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EPISTEMOLOGICAL PERSPECTIVE ON MATHEMATICAL THINKING PATTERNS OF LOWER-GRADE ELEMENTARY STUDENTS

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Abstract

This study aims to analyze the mathematical thinking patterns of lower-grade elementary school students in solving numeracy problems from an epistemological perspective. The study employed a qualitative case study approach involving six third-grade students at SDN Purworejo, selected purposively based on variations in numeracy ability. Data were obtained from students' numeracy problem-solving tasks, classroom observations, and semi-structured interviews, while secondary data were taken from school documents such as lesson plans and assessment records. The collected data were analyzed using thematic analysis following the Miles, Huberman, and Saldaña (2020) framework, consisting of data reduction, data display, and conclusion drawing. The results revealed three general patterns of mathematical thinking among students: intuitive, procedural, and emerging logical thinking. These findings indicate that most lower-grade students still rely on intuitive and procedural approaches, highlighting the need for learning strategies that promote conceptual understanding, multiple representations, and teacher scaffolding to strengthen early numeracy skills.

Keywords Mathematical thinking patterns; Problem solving; Numeracy.

INTRODUCTION

Numeracy skills are currently one of the main issues in education, both nationally and internationally (Grotlüschen et al., 2020) (Geiger et al., 2015). Numeracy is not only understood as basic arithmetic skills, but also includes the ability to understand, use, and interpret number concepts and mathematical symbols to solve various problems in everyday life (Westwood, 2021)(Muñez & Cheung, 2024) (Naibaho, 2022). Within the framework of the Merdeka Curriculum, mastery of numeracy is even seen as one of the Pancasila learner profiles that students must possess from elementary school level (Setiawati & Mariana, 2025). Ideally, elementary school students, including those in lower grades, should be able to develop logical, systematic, and concept-based mathematical thinking patterns (Erickson, 2007). However, the reality on the ground shows a gap between this ideal and the actual conditions. Many lower grade students still experience academic anxiety when faced with numeracy problems, tend to use trial and error strategies, and emphasize procedural memorization without understanding the underlying conceptual meaning (ALFARUQI, n.d.)(Samaloisa & Bilo, 2024). This condition shows a gap between the curriculum requirements and the actual competencies of students in the field (Ayuningtyas et al., 2023) (Triyono et al., 2024).

This gap is reinforced by international findings, such as the Programme for International Student Assessment (PISA) report, which places Indonesian students' numeracy skills in the low category, particularly in mathematical reasoning indicators (PISA, 2019). Wijaya's (2017) research confirms that the low numeracy scores of Indonesian students are not only due to limited calculation abilities but also weak mathematical thinking processes, which should be the foundation for problem solving (Jupri & Drijvers, n.d.). This finding is reinforced by research by Sari and Lestari (2022), which reveals that lower-grade elementary school students more often rely on mechanical procedures than conceptual reasoning (Helwig et al., 2002). This shows that students' mathematical thinking processes are still at the intuitive and procedural stages, with limitations in connecting concrete representations to abstract symbols. On the other hand, research by Hidayat and Prabawanto (2022) highlights the importance of epistemological analysis in understanding students' mathematical thinking patterns, as this approach is able to reveal how students construct mathematical knowledge through the interaction between learning experiences, cognitive strategies, and representations used (Rahaju et al., 2020).

In the field context, the phenomenon of weak conceptual mathematical thinking is also clearly evident at SDN Purworejo, the site of this research. Based on preliminary observations and interviews with teachers in grades I–III, most students still struggle to understand basic number concepts, arithmetic operations, and the relationships between mathematical symbols in contextual situations. When presented with story-based numeracy problems, students tend to use trial-and-error strategies without linking the meaning of numbers to real situations. For instance, when solving a problem about "distributing marbles equally," many students immediately perform subtraction instead of interpreting division as a process of sharing or distribution. Teachers reported that this occurs because students are accustomed to memorizing calculation procedures without grasping their underlying concepts and have limited representational skills to connect concrete experiences with symbolic forms. This condition indicates that the mathematical thinking patterns of lower-grade students at SDN Purworejo remain intuitive and procedural, rather than conceptual and reflective, as expected in numeracy learning aligned with the *Merdeka Belajar* framework.

In response to these challenges, the school has implemented several initiatives to strengthen students' numeracy abilities. SDN Purworejo, for example, has introduced a *weekly numeracy literacy program* integrated into thematic learning activities and has provided limited teacher training to develop context-based teaching materials. However, based on interviews with the principal and numeracy coordinator, the implementation of these programs has remained largely administrative and has not yet focused on deepening students' thinking processes. Teachers tend to prioritize achieving internal numeracy assessment scores over understanding how students construct their mathematical knowledge. The absence of an epistemological analysis of students' thinking patterns means that the learning strategies employed have not been able to reveal how students actually make sense of mathematical ideas within each numeracy problem. Therefore, this study is crucial in providing a comprehensive picture of the mathematical thinking patterns of lower-grade students at SDN Purworejo from an epistemological perspective and in forming a foundation for developing more reflective and student-centered numeracy learning policies.

Theoretically, research on the mathematical thinking patterns of elementary school students has been conducted, but most of it still focuses on upper grade students or solely on numeracy skills (Marliza et al., 2021). Research that examines in depth the mathematical thinking patterns of lower grade students—especially in the context of numeracy problem solving—is still relatively limited. In fact, the lower grade period is a crucial period for the development of children's mathematical thinking foundations (Fennema et al., 1996) (Fraivillig et al., 1999). From an epistemological point of view, it is important to understand how students build, construct, and apply their mathematical knowledge in dealing with numeracy problems. Thus, this study has a significant position in filling the existing research gap, while also providing new contributions to the study of mathematical thinking at the elementary education level.

Practically, the results of this study are expected to have direct implications for teachers and primary education practitioners. Understanding the mathematical thinking patterns of lower grade students can be the basis for teachers in designing numeracy learning strategies that are more appropriate to the cognitive development stage of students. For example, by integrating multiple representations, *scaffolding*, and a contextual problem-based approach, teachers can help students develop more conceptual and systematic thinking skills (Broman et al., 2018) (Tawfik & Kolodner, 2016). Therefore, the purpose of this study is to analyze the mathematical thinking patterns of lower grade elementary school students in solving numeracy problems from an epistemological perspective (Schommer-Aikins et al., 2005) (Muis, 2004). Theoretically, this study enriches the literature on mathematical thinking at the elementary education level. Pragmatically, this study provides strategic recommendations for improving the quality of numeracy learning in elementary schools, particularly in supporting the implementation of the Merdeka Curriculum and improving student learning outcomes in the future.

Several previous studies have explored mathematical thinking and numeracy development in elementary education with various focuses and methodologies. For instance, Wijaya (2017) identified that students' difficulties in solving mathematical problems were rooted in their weak mathematical reasoning and inability to translate real-life contexts into mathematical representations. Utami and Trisnawati (2020) examined upper-grade students and found that mathematical thinking was dominantly procedural rather than conceptual, indicating that students often prioritized obtaining answers over understanding problem structures. Fitriani and Alsarawi (2025) investigated numeracy difficulties among lower-grade students and discovered that anxiety and dependence on memorization hindered their conceptual understanding of numbers (Alsarawi, 2025). Saadati (2025) highlighted that the use of concrete media and contextual tasks could improve conceptual reasoning, but such interventions were rarely applied consistently in early elementary levels (Saadati et al., 2025). Furthermore, Hidayat and Prabawanto introduced an epistemological perspective in analyzing mathematical thinking, emphasizing that understanding how students construct mathematical knowledge requires attention to their reasoning processes and representational strategies (Viro & Joutsenlahti, 2020). Based on these findings, this study differs by specifically focusing on the epistemological analysis of lower-grade students' mathematical thinking patterns in numeracy problem solving, a perspective that has not been comprehensively addressed in previous research, particularly within the context of the Merdeka Curriculum framework. Therefore, the objective of this study is to analyze and describe how lower-grade elementary school students construct and apply their mathematical thinking processes when solving numeracy problems from an epistemological perspective, thereby providing theoretical contributions to the study of mathematical cognition and practical insights for improving numeracy learning strategies in early elementary education.

METHOD

The type of research used is descriptive-exploratory qualitative. This type aims to describe in detail, depth, and systematically the phenomenon of elementary school students' mathematical thinking in the context of contextual numeracy. The main focus of the research is not on quantifying results, but on understanding the epistemological processes behind how students understand, plan, execute, and reflect on solving mathematical problems. Therefore, the research data is narrative and descriptive, describing the actions, statements, and thoughts of students during the learning process.

The research was conducted at Purworejo Public Elementary School (SDN Purworejo), Central Java, Indonesia, during the second semester of the 2024/2025 academic year. This school was chosen because it implements the Merdeka Curriculum and has a diverse student population in terms of numeracy abilities, making it relevant to the objectives of this study. The natural classroom setting allowed researchers to observe students' genuine mathematical thinking processes in an authentic learning environment.

The subjects of this study were six third-grade students, selected using purposive sampling to represent variations in numeracy ability (high, medium, and low). The selection was based on teacher recommendations and the results of initial diagnostic assessments. In qualitative research, the integrity of the context and the depth of information are prioritized over the number of participants (Fischer, 2010).

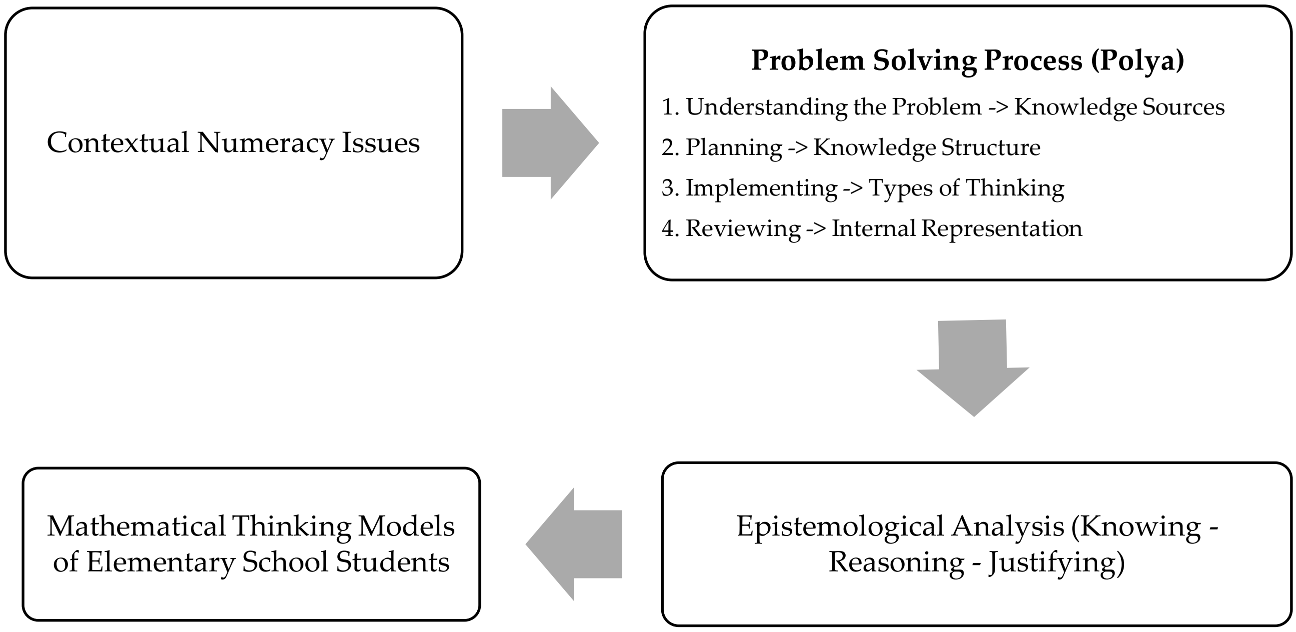
The data and data sources in this study consisted of two main categories, namely primary and secondary data. Primary data were obtained directly from students through three techniques: contextual numeracy tasks, classroom observations, and clinical interviews. These data include students' written work, verbal explanations, and observed behaviors during problem-solving activities. Secondary data were collected from supporting documents such as lesson plans, teacher notes, student assessment records, and school learning reports, which provided contextual information about the teaching environment. The integration of these two data sources allows for a comprehensive understanding of students' mathematical thinking patterns both cognitively and contextually.

Data were collected using three main techniques: contextual numeracy tasks, observation of thinking processes, and clinical interviews. First, numeracy tasks were given to elicit students' mathematical thinking processes through open-ended contextual questions that required reasoning and problem-solving strategies. Second, observations were conducted to record the students' behaviors, expressions, and solution strategies, including visual, symbolic, or verbal representations. Third, clinical interviews were conducted after students completed the tasks, using the stimulated recall method, in which students were asked to explain their thought processes during problem solving. This technique allows researchers to trace the sources of knowledge (intuitive, empirical, conceptual), knowledge structures (organized or fragmentary), and forms of epistemic reflection on the validity of results (DiSessa, 2018). All interview sessions were recorded, transcribed, and validated through member checking to ensure data credibility.

The data obtained were analyzed using a thematic analysis approach referring to the Miles, Huberman, and Saldaña (2020) model, which includes three main stages: data reduction, data presentation, and conclusion drawing. In the data reduction stage, the researchers selected relevant information based on Polya's problem-solving stages (understanding the problem, planning, implementing, and reviewing) and epistemological dimensions (knowledge sources, structure, representation, and types of thinking) (Mihas, 2022). In the data presentation stage, the analysis results were organized in the form of a categorization matrix and descriptive narrative for each subject, supported by interview excerpts and visual documentation. The conclusion drawing stage aimed to identify common patterns in students' mathematical thinking, the relationships between epistemological aspects, and implications for numeracy learning. To maintain the trustworthiness of findings, this study employed source triangulation (student work, observation, and interviews), peer debriefing, and validation with teachers and students (Zubkov & Pondi, 2022).

Conceptually, this study is based on an integrative framework between Polya's problem-solving model (1957) and the epistemological dimensions of mathematics education (Silverman, 2019). Polya's four stages—understanding the problem, planning, implementing, and reviewing—

are analyzed through four epistemological dimensions: (1) sources of knowledge, (2) knowledge structure, (3) types of thinking (procedural, conceptual, reflective), and (4) internal representation. The interaction between these frameworks forms the conceptual foundation of this study, as illustrated below:



Bagan 1. Conceptual Framework

FINDINGS AND DISCUSSION

Findings

This study was conducted at Purworejo State Elementary School (SDN Purworejo), in September 2024, involving six third-grade students selected through purposive sampling based on variations in numeracy abilities (high, medium, low). Data collection was carried out through contextual numeracy assignments, observation of thinking processes, and clinical interviews based on Polya's (1957) framework and epistemological aspects (sources of knowledge, knowledge structure, and internal representation). Data analysis was conducted thematically following the stages outlined by Miles, Huberman & Saldaña (2020): data reduction, data presentation, and conclusion drawing. The focus of the analysis was on how students understood, planned, implemented, and reflected on solving numeracy problems in the context of long and short column addition.

Findings Based on Polya's Problem-Solving Stages and Epistemological Dimensions

1. Understanding the Problem

   Most students were able to identify important information in the questions, especially those related to numbers and story contexts (e.g., the number of balls, fish, or items). However, there were variations in the depth of understanding:

   a. ANW and SAP subjects were able to accurately identify the "known" and "unknown" parts, demonstrating conceptual cognitive processes.
   b. GNS and IZU subjects understand the context partially, often misreading numbers or ignoring the instructions in the question.
   c. MJ and RAW subjects still tend to rely on memorization and intuition without analyzing the meaning of the context.

   Thus, the source of knowledge at this stage is a mixture of conceptual and empirical, depending on previous learning experiences.

2. Devising a Plan

   At this stage, all students tend to choose the procedural strategy of "long division" or "short division" as written in the question instructions. The choice of this strategy indicates the dominance of algorithmic thinking over reflective thinking. However, there are variations in the reasons for choosing a strategy:

   a. Subjects ANW, SAP, and GNS stated that they chose this method because it was "easier" and "in accordance with the instructions."
   b. Subjects IZU and MJ showed confusion, admitting that they only followed the teacher's example without understanding the conceptual reasons behind the strategy.
   c. Subject RAW understood the long-form writing style but had difficulty breaking down numbers into place values.

   From an epistemological perspective, students' knowledge structure is still mechanistic and unstable, where planning is based on taught procedures rather than the construction of personal knowledge.

3. Carrying Out the Plan

   The implementation stage revealed the students' basic algorithmic abilities. Students with high abilities (ANW and SAP) were able to complete the operations in the correct order (from units to hundreds). Meanwhile, students with moderate and low abilities made several types of errors:

a. Place value errors — occur in IZU and GNS.
b. Vertical addition errors — occurred in RAW and MJ due to lack of focus.
c. Inability to interpret results in the context of the problem — students have not yet associated the final number with the situational meaning.

Most students demonstrated procedural thinking, which focuses on calculation steps rather than logical validation of results.

4. Looking Back

Epistemological reflection is still limited. Only two students (ANW and SAP) rechecked their results and showed confidence with rational reasons ("because the steps were correct"). In contrast, students with low abilities tended to be confident without clear reasons — showing intuitive epistemic confidence**.** No students performed re-proofs using alternative strategies (e.g., finger counting or counting forward), even though some were familiar with these methods.

Table 1. Mapping of Students' Mathematical Thinking Processes Based on Polya's Stages and Epistemological Dimensions

Subject	Polya Stage Mastered	Source of Knowledge	Knowledge Structure	Type of Thinking	Internal Representation	Epistemological Level
ANW	Complete (1–4)	Conceptual, learning experience	Organized and stable	Conceptual-reflective	Symbolic & verbal	High
SAP	Complete (1– 4) with minor errors	Conceptual & Empirical	Fairly stable	Conceptual-procedural	Symbolic	Moderate-High
GNS	Stages 1–3, weak reflection	Memorization & experience	Less stable	Procedural	Symbolic	Moderate
IZU	Stages 1–3	Memorization	Fragmentary	Procedural	Symbolic & limited verbal	Low
MJ	Stages 1–3	Intuitive & memorization	Fragmentary	Procedural	Writing	Low
RAW	Stage 1–2	Empirical (classroom experience)	Unstable	Procedural	Writing	Low

Source: Primary data from interviews with third-grade students at Purworejo Public Elementary School (2024)

Thematic analysis shows three main patterns of elementary school students' mathematical thinking in the context of numeracy, namely:

Table 2. Main Patterns of Elementary School Students' Mathematical Thinking

Category	Epistemological Characteristics	Subject	Percentage
Conceptual-Reflective Thinking	Able to explain reasons, relate to place value concepts, and examine results	ANW	16.7
Conceptual-Procedural Thinking	Able to follow the correct steps, but reflection is still limited	SAP, GNS	33.3
Procedural-Intuitive Thinking	Relies on memorization, follows instructions without understanding concepts	IZU, MJ, RAW	50

Source: Interview data analysis (2024)

These findings confirm that the majority of students still operate at the procedural-intuitive level of thinking, where mathematical knowledge is viewed as a procedure to be followed, rather than a logical construction that can be explained.

Table 3. Thematic Analysis Based on Epistemological Dimensions

Epistemological Dimensions	Description of Field Findings
Source of Knowledge	The main source comes from classroom experience and teacher examples; only a few students (ANW, SAP) associate it with an understanding of place value concepts.
Knowledge Structure	Most students have a fragmented knowledge structure, as evidenced by errors in number decomposition.
Internal Representation	Symbolic representation (numbers and vertical operations) is most dominant; no use of visual or concrete models was found.
Justification/Reflection	Only two students provided logical justifications for their answers; the others demonstrated confidence without rational reasoning.

Based on the results of interviews and observations, the following picture emerges:

1. The mathematical thinking process of elementary school students is more prominent in the procedural dimension than in the conceptual dimension.
2. Their knowledge structure is formed from repetitive learning experiences, not from reflective understanding of the meaning of number operations.
3. Epistemic awareness, namely the ability to explain the reasoning behind a mathematical step, is still low.
4. Teachers play an important role as epistemological mediators; learning approaches that only emphasize procedures reinforce mechanistic thinking patterns.

5. An epistemology-based numeracy learning approach needs to be designed so that students not only know *how* to calculate, but also *why* that method is logical.

Discussion

The research findings at SDN Purworejo show that the mathematical thinking of lower-grade elementary school students in solving numeracy problems is still dominated by procedural–intuitive patterns, while their reflective and conceptual abilities remain limited. During classroom observations, many students were seen to solve problems mechanically—copying the teacher's example or memorizing arithmetic procedures—without understanding why certain operations were used. For example, when confronted with a contextual division problem, several students performed subtraction repeatedly, believing that any numerical manipulation would lead to the right answer. This finding supports Hasratuddin's (2018) conclusion that mathematics learning in elementary schools tends to emphasize procedural fluency rather than conceptual reasoning. However, the situation at SDN Purworejo also reveals a deeper epistemological gap: even students who answered correctly could not justify their reasoning when asked to explain their strategies. This shows that their mathematical knowledge structure is fragmented and lacks reflective coherence, a pattern that mirrors Sari and Lestari's (2022) findings but provides concrete local evidence of how such thinking appears in classroom interaction.

From an epistemological perspective, students' mathematical thinking processes at SDN Purworejo reflect three observable levels of knowledge awareness—intuitive–procedural, conceptual–procedural, and conceptual–reflective. Only a few students demonstrated early epistemic awareness by being able to verbalize the reasons behind their problem-solving steps. For instance, one second-grade student could explain that "division is about sharing things equally," showing an emerging understanding of mathematical meaning. Meanwhile, most students remained at the procedural stage, focusing on getting answers quickly rather than reasoning conceptually. This pattern strengthens Ernest's (2019) view that children's mathematical understanding develops through meaning-making and contextual experience, not through repetition alone. The classroom context at SDN Purworejo exemplifies Piaget's concrete operational stage (Slavin, 2020), where students still rely heavily on tangible objects—such as counting sticks or marbles—to comprehend abstract numerical relations.

The data also confirm Polya's (1957) four stages of problem solving: understanding, planning, executing, and checking. At SDN Purworejo, most students successfully completed the first three stages but rarely engaged in the final reflective stage of "checking." When interviewed, they stated that as long as their answer matched the teacher's example, they believed it was correct. This indicates that the ability to "look back" as a marker of reflective thinking has not developed optimally. Such a pattern resonates with Suryadi's (2019) findings that classroom mathematics practices in Indonesia often reward speed and accuracy over reasoning and reflection. The difference is that at SDN Purworejo, this tendency was reinforced by the school's assessment policy, which still prioritizes numerical correctness rather than process explanation.

From an affective perspective, the data from SDN Purworejo also reveal a close relationship between academic anxiety and the quality of mathematical thinking. Several students displayed visible hesitation, prolonged silence, or avoidance when faced with non-routine numeracy problems. During interviews, they expressed fear of being wrong or "scolded" if their answers differed from the teacher's model. This supports Budiharti and Mustaqim's (2023) finding that mathematical anxiety negatively affects students' achievement and willingness to take intellectual risks. In the SDN Purworejo context, anxiety also influenced students' epistemological engagement: anxious students rarely justified their reasoning, skipped checking steps, and reverted to memorized procedures. These local findings reinforce Mukhlisa, Zainal, and Paulina's (2022) conclusion that anxiety suppresses higher-order thinking and reflective awareness.

The results also indicate that the mathematics learning culture at SDN Purworejo has not yet cultivated students' epistemic awareness—the ability to understand, explain, and justify their knowledge. Classroom observations show that teachers often use structured worksheets that emphasize procedural completion rather than inquiry-based reasoning. This condition illustrates Ball et al.'s (2001) and Stylianides et al.'s (2016) assertion that epistemological understanding in mathematics education involves more than mastering operations; it requires knowing why and how mathematical ideas work. At SDN Purworejo, the absence of epistemological mediation from teachers results in students perceiving mathematics as a set of fixed rules. To overcome this, teachers need to act as epistemological facilitators who guide students to reflect through meaningful discussions, open-ended questions, and contextual problem-solving tasks (Ball et al., 2001) (Miranda, 2009) (Stylianides et al., 2016).

From a theoretical standpoint, the field findings at SDN Purworejo also resonate with the principles of Realistic Mathematics Education (RME), which emphasize constructing knowledge through contextual situations and reflection (Verschaffel et al., 2010) (Lesh & Doerr, 2003). When teachers at SDN Purworejo used locally relevant contexts—such as distributing fruits among classmates or counting classroom objects—students showed greater conceptual engagement and curiosity. However, these practices were not yet systematically implemented. Hence, the study's findings highlight the need for epistemology-based and context-driven numeracy instruction to foster reflective and conceptual thinking from early grades (Van Oers, 2013) (Schoenfeld, 2020) (Schoenfeld, 2010).

Empirically, the research at SDN Purworejo strengthens the understanding that the relationship between affective factors and mathematical epistemology is dynamic and reciprocal. Students with higher self-confidence and lower anxiety displayed more stable knowledge structures and were able to articulate logical explanations for their problem-solving choices. Conversely, those with high anxiety exhibited fragile conceptual structures and tended to imitate teacher demonstrations without understanding their purpose. Therefore, improving numeracy learning quality requires not only methodological innovation but also epistemological approaches that nurture students' confidence, reflective awareness, and intellectual courage in engaging with mathematics.

The implications of these findings operate at two levels. Theoretically, this study broadens the discussion of mathematical epistemology in Indonesian elementary education by integrating affective dimensions, particularly academic anxiety. Practically, it provides concrete insights for teachers and curriculum developers at SDN Purworejo and similar schools to design numeracy learning that is contextual, reflective, and emotionally supportive. Teachers are encouraged to create safe learning environments that allow students to ask, reason, and make mistakes without fear. In this way, mathematics becomes not a source of anxiety but a means of developing logic, creativity, and confidence. Thus, this study affirms that cultivating logical and reflective mathematical thinking should be the central focus of numeracy learning in lower-grade classrooms.

CONCLUSION

This study confirms that the mathematical thinking of elementary school students is not only influenced by cognitive abilities but also by epistemological and affective aspects that interact with each other. Through analysis of students' thinking processes in solving numeracy problems, it appears that mathematics learning still tends to emphasize procedures rather than reflection on meaning. Thus, the development of comprehensive mathematical thinking skills requires learning that not only teaches algorithmic steps but also fosters epistemic awareness, curiosity, and self-confidence in interpreting basic mathematical concepts. More broadly, this study contributes to the development of basic mathematics education theory and practice in Indonesia. From a theoretical perspective, this study reinforces the importance of an epistemological approach in understanding students' thinking processes, while from a practical perspective, the results confirm the need for a safe, reflective, and contextual learning environment to reduce anxiety and improve the quality of students' mathematical reasoning. By integrating cognitive, affective, and epistemological dimensions, numeracy learning can become a means of shaping critical and reflective thinking that is more humane in accordance with the demands of the Merdeka Curriculum.

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