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The Impact of Numeracy on Early Childhood Development: A Meta-Analysis of Experimental Studies

Fitri Nur Hidayah [1], **Heri Retnawati** [2]
[1,2]Universitas Negeri Yogyakarta, Indonesia.

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Correspondence to
Fitri Nur Hidayah, Universitas Negeri Yogyakarta, Indonesia.
e-mail:
fitrinur.2022@student.uny.ac.id

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Abstract

Early numeracy is widely recognized as a critical factor in child development, yet disparities in access to effective numeracy education persist, particularly in underserved communities. Addressing this issue, this study employs a meta-analytic approach to evaluate the impact of numeracy on early childhood development. By analyzing 41 experimental studies, the research aggregates data to precisely estimate numeracy's effect size, enhancing the generalizability of findings. A random-effects model was applied due to high heterogeneity among studies ($I^2 = 91.32\%$), reflecting significant variability across geographical regions, sample sizes, and intervention durations. The findings revealed a statistically significant positive effect of numeracy on early childhood abilities, with a coefficient estimate of 0.56834 ($p < 0.001$). This result underscores the critical role of early numeracy interventions in fostering cognitive, social, and academic growth in young learners, making it a cornerstone for lifelong learning. However, significant challenges remain, particularly in addressing the contextual factors influencing variability in intervention outcomes. The study highlights the importance of tailoring programs to local conditions, including cultural and socioeconomic factors, to maximize their impact. Additionally, publication bias was identified, as evidenced by funnel plot symmetry and a fail-safe N of 7,159, indicating robust findings despite potential limitations in the literature. These results prove that well-designed numeracy programs can significantly enhance early childhood outcomes. Future research should investigate the specific mechanisms driving these outcomes, focusing on strategies to address educational disparities and foster equitable access to high-quality numeracy interventions. A collaborative effort among researchers, educators, and policymakers is essential to ensure the sustainability and scalability of these programs globally.

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Introduction

In today's increasingly complex world, early numeracy is more than just learning to count or recognize numbers; it's a critical foundation for a child's overall development. These early math skills don't just predict future success in mathematics; they also influence cognitive abilities that are essential for navigating daily life, from problem-solving to logical reasoning (Liu & Abdul Rahman, 2022; Xu & Lefevre, 2018). As children grow, the numeracy skills they acquire in their early years can significantly impact their educational trajectory and even their career prospects (Nelson et al., 2024; Zhang et al., 2019). Yet, despite its importance, there remains a significant gap in access to quality numeracy education, especially in underserved communities worldwide (Lim et al., 2023; Manu et al., 2019). This disparity isn't just an academic issue—it's a societal challenge that demands our attention.

Numerous studies have highlighted the importance of nurturing early numeracy through both home and educational settings. For example, engaging children in simple number games or talking about numbers during everyday activities has been shown to boost their early math

skills (Cheung et al., 2023; Elliott et al., 2023). Similarly, the environment in which children learn, including the peers they interact with, can greatly influence their numeracy development (Niklas & Tayler, 2018; Wei et al., 2022). The use of innovative tools, like educational technology and specialized early numeracy programs, has also proven to be effective, particularly for children facing learning challenges (Nelson et al., 2024; Wright et al., 2020). These findings collectively emphasize the diverse ways in which early numeracy can be nurtured, but they also raise questions about which methods work best in different contexts.

While the role of the home environment is undisputed, its effectiveness is often shaped by broader socio-economic and cultural factors. Research shows that parents' beliefs about math and the resources they can provide at home significantly impact their children's numeracy skills (Chiu, 2018; Hossain et al., 2023). However, not all interventions yield equal benefits. The outcomes of early numeracy programs can vary widely depending on factors such as a child's initial abilities and the specific design of the intervention itself (Hudson et al., 2021; Scalise et al., 2022). Moreover, unexpected events like the COVID-19 pandemic have added new challenges, disrupting children's learning and widening existing gaps in numeracy skills (Aurini & Davies, 2021; Gao et al., 2023). These complexities suggest that while we know a lot about what influences early numeracy, there's still much to learn.

Beyond the environment, there's a fascinating connection between numeracy skills and brain development that has captured the attention of researchers. Studies reveal that the brain's fronto-parietal network, which plays a key role in numerical processing, starts developing in early childhood and is linked to later math abilities (Chan & Scalise, 2022; Zhang et al., 2019). Additionally, tasks like number line estimation have been found to correlate with general mathematical skills, although their predictive power is still debated (Ellis et al., 2021; Nelson et al., 2024). Cognitive abilities, such as working memory and executive function, also contribute significantly to how children develop numeracy skills, serving as a bridge between early learning experiences and later academic success (Mills et al., 2018; Shvartsman & Shaul, 2024). These insights into the brain and cognition add another layer to our understanding of numeracy, showing that it's not just about numbers—it's about how we think and process the world around us.

However, the story of early numeracy isn't complete without considering the powerful role of socio-environmental factors. Research consistently shows that socio-economic status, along with related factors like parental education and access to resources, plays a crucial role in shaping a child's numeracy development (Lim et al., 2023; Susperreguy et al., 2020). Unfortunately, children from lower socio-economic backgrounds often start school with fewer numeracy skills, and without intervention, these gaps can widen as they progress through their education (Merkley et al., 2023; Sepúlveda et al., 2020). Cultural differences also matter, influencing how numeracy is perceived and taught, which can either help or hinder a child's early math development (Bar & Shaul, 2021; Chiu, 2018). Understanding these dynamics is essential if we are to create more equitable educational opportunities for all children.

Despite the wealth of research on early numeracy, there are still significant gaps and challenges that need to be addressed. One of the key limitations is that not all interventions are equally effective across different contexts, highlighting the need for more culturally sensitive approaches (Luomaniemi et al., 2021; Trickett et al., 2022). Additionally, while we have made progress in understanding the cognitive and neurological aspects of numeracy, there is still a lack of comprehensive models that integrate these findings with the socio-environmental factors that also play a crucial role (Charitaki et al., 2024; Gilligan-Lee et al., 2023). Moreover, much of the existing research focuses on short-term outcomes, with less attention given to the long-term impacts of early numeracy skills on later life success (McLeod et al., 2019; Vetter et al.,

2020). Addressing these gaps is critical for developing more effective and equitable strategies to support numeracy development in early childhood.

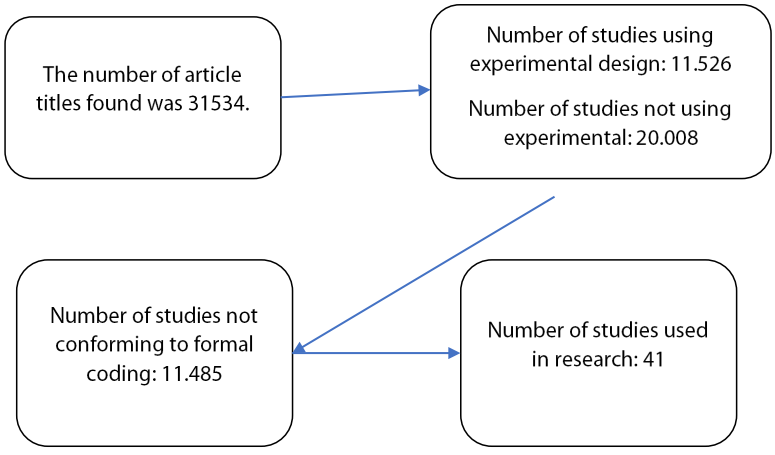
This study seeks to address these challenges by conducting a meta-analysis of the impact of early numeracy on child development, to identify the most effective strategies for nurturing these skills across different contexts. By analyzing data from a wide range of studies, this research aims to provide a more nuanced understanding of the factors that influence early numeracy development and to offer insights into best practices for supporting young learners (Lynch et al., 2023; Neneng et al., 2023). The findings of this study are expected to contribute to the development of targeted interventions and inform educational policies aimed at reducing disparities in numeracy outcomes (Elliott et al., 2021; Zahra et al., 2022). Ultimately, this research hopes to ensure that all children, regardless of their background, have the opportunity to develop the numeracy skills they need to succeed in school and life.

Methods

This study employed a meta-analytic approach to synthesize the results of experimental studies on early childhood numeracy skills. Meta-analysis is a statistical technique that combines the quantitative findings from multiple independent studies to provide a more precise estimate of the effect size, thereby enhancing the generalizability of the results (Mills et al., 2018). The meta-analytic approach is informed by the theory of effect size measurement, which provides a statistical basis for comparing interventions across studies. The primary focus was to evaluate the efficacy of various interventions to improve numeracy skills in young children by aggregating data across studies that meet specific inclusion criteria.

The procedures followed a systematic process beginning with a comprehensive literature search in the Scopus database, using keywords such as "numeracy" and "early child*". This search yielded a preliminary pool of studies screened based on pre-established inclusion and exclusion criteria. Specifically, studies were included if they utilized quantitative research methods, emphasizing experimental designs that compared an intervention group with a control group. Additionally, eligible studies were required to report numerical data, including the population sizes of experimental and control groups and their means and standard deviations, to allow for effect size calculation. To ensure consistency and accuracy in data extraction, a coding format was developed and implemented using Microsoft Excel. The coding sheet captured essential details such as the study's title, intervention materials, and relevant statistical data (e.g., means and standard deviations). Two researchers independently coded the data, and any discrepancies were resolved through discussion to maintain the reliability of the extracted data.

Figure 1. Article Mapping



Data analysis involved calculating the effect sizes for each study, which were then synthesized using a random-effects model to account for variability between studies. Statistical heterogeneity was assessed using the I^2 statistic to determine the extent of variation across the included studies. Sensitivity analyses were also conducted to evaluate the robustness of the findings by excluding outliers and studies of lower methodological quality. To enhance the validity of the results, a comprehensive quality assessment of the included studies was performed. This involved evaluating the methodological rigor of each study, including randomization procedures, blinding, and the handling of missing data. Furthermore, publication bias was assessed using funnel plots and Egger's regression test, ensuring that the results were not unduly influenced by selective reporting.

Result

This study aims to examine the impact of numeracy on early childhood abilities through a meta-analysis approach. 41 studies were analyzed, encompassing various methods and populations across multiple locations. Considering the high level of heterogeneity identified in this analysis, with an I^2 value reaching 91.32%, a Random Effects model was chosen as a more appropriate estimation method. This model allows for the aggregation of effects across studies with significant variations in populations and methods, providing a more general and robust estimation of the influence of numeracy on early childhood abilities.

The high heterogeneity indicates variability not solely due to random factors but also to differences in the characteristics of the studies included in this analysis. Therefore, the Random Effects model is more suitable for accommodating this variability than the Fixed Effects model, which assumes that all studies estimate the same effect. Through this approach, the meta-analysis results are expected to offer deeper insights into how numeracy impacts the development of early childhood abilities across diverse contexts.

Descriptive Characteristics of Included Studies

This research involved analyzing 41 studies exploring the influence of numeracy on early childhood abilities. These studies span various geographic regions, use different sample sizes, and vary the duration of interventions and numeracy measurement methods. Grouping the studies by year of publication, sample size, region, intervention duration, and method category provides a comprehensive overview of the analyzed research characteristics.

Below is Table 1 summarizing the distribution of studies based on these criteria, offering a clearer perspective on each category's key characteristics.

Table 1. Characteristics of Meta-Analysis Studies

Characteristic	Group	Number	Percentage (%)
Year	2011–2015	10	24%
	2016–2020	20	49%
	2021–2025	11	27%
Total		41	100%
Sample Size	≤50	12	29%
	51–100	15	37%
	101–200	9	22%
	>200	5	12%
Total		41	100%
Region	West Africa	5	12%
	North America	10	24%
	Europe	17	41%
	South Asia	9	22%
Total		41	100%

Characteristic	Group	Number	Percentage (%)
Intervention Duration	≤10 weeks	15	37%
	11–20 weeks	18	44%
	21–30 weeks	8	19%
Total		41	100%
Measurement Method	Standardized Numeracy Tests	22	54%
	Specialized or Targeted Tests	12	29%
	Classroom-Based Tests	7	17%
Total		41	100%

Table 1 illustrates the distribution of analyzed studies based on five key categories: year of publication, sample size, region, intervention duration, and measurement methods. Most studies were conducted between 2016 and 2020, reflecting an increasing interest in the topic of numeracy's impact on early childhood development. Studies conducted in North America and South Asia tended to use larger sample sizes, with experimental sample averages exceeding 100 participants. This may reflect greater resources or a wider availability of research populations in these regions. Meanwhile, studies in Europe and Southeast Asia often employed smaller sample sizes but still yielded significant effect sizes, albeit with more variability.

Intervention durations also varied significantly, with most studies lasting between 11 and 20 weeks. Studies with longer intervention durations tended to demonstrate larger effect sizes, suggesting that extended numeracy interventions might have a deeper impact on children's numeracy skills. The methods used to measure numeracy abilities were also diverse, with most studies employing standardized numeracy and mathematics tests. This indicates a widely accepted standard for assessing numeracy skills, although some studies utilized more specific and targeted approaches. This variation in methods could influence the results, particularly in terms of the magnitude of effects detected by each study.

Heterogeneity Analysis

Heterogeneity in meta-analysis measures the extent to which variations in study results can be explained by differences among the studies analyzed. In the context of research on the impact of numeracy on early childhood abilities, understanding heterogeneity is crucial as it highlights the degree of variability among the studies included. Based on the data, a τ^2 (tau-squared) value of 0.18908 indicates the estimated variance of random effects among the analyzed studies. The larger the τ^2 value, the greater the variation between studies that cannot be explained solely by sampling error, implying the presence of other factors influencing the differences in results.

Table 2. Residual Heterogeneity Estimates

Estimate	Value
τ^2	0,18908
τ	0,43484
I^2 (%)	89,62544
H^2	9,63896

The τ (tau) value of 0.43484, the square root of τ^2, represents the standard deviation of random effects. This provides insight into the extent of differences among studies in effect size units (e.g., the impact of numeracy on early childhood abilities). An I^2 (I-squared) value of 89.62544% indicates that a significant proportion of the total variance is attributable to heterogeneity among studies, rather than sampling error. Such a high I^2 value suggests that most variation across studies is due to genuine differences, potentially arising from variations in study design, populations, methods, or other uncontrolled factors. The H^2 (H-squared) value of 9.63896 serves as an absolute measure of heterogeneity. Values above 1 indicate significant heterogeneity, and the observed value suggests that the results of studies in this meta-analysis

are not homogeneous. As such, the interpretation of aggregated results should be approached cautiously, considering the variability among the studies.

Overall Effect Size

This meta-analysis evaluates the impact of numeracy on early childhood abilities. The analysis yielded an estimated coefficient (Estimate) for the intercept of 0.56834 with a standard error of 0.07496. The Wald test produced a z-value of 7.58218 and a p-value of less than 0.001, indicating a statistically significant effect of numeracy on early childhood abilities.

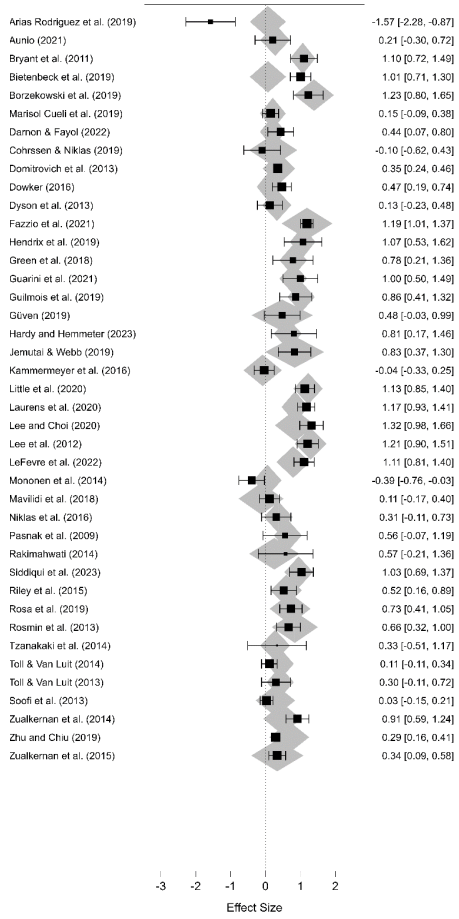
Table 3. Coefficients

	Estimate	Standard Error	z	p
intercept	0.56834	0.07496	7.58218	< .001

Note. **Wald test.**

The positive coefficient indicates a positive relationship between numeracy and early childhood abilities. This means that improvements in numeracy skills are significantly correlated with better outcomes in other developmental areas measured in this research. The relatively small standard error (0.07496) reflects the stability and accuracy of the coefficient estimate, providing greater confidence in these results. The high z-value (7.58218) further supports the significance of the findings, and the extremely small p-value (< 0.001) strongly indicates that these results are unlikely due to chance. A forest plot can provide a detailed visual representation of the effect size from each study.

Figure 2. Forest Plot



Subgroup Analysis

The meta-analysis's subgroup analysis of the impact of numeracy on early childhood abilities reveals variations in effects based on geographic regions and measurement methods. The coefficient estimates show that certain regions significantly impact early childhood numeracy abilities, though not all reach high statistical significance.

Table 4. Subgroup Analysis

	Estimate	Standard Error	z	p
Intercept	0.20923	0.18796	1.11315	0.26565
Region (North America)	0.27391	0.18327	1.49453	0.13504
Region (South America)	-0.14232	0.28074	-0.50697	0.61218
Region (South Asia)	0.37002	0.27559	1.34262	0.17940
Region (Oceania)	0.01073	0.36504	0.02939	0.97655
Region (West Africa)	0.16828	0.42282	0.39799	0.69064
Region (Europe/West Asia)	0.11467	0.49365	0.23228	0.81632
Region (South Africa)	0.55610	0.48457	1.14763	0.25112
Region (East Asia)	-0.16840	0.31739	-0.53057	0.59572
Region (Southeast Asia)	-0.11152	0.36151	-0.30849	0.75771
Region (West Asia)	-0.61438	0.43642	-1.40777	0.15920
Intervention Duration Group (11-20 weeks)	0.06948	0.24081	0.28853	0.77294
Intervention Duration Group (≤10 weeks)	-0.15538	0.20676	-0.75151	0.45235
Intervention Duration Group (>30 weeks)	-0.10172	0.21583	-0.47127	0.63745
Method Group (Standardized Numeracy and Math Tests)	0.74089	0.18089	4.09586	< .001
Method Group (Early Education Numeracy Assessment)	0.31110	0.21023	1.47982	0.13892
Method Group (Classroom-Based or Academic Achievement Tests)	-0.18895	0.29798	-0.63410	0.52602

Note. **Wald test.**

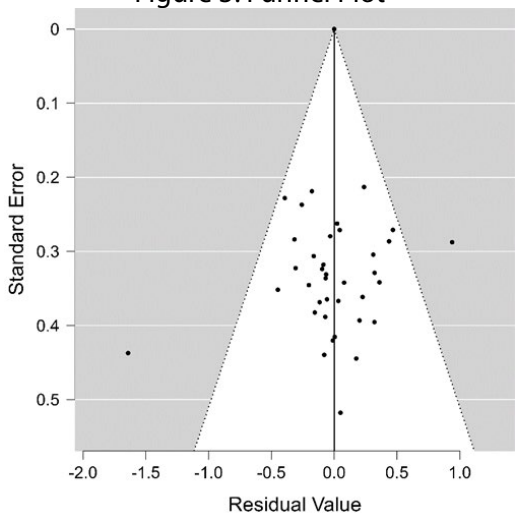
The North American region showed a positive coefficient of 0.27391 with a standard error of 0.18327, yielding a z-value of 1.49453 and a p-value of 0.13504. Although it did not reach conventional levels of significance ($p < 0.05$), this indicates that numeracy interventions in North America might have a greater impact compared to other regions. Conversely, regions such as South America and East Asia showed negative coefficients, -0.14232 and -0.16840 respectively, suggesting that numeracy interventions in these regions may be less effective or produce more variable results. South Asia and Southern Africa also showed relatively high positive coefficients (0.37002 and 0.55610), although the p-values indicated that these results are not statistically significant. This could be due to variations in the context of implementing numeracy interventions or insufficient sample sizes to detect more significant effects. These findings highlight the importance of considering local factors when designing and implementing numeracy interventions.

Furthermore, analysis based on the duration of interventions indicated that groups with shorter intervention durations (≤10 weeks) tended to have adverse effects (-0.15538), although this result was also not statistically significant. Conversely, groups with longer intervention durations (11-20 weeks and >30 weeks) showed lower coefficients, which were also insignificant. This might suggest that the duration of the intervention alone is insufficient to ensure the success of numeracy programs; instead, the quality and intensity of the interventions should also be considered. The measurement methods used in the analyzed studies also demonstrated variations in their impact. Groups that used standardized numeracy and mathematics tests showed a highly significant positive coefficient (0.74089, $p < 0.001$), indicating that this method is very effective in measuring the impact of numeracy interventions. Conversely, classroom-based or academic performance measurement methods showed a negative but non-significant coefficient (-0.18895), suggesting that classroom-based tests may not be as practical as standardized tests in accurately assessing numeracy skills.

Assessment of Publication Bias

A funnel plot was employed to detect potential publication bias in the meta-analysis to evaluate numeracy's impact on early childhood children's abilities. The funnel plot is a commonly used visual method in meta-analysis to assess whether the results of included studies have been selectively published based on their statistical significance.

Figure 3. Funnel Plot



In the resulting funnel plot, the distribution of data points appears relatively symmetrical around the vertical line representing the overall average effect. This symmetrical distribution indicates that the studies included in this meta-analysis do not show a pattern suggestive of publication bias. In this context, the absence of asymmetry means that results from both significant and non-significant studies are included in the analysis, reducing concerns about an unfair data representation.

The absence of publication bias strengthens the validity of the meta-analysis results. Given that publication bias can lead to an overestimation of the actual effect, its absence suggests that the estimated effect of numeracy on early childhood abilities is likely close to the exact condition in the broader population. Thus, the results of this meta-analysis can be considered representative and reliable for use in educational policy decisions and numeracy interventions for young children.

A File Drawer Analysis was also performed to further support the analysis of publication bias in this meta-analysis. This method measures the potential for publication bias by calculating the number of non-significant studies ("file drawer studies") required to nullify the significant effects found in the meta-analysis.

Table 4. File Drawer Analysis

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	7159.00000	0.05000	< .001

The results from the File Drawer Analysis, as indicated by the Fail-safe N value, show a number of 7,159. This figure represents the number of additional non-significant studies required to reduce the significance level of this meta-analysis to a non-significant level of 0.05. In other words, a substantial number of non-significant studies would be needed to invalidate the observed effects, further reinforcing confidence that the results of this meta-analysis are not the result of publication bias. Moreover, the target significance set in this analysis is 0.05, the common standard in scientific research. However, the observed significance in this meta-analysis is much lower, at <0.001. This indicates that the results are statistically significant, even considering potential publication bias.

By combining the results from the funnel plot, which does not indicate significant asymmetry, with the results of the File Drawer Analysis, which show that thousands of non-significant studies would be needed to negate the observed effects, it can be concluded that this meta-analysis has a low risk of publication bias. The findings related to the impact of numeracy on early childhood abilities can be considered valid and representative, supporting the reliability of the conclusions derived from this meta-analysis.

Discussion

The impact of numeracy on early childhood development has long intrigued educators and researchers alike. In this meta-analysis, we sought to unravel how early numeracy skills shape cognitive growth during these formative years, an area where previous research has often yielded mixed results (Charitaki et al., 2021). Despite the variations in methodologies and populations across studies, the consensus remains that numeracy plays a critical role in a child's overall development (Liu & Abdul Rahman, 2022). By employing a random effects model, we aimed to bridge the gaps in existing literature, offering a more nuanced understanding of how numeracy influences young minds across diverse contexts (Charitaki et al., 2021; Parr et al., 2019).

Our findings leave little doubt about the positive impact of numeracy on early childhood abilities. The overall effect size was statistically significant, reinforcing that developing numeracy skills early on can lead to substantial cognitive benefits (Manu et al., 2019; Zhang et al., 2019). However, the considerable heterogeneity, with an I^2 value of 91.32%, indicates that the effects of numeracy vary widely depending on the study context (Best et al., 2022; Peters et al., 2019). This variability suggests that while numeracy is beneficial, the extent of its impact may differ based on specific factors, such as geographic region, socio-economic conditions, and educational practices (Ellefson et al., 2020; Guhl, 2019). These insights underscore the need for a tailored approach when implementing numeracy programs (Charitaki et al., 2021).

Digging deeper into the data, we found that the effect of numeracy interventions was not uniform across different regions. For instance, studies conducted in North America reported higher effect sizes compared to those in other areas (Niklas & Tayler, 2018; Xu & Lefevre, 2018). This could be due to various factors, including differences in educational systems, cultural attitudes towards numeracy, or even the availability of resources (Gao et al., 2023; Ulferts et al., 2019). Similarly, longer interventions tended to produce more substantial improvements in

numeracy skills, suggesting that sustained efforts may be necessary to yield the best outcomes (Charitaki et al., 2021; Nelson et al., 2024). Yet, it's essential to remain cautious in interpreting these results, given the high variability.

Another interesting finding was the influence of the measurement tools used. Standardized numeracy tests appeared to be more effective in capturing interventions' true impact than classroom-based assessments (Neneng et al., 2023; Wright et al., 2020). This raises important questions about assessing numeracy in young children and whether our current tools are up to the task (Hellstrand et al., 2020; Thomas et al., 2023). It's clear that the choice of assessment method can significantly influence the results, pointing to the need for further refinement and standardization in this area (Liu & Abdul Rahman, 2022).

Compared with previous studies, our analysis reaffirms the critical role of numeracy in early childhood development but also highlights some important nuances (Chiu, 2018; Susperreguy et al., 2020). While earlier research sometimes downplayed the effects of home numeracy activities, our findings suggest that these activities can significantly impact—especially when robust measurement tools are employed (Charitaki et al., 2021; Trickett et al., 2022). Moreover, this analysis's strong relationship between numeracy and cognitive development aligns well with the broader literature, which underscores numeracy as a foundational skill (Niklas & Tayler, 2018). However, the high heterogeneity observed reminds us that this relationship is complex and influenced by various factors, including cultural and educational differences (Chan & Scalise, 2022; Silver et al., 2024).

The variation in effect sizes across different studies also shines a light on the multifaceted nature of numeracy's impact (Dardani et al., 2020; Rey-Guerra et al., 2024). Differences in study design—such as sample size, intervention duration, and the tools used to measure outcomes—contribute to the diverse results we see (Charitaki et al., 2023; Parr et al., 2019). These findings suggest that while numeracy generally promotes cognitive growth, the extent of its impact is context-dependent, shaped by the specific needs and circumstances of each population (Aurini & Davies, 2021; Zhang et al., 2019). This underscores the importance of designing numeracy interventions sensitive to local conditions and tailored to meet the unique needs of different communities (Nelson et al., 2024; Nisan & Kiziltepe, 2019).

The implications of our findings are far-reaching, particularly for policymakers and educators. The significant positive effect of numeracy on early childhood development suggests that investing in early numeracy programs could yield long-lasting benefits (Liu & Abdul Rahman, 2022). However, given the high variability in results, it is crucial to approach these programs with an understanding of the specific context in which they will be implemented (Ulferts et al., 2019; Wright et al., 2020). Policymakers should consider the unique needs of their populations and the available resources when designing these programs, ensuring they are both practical and sustainable (Niklas & Tayler, 2018; Parr et al., 2019). Future research should continue to explore these contextual factors to refine our understanding and enhance the effectiveness of early numeracy interventions (Charitaki et al., 2021; Xu & Lefevre, 2018).

This meta-analysis reinforces the importance of early numeracy as a cornerstone of cognitive development in young children (Charitaki et al., 2021). The significant impact of numeracy on early cognitive abilities emphasizes the need for well-designed interventions that can be adapted to various educational contexts (Liu & Abdul Rahman, 2022). However, the high level of heterogeneity observed suggests that these interventions should be tailored to fit the specific needs and circumstances of different populations (Parr et al., 2019; Susperreguy et al., 2020). By continuing to investigate the factors that influence the effectiveness of numeracy

programs, we can better inform educational practices and policies, ultimately supporting the cognitive development of children worldwide (Ulferts et al., 2019; Zhang et al., 2019).

Conclusion

This meta-analysis aimed to evaluate the impact of numeracy on early childhood abilities, analyzing 41 studies with diverse methodological approaches across various geographical regions. The findings demonstrate a significant positive effect of numeracy on early childhood development, highlighting the potential benefits of early numeracy interventions. However, the high heterogeneity observed among the studies suggests variability in results based on contextual factors such as region, sample size, and intervention duration. This underscores the need for tailored approaches in designing numeracy programs to ensure their effectiveness and sustainability. Despite the strong evidence, the study acknowledges limitations, including the potential for unexplained variability and publication bias, and recommends further research to explore these factors and enhance the effectiveness of early numeracy initiatives.

References

Aurini, J., & Davies, S. (2021). COVID-19 school closures and educational achievement gaps in Canada: Lessons from Ontario summer learning research. *Canadian Review of Sociology/Revue Canadienne de Sociologie*, *58*(2), 165–185. https://doi.org/10.1111/cars.12334

Bar, L., & Shaul, S. (2021). Early Numeracy and Literacy Skills Among Monolingual and Bilingual Kindergarten Children. *Frontiers in Psychology*, *12*. Scopus. https://doi.org/10.3389/fpsyg.2021.732569

Best, R., Carman, K. G., Parker, A. M., & Peters, E. (2022). Age declines in numeracy: An analysis of longitudinal data. *Psychology and Aging*, *37*(3), 298–306. https://doi.org/10.1037/pag0000657

Chan, J. Y.-C., & Scalise, N. R. (2022). Numeracy skills mediate the relation between executive function and mathematics achievement in early childhood. *Cognitive Development*, *62*. Scopus. https://doi.org/10.1016/j.cogdev.2022.101154

Charitaki, G., Alevriadou, A., & Soulis, S.-G. (2024). Early numeracy profiles in young children with intellectual disabilities: The role of cognitive functions. *Journal of Intellectual Disabilities*, *28*(1), 48–66. Scopus. https://doi.org/10.1177/17446295221117021

Charitaki, G., Soulis, S.-G., & Alevriadou, A. (2023). Early numeracy skills in children with intellectual disabilities between age groups 4–7 years: Developmental patterns and interrelationships. *International Journal of Developmental Disabilities*. Scopus. https://doi.org/10.1080/20473869.2023.2232555

Charitaki, G., Tzivinikou, S., Stefanou, G., & Soulis, S.-G. (2021). A meta-analytic synthesis of early numeracy interventions for low-performing young children. *SN Social Sciences*, *1*(5), 105. https://doi.org/10.1007/s43545-021-00094-w

Cheung, S. K., Chan, W. W. L., & Fong, R. W.-T. (2023). Parents' perfectionistic tendencies and children's early numeracy competence: The mediating roles of children's executive functions and numeracy interest. *European Journal of Psychology of Education*, *38*(3), 1185–1200. Scopus. https://doi.org/10.1007/s10212-022-00640-x

Chiu, M.-S. (2018). Effects of early numeracy activities on mathematics achievement and affect: Parental value and child gender conditions and socioeconomic status mediation. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(12). Scopus. https://doi.org/10.29333/ejmste/97191

Dardani, C., Howe, L. J., Mukhopadhyay, N., Stergiakouli, E., Wren, Y., Humphries, K., Davies, A., Ho, K., Weinberg, S. M., Marazita, M. L., Mangold, E., Ludwig, K. U., Relton, C. L., Davey Smith, G., Lewis, S. J., Sandy, J., Davies, N. M., & Sharp, G. C. (2020). Cleft lip/palate and educational attainment: Cause, consequence or correlation? A Mendelian randomization study. *International Journal of Epidemiology*, *49*(4), 1282–1293. Scopus. https://doi.org/10.1093/ije/dyaa047

Ellefson, M. R., Zachariou, A., Ng, F. F.-Y., Wang, Q., & Hughes, C. (2020). *Do executive functions mediate the link between socioeconomic status and numeracy skills? A cross-site comparison of Hong Kong and the United Kingdom.* https://doi.org/10.17863/CAM.45172

Elliott, L., Votruba-Drzal, E., Miller, P., Libertus, M. E., & Bachman, H. J. (2023). Unpacking the home numeracy environment: Examining dimensions of number activities in early childhood. *Early Childhood Research Quarterly*, *62*, 129–138. Scopus. https://doi.org/10.1016/j.ecresq.2022.08.002

Elliott, L., Zheng, P., & Libertus, M. (2021). Individual differences in parental support for numeracy and literacy in early childhood. *Education Sciences*, *11*(9). Scopus. https://doi.org/10.3390/educsci11090541

Ellis, A., Susperreguy, M. I., Purpura, D. J., & Davis-Kean, P. E. (2021). Conceptual replication and extension of the relation between the number line estimation task and mathematical competence across seven studies. *Journal of Numerical Cognition*, *7*(3), 435–452. Scopus. https://doi.org/10.5964/jnc.7033

Gao, C. X., Broder, J. C., Brilleman, S., Campbell, T. C. H., Berger, E., Ikin, J., Smith, C. L., Wolfe, R., Johnston, F., Guo, Y., & Carroll, M. (2023). Evaluating the impact of the Hazelwood mine fire event on students' educational development with Bayesian interrupted time-series hierarchical meta-regression. *PLoS ONE*, *18*(3 March). Scopus. https://doi.org/10.1371/journal.pone.0281655

Gilligan-Lee, K. A., Fink, E., Jerrom, L., Davies, M. P., Dempsey, C., Hughes, C., & Farran, E. K. (2023). Building Numeracy Skills: Associations between DUPLO® Block Construction and Numeracy in Early Childhood. *Journal of Intelligence*, *11*(8). Scopus. https://doi.org/10.3390/jintelligence11080161

Guhl, P. (2019). *The Impact of Early Math and Numeracy Skills on Academic Achievement in Elementary School*. https://www.semanticscholar.org/paper/The-Impact-of-Early-Math-and-Numeracy-Skills-on-in-Guhl/8fb60b45018e795d8de27b6acc8e076f74204563?utm_source=consensus

Hellstrand, H., Korhonen, J., Räsänen, P., Linnanmäki, K., & Aunio, P. (2020). Reliability and validity evidence of the early numeracy test for identifying children at risk for mathematical learning difficulties. *International Journal of Educational Research*, *102*. Scopus. https://doi.org/10.1016/j.ijer.2020.101580

Hossain, M. I., Haq, I., Hossain, M. S., Habib, M. J., Islam, F. B., Roy, S., & Rahman, M. (2023). Factors associated with early literacy and numeracy development among children under five years in Bangladesh: Multivariate two-level mixed effect approach. *International Journal of Social Economics*, *50*(3), 345–358. Scopus. https://doi.org/10.1108/IJSE-10-2021-0595

Hudson, K. N., Ballou, H. M., & Willoughby, M. T. (2021). Short report: Improving motor competence skills in early childhood benefits executive function and numeracy skills. *Developmental Science*, *24*(4), e13071. https://doi.org/10.1111/desc.13071

Lim, I. E., Mahmud, I., Chowdhury, M. U., Kaiser, A., Bonny, F. A., Akanbonga, S., & Hasan, M. T. (2023). Early Childhood Development (ECD) in Ghana: Assessing the Status and Determinants of the Literacy–Numeracy, Physical, Social–Emotional, and Learning

Domains. *International Journal of Early Childhood*. Scopus. https://doi.org/10.1007/s13158-023-00349-y

Liu, C., & Abdul Rahman, M. N. (2022). Evidence of Using of ICTs on Mathematics Achievement for Preschool Children: A Meta-analysis. *ACM Int. Conf. Proc. Ser.*, 373–379. Scopus. https://doi.org/10.1145/3551708.3551754

Luomaniemi, K., Mattinen, A., McMullen, J., Sorariutta, A., & Hannula-Sormunen, M. (2021). The Effects of a SFON-Based Early Numeracy Program on Multilingual Children's Early Numeracy and Oral Language Skills. *Journal of Cognitive Education and Psychology*, *20*(2), 138–160. Scopus. https://doi.org/10.1891/JCEP-D-20-00006

Lynch, K., Lee, M., & Loeb, S. (2023). An investigation of Head Start preschool children's executive function, early literacy, and numeracy learning in the midst of the COVID-19 pandemic. *Early Childhood Research Quarterly*, *64*, 255–265. Scopus. https://doi.org/10.1016/j.ecresq.2023.04.002

Manu, A., Ewerling, F., Barros, A. J. D., & Victora, C. G. (2019). Association between availability of children's book and the literacy-numeracy skills of children aged 36 to 59 months: Secondary analysis of the UNICEF Multiple-Indicator Cluster Surveys covering 35 countries. *Journal of Global Health*, *9*(1). Scopus. https://doi.org/10.7189/jogh.09.010403

McLeod, S., Harrison, L. J., & Wang, C. (2019). A longitudinal population study of literacy and numeracy outcomes for children identified with speech, language, and communication needs in early childhood. *Early Childhood Research Quarterly*, *47*, 507–517. Scopus. https://doi.org/10.1016/j.ecresq.2018.07.004

Merkley, R., Sernoskie, E., Cook, C. J., Howard, S. J., Makaula, H., Mshudulu, M., Tshetu, N., Draper, C. E., & Scerif, G. (2023). "We Don't Have Things for Counting": An Exploration of Early Numeracy Skills and Home Learning Experiences of Children Growing up in Poverty in South Africa. *Journal of Numerical Cognition*, *9*(2), 268–284. Scopus. https://doi.org/10.5964/jnc.8061

Mills, R., McCusker, C. G., Tennyson, C., & Hanna, D. (2018). Neuropsychological outcomes in CHD beyond childhood: A meta-analysis. *Cardiology in the Young*, *28*(3), 421–431. https://doi.org/10.1017/S104795111700230X

Nelson, G., Carter, H., Boedeker, P., Knowles, E., Buckmiller, C., & Eames, J. (2024). A Meta-Analysis and Quality Review of Mathematics Interventions Conducted in Informal Learning Environments with Caregivers and Children. *Review of Educational Research*, *94*(1), 112–152. https://doi.org/10.3102/00346543231156182

Neneng, T., Diana, S., & Tias, M. (2023). Teacher Information Literacy for Inclusive Early Childhood Education (ECE) to Provide Literacy and Numeracy for Special Needs Children in Central Java-Indonesia. *International Journal of Learning, Teaching and Educational Research*, *22*(12), 262–278. Scopus. https://doi.org/10.26803/ijlter.22.12.13

Niklas, F., & Tayler, C. (2018). Room quality and composition matters: Children's verbal and numeracy abilities in Australian early childhood settings. *Learning and Instruction*, *54*, 114–124. Scopus. https://doi.org/10.1016/j.learninstruc.2017.08.006

Nisan, M., & Kiziltepe, G. I. (2019). The effect of early numeracy program on the development of number concept in children at 48-60 months of age. *Universal Journal of Educational Research*, *7*(4), 1074–1083. Scopus. https://doi.org/10.13189/ujer.2019.070419

Parr, N. J., Schweer-Collins, M. L., Darlington, T. M., & Tanner-Smith, E. E. (2019). Meta-analytic approaches for examining complexity and heterogeneity in studies of adolescent development. *Journal of Adolescence*, *77*(1), 168–178. https://doi.org/10.1016/j.adolescence.2019.10.009

Peters, E., Tompkins, M. K., Knoll, M. A. Z., Ardoin, S. P., Shoots-Reinhard, B., & Meara, A. S. (2019). Despite high objective numeracy, lower numeric confidence relates to worse financial

and medical outcomes. *Proceedings of the National Academy of Sciences*, *116*(39), 19386–19391. https://doi.org/10.1073/pnas.1903126116

Rey-Guerra, C., Yousafzai, A. K., & Dearing, E. (2024). Gender similarities and differences in early childhood development in low- and middle-income countries. *International Journal of Behavioral Development*, *48*(3), 279–289. Scopus. https://doi.org/10.1177/01650254231217465

Scalise, N. R., Depascale, M., Tavassolie, N., McCown, C., & Ramani, G. B. (2022). Deal Me in: Playing Cards in the Home to Learn Math. *Education Sciences*, *12*(3). Scopus. https://doi.org/10.3390/educsci12030190

Sepúlveda, F., Rodríguez, C., & Peake, C. (2020). Differences and Associations in Symbolic and Non-Symbolic Early Numeracy Competencies of Chilean Kinder Grade Children, considering Socioeconomic Status of Schools. *Early Education and Development*, *31*(1), 137–151. Scopus. https://doi.org/10.1080/10409289.2019.1609819

Shvartsman, M., & Shaul, S. (2024). Working Memory Profiles and Their Impact on Early Literacy and Numeracy Skills in Kindergarten Children. *Child and Youth Care Forum*. Scopus. https://doi.org/10.1007/s10566-023-09788-z

Silver, A. M., Alvarez-Vargas, D., Bailey, D. H., & Libertus, M. E. (2024). Assessing the association between parents' math talk and children's math performance: A preregistered meta-analysis. *Journal of Experimental Child Psychology*, *243*. Scopus. https://doi.org/10.1016/j.jecp.2024.105920

Susperreguy, M. I., Di Lonardo Burr, S., Xu, C., Douglas, H., & LeFevre, J.-A. (2020). Children's Home Numeracy Environment Predicts Growth of their Early Mathematical Skills in Kindergarten. *Child Development*, *91*(5), 1663–1680. Scopus. https://doi.org/10.1111/cdev.13353

Thomas, A., Tazouti, Y., Hoareau, L., Luxembourger, C., Hubert, B., & Jarlégan, A. (2023). Early Numeracy Assessment In French preschool: Structural analysis and links with children's characteristics. *International Journal of Early Years Education*, *31*(4), 1018–1035. Scopus. https://doi.org/10.1080/09669760.2021.1938518

Trickett, J., Batchelor, S., Brittle, B., Foulkes, M., Pickering, J., Slocombe, F., & Gilmore, C. (2022). The role of parent-led and child-led home numeracy activities in early mathematical skills. *Cognitive Development*, *63*. Scopus. https://doi.org/10.1016/j.cogdev.2022.101189

Ulferts, H., Wolf, K. M., & Anders, Y. (2019). Impact of Process Quality in Early Childhood Education and Care on Academic Outcomes: Longitudinal Meta-Analysis. *Child Development*, *90*(5), 1474–1489. https://doi.org/10.1111/cdev.13296

Vetter, M., Orr, R., O'Dwyer, N., & O'Connor, H. (2020). Effectiveness of Active Learning that Combines Physical Activity and Math in Schoolchildren: A Systematic Review. *Journal of School Health*, *90*(4), 306–318. https://doi.org/10.1111/josh.12878

Wei, W., Wang, Q.-Y., Luo, Q., & Li, Y. (2022). Cross-lagged relationship between home numeracy practices and early mathematical skills among Chinese young children. *Frontiers in Psychology*, *13*. Scopus. https://doi.org/10.3389/fpsyg.2022.1033065

Wright, J. C., Lemons, C. J., Knight, V. F., Lindström, E., & Strauss, J. (2020). Enhancing early numeracy skills of children with severe disabilities and complex communication needs. *Education and Training in Autism and Developmental Disabilities*, *55*(3), 277–289. Scopus.

Xu, C., & Lefevre, J.-A. (2018). Cross-cultural comparisons of young children's early numeracy performance: Effects of an explicit midpoint on number line performance for canadian and chinese-canadian children. *Bordon, Revista de Pedagogia*, *70*(3), 131–146. Scopus. https://doi.org/10.13042/Bordon.2018.60966

Zahra, F., Haberland, N., & Psaki, S. (2022). PROTOCOL: Causal mechanisms linking education with fertility, HIV, and child mortality: A systematic review. *Campbell Systematic Reviews*, *18*(2). Scopus. https://doi.org/10.1002/cl2.1250

Zhang, H., Wee, C.-Y., Poh, J. S., Wang, Q., Shek, L. P., Chong, Y.-S., Fortier, M. V., Meaney, M. J., Broekman, B. F. P., & Qiu, A. (2019). Fronto-parietal numerical networks in relation with early numeracy in young children. *Brain Structure and Function*, *224*(1), 263–275. Scopus. https://doi.org/10.1007/s00429-018-1774-2