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Early Childhood Numeracy Literacy Development: A Survey of Five Core Mathematical Domains in East Java, Indonesia

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ABSTRACT

Indonesia faces persistent challenges in early childhood numeracy, as national and international assessments report low mathematical literacy. This study aims to evaluate numeracy literacy levels across five core mathematical domains numbers, algebra, geometry, measurement, and data analysis among young children, while examining potential gender differences. A quantitative survey design was employed involving 50 children aged 5–6 years (25 boys, 25 girls; Mean age = 5.4 years) selected via random sampling from five early childhood education institutions in East Java, Indonesia. Data were collected using an observation-based instrument (10 items, Cronbach's α=0.646) and analyzed using descriptive statistics and an independent samples t-test. Results indicate that 58% of children exhibited high numeracy literacy, while 42% were in the moderate category. The highest competence was observed in pattern recognition (algebra, Mean=6.30), whereas data analysis yielded the lowest score (Mean=5.48). Furthermore, female children significantly outperformed male children (t(48)=2.375,p=0.022). These findings highlight the need for early childhood educators to integrate contextual, data-oriented, and spatial play activities to build balanced foundational numeracy before primary school transition.

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1. Introduction

Indonesia has set an ambitious goal to achieve developed nation status by 2045 under the vision of Indonesia Emas 2045, which heavily relies on developing high-quality human capital (Masykur, 2024; Sutikno, 2020). A critical foundation of this human resource strategy is early numeracy literacy, the ability to understand, interpret, and apply basic mathematical concepts in everyday situations (Westwood, 2021). The National Council of Teachers of Mathematics (NCTM, 2000) emphasizes structuring early mathematics around core content standards: numbers and operations, algebra, geometry, measurement, and data analysis. In response to learning gaps, the Indonesian Ministry of Education has considered introducing a structured mathematics curriculum at the kindergarten level to strengthen early numeracy foundations before formal schooling (Prahmana et al., 2026).

Despite these policy initiatives, international and national assessments highlight persistent challenges in mathematics education. According to the 2022 Programme for International Student Assessment (PISA), Indonesia's mathematics score decreased by 13 points compared to 2018 (OECD, 2023), while the country ranks 112th globally on the Human Development Index (UNDP, 2024, p. 275). Within ASEAN, Indonesia is positioned 6th out of 11 countries. This ranking underscores the urgent need for enhanced efforts to improve the quality of human resources, particularly by strengthening primary education to prioritize early literacy and numeracy development. Studies show that a weak numeracy foundation early in education adversely impacts students' later mathematical achievements (Rakhmawati & Mustadi 2022) and is closely linked to executive function development (Chan & Scalise 2022). Furthermore, a meta-analysis of 54 longitudinal studies showed that early numeracy measured at or before the first year

of formal schooling significantly predicts later mathematics achievement (Liu et al., 2025) and school-entry mathematics skills have been identified as among the strongest predictors of later academic achievement (Duncan et al., 2007). At the local level, preliminary diagnostic assessments in East Java reveal parallel concerns, where children entering primary school often encounter challenges with advanced number recognition (above 10), backward counting, and data analysis, indicating that specific numeracy gaps emerge well before primary education.

The primary research gap in the literature is that existing studies in Indonesia predominantly focus on primary or secondary education rather than the preschool period, leaving early childhood learning trajectories underexplored (Rakhmawati & Mustadi 2022). Furthermore, many preschool studies evaluate mathematical performance as a single composite score or focus on a limited set of domains, such as arithmetic, geometry, and patterns (Nur, Herman, and Dahlan 2022), leaving a substantive empirical gap regarding how young children perform across integrated mathematical domains. The unique contribution of this study lies in providing a domain-specific diagnosis across five core mathematical areas: numbers, algebra, geometry, measurement, and data analysis, within the Indonesian early childhood context. Rather than treating early math as a monolithic skill, this study describes children's relative strengths and weaknesses, offering empirical foundations for targeted early childhood curricular design and pedagogical interventions.

To address this empirical gap, the present study investigates early childhood numeracy literacy across five core mathematical domains in East Java, Indonesia. The primary research objectives of this study are threefold to evaluate the overall numeracy literacy levels of children aged 5-6 years, diagnose and compare children's performance across the five core mathematical domains (numbers, algebra, geometry, measurement, and data analysis), and determine whether statistically significant differences exist in early numeracy achievement based on gender.

2. Method

This study adopted a quantitative survey design to describe and evaluate early childhood numeracy literacy across multiple core domains. The population comprised kindergarten children aged 5-6 years attending early childhood education institutions in East Java, Indonesia. A sample of 50 preschool children (25 boys and 25 girls; mean age = 5.4 years) was selected using random sampling from five accredited kindergarten institutions in East Java. Prior to data collection, official research clearance and ethical approval were obtained from institutional authorities, and informed consent was secured from school administrators and parents/guardians to guarantee participant confidentiality and voluntary involvement.

Data were collected using a structured observation instrument adapted from the early mathematics content standards of NCTM (2000) and Henniger (2013). The instrument consisted of 10 items, two for each of five domains: numbers and operations, algebra (patterning and relational reasoning), geometry (spatial awareness and shape recognition), measurement, and data analysis (sorting and simple classification). Observational scoring was recorded using a 4-point rating scale ranging from 1 (Needs Development/Needs Assistance) to 4 (Consistently Demonstrated/Independent). Consequently, each mathematical domain yielded a maximum potential score of 8 points, resulting in a total achievable numeracy score ranging from 10 to 40.

Observations were conducted by 2 trained observers during structured play-based and interactive numeracy tasks lasting approximately 20-30 minutes per child in early childhood classrooms and outdoor activity areas across five kindergartens in Ponorogo Regency, East Java, Indonesia. Inter-rater agreement was not quantitatively calculated, and internal consistency reliability was assessed on 20 children (Cronbach's alpha = 0.646). Total scores were classified into low, moderate, and high numeracy literacy using a normal distribution assumption based on the theoretical mean and standard deviation ($M = 25$, $SD = 5$): low = $X < 20$, moderate = $20 \leq X < 30$, and high = $30 \leq X$ (or $X \geq 30$).

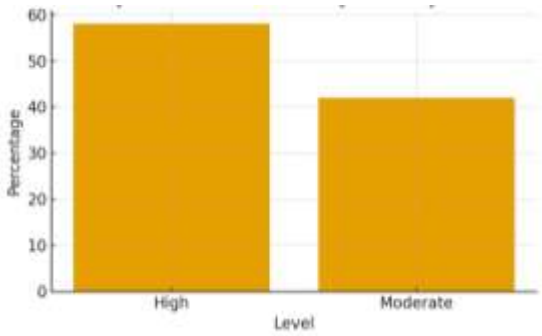
Content validity was established through expert judgment by two specialists in early childhood education and mathematics education, who evaluated the relevance and developmental appropriateness of each item using qualitative review and content validity judgment, with statement items approved and revised prior to administration. Internal consistency was estimated using Cronbach's alpha, which yielded $\alpha = 0.646$. This value is below the conventional 0.70 benchmark; however, alpha tends to be lower for short scales (here, 10 items across five domains), and values in this range have been considered acceptable for exploratory research when interpreted with caution (Taber, 2018). The reliability of the instrument is therefore acknowledged as a limitation.

Data were analyzed using IBM SPSS Statistics version 25. Descriptive statistics (frequencies, percentages, means, and standard deviations) were computed for the total score and for each domain. Normality of total scores within each gender group was examined using the Kolmogorov–Smirnov test (male: $p > 0.05$, female: $p > 0.05$, indicating normal distribution), and homogeneity of variances using Levene's test ($F = 0.724$, $p = 0.399$, indicating equal variances). Gender differences in total scores were tested using an independent-samples t-test ($\alpha = 0.05$). Cohen's d and the 95% confidence interval of the mean difference (95% CI [0.18, 2.22]) were reported as effect-size indicators.

3. Result And Discussion

Of the 50 children aged 5–6 years from five kindergartens in Ponorogo Regency, 58% (n = 29) were in the high numeracy literacy category and 42% (n = 21) in the moderate category; none was in the low category (Figure 1).

Figure 1. Level of Numeracy Literacy



Girls (M = 30.36, SD = 1.63) scored higher than boys (M = 29.16, SD = 1.93), $t(48) = 2.375$, $p = .022$ (Table 1). The mean difference was 1.20 points (95% CI [0.18, 2.22]), corresponding to a medium effect size (Cohen's $d = 0.67$).

Table 1. Descriptive Statistics by Gender

Group	N	Mean	SD	95% CI of M difference
Male	25	29.16	1.93	
Female	25	30.36	1.63	[0.18, 2.22]

Across domains (Figure 2, Table 2), algebra had the highest mean score (M=6.30, SD=0.91), followed by measurement (M=6.08, SD=0.88), numbers (M=5.96, SD=0.83), and geometry (M=5.94, SD=0.94). Data analysis had the lowest mean (M=5.48, SD=1.15) and the widest spread. The four highest domains differed by less than 0.4 points, so their ordering should be interpreted cautiously.

Figure 2. The
Figure 2 illustra
four domains clustered t
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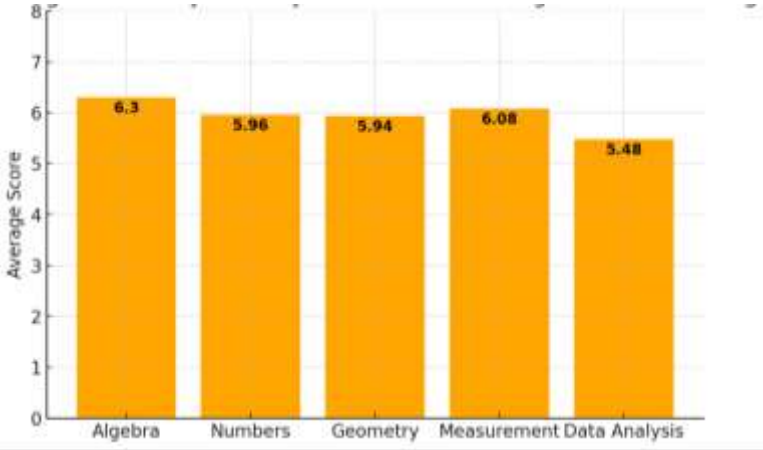

the other

	N	Minimum	Maximum	Mean	Std. Deviation
1st aspect	50	5	8	6.30	.909
2ndaspect	50	5	8	5.96	.832
3rd aspect	50	4	8	5.94	.935
4th aspect	50	5	8	6.08	.877

5th aspect	50	4	7	5.48	1.147
Valid N (listwise)	50				

In the early algebra domain, children demonstrated strong competence in pattern recognition and sequence continuation. Most participants successfully identified repeated visual arrangements of colors and shapes, with some children capable of creating original patterns. The majority of children achieved a score of 7, reflecting high proficiency in relational reasoning (Table 3).

Table 3. Distribution of Scores in the Algebra Aspect

1st Aspect					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	11	22.0	22.0	22.0
	6	17	34.0	34.0	56.0
	7	18	36.0	36.0	92.0
	8	4	8.0	8.0	100.0
	Total	50	100.0	100.0	

Regarding numbers and operations, most children reliably recognized numerals 1–20 and associated them with concrete quantities. Children also demonstrated an emerging understanding of basic relational concepts such as "more" and "less." However, performance was constrained by challenges in recognizing numerals above 10 and inconsistent backward counting skills. Score distributions peaked at a score of 6 (Table 4).

Table 4. Distribution of Scores in the Number Aspect

2nd Aspect					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5	15	30.0	30.0	30.0
	6	25	50.0	50.0	80.0
	7	7	14.0	14.0	94.0
	8	3	6.0	6.0	100.0
	Total	50	100.0	100.0	

Performance in geometry showed solid basic shape recognition (e.g., circles, triangles, squares) and positional awareness (e.g., above, below, beside). Nevertheless, performance declined when children were assessed on complex, composite 3D geometric structures and spatial transformations. The score distribution was concentrated at a score of 6 (Table 5).

Table 5. Distribution of Scores in the Geometry Aspect

3rd Aspect					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	2	4.0	4.0	4.0
	5	11	22.0	22.0	26.0
	6	31	62.0	62.0	88.0
	8	6	12.0	12.0	100.0
	Total	50	100.0	100.0	

In the measurement domain, children effectively made direct visual comparisons involving length (long/short), weight (heavy/light), and size (big/small). However, difficulties emerged when tasks required using non-standard measuring tools or comparing more than two objects simultaneously. The majority of participants scored 6 (Table 6).

Table 6 Distribution of Scores in the Measurement Aspect

4th Aspect					
		Frequency	Percent	Valid Percent	Cumulative Percent

	5	13	26.0	26.0	26.0
	6	24	48.0	48.0	74.0
Valid	7	9	18.0	18.0	92.0
	8	4	8.0	8.0	100.0
	Total	50	100.0	100.0	

The data analysis domain recorded the lowest overall achievement. While children could group objects by single attributes, they struggled with multi-attribute classification, organizing simple data arrays, and interpreting collective data representations. Scores in this domain were broadly distributed, with peak frequencies occurring at scores of 4 and 6 (Table 7).

Table 7. Distribution of Scores in the Data Analysis Aspect

5th Aspect					
		Frequency	Percent	Valid Percent	Cumulative Percent
	4	14	28.0	28.0	28.0
	5	10	20.0	20.0	48.0
Valid	6	14	28.0	28.0	76.0
	7	12	24.0	24.0	100.0
	Total	50	100.0	100.0	

3. Discussion

The findings indicate that most early childhood learners in East Java possess numeracy literacy skills at a high level (58%), while the remaining 42% fall into the moderate category. It shows that most children already have a solid foundational understanding of number concepts, geometric shapes, patterns, measurement, and object classification. Based on five numeracy literacy components algebra, numbers, geometry, measurement, and data analysis the algebra component stands out as the highest, followed by measurement, numbers, and geometry. In contrast, data analysis emerges as the lowest-scoring aspect.

Girls outperformed boys in overall numeracy literacy, with a medium effect size (d=0.67). This result should be interpreted cautiously. Large-scale evidence indicates that gender differences in mathematics-related tasks in early childhood are typically near zero and vary across cultures and testing conditions (Martinot et al., 2025). Several features of the present study may have contributed to the observed difference: the small sample (n=25 per group), the clustering of children within five institutions, and the use of observation-based scoring, which may be influenced by children's classroom behavior, attention, or language engagement, as well as by observer expectations. In this study, the observers were the primary researchers who designed the study framework and were aware of the research objectives. The finding therefore needs to be replicated with larger, more representative samples and with direct task-based assessment before conclusions about gender differences are drawn.

The algebra aspect relates to the children's ability to recognize patterns, understand relationships between ideas, and use mathematical symbols to solve problems (Ünal et al. 2023). Children who excel in this aspect demonstrate strong abstract and logical thinking skills. Their high performance cannot be separated from the nature of learning experiences commonly provided in early childhood contexts, such as practicing numerical patterns, solving multi-step operations, and engaging in play-based problem-solving using symbols. Early algebraic reasoning bridges the iconic representation stage (visual pattern recognition) and the emerging symbolic stage, enabling children to gradually transform concrete play into flexible mathematical reasoning (Zuliana et al. 2019).

Skemp's theory of relational understanding also strengthens this interpretation. He argues that mathematical proficiency extends beyond rote procedural application toward the ability to internalize conceptual relationships (Makonye & Fakude 2016). Children with a strong sense of relationships tend to be more flexible in applying algebraic concepts to various types of problems, especially those encountered in real-life contexts. Meanwhile, Vygotsky's socio-cultural theory, as cited by Thompson, emphasizes the essential role of social interaction and scaffolding from teachers in supporting the development of algebraic reasoning (Thompson 2023). With appropriate guidance, children can develop a deeper understanding of symbols, patterns, and mathematical concepts. Therefore, the high achievement in the algebra component reflects not only the children's individual cognitive strengths but also the effectiveness of learning processes that encourage critical, creative, and collaborative mathematical thinking (İŞler Baykal et al. 2023).

The unexpectedly high performance in the algebra domain warrants nuanced interpretation. In early childhood education, algebraic reasoning does not involve abstract symbolic manipulation; rather, it centers on pattern recognition, sequence continuation, and visual symmetry ((Ünal et al. 2023). Young children naturally engage with these concepts during daily play routines, such as organizing colored blocks or repeating rhythmic sequences. This intuitive engagement aligns with Bruner's iconic representation stage, where visual pattern recognition serves as a natural bridge toward formal mathematical reasoning (Zuliana et al., 2019).

The measurement component, which also shows relatively strong performance, reflects children's ability to recognize units, understand measurement tools, and apply them in daily activities. Learning in this domain typically incorporates concrete and familiar experiences such as measuring table length, comparing volumes, or estimating time. This approach aligns with Piaget's constructivist view, which posits that direct experiences and concrete activities help children build understanding of more abstract concepts.

Meanwhile, the number component-which includes understanding place value, performing basic arithmetic operations, and applying numerical concepts-shows moderate achievement. It suggests that while children have mastered foundational numerical knowledge, they may require more varied opportunities to apply numerical operations flexibly in authentic contexts (Bisaillon 2023). Siegler and Booth explain that numeracy development progresses gradually, beginning with concrete recognition before progressing to a deeper understanding of numerical relations (Siegler & Booth 2005). The moderate performance aligns with this notion, indicating that children in East Java are still developing more sophisticated flexibility in number manipulation.

Regarding the geometry component, which shows lower performance compared to algebra and measurement, children's limited engagement with hands-on exploratory activities may contribute to this outcome. Activities such as manipulating blocks, sorting shapes, or observing spatial relationships are essential in developing geometric thinking (Fujita et al. 2020). Van Hiele's geometric thinking theory, as cited by Hartono et al., explains that children's geometric understanding develops through sequential levels, starting with visual recognition and progressing toward descriptive, analytical, and deductive reasoning (Hartono et al. 2025). Adequate exposure to activities requiring visualization and manipulation of concrete objects is necessary for children to progress through the Van Hiele levels.

The lowest performance appears in the data analysis component, which requires the ability to read, interpret, and present information through tables, graphs, or diagrams. Low achievement may stem from instructional practices that emphasize procedural computation but underemphasize the interpretation of contextual data. Steen's theory of quantitative literacy describes data analysis as requiring the integration of mathematical skills with real-world reasoning (Baker & Galanti 2017). Yet, early childhood programs often give insufficient focus to data-based tasks.

Mathematical thinking, according to Smith, strengthens as children learn to organize statements logically, understand correspondences, and classify objects (Smith 2002). These abilities are foundational to numeracy. For example, when children compare quantities determining whether one value is greater than, smaller than, or equal to another they engage in essential numeracy practices. Walle further explains that numeracy involves understanding numbers, their relationships, place value, and how operations transform values. Even expressing the size of an object in real-life contexts contributes to the development of numeracy. This perspective aligns with Walle's explanation that numeracy represents a sense of number, which includes understanding the meaning of numbers, relationships among numbers, place value, and how operations such as addition, subtraction, multiplication, and division affect numerical values (Van de Walle, Karp, and Bay-Williams 2016). Even the ability to express the size of an object in real contexts is part of numeracy development.

The findings also align with Jean Piaget's cognitive development theory, which positions children aged 5–6 years in the preoperational stage (Piaget 1964). During this period, children begin to engage in symbolic thinking using words, pictures, or objects as representations. They recognize patterns, shapes, sizes, and simple quantitative relationships competencies that form the foundation of numeracy development. However, children at this stage still rely heavily on intuitive and perceptual understanding, which explains why more concrete aspects, such as pattern recognition and measurement, are stronger, while abstract domains, such as data interpretation, remain challenging.

These findings are further supported by empirical research. Lyons et al. demonstrate that early numeracy develops through a combination of non-symbolic skills (such as estimating without counting) and symbolic skills (such as recognizing numerals) (Lyons et al. 2018). Meanwhile, Nur et al. found that children aged 5–6 typically recognize numbers 1-20, identify simple patterns, and perform grouping

activities; however, they still struggle with more abstract skills, such as data analysis (Nur, Herman, and Dahlan 2022). This consistency reinforces the interpretation that the cognitive characteristics of children in East Java align with the preoperational stage as theorized by Piaget.

These findings are broadly consistent with research on early mathematical learning trajectories, which describes development as progressing from concrete, perceptually supported competencies toward more complex forms of organization (Clements & Sarama, 2026). Chan & Scalise (2022) also showed that numeracy skills mediate the relation between executive function and mathematics achievement in early childhood, suggesting that domain-specific numeracy skills deserve attention alongside general cognitive skills. The importance of identifying early strengths and weaknesses is underscored by a meta-analysis of 54 longitudinal studies, which found that early numeracy measured at or before the first year of formal schooling significantly predicts later mathematics achievement (Liu et al., 2025).

Overall, children in this sample showed their strongest performance in pattern-based algebra and measurement tasks and their weakest performance in data analysis, with geometry and numbers in between. This profile is consistent with a developmental period in which concrete, perceptually supported tasks are mastered earlier than tasks requiring the organization and interpretation of data. The findings suggest that instruction should give more attention to data analysis and geometry so that children develop balanced numeracy readiness for primary school.

These findings offer practical guidance for early childhood teachers and curriculum developers. First, early mathematics instruction should move beyond traditional counting drills to incorporate interactive data-sorting activities (e.g., grouping toys by multiple attributes or creating classroom pictographs). Second, teachers should utilize 3D building blocks and spatial manipulation games to scaffold children's geometric thinking across Van Hiele's levels. Guided teacher scaffolding remains crucial in transforming concrete play experiences into structured mathematical concepts.

Several limitations should be noted. First, the sample consisted of 50 children from five institutions in East Java, which limits generalizability to the wider population of Indonesian preschool children, and the clustering of children within institutions may violate the independence assumption of the t-test. Second, the observation instrument had modest internal consistency (α=0.646) and only two items per domain, so domain-level scores should be interpreted with caution; inter-rater agreement was not quantitatively calculated, though content validity was established through expert judgment by two early childhood education specialists. Third, observation-based scoring may be subject to observer bias, as data collection was conducted directly by the primary researchers. Fourth, the cross-sectional design captures performance at a single point in time; future longitudinal studies and direct task-based interviews are recommended to track children's mathematical reasoning over time.

4. Conclusion

This study evaluated early childhood numeracy literacy across five core mathematical domains in East Java, Indonesia. The findings demonstrate that young children possess solid foundational numeracy competencies, achieving their highest proficiency in pattern-based early algebra and measurement. Conversely, data analysis emerges as the most challenging domain, while girls scored significantly higher, although this finding should be interpreted cautiously in overall numeracy engagement. Scientifically, this study contributes to the early childhood education literature by moving beyond monolithic numeracy scores to provide a domain-specific diagnosis across five integrated mathematical areas. The results suggest that, at this age, children's strongest competencies lie in concrete, pattern-based tasks, whereas domains that require organizing and interpreting data remain less developed. Practically, these findings underscore the need for early childhood educators and curriculum developers to rebalance mathematics instruction. Rather than focusing solely on traditional counting drills, early childhood programs should integrate interactive multi-attribute data sorting, spatial geometry play, and guided teacher scaffolding to build well-rounded mathematical readiness before formal primary schooling. This study is limited by its relatively small sample size (N = 50) and geographic focus on East Java, which restricts the generalizability of the findings across the diverse socio-economic landscapes of Indonesia. Additionally, the cross-sectional observational design captures performance at a single point in time. Future research should expand to larger, multi-regional samples across different geographic and socio-economic contexts. Longitudinal studies and direct diagnostic task interviews are also recommended to examine how domain-specific preschool numeracy competencies predict formal primary school mathematics achievement over time.

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