Literature Review

Mathematical Linguistics: An Approach to Improve Non-Routine Mathematical Problem-Solving Ability

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Abstract: The literacy ability of Indonesian students is in the low category. The majority of Indonesian students have not been able to model complex situations mathematically, meaning that they have not been able to choose, compare, and evaluate appropriate problem-solving strategies from these complex situations. Based on the trend of PISA scores in reading, mathematics, and science, there is a similar pattern between reading and mathematics scores. Therefore, there is a correlation between language and mathematical intelligence. Several studies show that there is a relationship between linguistic intelligence and learning outcomes in mathematics. This study aims to analyze the mathematical linguistic approach as a solution to improve non-routine problem-solving skills systematically. This study was compiled using descriptive analysis techniques through literature review or library research. Mathematical linguistics dates back to Euclid's axiomatics circa 325-265 BC and to Panini's method of grammatical description in 520-460 BC. Both Euclid and Panini developed two well-known and fundamental books entitled Elements and Ashtadhyayi. Linguistic and mathematical intelligence has the same character, which is an intelligence that can reconstruct something abstract or a complex problem into a concrete solution and its solution accurately and systematically. The combination of the two is a capable ability to solve non-routine mathematical problems. Therefore, mathematical linguistics is an approach that can directly connect linguistic and mathematical intelligence to create a complete competence that can be used to solve complex problems mathematically.

Keywords: mathematical linguistics; non-routine problems; mathematical literacy; linguistic intelligence

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1. Introduction

Mathematics education plays a crucial role in developing students' logical thinking, problem-solving abilities, and analytical skills (Kholid et al., 2024). In the modern era, the learning of mathematics is no longer limited to mastering computational procedures but also emphasizes the ability to understand, interpret, and apply mathematical concepts in real-life situations. These competencies are essential for preparing students to face complex challenges in society, where quantitative reasoning and critical thinking are increasingly required (Tamaulina, 2025).

In recent decades, educational researchers and policymakers have increasingly emphasized the importance of mathematical literacy as a key component of mathematics education. Mathematical literacy refers to an individual's capacity to formulate, employ, and interpret mathematics in various contexts. It enables learners to use mathematical reasoning to solve problems, make decisions, and communicate ideas effectively in everyday life, academic environments, and professional settings (Ozrecberoglu et al., 2022).

However, many students still experience difficulties in applying mathematical knowledge to unfamiliar or complex problems. Traditional learning approaches that focus mainly on procedural knowledge often fail to encourage deeper conceptual understanding and flexible thinking. As a result, students may be able to solve routine exercises but struggle when faced with problems that require interpretation, reasoning, or strategic decision-making (Talasi & Krishnanair, 2024).

The development of mathematical literacy has therefore become a central concern in many educational systems around the world. International assessments have been widely used to evaluate how well students can apply mathematical knowledge in practical and real-world contexts. These assessments provide valuable insights into students' competencies and help identify areas where educational improvements are needed.

One of the most widely recognized international assessments measuring students' mathematical literacy is the Programme for International Student Assessment (PISA). Conducted by the Organisation for Economic Co-operation and Development (OECD), PISA evaluates students' ability to apply their knowledge and skills in mathematics, science, and reading to real-life situations. The results of PISA often serve as a benchmark for comparing the quality of education systems across different countries (Talasi & Krishnanair, 2024).

Mathematical literacy is an individual's ability to select, compare, and evaluate appropriate strategies for problems in complex situations. These situations are referred to in this study as non-routine problems. Indonesia is one of the countries where the majority of the population has weak literacy in mathematics compared to other countries considered "developed." This fact is demonstrated by the PISA scores during Indonesia's six participations. During that period, Indonesia's scores have consistently been below the international average (OECD, 2019). To add, PISA is a program initiated by an organization in France, the OECD. And this PISA test measures the language, mathematics, and science literacy skills of 15-year-old students.

Through simple analysis that the curve for reading literacy and mathematics scores is relatively similar compared to the science literacy curve, which shows relatively constant values. This raises the assumption that there is a relationship between reading literacy and mathematics. Several studies show that students' reading ability tends to influence their mathematical ability. Reading literacy is considered to explain a fairly large proportion of the variance in mathematical literacy. Additionally, there are sub-areas in reading literacy that have a significant influence on mathematical literacy (Ajello et al., 2018; Akbasli et al., 2016; Ding & Homer, 2020; Stoffelsma & Spooren, 2019). Several previous studies also illustrate that there is an influence between language ability and mathematics as seen from the National Examination scores, both at the junior high and senior high school levels in Lampung Province using Maximum Graph Spanning Tree analysis (Maskar & Herman, 2024; Maskar, 2020). The results of these studies successfully grouped National Examination subjects based on the level of influence proximity between subjects, where the first group was occupied by mathematics, English, and science. These findings indicate that the three literacies are not separate, including language literacy and mathematics (Nguyen et al., 2020).

Ironically, the reading literacy of Indonesian students is still deficient. Another study related to the evaluation of Indonesian PISA scores shows that there is a significant correlation between the low reading literacy of Indonesian students and the PISA results in mathematics and science (Patria, 2021). The low reading literacy is related to students' difficulty in creating mathematical models from complex problems originating from real life. This means that one of the problems with low mathematical literacy is the low ability to interpret complex problems into Mathematical symbols (Cascella, 2020; Collins & Laski, 2018). Therefore, the purpose of this study is to analyze the mathematical linguistics approach as a solution to improve non-routine problem-solving skills systematically.

2. Theoretical Framework

Mathematical literacy is grounded in several fundamental theories that emphasize the integration of knowledge, skills, and contextual understanding. One of the primary theoretical foundations is the constructivist learning theory, which posits that learners actively construct knowledge through interaction with their environment and experiences (Kholid et al., 2024). In the context of mathematics education, constructivism highlights that students develop understanding not merely by memorizing formulas, but by engaging in meaningful problem-solving activities that require interpretation and reasoning. This perspective supports the idea that mathematical literacy involves the ability to connect abstract concepts with real-world situations (Lit et al., 2026).

Another important theoretical basis is the theory of mathematical cognition, which explains how individuals process, understand, and apply mathematical information. This theory suggests that mathematical problem-solving involves multiple cognitive processes, including comprehension, representation, strategy selection, and evaluation. In non-routine problem contexts, students must interpret linguistic information, translate it into mathematical representations, and apply appropriate strategies. Therefore, the interaction between language and mathematical thinking becomes essential, particularly in understanding complex problem statements (Lit et al., 2026).

The concept of mathematical literacy as defined by the OECD also serves as a key theoretical reference in this study. Mathematical literacy is described as an individual's ability to formulate, employ, and interpret mathematics in various contexts. This definition implies that mathematical competence is not limited to procedural skills but extends to reasoning, communication, and the application of knowledge in real-life situations. The OECD framework further categorizes mathematical processes into three main components: formulating situations mathematically, employing mathematical concepts, and interpreting mathematical results.

The theory of language and mathematics interaction provides a crucial foundation for understanding students' difficulties in solving non-routine problems. Language plays a significant role in shaping mathematical understanding, as mathematical problems are often presented in textual form that requires careful reading and interpretation (Kholid et al., 2024). Linguistic complexity can hinder students' ability to identify relevant information, construct mathematical models, and determine appropriate solution strategies. Therefore, the integration of linguistic approaches in mathematics learning is considered essential to enhance comprehension and problem-solving abilities (Lit et al., 2026).

The mathematical linguistics approach, which combines elements of language analysis and mathematical reasoning, is particularly relevant in addressing these challenges. This approach emphasizes the role of syntax, semantics, and discourse in understanding mathematical problems. By analyzing the structure and meaning of problem statements, students can better identify relationships between variables and translate them into mathematical expressions (Muhaimin et al., 2024). This aligns with the idea that improving students' reading literacy can significantly contribute to the development of mathematical literacy.

Furthermore, the theory of problem-solving proposed by Polya provides a structured framework for analyzing students' strategies in solving mathematical problems. Polya's four-step model illustrates the importance of both cognitive and metacognitive processes (Kholid et al., 2024). In the context of non-routine problems, the first step, understanding the problem, is highly dependent on students' linguistic abilities. This reinforces the argument that reading comprehension is closely linked to mathematical performance (Wahyuni et al., 2025).

Based on these theoretical perspectives, it can be assumed that mathematical literacy is influenced by multiple interconnected factors, including cognitive processes, language skills, and instructional approaches (Muhaimin et al., 2024). The integration of mathematical linguistics into learning is expected to bridge the gap between reading literacy and mathematical understanding. By strengthening students' ability to interpret problem contexts and construct mathematical models, this approach can enhance their performance in solving non-routine problems.

This study adopts a theoretical framework that integrates constructivist learning theory, mathematical cognition, OECD's mathematical literacy framework, language-mathematics interaction theory, and Polya's problem-solving model. This integrated framework provides a comprehensive basis for analyzing how the mathematical linguistics approach can improve students' ability to solve complex mathematical problems systematically (Muhaimin et al., 2024). The PISA framework also provides empirical evidence supporting the importance of mathematical literacy and its relationship with other domains such as reading and science. PISA results not only measure students' competencies but also illustrate trends and patterns that reflect the effectiveness of educational systems in developing essential skills (Aulia et al., 2025).

Indonesia's performance in PISA over several cycles demonstrates consistently lower scores compared to the international average. These results highlight ongoing challenges in students' ability to apply mathematical knowledge in real-world contexts (Aulia et al., 2025). Furthermore, the trend of PISA scores indicates a close relationship between reading literacy and mathematical literacy, suggesting that students' ability to understand textual information significantly influences their performance in mathematics.

Figure 1 presents the trend of PISA scores in reading, mathematics, and science in Indonesia over multiple assessment cycles. The figure illustrates that the patterns of reading and mathematics scores tend to be relatively similar, while science scores appear more stable. This similarity strengthens the assumption that reading literacy plays a crucial role in shaping mathematical literacy.

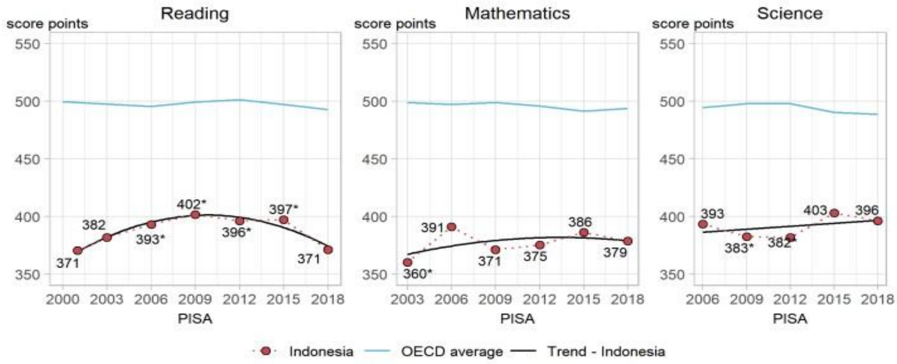

Figure 1. Trend of PISA reading, mathematics, and science scores in Indonesia.

This empirical evidence supports the theoretical perspective that language ability, particularly reading comprehension, is closely related to mathematical performance. Students with higher reading literacy are generally better able to interpret problem statements, construct mathematical models, and apply appropriate solution strategies. Conversely, low reading literacy often leads to difficulties in understanding complex problems, which in turn affects mathematical achievement. (Aulia et al., 2025).

Therefore, integrating a mathematical linguistics approach within the theoretical framework is highly relevant. This approach emphasizes the role of language in mathematical thinking and provides a structured way to analyze how students interpret and respond to non-routine problems (Nurlita et al., 2025). By strengthening the connection between linguistic competence and mathematical reasoning, this framework aims to improve students' overall mathematical literacy.

3. Materials and Methods

3.1. Research Design

This study employed a qualitative descriptive design using a literature review approach. The objective of this design was to systematically examine, synthesize, and interpret existing studies related to mathematical literacy, linguistic intelligence, and the mathematical linguistics approach (Idhartono, 2020; Bahri, 2023; Surani, 2019). The qualitative approach was chosen because the study focuses on conceptual analysis rather than statistical testing or experimental intervention.

This research utilized a library research framework, allowing the researcher to explore interdisciplinary perspectives from mathematics education, linguistics, and cognitive science (Nurlita et al., 2025). The approach aims to construct a comprehensive theoretical foundation and propose a systematic solution for improving students' non-routine problem-solving abilities.

3.2. Samples and Data Sources

This study did not involve human participants; instead, it relied on a systematic analysis of relevant academic literature. The data corpus comprised peer-reviewed journal articles, scholarly books, conference proceedings, and official reports. The selection of sources was guided by their direct relevance to the fields of mathematical literacy, linguistic intelligence, and mathematical linguistics, as well as their publication in reputable academic outlets. Priority was given to works that made a substantive theoretical or empirical contribution to the topic, while particular attention was also paid to the recency of publications and their alignment with current educational challenges. To ensure a comprehensive and balanced perspective, both international and national studies were incorporated into the analysis.

3.3. Data Collection Methods

Data were collected through a systematic literature review process designed to ensure both rigor and relevance. Relevant sources were identified using targeted keywords, including mathematical literacy, linguistic intelligence, mathematical linguistics, and non-routine problems. The search was conducted across major academic databases, followed by an initial screening of titles and abstracts to determine potential suitability. Subsequently, full-text versions of selected studies were examined to assess their eligibility and substantive relevance to the research focus. Key findings and theoretical constructs were then extracted and synthesized, with the data organized into coherent thematic categories. This structured and iterative approach contributed to the validity, reliability, and overall relevance of the collected material.

3.4. Data Analysis Methods

The study employed a combination of descriptive and content analysis techniques to ensure a comprehensive examination of the selected literature. The analytical process was carried out in several interrelated stages. Initially, the data were organized through thematic classification, with particular attention to core domains such as mathematical literacy, linguistic intelligence, and problem-solving. This was followed by a comparative analysis, in which findings from different studies were systematically examined to identify recurring patterns, similarities, and points of divergence. An interpretative dimension was subsequently introduced, allowing for an in-depth exploration of the relationships between language and mathematical thinking. In parallel, content analysis was conducted to investigate how specific linguistic structures shape and influence mathematical problem-solving processes. Finally, the insights derived from these analytical stages were synthesized into an integrated conceptual framework of mathematical linguistics, providing a coherent representation of the interconnections identified in the study.

3.5. Research Framework

This study is grounded in an integrated theoretical framework that draws on key perspectives from constructivism, mathematical cognition, and mathematical literacy, particularly as conceptualized within the OECD framework. It also incorporates insights from theories addressing the interaction between language and mathematics, as well as problem-solving theory. Synthesizing these complementary approaches, the study establishes a cohe-

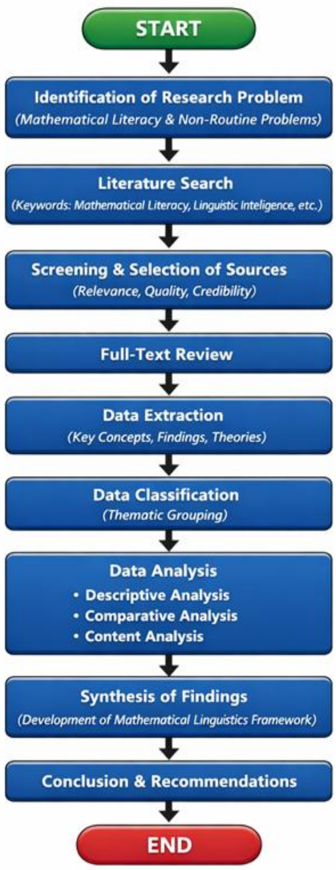

Figure 2. Research methodology flowchart.

sive conceptual foundation for the development of a mathematical linguistics perspective, aimed at enhancing learners' ability to engage effectively with non-routine problem-solving tasks.

Therefore, the research design integrates a qualitative literature-based approach with systematic data collection and rigorous analytical procedures to ensure a coherent and comprehensive examination of the topic. When thematic, comparative, and interpretative analyses are combined within a well-defined theoretical framework, the study establishes a solid conceptual foundation for understanding the interplay between mathematical literacy, linguistic intelligence, and problem-solving. This methodological structure not only enhances the validity and depth of the findings but also supports the development of a mathematical linguistics perspective as a viable approach to improving non-routine problem-solving abilities.

4. Results

4.1. Theoretical Study of Mathematical Linguistics

Mathematical linguistics originated with Euclid's axiomatics around 325-265 BC and with Panini's method of grammatical description around 520-460 BC. Both Euclid and Panini developed two famous and fundamental books entitled Elements and Ashtadhyayi (Gladkij & Melcuk, 1983; Kornai, 2008; Partee et al., 1993). Both methods are fundamentally similar: Euclid's axiomatic method begins with a set of statements considered true and then transfers the truth from the axioms to other statements through a consistent set of logical rules, while the grammatical method begins with a set of expressions that are considered good in form and grammatical meaning and then transfers them to other expressions through a consistent set of grammatical rules.

Gladkij and Melcuk (1983) defined mathematical linguistics as the presentation of an imaginary situation in which a mathematician builds a model of human linguistic behavior. The observations conducted by the researchers (Aldridge, 1992; Gladkij & Melcuk, 1983) established two sides of the field: one side is a set of meanings and the other is an expression of a set of texts or speeches.

Global developments can rapidly increase the diversity of fields and create independent research on the complexity of computational processes that can give rise to new ways of modeling linguistic phenomena in logical and more flexible systems, as well as mathematical characterization of various ideas about linguistic complexity. In the digital era, the need for collaboration between disciplines has developed mathematical linguistics to include not only mathematical and logical data but also computational linguistics (Tanfidiyah & Utama, 2019).

Computational linguistics is closely related to mathematical modeling; to be able to formulate solutions to complex problems, good abilities in linguistic and mathematical intelligence are needed. This is the answer to the low level of mathematical literacy. The curriculum demands that students have good competence in mathematical literacy, as indicated by the minimum competency assessment with questions based on high-order thinking skills. However, in the process, there has not been a complete connection between the expected process and results.

4.2. Linguistic and Mathematical Intelligence

Linguistic intelligence is the ability to use words effectively, both orally and in writing. A person with linguistic intelligence can manipulate language structures, language sounds, language meanings, and practical language use. Simply put, a person with linguistic intelligence can listen well, speak or express ideas effectively, interpret reading material well, and write skillfully. However, not many people have all these abilities, so linguistic intelligence has various levels (Mukhlesiyeni, 2024).

Students with high linguistic intelligence have excellent communication skills, memory, and ability to use language spelling according to good and correct language rules, and have high enthusiasm and love for language. A person with high linguistic intelligence can express ideas or thought processes critically, creatively, and systematically (Mufidah & Mukhlisin, 2020; Ernawati et al., 2014). Based on this, a person with high linguistic intelligence can understand complex problems and associate them with an idea systematically and logically.

Mathematical intelligence is the ability to operate calculations accurately and correctly (Ardiansyah, 2020). Furthermore, Nisa et al. (2020) state that a person with mathematical intelligence has the ability to calculate and reason systematically and can involve mathematical concepts in recognizing, identifying, and finding solutions to complex problems.

An intelligence is essentially not something concrete but an abstract thing to measure individual behavior related to logical and intellectual abilities. Similar to linguistic intelligence, mathematical intelligence also has levels, meaning that not all students are at the same level of Mathematical intelligence (Mastika Yasa & Bhoke, 2019; Pramudiani & Herman, 2021).

Ultimately, linguistic and mathematical intelligence share similar characteristics: they are intelligences that can reconstruct something abstract or a complex problem into a concrete solution along with its solution accurately and systematically. The combination of the two is a capable ability to solve non-routine mathematical problems. Non-routine problems themselves are abstract problems originating from real life that can be effectively solved using mathematics.

4.3. Theoretical Development

Previous studies related to improving linguistic and mathematical intelligence were in the realm of developing learning methods or strategies to improve students' reading ability (Fitriani et al., 2018; Marlina, 2019). These studies emphasized that the main problem of low Mathematical literacy is the lack of students' reading literacy, so an appropriate method is needed so that students can understand complex problems in real life. The fact is that these methods have not been able to fully connect linguistic and mathematical intelligence. Below, there is an illustration of the relationship between linguistic and mathematical intelligence that currently occurs (figure 3).

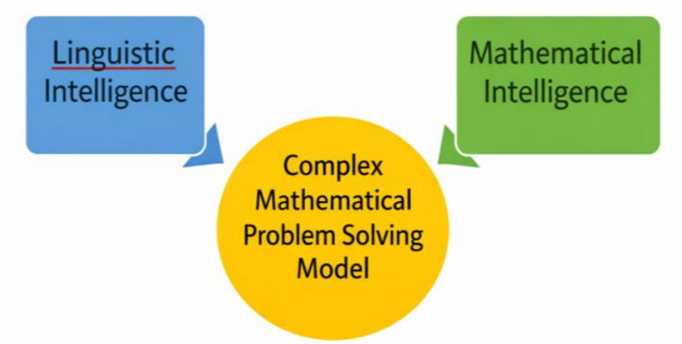

Figure 3. Structure of the relationship between linguistic and mathematical intelligence in the mathematical complex problem-solving model.

Figure 3 shows that there is a deficiency in this structure: there is no direct relationship between linguistic intelligence and mathematical intelligence, so the process is carried out independently. Several studies used methods to improve linguistic intelligence alone to support mathematical intelligence for complex problem-solving. However, in reality, students are still not very skilled at creating mathematical models from the ideas they formulate based on existing problems.

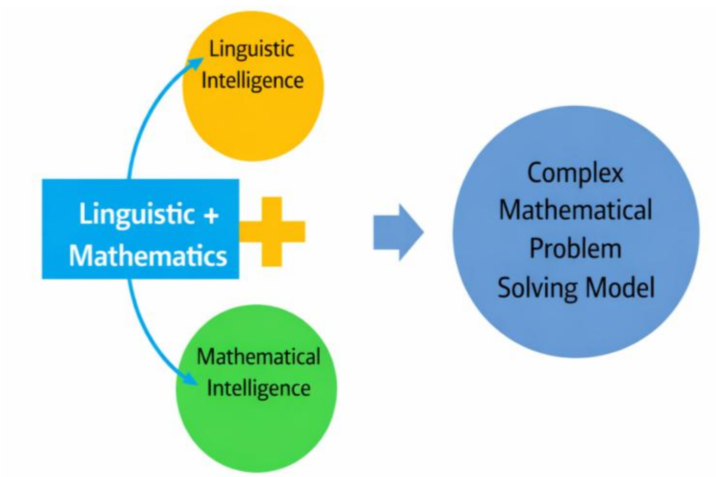

Figure 4. Theoretical framework of the relationship between linguistic and mathematical intelligence through mathematical linguistics in the mathematical complex problem-solving model.

Therefore, mathematical linguistics is an approach that can directly connect linguistic and mathematical intelligence, making it a complete competence that can be used to solve complex problems mathematically. Figure 4 shows a theoretical framework for the mathematical linguistics approach to improve linguistic and mathematical intelligence.

Taking this into consideration, the analysis of previous studies indicates that although various instructional approaches have been developed to improve either linguistic or mathematical intelligence, these efforts tend to treat both domains separately rather than as an integrated cognitive system. This separation limits students' ability to effectively translate complex verbal information into mathematical representations, which is essential in solving non-routine problems. The proposed mathematical linguistics approach addresses this gap by establishing a direct and systematic connection between linguistic and mathematical intelligence. Through this integrated framework, students are expected to develop a more comprehensive competence that enables them to interpret, model, and solve complex problems accurately and efficiently. Therefore, the mathematical linguistics approach not only provides a theoretical contribution but also offers a promising direction for future instructional practices aimed at enhancing mathematical literacy in a more holistic and meaningful way.

5. Discussion

5.1. Mathematical Linguistics as an Integrated Framework for Enhancing Mathematical Literacy and Problem-Solving

Based on the analysis conducted, mathematical linguistics emerges as a promising approach to address the persistent challenge of low mathematical literacy among Indonesian students. The parallel trends observed in PISA reading and mathematics scores provide empirical support for the theoretical connection between linguistic and mathematical abilities. This connection is not merely correlational but appears to be functionally significant in how students process and solve complex problems.

The historical foundations of mathematical linguistics, tracing back to Euclid's axiomatics and Panini's grammatical descriptions, demonstrate that the intersection of language and mathematics has long been recognized as fundamental to human reasoning. Both systems share a common logical structure: they begin with accepted premises (axioms or grammatically correct expressions) and apply consistent rules to derive new, valid conclusions. This parallel suggests that training in one domain may reinforce abilities in the other (Nguyen et al., 2020).

Current educational practices, however, have failed to leverage this connection effectively. As it was mentioned above, linguistic and mathematical intelligences are typically treated as separate competencies that operate independently. Students are expected to develop reading skills to understand problems and then separately apply mathematical skills to solve them, with no explicit bridge between these cognitive processes. This fragmented approach leaves students struggling to translate their verbal understanding into mathematical models – precisely the skill measured by PISA and other international assessments (Nguyen et al., 2020).

The consequences of this disconnect are evident in Indonesian students' performance. Despite years of educational reforms and various pedagogical interventions, mathematical literacy remains stubbornly low. The persistence of this problem suggests that piecemeal solutions focusing solely on either reading comprehension or mathematical drill are insufficient. What is needed is an integrated approach that explicitly teaches students how to move between linguistic and mathematical representations of problems (Nguyen et al., 2020).

Mathematical linguistics offers precisely such an integrated framework. According to Saygılı (2017), by positioning itself at the intersection of language and mathematics, it provides students with explicit strategies for: (1) parsing complex, real-world problems described in natural language; (2) identifying the mathematical structures embedded within verbal descriptions; (3) translating those structures into formal mathematical representations; (4) manipulating mathematical symbols according to logical rules; and (5) interpreting mathematical results back into meaningful, real-world conclusions.

5.1.1. Parsing Complex Real-World Problems Described in Natural Language

One of the fundamental competencies emphasized in mathematical linguistics is the ability to systematically parse complex real-world problems expressed in natural language. In many authentic contexts, mathematical problems are not presented in symbolic form but rather embedded within narratives, descriptions, or contextual scenarios. Consequently, students must first interpret linguistic structures before engaging in mathematical reasoning. A common challenge in mathematics learning arises from students' limited ability to extract relevant quantitative information from textual descriptions. Long sentences, ambiguous wording, and implicit relationships between variables often hinder students' comprehension of the problem situation. As a result, students may misinterpret the problem structure even before initiating the mathematical solution process. Mathematical linguistics addresses this challenge by emphasizing the analytical examination of linguistic elements within mathematical discourse. Through this approach, students learn to identify key entities, relationships, and constraints embedded within the textual description of a problem. Such analytical reading promotes deeper engagement with the semantic structure of mathematical problems. Furthermore, the approach strengthens what is often referred to as mathematical reading literacy. Students are trained to differentiate between known information, unknown quantities, and relational statements within a problem statement. This structured parsing process enables learners to construct a clearer conceptual representation of the problem. Therefore, the ability to parse complex linguistic descriptions constitutes a critical initial stage in mathematical problem solving. By integrating linguistic analysis into mathematical reasoning, mathematical linguistics provides students with systematic strategies for interpreting complex problem situations (Sinniah et al., 2022).

5.1.2. Identifying the Mathematical Structures Embedded within Verbal Descriptions

Following the comprehension of the linguistic structure of a problem, the next essential step involves identifying the mathematical structures embedded within the verbal description. Many real-world problems implicitly represent mathematical relationships that must be recognized before they can be formally modeled. In educational contexts, mathematical structures may manifest as proportional relationships, functional dependencies, algebraic expressions, or quantitative comparisons. However, these structures are often concealed within everyday language rather than explicitly stated in symbolic form. Students therefore require the ability to detect underlying mathematical patterns within textual information. Mathematical linguistics facilitates this process by encouraging the analysis of semantic cues and relational expressions that signal mathematical operations or relationships. Words such as "increase," "difference," "ratio," or "combined" frequently indicate specific mathematical structures that can guide the modeling process. Developing the ability to recognize these implicit structures promotes higher-order mathematical thinking. Students move beyond superficial reading of problem narratives and begin to conceptualize the problem as a representation of abstract mathematical relationships. Consequently, identifying mathematical structures within verbal descriptions is a crucial bridge between linguistic comprehension and mathematical modeling. This process enables students to transform contextual information into conceptual mathematical frameworks (Murdiyani, 2018).

5.1.3. Translating Mathematical Structures into Formal Mathematical Representations

Once the underlying mathematical structure has been identified, the next stage involves translating this structure into formal mathematical representations. This process constitutes a critical component of mathematical modeling and requires the transformation of natural language descriptions into symbolic expressions, equations, diagrams, or other formal representations. Many students encounter difficulties at this stage because they struggle to connect linguistic representations with symbolic mathematical forms. Although they may understand the contextual narrative, they often lack strategies for converting the problem into formal mathematical language. Mathematical linguistics provides a systematic framework for addressing this challenge. By explicitly examining how linguistic expressions correspond to mathematical symbols, students learn to construct equations, define variables, and represent relationships in a formalized manner. The use of multiple representations is particularly valuable in this process. Graphs, tables, diagrams, and algebraic expressions each provide different perspectives on the same mathematical relationship. Integrating these representations helps strengthen conceptual understanding and supports flexible problem-solving strategies. Thus, the translation of verbal structures into formal mathematical representations constitutes a pivotal stage in the problem-solving process. It allows learners to move from contextual interpretation to mathematical analysis in a structured and coherent manner (Sinniah et al., 2022).

5.1.4. Manipulating Mathematical Symbols According to Logical Rules

After the problem has been represented in formal mathematical form, the next phase involves manipulating mathematical symbols according to established logical and procedural rules. This stage encompasses algebraic transformations, equation solving, symbolic simplification, and logical reasoning. Traditional mathematics instruction has often emphasized symbolic manipulation as a procedural activity. However, within the framework of mathematical linguistics, symbolic manipulation is understood as part of a broader semiotic system in which symbols function as elements of a formal language governed by syntactic and semantic rules. Students therefore learn not only how to perform mathematical operations but also why those operations are logically valid within the mathematical system. This perspective promotes deeper conceptual understanding rather than mere procedural competence. Furthermore, the integration of linguistic reasoning with symbolic manipulation supports students in explaining and justifying their mathematical procedures. The ability to articulate reasoning strengthens both mathematical communication and metacognitive awareness. Consequently, manipulating mathematical symbols should be viewed as an intellectually meaningful activity that reflects logical reasoning within a structured symbolic language. This perspective reinforces the coherence between linguistic interpretation and mathematical formalism (Sinniah et al., 2022).

5.1.5. Interpreting Mathematical Results into Meaningful Real-World Conclusions

The final stage in the mathematical linguistics framework involves interpreting mathematical results in relation to the real-world context from which the problem originated. After obtaining a solution in symbolic or numerical form, students must translate this result back into meaningful conclusions. In many classroom settings, students tend to conclude the problem-solving process once a numerical answer is obtained. However, mathematical literacy requires learners to go beyond calculation and evaluate the relevance and implications of the solution within the given context. Interpretation involves explaining the meaning of the result, assessing its plausibility, and connecting it to the original problem situation. This step requires students to integrate mathematical reasoning with contextual understanding and critical reflection. Moreover, interpreting results encourages students to evaluate the assumptions and limitations of the mathematical model used. Through this reflective process, learners can determine whether the solution is realistic and applicable in real-world scenarios. Therefore, interpreting mathematical results represents the culmination of the mathematical problem-solving process. It ensures that mathematical reasoning ultimately contributes to meaningful understanding of real-world phenomena rather than remaining confined to abstract symbolic manipulation (Sinniah et al., 2022).

This process mirrors the dual nature of mathematical linguistics itself, which encompasses both the set of meanings (the conceptual understanding of a problem) and the set of expressions (the mathematical representation and solution). When students learn to move fluidly between these two domains, they develop what might be called “mathematical fluency” – the ability to think mathematically about linguistically presented problems (Kappassova et al., 2025).

5.2. Discussion and Implications of Mathematical Linguistics for Mathematical Literacy Development

The theoretical framework illustrates how mathematical linguistics creates a direct pathway between linguistic and mathematical intelligence. Rather than treating these as separate competencies that must be individually developed and then somehow combined, mathematical linguistics recognizes them as fundamentally interconnected (Kappassova et al., 2025). Developing this connection explicitly may be more efficient and effective than developing each intelligence in isolation.

For classroom practice, this implies several pedagogical shifts. First, mathematics instruction must incorporate more explicit attention to language. Students need to learn how to read mathematical problems strategically, identifying key information, recognizing problem types, and understanding the relationships described in words. Second, language instruction should include opportunities to engage with mathematical and logical texts, helping students develop the precision of expression that mathematical communication requires. Third, and most importantly, students need guided practice in the translation process itself – moving from words to symbols and back again (Sinniah et al., 2022).

The potential impact of such an integrated approach extends beyond test scores. In an increasingly data-driven world, the ability to interpret complex situations, model them mathematically, and communicate findings clearly is essential for civic participation and professional success. Mathematical literacy, properly understood, is not merely an academic skill but a fundamental competency for navigating modern life.

The potential impact of such an integrated approach extends beyond the improvement of standardized test performance. In contemporary education systems, the ultimate goal of mathematics learning is not merely to increase students' ability to answer examination questions correctly, but to develop deeper intellectual competencies. An integrated approach that connects language, reasoning, and mathematical modeling encourages students to engage with mathematics as a meaningful tool for understanding the world (Kappassova et al., 2025). This perspective shifts the focus of learning from procedural calculation toward conceptual comprehension and analytical thinking. When students are trained to interpret problems linguistically and mathematically, they become more capable of constructing logical arguments and justifying their reasoning. Such competencies are essential for developing higher-order thinking skills that go beyond routine classroom tasks. Moreover, this integrated framework supports the development of metacognitive awareness, allowing learners to reflect on how they interpret and solve mathematical problems. Consequently, the impact of this approach should be evaluated not only in terms of improved academic scores but also in terms of the broader cognitive and intellectual development of learners (Kurniawan et al., 2022).

To academic development, mathematical literacy plays an increasingly critical role in modern societies characterized by rapid technological and informational growth. Individuals are constantly confronted with quantitative information presented through graphs, statistics, and numerical reports in various media platforms. Without sufficient mathematical literacy, people may struggle to interpret such information accurately and may become vulnerable to misinformation or misinterpretation of data. Therefore, the ability to critically evaluate quantitative claims has become an essential skill in the information age. Mathematical literacy enables individuals to understand statistical trends, assess probabilities, and interpret numerical evidence presented in public discourse. These abilities are particularly important in areas such as health, economics, environmental issues, and public policy. When citizens possess strong mathematical literacy, they are better equipped to make informed decisions based on evidence rather than assumptions. Thus, strengthening mathematical literacy contributes directly to the development of a more informed and critically engaged society.

The capacity to model complex situations mathematically has become increasingly important in the contemporary workforce. Many professional fields rely heavily on quantitative analysis, including economics, engineering, technology, data science, and social research. In these domains, professionals are expected not only to perform calculations but also to interpret real-world phenomena using mathematical frameworks. Mathematical modeling allows individuals to represent complex systems through equations, simulations, or computational models. Through these models, professionals can analyze patterns, predict outcomes, and design effective solutions to real-world problems. The ability to construct and interpret such models requires a strong foundation in mathematical reasoning and conceptual understanding. Students who develop these competencies during their education are better prepared to adapt to professional environments that demand analytical and quantitative skills. Therefore, promoting mathematical literacy in education contributes to the development of a workforce capable of addressing complex global challenges (Kholil et al., 2025).

Equally important is the role of mathematical communication in ensuring that mathematical insights can be effectively shared and understood. Mathematical ideas often involve abstract concepts that must be clearly explained to diverse audiences. The ability to communicate mathematical reasoning through language, symbols, graphs, and visual representations is therefore a crucial component of mathematical literacy. Professionals in many fields must translate complex numerical analyses into explanations that policymakers, stakeholders, or the general public can understand. Without effective communication, even accurate mathematical analyses may fail to influence decision-making processes. Mathematical linguistics contributes to this aspect by emphasizing the relationship between linguistic expression and mathematical reasoning. By integrating language awareness into mathematics learning, students develop the ability to articulate their reasoning clearly and logically. As a result, they become more capable of presenting mathematical arguments and explaining quantitative evidence in meaningful ways (Kurniawan et al., 2022).

Another important dimension of mathematical literacy relates to its role in fostering critical thinking and reflective judgment. In real-life contexts, mathematical problems rarely appear in simplified or clearly structured forms. Instead, individuals must interpret incomplete information, evaluate assumptions, and determine appropriate problem-solving strategies.

Mathematical literacy equips learners with the intellectual tools needed to approach such complex situations systematically. By analyzing relationships between variables and evaluating the plausibility of solutions, individuals develop stronger analytical reasoning abilities. This capacity is particularly valuable in situations where decisions must be made under conditions of uncertainty. Through the integration of linguistic interpretation and mathematical modeling, learners gain a deeper understanding of how mathematical reasoning can guide practical decision making. Consequently, mathematical literacy contributes not only to cognitive development but also to responsible and rational decision-making practices (Kholil et al., 2025).

The cultivation of mathematical literacy supports lifelong learning and adaptability in a rapidly changing world. As technological advancements continue to transform economic and social structures, individuals must constantly update their knowledge and skills. Mathematical reasoning provides a foundation for understanding new technological tools, data systems, and analytical frameworks (Lessing & Ogbonnaya, 2026). Individuals who possess strong mathematical literacy are more capable of adapting to emerging fields that require quantitative analysis and computational thinking. This adaptability is particularly important in the context of the digital economy, where data interpretation and algorithmic reasoning are becoming increasingly significant. Educational systems therefore have a responsibility to prepare students for these evolving demands. By integrating linguistic interpretation, mathematical modeling, and critical reasoning, the educational process can cultivate learners who are capable of navigating complex intellectual environments. Such preparation ensures that students remain competitive and intellectually resilient in the face of future challenges.

Mathematical literacy should be understood as a fundamental competency for navigating the complexities of modern life. It empowers individuals to interpret the quantitative dimensions of social, economic, and scientific phenomena. Rather than being confined to the classroom, mathematical literacy functions as a practical tool for understanding and engaging with the world (Lessing & Ogbonnaya, 2026). Individuals who possess this competency are better equipped to participate in democratic processes, evaluate policy proposals, and interpret statistical evidence presented in public discussions. In addition, mathematical literacy supports responsible decision making in personal financial planning, health management, and environmental awareness. These everyday applications demonstrate that mathematics is deeply interconnected with real-world experiences. Consequently, educational efforts aimed at strengthening mathematical literacy have far-reaching implications for both individual empowerment and societal development. Recognizing this broader significance highlights the importance of innovative educational approaches that integrate language, reasoning, and mathematical thinking in a coherent framework (Kholil et al., 2025).

Implementing mathematical linguistics approaches in Indonesian classrooms faces several challenges. Teacher preparation programs rarely address the intersection of language and mathematics, leaving educators without the conceptual tools to teach this integration. Curriculum materials typically separate language and mathematics instruction, reinforcing the artificial divide. Assessment systems, including high-stakes national examinations, may not adequately measure integrated competencies. Overcoming these structural barriers will require coordinated efforts across teacher education, curriculum development, and assessment design.

Implementing mathematical linguistics approaches in Indonesian classrooms presents a range of structural and pedagogical challenges. One of the most significant barriers lies in the limited integration of language awareness within mathematics instruction. In many educational settings, mathematics is traditionally taught as a purely symbolic discipline, while language learning is confined to separate subjects. This separation creates an artificial boundary between linguistic interpretation and mathematical reasoning. As a result, students often struggle to interpret contextual problems that require both language comprehension and mathematical modeling. The absence of explicit instructional strategies linking language and mathematics further exacerbates this difficulty. Teachers frequently focus on procedural problem-solving techniques without addressing the linguistic complexities embedded within mathematical problems. Consequently, the implementation of mathematical linguistics requires a fundamental shift in how mathematics education is conceptualized and practiced in classrooms (Kurniawan et al., 2022).

A major challenge in implementing such an integrated approach concerns the preparation of teachers themselves. Teacher education programs in Indonesia generally emphasize subject-specific competencies rather than interdisciplinary integration. Prospective mathematics teachers are typically trained to master mathematical content knowledge and pedagogical strategies related to problem solving, but less attention is given to the linguistic dimensions of mathematical discourse (Yeza et al., 2025). As a result, many educators enter the classroom without sufficient conceptual understanding of how language shapes mathematical thinking. Without adequate training, teachers may feel uncertain about how to guide students in interpreting complex problem statements. This lack of preparation can lead to reliance on traditional teaching methods that prioritize formula memorization and procedural practice. Furthermore, teachers may perceive linguistic analysis as outside the scope of mathematics instruction. Addressing this issue requires teacher preparation programs to incorporate interdisciplinary perspectives that highlight the role of language in mathematical cognition (Kholil et al., 2025).

Another significant barrier involves the structure of existing curriculum materials. Most textbooks and instructional resources used in mathematics classrooms present content primarily through symbolic representations and procedural examples. Although contextual problems may appear in certain sections, these tasks often emphasize obtaining numerical answers rather than analyzing linguistic structures. As a result, students are rarely guided through systematic processes of interpreting problem statements, identifying key relationships, and translating them into mathematical models. This limitation reinforces the misconception that language comprehension is secondary to mathematical calculation. Moreover, curriculum design frequently treats mathematics and language education as independent learning domains. Such compartmentalization prevents the development of integrated instructional strategies that support mathematical literacy. To effectively implement mathematical linguistics approaches, curriculum materials must be redesigned to highlight the interaction between linguistic interpretation and mathematical reasoning (Kurniawan et al., 2022).

Assessment practices also present significant challenges to the adoption of integrated approaches. In many educational systems, assessment plays a powerful role in shaping classroom practices. When examinations primarily evaluate procedural accuracy and computational skills, teachers may feel compelled to prioritize these aspects of learning. In Indonesia, large-scale assessment systems, including national examinations, often emphasize the correct application of formulas and algorithms (Yeza et al., 2025). Although contextual problems may be included, they do not always measure students' ability to interpret complex linguistic information or construct mathematical models. This misalignment between assessment and instructional goals discourages teachers from adopting innovative pedagogical strategies. If mathematical linguistics approaches are to be implemented effectively, assessment frameworks must evolve to evaluate integrated competencies. Such competencies include problem interpretation, reasoning, communication, and the ability to connect mathematical representations with real-world contexts (Kholil et al., 2025).

In addition to institutional barriers, classroom-level factors also influence the feasibility of implementing mathematical linguistics approaches. Many classrooms in Indonesia are characterized by large student populations and limited instructional time. These conditions make it challenging for teachers to facilitate in-depth discussions about language interpretation and mathematical reasoning (Johar et al., 2025). Traditional lecture-based instruction is often perceived as more efficient in covering the required curriculum within limited time frames. However, such approaches may limit opportunities for students to engage in reflective dialogue about problem interpretation. Mathematical linguistics, by contrast, encourages collaborative learning environments where students analyze problems, discuss interpretations, and justify their reasoning. Implementing this approach therefore requires pedagogical adjustments that promote interactive learning. Teachers must balance the demands of curriculum coverage with the need to cultivate deeper conceptual understanding (Kurniawan et al., 2022).

Cultural perceptions of mathematics learning may also influence the adoption of integrated instructional approaches. In many educational contexts, mathematics is often viewed as a discipline based primarily on calculation and exact procedures. This perception can lead both teachers and students to underestimate the importance of language and interpretation in mathematical problem solving. Students may assume that success in mathematics depends mainly on memorizing formulas rather than understanding problem contexts. Such beliefs can reduce students' motivation to engage in linguistic analysis of mathematical problems (Yeza et al., 2025). Mathematical linguistics challenges these assumptions by emphasizing the interpretive and communicative dimensions of mathematical thinking. By recognizing mathematics as both a symbolic and linguistic system, learners develop a more holistic understanding of the discipline. However, shifting entrenched beliefs about mathematics education requires sustained efforts across educational institutions (Kholil et al., 2025).

Overcoming these structural and cultural barriers will require coordinated reforms across multiple dimensions of the education system. Teacher education programs must integrate interdisciplinary perspectives that emphasize the relationship between language and mathematical reasoning. Curriculum developers should design learning materials that encourage students to analyze problem statements, identify underlying mathematical structures, and construct formal representations. At the same time, assessment frameworks must be aligned with these objectives by evaluating students' ability to interpret, model, and communicate mathematical ideas (Tasarib et al., 2025). Professional development initiatives can also support in-service teachers in adopting innovative instructional practices. Through collaborative workshops and reflective teaching communities, educators can gradually develop the skills required to implement mathematical linguistics approaches effectively. Ultimately, the successful integration of language and mathematics in classroom practice has the potential to strengthen students' mathematical literacy and improve their capacity to address complex real-world problems (Johar et al., 2025).

The findings of this study are consistent with, yet extend, recent research in the field of mathematics education, particularly those emphasizing the relationship between language and mathematical performance. Several contemporary studies have confirmed that reading literacy significantly influences students' ability to solve mathematical problems, especially those categorized as non-routine or context-based tasks. For instance, studies by Sinniah et al. (2022) and Kurniawan et al. (2022) highlight that students often struggle not because of a lack of computational skills, but due to difficulties in interpreting problem statements. These findings align with the present study, which identifies linguistic comprehension as a critical entry point in mathematical problem-solving (Yeza et al., 2025).

While previous studies predominantly focus on improving reading comprehension as a supporting factor for mathematical achievement, they tend to treat linguistic ability as an auxiliary skill rather than an integral component of mathematical thinking. In contrast, the findings of this study suggest that linguistic and mathematical intelligence should not be viewed as separate domains. Instead, they function as an interconnected system that must be developed simultaneously. This perspective represents a conceptual advancement over prior research, which often addresses the two competencies in isolation.

Research by Murdiyani (2018) and Saygılı (2017) emphasizes the importance of recognizing mathematical structures within verbal problems. While these studies acknowledge the role of language in identifying mathematical relationships, they do not propose a comprehensive framework that systematically integrates linguistic analysis into all stages of problem solving. The present study contributes to the literature by offering a structured mathematical linguistics framework that spans the entire problem-solving process—from parsing linguistic information to interpreting mathematical results.

Recent studies in mathematical literacy, particularly those informed by large-scale assessments such as PISA, have consistently reported that students' performance is closely linked to their ability to model real-world situations mathematically (Tasarib et al., 2025). However, these studies often stop at identifying the problem without providing a clear pedagogical solution. The current study addresses this gap by proposing mathematical linguistics as a practical and theoretically grounded approach that directly targets the core difficulty: the translation between language and mathematical representation.

Another important distinction lies in the scope of the proposed approach. Previous research, such as that by Kholil et al. (2025), highlights the importance of mathematical literacy for critical thinking and workforce readiness but does not fully address the cognitive mechanisms underlying this competency. But this study provides a deeper theoretical explanation by linking linguistic processing, symbolic reasoning, and problem-solving within a unified framework. This integration allows for a more comprehensive understanding of how students construct meaning and solve complex problems (Johar et al., 2025).

Moreover, while earlier studies have suggested the integration of interdisciplinary approaches, they often lack concrete instructional strategies (Tasarib et al., 2025). The present study contributes by outlining a clear sequence of cognitive processes which can be directly applied in classroom practice. This step-by-step framework not only bridges theory and practice but also offers actionable guidance for educators (Yeza et al., 2025).

Despite these contributions, the findings of this study also reinforce conclusions from prior research regarding the challenges of implementation. Similar to findings reported by Kurniawan et al. (2022), structural barriers such as limited teacher preparation, rigid curricula, and assessment misalignment remain significant obstacles. Therefore, while the mathematical linguistics approach offers a promising solution, its effectiveness will depend on systemic educational reforms (Tasarib et al., 2025).

In summary, this study confirms existing evidence on the importance of linguistic competence in mathematical learning while advancing the field by proposing an integrated and systematic framework. Unlike previous studies that treat language as a supporting factor, this research positions mathematical linguistics as a central mechanism for developing mathematical literacy. This contribution not only enriches theoretical understanding but also provides practical implications for improving mathematics education in contexts where students continue to struggle with non-routine problem solving.

6. Conclusions

This study has analyzed the potential of mathematical linguistics as an approach to improve students' ability to solve non-routine mathematical problems. The theoretical analysis reveals several key conclusions:

First, there is a demonstrable relationship between linguistic and mathematical intelligence, as evidenced by parallel trends in international assessment data and research on cognitive development. Students who struggle with reading comprehension also tend to struggle with mathematical problem-solving, particularly when problems are presented in complex, real-world contexts.

Second, current educational approaches treat linguistic and mathematical intelligences as separate competencies, missing opportunities to leverage their natural connection. This fragmentation may contribute to the persistent difficulties Indonesian students face in mathematical literacy.

Third, mathematical linguistics offers a theoretical framework for integrating these intelligences. By explicitly teaching students to move between linguistic and mathematical representations of problems, this approach addresses the core difficulty identified in international assessments: the inability to model complex situations mathematically.

Fourth, the historical foundations of mathematical linguistics in both Eastern and Western intellectual traditions suggest that this integration is not merely a modern pedagogical innovation but reflects fundamental structures of human reasoning. Euclid's axiomatics and Panini's grammatical descriptions, developed independently in different cultural contexts, both recognized the logical parallels between language and mathematics.

Fifth, implementing mathematical linguistics approaches will require systemic changes in teacher preparation, curriculum design, and assessment practices. These changes, while challenging, are necessary to address the persistent gaps in Indonesian students' mathematical literacy.

In conclusion, mathematical linguistics represents a promising direction for educational research and practice in Indonesia. By bridging the artificial divide between language and mathematics instruction, this approach may help students develop the integrated competencies needed to solve complex, non-routine problems – precisely the skills measured by international assessments and demanded by the modern world. Future research should focus on developing and testing instructional materials based on mathematical linguistics principles, preparing teachers to implement integrated approaches, and designing assessments that capture students' ability to move fluidly between linguistic and mathematical representations.

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