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Research paper

Assessing STEM Thinking in Elementary Classrooms: Evidence from Teachers' Perspectives

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ABSTRACT

The assessment of STEM thinking in elementary education remains dominated by product-oriented measurement, often overlooking the lived processes through which students' reasoning develops in classroom practice. This study employs a qualitative phenomenological approach to explore how elementary school teachers experience, interpret, and negotiate the assessment of STEM thinking within authentic learning contexts. Data were generated through in-depth semi-structured interviews with teachers experienced in implementing STEM-related activities and analyzed using phenomenological thematic procedures to reveal the essential structure of their experiences. Findings indicate that assessment is lived as (1) process-oriented yet constrained by product accountability, (2) centered on interpreting invisible, relational, and evolving student thinking, and (3) continuously negotiated between structural limitation and pedagogical possibility. These insights support a conceptual shift from viewing STEM assessment as outcome measurement toward understanding it as situated meaning-making shaped by teacher agency and classroom context. The study proposes a phenomenology of STEM assessment that contributes to global discussions on authentic evaluation, teacher professionalism, and 21st-century learning. Empirically, the findings highlight how teachers negotiate between institutional accountability and the evolving nature of students' STEM thinking in authentic classroom contexts. Practically, the study underscores the importance of developing more process-sensitive and interpretive assessment practices in elementary STEM education.

Keywords: STEM thinking, phenomenology, assessment in elementary education, teacher interpretation, authentic STEM assessment

In recent years, STEM education has been widely recognized as a critical framework for fostering essential competencies such as problem-solving, creativity, and interdisciplinary reasoning (Bakytkazy et al., 2025). This shift reflects a broader movement from content-oriented instruction toward competency-based learning, where emphasis is placed not only on what students know but on how they think, reason, and engage with complex problems (Lesseig et al., 2023; Tan & Wei, 2024; Mishra & Gupta, 2023). Within this paradigm, STEM learning is increasingly understood as a process involving inquiry, collaboration, and iterative design rather than the mere production of correct answers (Zhong, 2024; Holincheck et al., 2024).

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Despite this conceptual shift, assessment practices in STEM education have not evolved at the same pace (Dolgopolovas & Dagienė, 2024). A substantial body of research indicates that classroom assessment continues to prioritize final products and correctness, often overlooking the cognitive and interpretive processes underlying students' learning (Rizki et al., 2022; Prahesti et al., 2023; Zainil et al., 2022). This misalignment creates a critical tension: while STEM education aims to develop higher-order thinking and problem-solving skills, existing assessment approaches frequently fail to capture these competencies in meaningful ways (Amrina et al., 2024; Alazri & Shahat, 2025; Melawati et al., 2022).

Furthermore, although previous studies have explored instructional models, assessment tools, and student outcomes in STEM education, they have largely approached assessment as a technical or procedural activity. As a result, limited attention has been given to how teachers themselves experience, interpret, and make sense of assessing students' thinking in real classroom contexts. This is particularly evident in elementary education, where teachers play a central role in mediating learning yet often lack structured frameworks for evaluating complex cognitive processes.

This study addresses this gap by arguing that the assessment of STEM thinking cannot be fully understood as a technical measurement process, but must be examined as a lived, interpretive experience shaped by teachers' meaning-making in classroom practice. By adopting a qualitative phenomenological approach, this study explores how elementary school teachers experience, interpret, and negotiate the assessment of STEM thinking within authentic learning environments. Specifically, it investigates how teachers recognize students' thinking processes, how they construct meaning from these observations, and how they navigate tensions between pedagogical intentions and institutional demands.

The novelty of this study lies in its reconceptualization of STEM assessment as a phenomenological and interpretive practice. Rather than focusing on the development of assessment instruments or the measurement of student outcomes, this research foregrounds teachers' lived experiences as a primary source of knowledge. In doing so, it contributes to the advancement of STEM education by offering (1) a phenomenological understanding of assessment as meaning-making, (2) a relational perspective on students' thinking as dynamic and socially mediated, and (3) an account of teacher agency in negotiating assessment within structural constraints.

This study is guided by the following research questions (RQ):

RQ1: How do elementary school teachers experience the assessment of STEM thinking in their classroom practices?

RQ2: How do teachers interpret and make meaning of students' thinking processes during STEM learning activities?

RQ3: What challenges and possibilities do teachers encounter when assessing STEM thinking in authentic classroom contexts?

METHODS

This study employed a qualitative hermeneutic phenomenological approach, drawing on the interpretive tradition of Max van Manen, to explore teachers' lived experiences in assessing STEM thinking in elementary classrooms. This approach was selected as it enables the interpretation of meaning embedded in participants' lived experiences, rather than merely describing phenomena. In the context of STEM assessment, hermeneutic phenomenology allows for an in-depth understanding of how teachers interpret, negotiate, and make sense of students' thinking processes within situated classroom practices.

The participants in this study consisted of 8 elementary school teachers who had experience implementing STEM-related learning activities. Participants were selected using purposive sampling to ensure relevance to the research focus. The selection criteria included: (1) having at least 5 years teaching experience, (2) prior engagement with STEM-based or integrated learning, and (3) willingness to reflect on assessment practices. Participants were drawn from public elementary schools in Gowa, Indonesia. Their teaching experience ranged from 5–15 years, encompassing diverse grade levels and subject integration. This diversity enabled a richer exploration of how STEM assessment is experienced across different classroom setting.

Data were collected through in-depth semi-structured interviews, allowing participants to articulate their lived experiences in assessing students' STEM thinking. The interviews focused on three main areas: (1) teachers' understanding of STEM thinking, (2) their assessment practices during classroom activities, and (3) challenges and possibilities encountered in evaluating students' thinking processes. Each interview lasted approximately 30–60 minutes. To enhance contextual depth, the researcher also maintained reflective field notes and reviewed relevant classroom-related documents where available.

Data analysis followed a phenomenological thematic approach inspired by Max van Manen, aimed at uncovering the essential structure of lived experience. The process was conducted iteratively, beginning with a holistic reading of interview transcripts to develop a general sense of the data, followed by the selective

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highlighting of significant statements that captured key aspects of participants' experiences. These statements were then interpreted through reflective meaning formulation, which enabled deeper understanding beyond surface-level descriptions. Subsequently, themes were clustered to identify patterns across participants, and finally, a textual and structural synthesis was carried out to construct the essence of the phenomenon under study. This recursive and reflective process allowed the researcher to move continuously between parts and the whole (the hermeneutic circle), ensuring that the resulting themes remained firmly grounded in participants' lived meanings.

RESULTS

Experiencing assessment as process-oriented yet uncertain practice

The first theme describes how teachers experienced STEM assessment as a process-oriented activity embedded within classroom interaction and ongoing learning experiences. Teachers consistently emphasized that assessing STEM thinking could not be separated from observing students' reasoning, collaboration, experimentation, and revision during learning activities. Rather than focusing solely on final answers or products, teachers attempted to understand how students arrived at ideas and solutions.

One teacher explained:

"I often pay more attention to how students discuss and try different ideas than to whether the final answer is correct. Sometimes the process shows deeper understanding than the final product." (Participant 3)

Similarly, another participant stated:

"During STEM activities, students may fail several times, but I see important thinking processes when they revise and improve their work." (Participant 7)

These experiences indicate that teachers positioned assessment as something occurring throughout the learning process rather than only at the end of instruction. However, despite valuing process-oriented assessment, participants also expressed uncertainty regarding how to formally evaluate and document students' thinking.

Several teachers reported difficulties in determining clear indicators of STEM thinking and translating observations into formal grading systems. One participant noted:

"I can see students thinking critically during discussion, but it is difficult to convert those observations into numbers or scores." (Participant 5)

Another teacher described the tension between pedagogical intentions and institutional expectations:

"The school system still asks for measurable results, so even when I value the process, I eventually have to reduce it into grades." (Participant 2)

These findings suggest that teachers experienced assessment as a dynamic process situated between pedagogical awareness and structural uncertainty. While teachers attempted to recognize students' reasoning and collaborative learning processes, they simultaneously struggled with the absence of clear frameworks for evaluating such processes within formal assessment systems.

The findings for RQ1 demonstrate that teachers experienced STEM assessment as an ongoing attempt to recognize students' thinking processes while simultaneously negotiating institutional demands for measurable outcomes. To further clarify this dynamic, Figure 1 visualizes the primary tension experienced by teachers between the recognition of students' thinking processes (process recognition) and structural uncertainty in assessment (structural uncertainty). The figure illustrates that teachers attempt to assess learning processes through collaboration, iterative problem-solving, and reflection, while simultaneously being confronted with pressures related to rubrics, ambiguous assessment standards, and systemic grading requirements. Thus, the integration of **Table 1** and **Figure 1** confirms that the assessment of STEM thinking in elementary classrooms is not a linear practice, but rather a continuous space of negotiation between teachers' pedagogical intentions to understand students' learning processes and the need for greater clarity in formal assessment structures.

Table 1

Phenomenological thematic structure of theme 1

Analytic Stage	Description	Illustrative Meaning
Significant statements	Teachers observe reasoning, discussion, trial-and-error, revision	Assessment occurs during learning, not only after
Meaning units	Valuing thinking processes; difficulty defining evidence; reliance on intuition	Process recognition coexists with uncertainty
Thematic clusters	(a) Process-oriented assessment (b) Assessment ambiguity and grading tension	Dual experiential poles
Essential structure	Process-oriented yet uncertain practice	Tension between pedagogical intention and structural clarity

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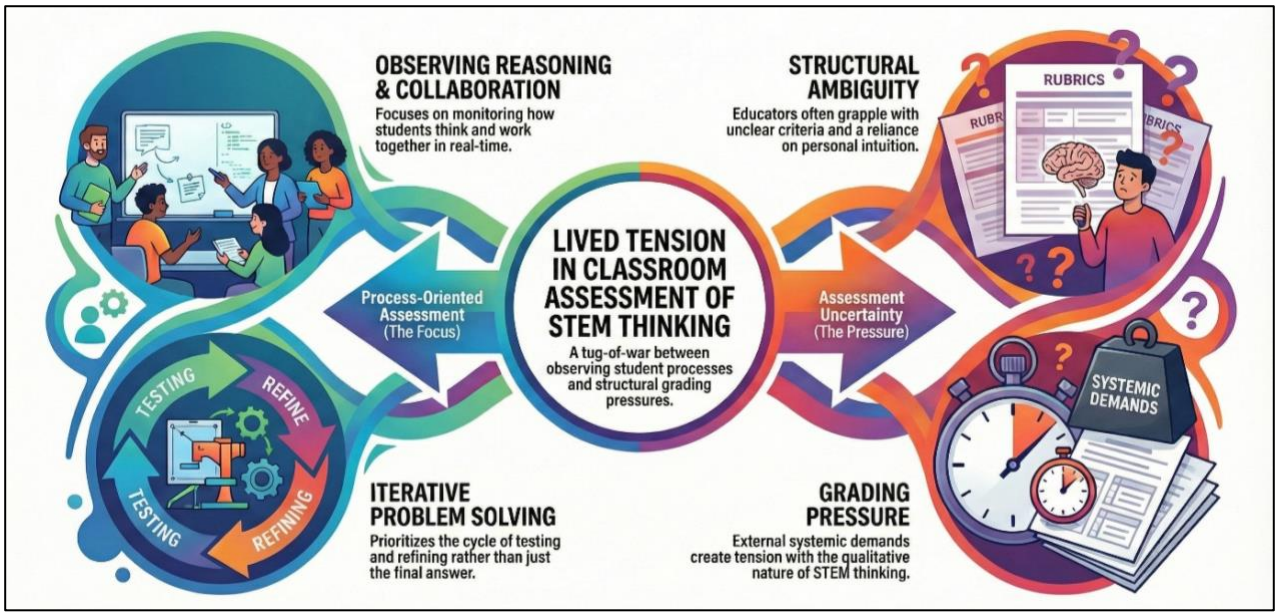
Figure 1

Tension in assessing STEM thinking: Process recognition vs. structural uncertainty



While Theme 1 reveals the tension embedded in teachers' immediate assessment practices, it also points toward a deeper interpretive layer concerning how teachers come to understand students' thinking itself. The uncertainty surrounding evidence and evaluation invites further exploration of the meanings teachers attribute to students' reasoning, interaction, and problem-solving within STEM learning contexts. This shift from experiencing assessment toward interpreting thinking forms the experiential ground from which the second theme emerges.

Interpreting students' STEM thinking as invisible, relational, and evolving

The second theme highlights how teachers interpreted students' STEM thinking as something not always directly visible through written work or final products. Participants frequently described students' understanding as emerging through discussion, peer interaction, gestures, questioning, and collaborative problem-solving.

One participant explained:

"Sometimes students who write very little actually show strong understanding when they explain ideas during group discussion." (Participant 1)

Another teacher stated:

"I cannot fully understand students' thinking just by looking at worksheets. Their reasoning appears more clearly when they interact with peers." (Participant 6)

Teachers also described STEM thinking as relational and continuously evolving. Understanding was perceived as developing gradually through interaction and revision rather than appearing as a fixed or static achievement.

For example, one teacher noted:

"Students often change their ideas after hearing other opinions. Their thinking develops during collaboration." (Participant 4)

Similarly, another participant explained:

"What students understand at the beginning of the activity is often very different from what they understand at the end." (Participant 8)

These findings indicate that teachers perceived STEM thinking as dynamic and socially mediated. Assessment therefore required continuous interpretation across multiple classroom interactions and learning moments.

The findings for RQ2 show that teachers interpreted STEM thinking not as a fixed cognitive outcome, but as a relational and evolving process that became visible through classroom interaction and collaborative learning. This understanding is further visualized through **Figure 2**, which depicts a three-layer model of STEM thinking as an ongoing and cyclical process. The figure illustrates that teachers' interpretations move back and forth between the outer layer of observable artifacts, the middle layer of social interaction, and the innermost layer of students' evolving reasoning. This visualization reinforces the findings in the table that the meaning of STEM thinking cannot be captured solely from written outputs, but must be understood through dialogue, negotiation of ideas, and conceptual changes that occur over time. Thus, the integration of **Table 2** and **Figure 2** confirms

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that assessing STEM thinking requires teachers to continuously interpret relational signs of cognition, making the assessment process resemble a dynamic interpretive journey rather than a static evaluative procedure.

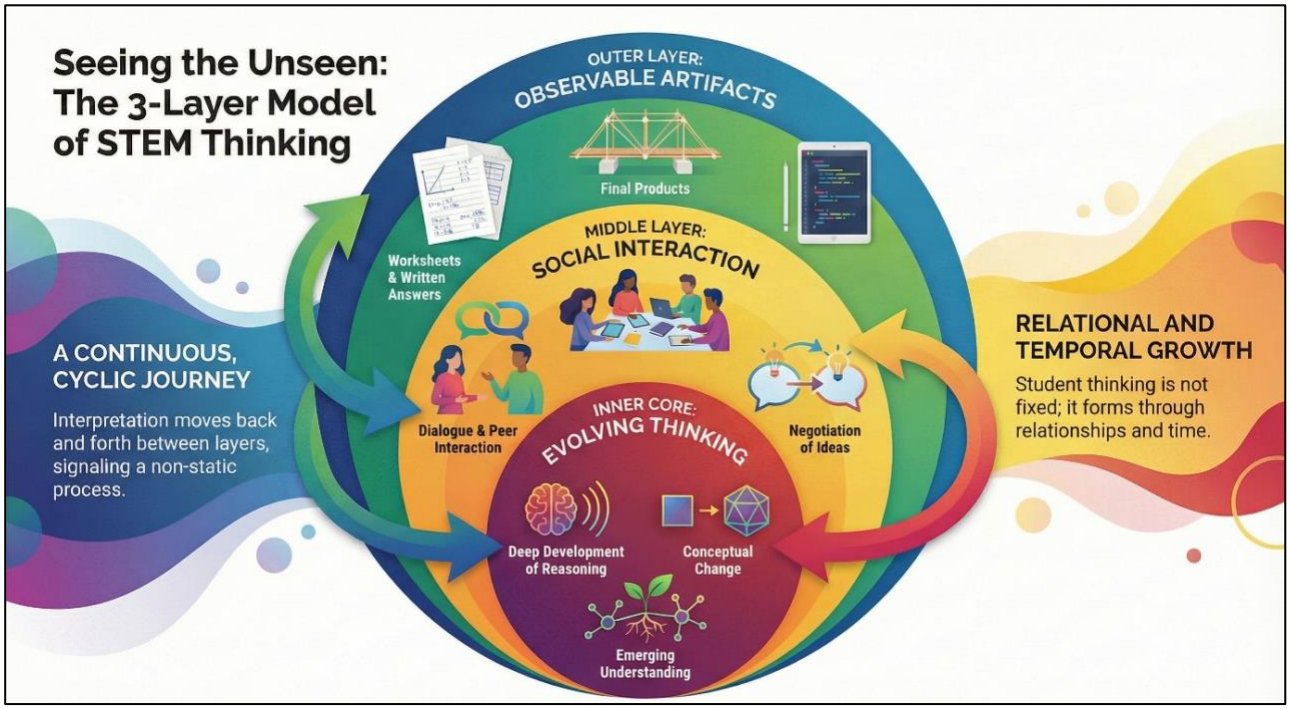
Table 2

Phenomenological thematic structure of theme 2

Analytic Stage	Description	Illustrative Meaning
Significant statements	Thinking seen in discussion, gestures, partial explanations, peer debate	Understanding not fully visible in products
Meaning units	Hidden cognition; socially mediated reasoning; shifting ideas over time	Thinking is dynamic and relational
Thematic clusters	(a) Invisible thinking (b) Relational emergence (c) Evolving understanding	Interpretation required across moments
Essential structure	Invisible, relational, and evolving STEM thinking	Teachers as continuous interpreters of cognition

Figure 2

A three-layer phenomenological model of interpreting students' STEM thinking



While Theme 2 illuminates the interpretive complexity through which teachers come to recognize students' STEM thinking, it simultaneously exposes the practical and structural consequences of such complexity. The invisibility, relationality, and evolving nature of thinking make assessment not only interpretive but also fragile within institutional constraints. These tensions open toward the third theme, which explores the challenges and possibilities teachers encounter when attempting to assess STEM thinking within authentic classroom realities.

Navigating Constraints and Imagining Possibilities in Assessing STEM Thinking

The third theme describes how teachers navigated tensions between institutional constraints and their efforts to implement meaningful STEM assessment practices. Participants frequently referred to limitations such as time pressure, curriculum demands, grading requirements, and the lack of suitable assessment tools.

One participant stated:

"There is not enough time to carefully observe every student's thinking process during STEM activities." (Participant 2)

Another teacher explained:

"The curriculum emphasizes completion and reporting, so teachers sometimes focus more on results than on understanding students' reasoning." (Participant 5)

Despite these constraints, participants also described various adaptive strategies to maintain more meaningful assessment practices. Teachers reported using classroom discussion, reflective questioning, observation notes, and peer feedback as alternative ways to understand students' thinking.

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For instance, one participant noted:

"I sometimes use reflective questions after activities because students can explain their thinking more openly." (Participant 7)

Another teacher explained:

"Even though formal rubrics are limited, I still try to record important moments when students demonstrate creative problem-solving." (Participant 3)

These findings indicate that teachers did not simply follow institutional assessment systems passively. Instead, they attempted to negotiate between administrative requirements and pedagogical goals by developing adaptive and context-sensitive assessment practices.

The findings for RQ3 reveal that assessing STEM thinking involved continuous negotiation between structural limitations and teachers' professional agency. Teachers attempted to sustain meaningful assessment practices despite institutional pressures emphasizing standardized and measurable outcomes. This dynamic is further visualized through **Figure 3**, which illustrates the balance between regulation and innovation in STEM assessment. The illustration shows that teachers stand at the intersection of two opposing forces: on the one hand, administrative demands such as curriculum standards, assessment systems, and procedural constraints; and on the other hand, the drive to develop assessment practices that are more dialogic, reflective, and oriented toward students' understanding. The figure emphasizes that teachers do not merely act as implementers of rules, but function as professional mediators who actively seek creative strategies to maintain pedagogical quality amid various constraints. Thus, the integration of **Table 3** and **Figure 3** demonstrates that the challenges of assessing STEM thinking simultaneously open up spaces of possibility for teachers to develop assessment innovations through professional agency and adaptive practice.

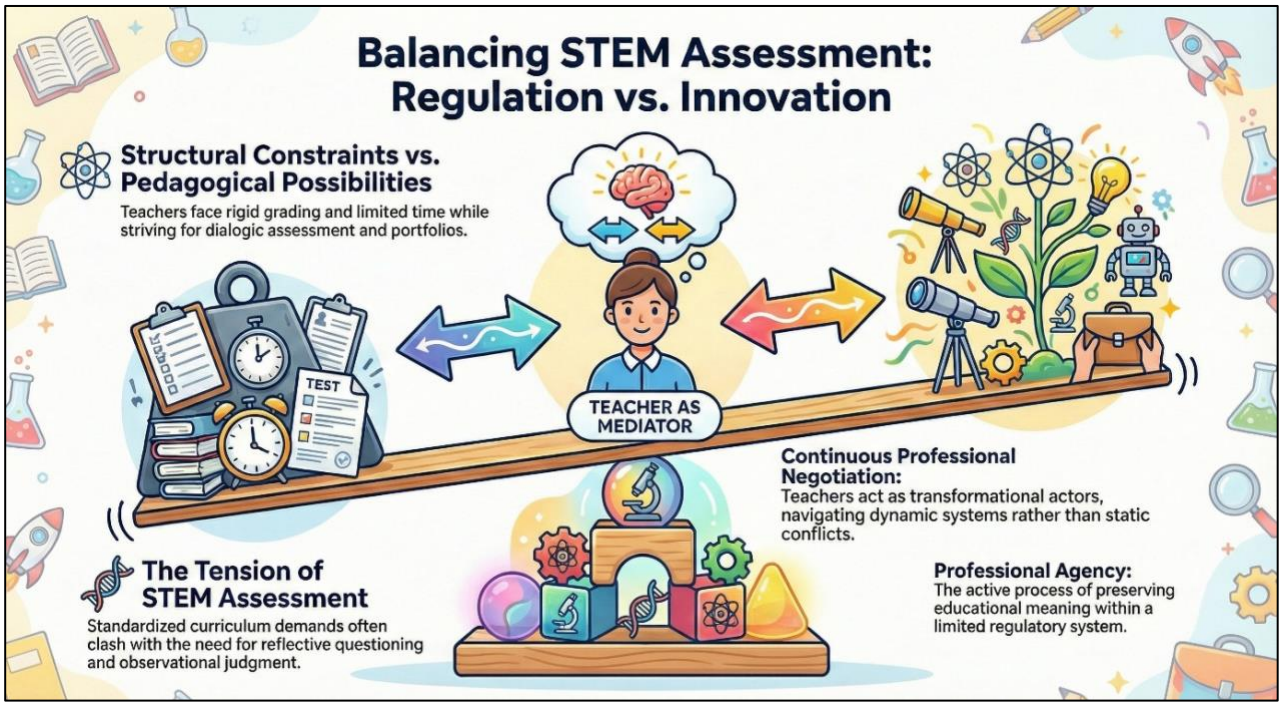
Table 3

Phenomenological thematic structure of Theme 3

Analytic Stage	Description	Illustrative Meaning
Significant statements	Time limits, grading systems, curriculum pressure, lack of tools	Structural restriction of assessment practice
Meaning units	Reduction of complex thinking into scores; institutional regulation	Tension between meaning and measurement
Thematic clusters	(a) Systemic constraints (b) Teacher agency and adaptive practice	Coexisting poles of experience
Essential structure	Continuous negotiation between constraint and possibility	Assessment as mediated professional action

Figure 3

Negotiating constraints and possibilities in STEM assessment: A phenomenological model of teacher agency



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Taken together, the three themes reveal a coherent phenomenological structure of teachers' lived experience in assessing STEM thinking. Teachers experience assessment as process-oriented yet product-bound (Theme 1), interpret students' thinking as invisible, relational, and evolving (Theme 2), and navigate assessment through a continuous negotiation between constraint and possibility (Theme 3).

This integrated structure shifts the understanding of STEM assessment from a purely technical procedure toward a deeply interpretive, relational, and contextually mediated professional practice. Such insight provides the conceptual foundation for the subsequent discussion on how assessment frameworks, teacher development, and educational policy might better align with the lived realities of STEM learning in elementary education.

DISCUSSION

Across the three themes, this study reveals that assessing STEM thinking is experienced by teachers as a process-oriented, interpretive, and contextually negotiated practice. Theme 1 highlights tensions between process-based assessment and formal grading systems, Theme 2 demonstrates the relational and evolving nature of students' STEM thinking, while Theme 3 illustrates teachers' continuous negotiation between institutional constraints and pedagogical possibilities. This study advances the understanding of STEM education by reconceptualizing assessment as a lived experience influenced by social, cultural, and institutional factors. By applying phenomenology, the research navigates the complex interplay between teachers' perceptions and their meaning-making processes surrounding assessments. This perspective diverges from traditional evaluations focused purely on psychometric data or instructional alignment, thereby re-emphasizing the importance of context in educational assessments (Neally, 2022; Mufanechiya & Makgalwa, 2024; Ma, 2021).

Engagement with students' STEM thinking, through a phenomenological lens, aligns with Husserl's concepts of essential meaning discovery and Heidegger's situated understanding both crucial to making sense of assessments as dynamic interactions that are contextually embedded (Aslam et al., 2023; Goos et al., 2023; Kulakoğlu & Kondakçı, 2022; AlGhamdi, 2025). Such interpretations highlight how teachers' assessment practices are not merely evaluative but are deeply intertwined with their lived experiences, fostering a more enriching learning environment (Yang et al., 2023; Bloodworth et al., 2023; Sohsomboon & Yuenyong, 2022).

The exploration of process-oriented STEM learning versus product-oriented assessment systems reveals a significant tension that is inherently lived by educators. This research contributes to the dialogue on educational assessment by showing that the mismatch between contemporary competencies and traditional evaluation practices is not merely theoretical but instead manifests within the experiences of teachers navigating these systems.

Teachers report that significant moments of STEM learning characterized by exploration, dialogue, and iterative reasoning are often undervalued within prevailing assessment frameworks, which prioritize quantifiable outputs over qualitative insights. These findings echo existing literature advocating for formative and authentic assessments that align more closely with real-world applications of knowledge (Neally, 2022; Mufanechiya & Makgalwa, 2024; Ma, 2021). Nonetheless, the institutional reliance on product accountability constricts the ability to authentically assess learning processes, resulting in knowledge simplification that can obscure deeper learning (Aslam et al., 2023; Goos et al., 2023). The study's key contribution lies in highlighting the phenomenological costs associated with prioritizing product over process in assessment practices, encouraging a critical reevaluation of accountability frameworks within STEM education (Kulakoğlu & Kondakçı, 2022; Yang et al., 2023; Bloodworth et al., 2023; Herwin et al., 2026).

The second theme of this study enhances the conceptual framework of STEM thinking by framing it as a lived cognitive experience that transcends individual cognition. It challenges the notion that thinking is an isolated mental construct, presenting instead a view of cognition as socially mediated and continuously evolving. This perspective aligns with sociocultural and constructivist theories, while incorporating phenomenological insights that elucidate how educators recognize and interpret STEM thinking in practice (Salamanca et al., 2023; Susanti et al., 2020).

Positioning teachers as interpreters of emergent meanings extends existing literature that often emphasizes evaluation tool design over interpretive skills. The findings suggest that traditional standardized assessments inadequately capture the nuances of student understanding, highlighting the necessity for assessments that embrace professional noticing, dialogic interactions, and temporal observations (Mufanechiya & Makgalwa, 2024; Moreira et al., 2025; Pérez-Montilla & Arnal-Palacián, 2023). This nuanced approach promotes a shift toward an interpretive-relational paradigm in STEM assessment, where cognition is viewed through the lenses of participation and experiential learning (Burton et al., 2020; Kononets et al., 2025; Gavrilas & Kotsis, 2025). In summary, the study underscores that effective assessment in STEM cannot rely solely on fixed metrics, but must reflect the dynamic and relational nature of learning that unfolds in collaborative environments (Aldiabat et al., 2025).

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While previous studies have primarily emphasized the development of STEM assessment instruments and measurable learning outcomes, the present findings suggest that teachers often rely on interpretive observation and classroom interaction to understand students' evolving reasoning. This indicates that STEM thinking may not always be adequately represented through written products or numerical scores alone (Prince, 2023).

The third theme of this study emphasizes assessment as a dynamic site of negotiation between systemic constraints and teacher agency. While prior research has typically focused on barriers such as time limitations and rigid curricula, this analysis reveals a more complex interplay where constraints and opportunities coexist within teachers' lived experiences. Rather than merely resisting or adhering to imposed structures, teachers actively mediate the meaning of their assessment practices (Beck et al., 2020; Yahaya & Mwila, 2024; Yılmaz et al., 2021).

This perspective aligns with theories that view teachers as adaptive decision-makers, asserting that assessment practices are rooted in professional agency rather than in fixed policies. The emergence of informal assessment strategies including dialogic questioning, the use of portfolios, and reflective observation illustrates how educational transformation can originate from classroom practices rather than exclusively from top-down initiatives (Ismail et al., 2024; Delcheva & Georgieva, 2020; Quileste, 2025).

Furthermore, recognizing these practices as integral to assessment reconfiguration suggests that assessment can become a tool for empowerment in educational settings, as teachers apply their agency to innovate within the constraints they face (Waheed et al., 2025; Kloser et al., 2022; Cao, 2025). This shifts the discourse on assessment towards a more relational model, where the interaction between teachers and their contexts is pivotal in shaping assessment outcomes (Sarkar, 2025).

The findings of this study propose a transformative view of STEM assessment as a phenomenological and interpretive practice focused on understanding evolving student thinking within existing structural constraints. This perspective suggests three major theoretical shifts: first, a movement from measurement to meaning, positioning assessment as a process of interpretive engagement rather than merely numerical evaluation, in line with calls for authentic and personalized assessment practices (Jiang et al., 2022; Herwin et al., 2022; Burus et al., 2024); second, a shift from individual cognition to relational thinking, recognizing that STEM understanding develops through dialogue, collaboration, and reflection over time, consistent with sociocultural perspectives on learning (Zakhari et al., 2021; Kusters et al., 2024); and third, a transition from compliance to negotiated agency, where teachers act as active mediators who balance institutional demands with pedagogical values instead of functioning as passive implementers of policy (Mayo-Rota et al., 2025; Vincent et al., 2023; Swanepoel & West, 2024). Through these conceptual shifts, the study advances a phenomenological framework for STEM assessment that contributes to global discussions on authentic evaluation, supports teacher professionalism, and aligns assessment practices with the broader goals of 21st-century learning (Martins, 2021; Ahn & Kim, 2025; Li & Ruppar, 2020).

Taken together, these findings demonstrate why conventional product-oriented assessment systems are often insufficient for capturing the complexity of STEM learning. Meaningful STEM thinking frequently emerges through interaction, collaboration, reflection, and iterative reasoning processes that cannot be fully represented through standardized scores alone. Therefore, the study highlights the need for more process-sensitive and interpretive assessment approaches in elementary STEM education.

Practically, the findings highlight the importance of supporting teachers in developing interpretive assessment competence, particularly in areas such as professional noticing, dialogic feedback, and systematic documentation of learning processes. At the policy level, the study suggests that educational systems need to move beyond predominantly product-based accountability models toward more flexible assessment architectures that acknowledge the evolving and process-oriented nature of student thinking. For future research, the study opens several promising pathways, including the design of phenomenologically informed assessment models, the investigation of teacher interpretation practices across diverse cultural contexts, and efforts to connect qualitative accounts of lived classroom experience with the development of innovative assessment instruments (Köşger & Görgülü, 2025). Collectively, these directions offer the potential to bridge the longstanding divide between traditional measurement approaches and the complex experiential realities of STEM learning and assessment.

The empirical contribution of this study lies in its phenomenological account of how teachers actually experience and interpret STEM assessment in everyday classroom contexts. Rather than focusing only on ideal assessment frameworks, this study foregrounds the lived realities of teachers navigating uncertainty, institutional pressure, and evolving student cognition. In doing so, the findings contribute a more experience-based understanding of STEM assessment that complements existing research emphasizing technical assessment design.

CONCLUSION

This study demonstrates that assessing STEM thinking in elementary classrooms is not merely a technical process of measuring learning outcomes, but an interpretive and contextually negotiated professional practice.

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Through a phenomenological perspective, the findings reveal that teachers experience STEM assessment as process-oriented yet constrained by formal accountability systems, interpret students' thinking as relational and evolving, and continuously negotiate between institutional limitations and pedagogical possibilities.

The study contributes theoretically by extending STEM assessment discourse beyond product-oriented measurement toward a phenomenological understanding of assessment as lived and interpretive practice. Empirically, the findings provide insight into how teachers make sense of students' thinking processes within authentic classroom interaction, highlighting the importance of teacher judgment, dialogue, and collaborative learning in STEM assessment.

Practically, the findings emphasize the need to strengthen teachers' interpretive assessment competence, particularly in observing students' reasoning, documenting learning processes, and implementing dialogic feedback strategies. Educational institutions and policymakers are encouraged to develop more flexible and process-sensitive assessment systems that better reflect the complexity of STEM learning.

This study is subject to several limitations. The research involved a limited number of participants within a specific educational context, which may restrict the transferability of findings to other settings. In addition, the study focused primarily on teachers' perspectives without incorporating direct classroom observation or students' voices.

Future research may explore phenomenologically informed STEM assessment models across broader educational and cultural contexts, integrate classroom observational data, and investigate how digital or technology-supported assessment practices can capture students' evolving STEM thinking processes more effectively. Overall, the study highlights the importance of reconceptualizing STEM assessment as an interpretive, relational, and experience-based educational practice capable of supporting more authentic and meaningful learning in contemporary elementary education.

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Ethical statement

This study was conducted in accordance with ethical research standards and received approval from the relevant institutional authority at Universitas Negeri Yogyakarta. The research was conducted in public elementary schools in Gowa. All participants voluntarily participated in the study and provided informed consent prior to data collection. Participant confidentiality and anonymity were maintained throughout the research process.

Competing interests

The authors declare that there are no competing interests regarding the publication of this article.

Author contributions

All authors contributed substantially to the study conception and design. The first author was responsible for data collection, data analysis, and manuscript drafting. The second and third authors contributed to the research design, validation of the instruments, and interpretation of the findings. The fourth author contributed to data analysis and critical revision of the manuscript. The fifth author supervised the overall research process and reviewed the final manuscript. All authors read and approved the final version of the manuscript.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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AI disclosure

The authors used OpenAI's ChatGPT to assist with language refinement and grammatical editing during manuscript preparation. All interpretations, analyses, and conclusions presented in this article remain the full responsibility of the authors.

Biographical sketch

Herwin Herwin is a lecturer and researcher at Universitas Negeri Yogyakarta, specializing in educational evaluation and elementary education. His research interests include learning assessment, instructional models, online learning, teacher performance, and educational technology. He has published extensively in reputable international journals, particularly in the fields of primary education, evaluation studies, and innovative learning strategies. His scholarly contributions focus on improving teaching quality, student learning outcomes, and educational practices in contemporary learning environments.

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