16.7% had attempted to implement it, and none had integrated STEAM with differentiation in a single instructional design. This combination of low conceptual understanding, limited resources, and minimal implementation experience creates an instructional landscape dominated by traditional teacher-centered practices. According to Tomlinson (2017) and Suprayogi, Valcke, & Godwin (2017), such conditions systematically reduce opportunities for students to engage in higher-order reasoning because instructional tasks tend to remain uniform, procedural, and heavily guided.

Taken together, these findings reveal a clear mechanism: low teacher readiness → limited classroom activation of inquiry, interdisciplinary exploration, and flexible learning pathways → restricted cognitive demand → low critical-thinking performance. This mechanism is well supported by existing literature. Vygotsky's (1978) sociocultural theory emphasizes that cognitive growth depends on mediated learning experiences within an enriched environment. When teachers do not design activities that encourage analysis, evaluation, or inference, students' "zone of proximal development" remains underutilized. Likewise, Facione (2011) stresses that critical thinking develops only when learners routinely engage in judgment-intensive reasoning tasks precisely the type of tasks that are characteristic of STEAM and differentiated instruction but largely absent in the observed context. Another condition affecting student outcomes is the near absence of classroom materials that enable hands-on, contextualized learning. The data show that 66.7% of schools lacked any STEAM-related modules, and 60% lacked differentiated materials. Without such resources, teachers rely on conventional textbooks that prioritize procedural fluency over conceptual investigation. Research in STEM and STEAM education consistently demonstrates that modules integrating authentic contexts, engineering design, and interdisciplinary reasoning promote higher levels of reflection, problem solving, and creativity (Martínez-García et al., 2022; Conradty & Bogner, 2020). Thus, the structural absence of supporting materials acts as another mechanism that constrains the emergence of student critical thinking.

The preliminary findings also highlight important contextual constraints that shape teacher and student performance. Many teachers reported challenges related to limited training exposure, lack of professional-development programs, and insufficient school support systems. These conditions resonate with broader empirical evidence showing that STEAM and differentiated instruction require strong pedagogical content knowledge, collaborative planning capacity, and sustained mentorship (Karampelas, 2023; Suprayogi et al., 2017). When such conditions are absent, teachers naturally revert to simpler, lecture-dominant instruction—even when curriculum guidelines encourage differentiation and inquiry-based learning.

Interestingly, when triangulating teacher readiness data with student diagnostic outcomes, a subtle pattern emerges. Schools where teachers had moderate familiarity with STEAM or some experience in adaptation practices tended to show slightly higher student scores in interpretation and explanation. Although the relationship is not strong enough to infer statistical significance, it aligns with established theoretical mechanisms: teachers who employ even limited forms of inquiry or contextual tasks offer students more opportunities to make sense of information, thus elevating lower-level critical-thinking indicators. This tentative pattern reinforces the premise that teacher readiness is a proximal predictor of students' cognitive performance, consistent with the findings of Hattie (2012) regarding teacher expertise as a core determinant of learning quality.

Overall, the findings demonstrate that the low baseline critical-thinking performance is not merely an individual student issue but is deeply rooted in systemic instructional conditions: insufficient teacher understanding of STEAM and differentiation, lack of pedagogical resources, entrenched traditional teaching norms, and minimal exposure to inquiry-oriented tasks. These interrelated conditions collectively restrict the emergence of high-order reasoning skills. Therefore, the development of a STEAM-based differentiated mathematics module is not only justified but necessary. By combining interdisciplinary exploration with flexible pathways tailored to learner readiness, interest, and profiles—as emphasized by Tomlinson (2014, 2017)—the proposed module addresses the very mechanisms and conditions identified in the preliminary study.

In conclusion, the results provide a strong empirical and theoretical foundation for the subsequent stages of the R&D process. They justify the development of a differentiated STEAM mathematics module as a strategic response to existing instructional gaps and as a means of promoting higher-level cognitive engagement among junior high school students. The discussion also clarifies how teacher readiness, resource availability, and instructional patterns jointly shape students' critical-thinking abilities, thereby ensuring that the next phase of product development is grounded in authentic classroom realities.

D. Conclusions

This study investigated mathematics teachers' readiness to implement STEAM and differentiated instruction and its relationship with students' critical thinking in mathematics. The findings revealed that both teacher readiness and students' critical-thinking performance remain at low levels, with only 10% of teachers applying STEAM-oriented practices and 16.7% adopting differentiation, while students achieved a mean score of 1.85 on a 0–4 scale categorized as low with particular weaknesses in evaluation and self-regulation. These results suggest that limited teacher readiness directly restricts opportunities for higher-order cognitive engagement in mathematics classrooms, which continue to emphasize procedural mastery rather than inquiry and reasoning. This situation aligns with global assessments such as PISA (OECD, 2023) and TIMSS (Mullis et al., 2020), which consistently show Indonesian students lagging behind international benchmarks in mathematical literacy and critical thinking. Therefore, strengthening teacher capacity in STEAM integration and differentiated pedagogy is crucial for transforming classroom practices into more inclusive, engaging, and cognitively demanding learning environments. The study's practical implication is the urgent need for sustained professional development programs that enhance teachers' formative assessment literacy, interdisciplinary task design, and management of diverse learners. Future research should build upon these findings through the development and validation of a differentiated STEAM-based mathematics module and experimental testing of its effectiveness in improving students' critical thinking. Overall, this study contributes to the growing body of literature emphasizing that teacher readiness is the key catalyst for bridging the gap between pedagogical innovation and student cognitive outcomes in 21st-century mathematics education.

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