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MODESTUM

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The effect of learning media on students' early numeracy skills: Meta-analysis

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ABSTRACT

This study presents a comprehensive meta-analysis of 83 research studies examining the impact of learning media on early numeracy skills development. The findings reveal a significant positive influence of educational media on students' early mathematical abilities, with notable variations across different contexts. Computer-based instruction emerged as particularly effective compared to tablet-based and traditional approaches. Geographical differences were observed, with interventions in North America and Europe demonstrating higher efficacy. Interestingly, neither the duration of media use nor the distinction between game-based and non-game-based formats showed significant differences in outcomes. These results highlight the importance of content quality and regional considerations in implementing educational media for early numeracy instruction. The study provides valuable insights for educators, policymakers, and researchers, emphasizing the need for context-sensitive approaches in educational technology deployment. Furthermore, it underscores the potential of computer-based learning in enhancing early mathematical skills, while challenging assumptions about the importance of intervention duration and game-based form.

Keywords: learning media, early numeracy skills, meta-analysis

INTRODUCTION

Early numeracy skills are skills that a child has before entering primary school. It relates to the use of basic mathematical concepts such as recognising numbers, relationships and arithmetic. (Purpura & Lonigan, 2015; Purpura & Napoli, 2015). Several studies have shown that students' early numeracy skills contribute significantly to the achievement and success of learning mathematics in school, especially in numeracy skills (Chang, 2023; Dunst et al., 2017; Lopez-Pedersen et al., 2023; Zhu & Chiu, 2019). Early numeracy skills can be improved through the intervention process in the form of treatments provided by teachers, such as the selection of learning processes and the selection of learning media.

The current body of research indicates that different types of learning media-Computer-Assisted Instruction (CAI), tablets, and traditional methods (neither CAI nor tablets)-play a pivotal role in the development of early numeracy skills. CAI has been shown to enhance cognitive skills by providing individualized instruction and adaptive feedback, allowing students to progress at their own pace (Escueta et al., 2017; Lysenko et al., 2020; Mera et al., 2019; Praet & Desoete, 2014; Rogowsky et al., 2018; Stubbé et al., 2016). Similarly, tablets have demonstrated exceptional promise in fostering engagement and improving mathematical reasoning through interactive, touchscreen-based interfaces that encourage active learning (Disney et al., 2019; Hubber et al., 2016; Lee & Choi, 2020; Papadakis et al., 2018; Schacter et al., 2016). On the other hand, traditional methods-neither CAI nor tablets-continue to play an essential role in environments where technology access is limited or where hands-on learning is emphasized (Borzekowski et al., 2019; Cheung & McBride, 2017; Hassinger-Das et al., 2015). However, the effectiveness of these types of media varies depending on how they are integrated into the learning process and the level of interaction they provide.

The duration of learning media interventions plays a critical role in determining their effectiveness in early numeracy. Short-term interventions, typically lasting less than 10 weeks, have shown immediate benefits, such as increased student engagement and motivation. For instance, studies indicate that brief, focused media interventions can significantly boost math performance, even in limited time frames (Berkowitz et al., 2015). On the other hand, long-term interventions, spanning several months or more, tend to produce deeper conceptual understanding and greater retention of mathematical skills. These long-term engagements allow for sustained practice and reinforcement, crucial for solidifying early numeracy foundations (Dietrichson et al., 2021; Lafay et al., 2019). However, few studies have comprehensively compared the effectiveness of short-term versus long-term use of learning media across different educational settings, leaving a gap in our understanding of how intervention duration shapes numeracy outcomes.

The form of learning media-whether game-based or non-game-based-also significantly influences its impact on early numeracy. Game-based learning media have shown great potential in enhancing student engagement and improving mathematical problem-solving abilities by offering interactive elements, immediate feedback, and adaptive challenges that cater to the learner's skill level (Clark et al., 2016; Pradja, 2023). These tools are effective in motivating young children and fostering deeper cognitive engagement (Plass et al., 2020). However, game-based learning is not without challenges, such as potential distractions and higher development costs (Chen et al., 2020). In contrast, non-game-based media such as digital worksheets, instructional videos, and simulations are more structured, focusing directly on achieving learning objectives. These non-game-based tools have been shown to be effective in conveying factual knowledge and developing critical thinking skills, particularly when implemented in traditional educational settings (Clark et al., 2016). Despite being less interactive, non-game-based media offer efficiency and adaptability across various learning styles, although they may be less engaging for younger learners compared to game-based formats (Talan et al., 2020).

Another important yet underexplored dimension is the geographic and cultural context of learning media interventions. Studies show that the effectiveness of learning media can vary across continents due to differences in educational systems, access to technology, and cultural attitudes toward learning. For example, in America, technology-integrated math lessons, including active learning strategies, have demonstrated substantial improvements in student performance (Berg et al., 2019; Hassinger-Das et al., 2015; Rogowsky et al., 2018). In Asia, the growing use of social media platforms and mobile applications as educational tools has been particularly beneficial for ethnic minority students, enhancing motivation and engagement in mathematics (Andika et al., 2019; Cheung & McBride, 2017; Hu et al., 2023; Pradana et al., 2020; Yaniawati et al., 2023). Similarly, in Europe, research highlights the critical role of teacher preparedness and confidence in successfully integrating digital learning media into the classroom (Maertens et al., 2016; Mera et al., 2019; Papadakis et al., 2018; Praet & Desoete, 2014; Schaeffer et al., 2021; Sella et al., 2016). Meanwhile, in Africa, game-based learning media have proven highly effective in resource-limited settings, increasing student engagement and understanding of mathematical concepts (Borzekowski et al., 2019; Lee & Choi, 2020; Lysenko et al., 2020; Pitchford, 2015; Stubbé et al., 2016). In Australia, culturally relevant media interventions have focused on addressing gender and cultural disparities, particularly among Indigenous populations, with significant improvements in student confidence and performance in numeracy (Cohrssen & Niklas, 2019; Disney et al., 2019; Han, 2019; Nand et al., 2019). Despite these regional insights, no comprehensive analysis has yet examined the differential impact of learning media across these diverse geographic contexts.

Although substantial progress has been made in understanding the impact of learning media on early numeracy, several critical gaps remain unaddressed in current literature. First, there is a lack of comprehensive research comparing the effectiveness of different types of learning media-CAI, tablets, and traditional methods-across game-based and non-game-based formats. Additionally, the relationship between the duration of media use and its effectiveness in fostering early numeracy development remains underexplored, particularly in diverse educational contexts. Understanding these dynamics is essential for developing strategies that optimize the use of learning media to enhance early numeracy outcomes globally.

Several studies that have relevant topics of study but produce different findings provide space for meta-analysis research designs to examine more deeply the differences that exist. Meta-analysis is a study that emphasises the use of quantitative research data by analysing effect size and standard error data from several studies that have relevant study topics for a comprehensive analysis process so as to draw in-depth conclusions based on the strength of the effect, correlation, and relationship between variables (Cooper et al., 2019; Harrer et al., 2021; Vishwanathan et al., 2020). In this study, calculating the average effect size, homogeneity test and publication bias test. In addition, this study also investigated the homogeneity of the moderator variables (Card, 2015; Suurmond et al., 2017).

This meta-analysis aims to address these gaps by investigating the effect of learning media on early numeracy, focusing on key subgroup variables: type of media (CAI, tablet, and neither), duration of use (short-term vs. long-term), form of media (game-based vs. non-game-based), and geographic context (continent). By synthesizing findings from a wide range of studies, this research will provide a nuanced understanding of how these variables influence early numeracy outcomes across different educational settings and cultural contexts.

The contribution of this research lies in its comprehensive and global approach. By integrating multiple subgroup variables into a single meta-analysis, this study will offer new insights into the intersection of media type, form, duration, and geographic context (continent) in shaping early numeracy development. The inclusion of continent as a variable introduces a unique cultural and geographical dimension, providing a global perspective on the effectiveness of learning media. The findings from this study will not only bridge existing gaps in the literature but also provide actionable recommendations for optimizing the use of learning media in early childhood education. This meta-analysis is expected to contribute significantly to the design of more effective learning strategies, ensuring that children worldwide receive the support they need to develop strong foundational numeracy skills.

MATERIALS AND METHODOLOGY

Literature Search

The research process (**Figure 1**) employed the Systematic Literature Review (SLR) method using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the systematic collection, screening, and evaluation of relevant studies. This detailed and structured approach ensures transparency and rigor, leading to a focused and reliable selection of studies. Below is a comprehensive breakdown of each step involved in the SLR process, including identification, screening, eligibility, and inclusion stages.

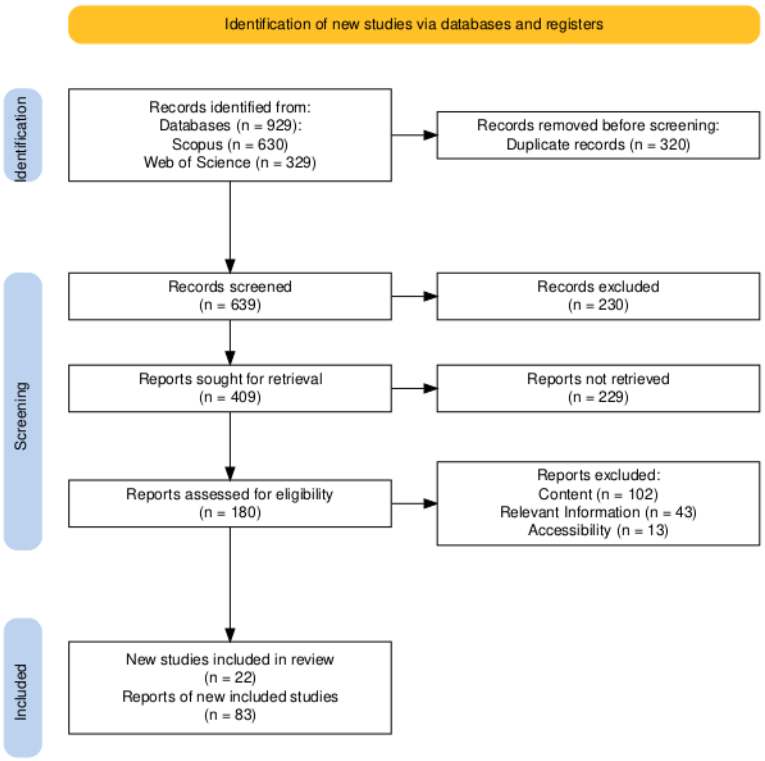

Figure 1. SLR Process (Source: Authors' own elaboration, using https://estech.shinyapps.io/prisma_flowdiagram/)

Identification

The first stage of the SLR process, identification, involves gathering all potentially relevant studies from reliable sources. For this research, the databases Scopus and Web of Science were chosen due to their extensive coverage of high-impact, peer-reviewed journals. A total of 929 records were initially identified, with 630 records sourced from Scopus and 329 records from Web of Science. To narrow the focus of the search, specific keywords were applied, including "early numeracy" AND "instructional media" OR "learning media". These keywords were selected to ensure that the studies retrieved were directly related to the research focus, which aims to explore instructional and learning media related to early numeracy development. The use of targeted keywords was essential in maximizing the relevance of the search results and minimizing irrelevant records. After collecting these records, a de-duplication process was undertaken. This step is crucial because many studies are indexed in multiple databases, leading to duplicate entries. A total of 320 duplicate records were identified and removed, resulting in 639 unique records. These records were then forwarded to the next stage for more detailed scrutiny and assessment.

Screening

Once the unique records were identified, the screening phase commenced. During this step, the 639 records were preliminarily evaluated based on predefined criteria to ensure they were relevant and accessible for further review. Two primary screening criteria were used: publication years and language.

Publication Years: To ensure that only recent and relevant research was included, only studies published within the last decade, between 2014 and 2023, were considered. This time frame was chosen to ensure that the studies reflect the most current developments and trends in the field of instructional and learning media for early numeracy.

English Language: Only studies published in English were considered for inclusion. This language requirement was imposed to ensure that the research team could accurately assess the study's content, methodology, and findings without translation barriers, which could introduce inaccuracies or misinterpretations.

As a result of the screening process, 230 records were excluded, primarily due to falling outside the specified publication years or being published in languages other than English. This left 409 reports that met the initial screening criteria and were then forwarded for retrieval. During the retrieval process, 229 reports could not be accessed. These studies may have been inaccessible due to paywalls, institutional access restrictions, or the unavailability of full-text versions. Consequently, only 180 reports were successfully retrieved for further evaluation in the next stage.

Eligibility

The eligibility stage involved a more in-depth assessment of the 180 reports that successfully passed the screening stage. This step is critical as it ensures that only the most relevant, high-quality studies are included in the final review. The eligibility evaluation was based on three specific criteria: content relevance, accessibility, and completeness of information.

Content Relevance: Studies were closely examined to determine whether their focus aligned with the specific research objectives of the review. Only studies that provided empirical data on early numeracy development using instructional media or

learning media were retained. Studies that focused on unrelated topics or did not address instructional media in the context of early numeracy were excluded. A total of 102 reports were excluded based on content relevance.

Accessibility: While many reports were retrieved in full, some were excluded because access to critical sections of the report, such as results or methodologies, was restricted. Studies that provided only abstracts or summaries without full access to the methodology, data, or analysis were excluded to avoid incomplete interpretations. This led to the exclusion of 13 reports.

Completeness of Information: Studies were required to provide sufficient detail in their methodology, data presentation, and analysis. Only studies that provided quantitative data, specifically those comparing experimental class and control class scores, were included. Moreover, studies had to report either effect size data or provide statistical values such as t-test or F-test results. This level of detail was necessary to perform a meaningful analysis and comparison. Studies that did not meet this requirement were excluded. 43 reports were removed due to incomplete information.

At the conclusion of the eligibility phase, 158 reports were excluded due to content, accessibility, or lack of detailed information, leaving 22 studies that met all the criteria for inclusion.

Inclusion

The final stage of the SLR process is inclusion, where the selected studies are confirmed for their relevance, quality, and contribution to the research. The 22 studies that passed the eligibility stage were thoroughly reviewed and incorporated into the systematic literature review. These studies were considered high-quality, as they met all the criteria set out in the previous phases. Furthermore, through an in-depth analysis of these 22 studies, an additional 83 studies were identified and included. These studies were either cited by or related to the original set of 22 studies, and they provided further data that was valuable to the research. The additional studies helped to broaden the scope of the review and enriched the overall analysis. The following outlines the Systematic Literature Review (SLR) process utilized in this research.

Coding and Determination of Moderator Variables

Researchers conducted coding based on established inclusion criteria and identified quantitative data and moderator variables for analysis. The study categorized moderator variables according to the characteristics of the selected research results. These categories encompassed four key aspects: media type, duration, form of media, and continent. Media types were classified as computer-assisted instruction, tablet-based, or neither, with digital media referring to electronically assisted tools and non-digital media encompassing learning materials not requiring electronic devices. Duration was bifurcated into two groups: media used for less than or equal to 10 weeks, and media used for more than 10 weeks, based on the weekly usage by teachers. The form of media was categorized as either game-based or non-game media, with game-based media incorporating game elements in the learning process, while non-game media did not involve such elements. Finally, the geographical context was considered by categorizing the use of learning media across five continents: America, Asia, Africa, Europe, and Australia. This comprehensive categorization of moderator variables allowed for a nuanced analysis of the factors influencing the effectiveness of learning media in various contexts.

Table 1 presents the research data used in this study, based on the Systematic Literature Review (SLR) process and the moderator variables employed.

Table 1. Analysis of article review

No	Studies	N	SE	ES	Type	Period	Form	Continent	Scopus
1	Rogowsky et al. (2018)	47	0.15	0.862	CAI	>10	Non game	America	Q1
2			0.151	1.133					
3	Borzekowski et al. (2019)	595	0.25	0.3	Neither	>10	Non game	Africa	Q1
4			0.84	0.52					
5			0.88	0.4					
6	Miller (2018)	13	0.316	0.136	Tablet	≤10	Game	America	Q1
7	Pitchford (2015)	283	0.15	0.916	Tablet	≤10	Non game	Africa	Q1
8			0.18	0.894					
9	Andika et al. (2019)	36	0.174	0.567	Neither	≤10	Game	Asia	Q4
10	Sella et al. (2016)	45	0.86	0.33	CAI	>10	Game	Europe	Q1
11	Lee and Choi (2020)	61	0.131	0.58	Tablet	>10	Game	Africa	Q1
12			0.131	0.78					
13			0.131	0.75					
14	Hubber et al. (2016)	61	0.44	0.76	Tablet	≤10	Non game	Africa	Q1
15			0.65	1.07					
16	Schacter et al. (2016)	227	1.82	1.09	Tablet	≤10	Game	America	Q1
17	Praet and Desoete (2014)	132	0.674	1.29	CAI	≤10	Game	Europe	Q1
18			0.695	0.68					
19			1.07	0.64					
20			1.1	0.59					
21			1.2	0.71					
22	Stubbé et al. (2016)	88	2.43	1.17	CAI	≤10	Game	Africa	Q3
23	Lysenko et al. (2020)	283	0.209	0.234	CAI	>10	Game	Africa	Q3
24			0.277	0.069					
25			0.188	0.769					
26			0.569	0.373					
27	Pradana et al. (2020)	83	1.169	0.772	CAI	≤10	Non game	Asia	Q1

Note: N: Sample; SE: Standard Error; ES: Effect Size

Table 1 (Continued). Analysis of article review

No	Studies	N	SE	ES	Type	Period	Form	Continent	Scopus
28			0.113	0.19					
29			0.112	0.16					
30	Disney et al. (2019)	80	0.114	0.31	Tablet	>10	Game	Australia	Q1
31			0.116	0.38					
32			0.133	0.92					
33	Yaniawati et al. (2023)	36	0.281	1.92	Neither	≤10	Non game	Asia	Q3
34			0.92	2.23					
35			0.98	2.29					
36			1.29	1					
37			1.26	0.55					
38			0.98	1.03					
39			0.93	0.53					
40	Hassinger-Das et al. (2015)	124	0.59	1	Neither	≤10	Game	America	Q2
41			0.57	0.58					
42			0.35	1.3					
43			0.13	0.2					
44			0.63	1.07					
45			0.61	1.19					
46			0.53	1.6					
47			0.64	2.01					
48	Nand et al. (2019)	120	0.185	0.47	CAI	≤10	Game	Australia	Q1
49			0.129	0.08					
50	Papadakis et al. (2018)	365	0.132	0.3	Tablet	>10	Game	Europe	Q1
51			0.126	0.34					
52			0.22	0.35					
53			0.22	0.17					
54			0.23	0.51					
55	Maertens et al. (2016)	88	0.22	0.29	Tablet	<10	Game	Europe	Q1
56			0.25	1.33					
57			0.25	1.2					
58			0.22	-0.04					
59			0.22	0.15					
60			0.278	0.02					
61			0.278	0.15					
62			0.282	0.38					
63	Cohrssen and Niklas (2019)	60	0.279	0.21	Neither	≤10	Game	Australia	Q2
64			0.29	0.65					
65			0.284	0.47					
66			0.279	0.22					
67			0.28	0.29					
68		17	0.25	0.62			Game		
69		18	0.24	0.39			Game		
70		16	0.25	0.1			Non game		
71		20	0.23	0.47			Game		
72		21	0.22	0.28			Game		
73	Cheung and McBride (2017)	18	0.24	0.34	Neither	≤10	Non game	Asia	Q1
74		20	0.23	0.35			Game		
75		22	0.22	0.33			Game		
76		20	0.23	0.42			Non game		
77		22	0.23	0.68			Game		
78		19	0.24	0.62			Game		
79		19	0.23	0.35			Non game		
80		35	0.42	3.48					
81	Mera et al (2019)	35	0.28	1.65	CAI	≤10	Game	Europe	Q1
82		15	0.47	2.02					
83		15	0.43	1.63					

Note: N: Sample; SE: Standard Error; ES: Effect Size

Table 2. The Cohen's classification of effect size

Effect size	Interpretation
$ES \leq 0.20$	Weak
$0.20 < ES \leq 0.50$	Moderate
$0.50 < ES \leq 1.00$	Strong
$ES > 1.00$	Very Strong

Statistical Analysis

In this meta-analysis study, each effect size was calculated using the Hedges-g formula (Brydges, 2019; Cooper et al., 2019). assisted by the JASP 0.19.1 application. A random-effects model was used to analyse the pooled combined effect of all studies. The selection of the random effects model assumes that the effect sizes used are from different analysed studies and come from different populations, where these populations have a sampling distribution (Cooper et al., 2019). **Table 2** is the interpretation of the effect size results classified into several interpretations.

The heterogeneity test was conducted by examining the Q statistic and p value to see the effect size variance between studies. There is no difference in effect size variance between studies which fulfils the null hypothesis (Ho) in the heterogeneity test. Whereas there is a difference in variance of effect size between studies between studies is the alternative hypothesis (Ha). If the results reject Ho, this indicates that the variance of the effect size of all the studies analysed is heterogeneous, so there is potential to analyse moderator variables to reveal the effect of heterogeneity on the effect of learning media on students' early numeracy skills. The analysis of moderator variables was conducted with JASP and Microsoft Excel with the following steps:

(1) Examining the mean effect size and Q statistic or variance of each category on moderator variables

(2) Calculating the variability of the within-group effect (Qw) by summing the variances

(3) Calculating the variability of the medium (Qb) by subtracting Q from Qw

(4) Calculating the chi-square distribution or p-value of the chi-square distribution or p-value by using the formula "=CHIDIST (Qb; df)." If $p < 0.05$, then the average effect size of each category in the moderator variable is significantly different so that the moderator variable moderator variable affects the effectiveness of learning media on students' early numeracy skills.

Publication bias analysis was conducted to examine how robust the results of the meta-analysis so that misrepresentation of the findings in the primary study can be prevented (Cooper et al., 2019). This meta-analysis study analyses publication bias using Funnel plot and Egger's test. The Funnel plot represents the distribution of the effect size for each main study, whether it is symmetrically distributed around the vertical line or not. If the distribution is symmetrical, then this meta-analysis study does not suffer from publication bias (Harrer et al., 2021). But if the Funnel plot is difficult to interpret symmetrically, then the Egger test is used to test whether the effect size distribution is symmetrical or not. In the Egger test, if the p-value > 0.05, then the effect size distribution on the Funnel plot is symmetrical, so it can be concluded that there is no publication bias in this research meta-analysis study. In addition, Fail-Safe N is also used to estimate the number of studies with insignificant results (unpublished data) needed, so that the average effect size becomes statistically insignificant. A metaanalysis does not suffer from publication bias if the fail-safe N result is more than 5k + 10, where k is the number of studies.

DISCUSSION

The effect size of the 83 meta-analysis studies conducted showed the interval [-0.04, 4.21] by showing the diversity of the influence of the use of learning media on students' early numeracy skills. The positive effect is based on the use of learning media that makes it easier for students to explore their early numeracy skills so that learning resources are more varied and innovative. Meanwhile, other studies show that there is a low effect size value (Miller, 2018) which shows an average of -0.04 with the interval [-0.47, 0.39], this indicates that not all learning media used can support the improvement of students' early numeracy skills. This is based on the incompatibility of learning media with student interest and attention. The following is a Forest Plot (**Figure 2**) of the results of the meta-analysis that has been carried out.

Figure 2 shows that the use of learning media has a positive effect on students' early numeracy skills. This is based on the effect size of this study of (gRE = 0.62; 95% CI [0.50, 0.73]; $p < 0.001$). So that the summary effect size is 0.62 and when converted to the Cohen classification table shows strong influence. Thus, it can be stated that the use of learning media has a strong effect on students' early numeracy skills. This is in line with several previous studies which state that the use of learning media contributes strongly to students' early numeracy skills (Lee & Choi, 2020; Pitchford, 2015; Rogowsky et al., 2018). However, the selection of media must accommodate the needs and interests of students in the media used (Bolkan & Griffin, 2018).

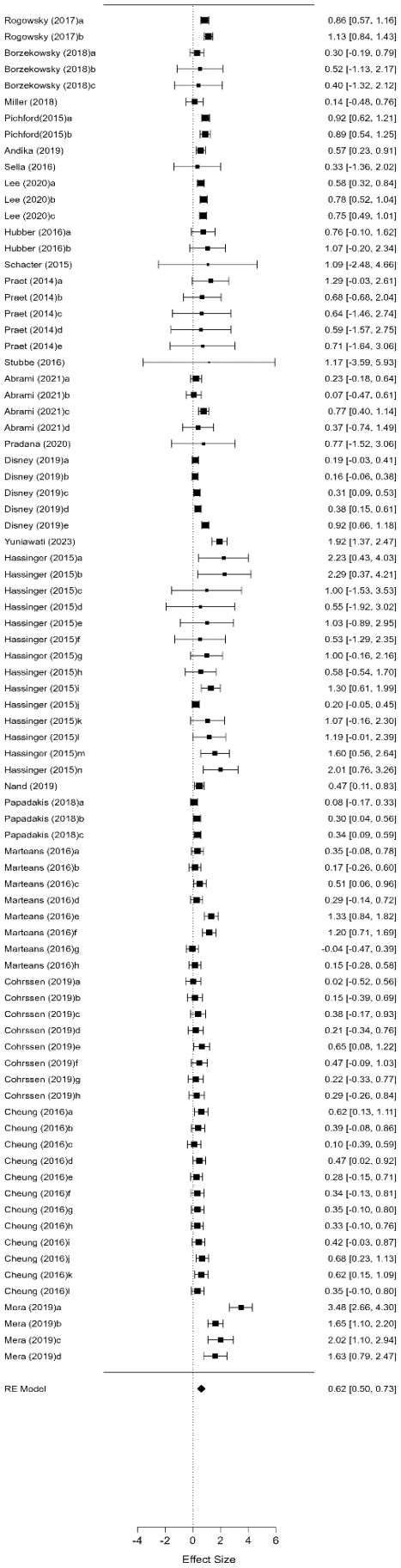

Figure 2. Forest plot (Source: Authors' own elaboration, using JASP 0.19.1.0)

Table 3. Moderator variable analysis results

Variable	Category	N	Gre	95%CI	Qvalue	Qw	Qb
Overall		83	0,62	[0.50,0.73]	286,49		
Type	CAI	16	0.97	[0.64,1.31]	87.82	256.47	30.02
	Neither	19	0.56	[0.39,0.73]	70.61		
	Tablet	48	0.49	[0.35,0.64]	98.04		
Duration	≤10	55	0.70	[0.54,0.85]	199.29	282.29	4.19
	>10	28	0.48	[0.34,0.63]	83		
Form	Game	59	0.59	[0.46,0.72]	218.38	262.68	23.8
	Non game	24	0.73	[0.49,0.98]	44.31		
Continent	Africa	18	0.66	[0.52,0.79]	18.15	253.74	32.74
	America	19	1.00	[0.61,1.38]	43.91		
	Asia	18	0.52	[0.33,0.71]	32.63		
	Australia	13	0.36	[0.21,0.50]	27.56		
	Europe	15	0.81	[0.46,1.16]	131.49		

The results of the meta-analysis of the 83 studies showed heterogeneity as there was a statistically significant difference in the effect size values (Q = 286,49, p < 0.001). This indicates that there is potential to analyse moderator variables to reveal the source of variance between effect sizes. **Table 3** shows the results of the moderator variable analysis in this meta-analysis.

Moderator Variable Analysis Results

Regarding the type of media, CAI demonstrated the highest effect size (Gre = 0.97), indicating a strong positive influence on early numeracy with a reliable confidence interval of [0.64, 1.31]. This finding is consistent with prior research that highlights CAI's ability to provide individualized instruction, real-time feedback, and adaptable content, which enhances learning outcomes (Escueta et al., 2017). The effectiveness of CAI is particularly notable in contexts where personalized learning pathways are essential for engaging young learners. In contrast, tablets showed a lower effect size (Gre = 0.49), suggesting a more modest impact on early numeracy. This is surprising given the literature, which often praises tablets for their engaging, touchscreen interface and portability, features that can enhance interaction and retention (Pitchford, 2015). The variability in tablet outcomes may be due to differences in implementation quality, app design, and the extent to which they are integrated into the curriculum. Traditional methods (neither CAI nor tablets) also showed a moderate effect (Gre = 0.56), reinforcing that while traditional approaches like worksheets and physical manipulatives remain beneficial, they may not provide the same level of individualized engagement and real-time feedback as digital media (Clark-Wilson et al., 2020).

The analysis of the duration of media use reveals that short-term interventions (less than 10 weeks) yield a higher effect size (Gre = 0.70) compared to long-term interventions (Gre = 0.48). Short-term interventions often provide immediate engagement and motivation, leading to quick improvements in early numeracy (Cohrssen & Niklas, 2019; Hubber et al., 2016; Mera et al., 2019; Pitchford, 2015). These findings are consistent with studies showing that brief, focused media interventions can generate significant short-term gains (Berkowitz et al., 2015). Long-term interventions, however, demonstrate a lower effect size, suggesting that the benefits of prolonged use of learning media may plateau over time unless instructional strategies are varied or enhanced to sustain engagement. This observation aligns with the literature indicating that sustained practice is critical for deeper conceptual understanding, but prolonged exposure without sufficient content variation can lead to diminishing returns (Dietrichson et al., 2021).

The form of media, whether game-based or non-game-based, also plays a critical role in its effectiveness. Game-based media showed a moderate effect size (Gre = 0.59), which is supported by research emphasizing the motivational and cognitive benefits of educational games, particularly for problem-solving and engagement (Clark et al., 2016; Plass et al., 2020). Game-based learning allows for dynamic interaction, immediate feedback, and adaptive difficulty levels, which have been shown to foster deeper learning in mathematics (Pradja, 2023). Non-game-based media, however, showed a slightly higher effect size (Gre = 0.73), which is somewhat surprising given that game-based learning is often viewed as more engaging. This result suggests that non-game-based tools such as instructional videos, digital worksheets, or structured simulations can be equally, if not more, effective when used in focused, well-structured educational settings (Chou et al., 2020). These tools may offer greater consistency in outcomes, as indicated by the lower heterogeneity within the non-game-based subgroup, making them a reliable option for educators aiming to achieve specific learning objectives.

Geographically, the effectiveness of learning media varied across continents, reflecting differences in educational systems, access to technology, and cultural attitudes toward learning. America showed the highest effect size (Gre = 1.00), suggesting that learning media have a particularly strong positive impact on early numeracy in this region. This may be attributed to better access to technology, teacher training, and a more widespread adoption of digital tools in classrooms (Berg et al., 2019). Similarly, Europe displayed a high effect size (Gre = 0.81), likely due to the region's focus on integrating learning media into curricula and ensuring teacher preparedness (Schaeffer et al., 2021). Africa (Gre = 0.66) and Asia (Gre = 0.52) also showed positive effects, though the variability in outcomes reflects differences in technological access, educational infrastructure, and implementation quality (Borzekowski et al., 2019; Lee & Choi, 2020). Australia demonstrated the lowest effect size (Gre = 0.36), which may be due to the unique challenges of engaging certain student populations, such as Indigenous learners, who may require more culturally relevant interventions to fully benefit from learning media (Disney et al., 2019; Han, 2019).

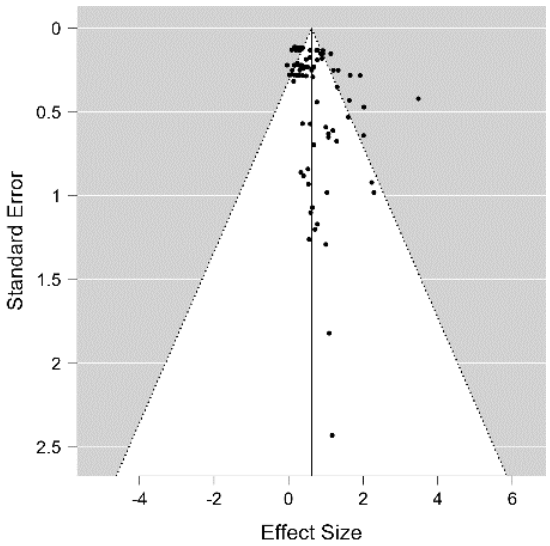

Figure 3. Funnel plot (Source: Authors' own elaboration, using JASP 0.19.1.0)

Publication bias

To check for publication bias, several methods were used, namely Funnel plot, Kendall and Egger test. In the existing Funnel plot results, it does not show a symmetrical distribution of data. Here is a picture of the Funnel plot of the effect size (**Figure 3**).

The results of the analysis provide clear evidence of funnel plot asymmetry, suggesting the presence of publication bias within the data. Starting with the rank correlation test for funnel plot asymmetry, the Kendall's τ value of 0.229 combined with a statistically significant p-value of 0.002 indicates a significant degree of asymmetry. This result implies that there is a systematic relationship between the effect sizes and their standard errors, suggesting that smaller studies with non-significant results may be underrepresented in the analysis, while larger or more significant studies are overrepresented. Such patterns are typical indicators of publication bias, where studies with more prominent findings are more likely to be published.

Further reinforcing this observation is the result from Egger's test for funnel plot asymmetry. With a z-value of 3.073 and a p-value of 0.002, this test also confirms that there is a statistically significant level of asymmetry in the funnel plot. Egger's test is specifically designed to detect bias in meta-analyses by examining the relationship between study effect sizes and their precision (standard error). The significant result suggests that smaller studies are showing larger effects, which further corroborates the likelihood of publication bias influencing the meta-analysis results.

Despite these signs of publication bias, the file drawer analysis (Rosenthal's fail-safe N) provides a different perspective. With a fail-safe N of 12,885, the analysis suggests that a very large number of unpublished or missing studies with null results would be needed to overturn the significance of the meta-analysis. This high number indicates that, even though there is evidence of publication bias, the overall conclusions drawn from the meta-analysis remain robust and are unlikely to be significantly affected by the missing studies.

CONCLUSIONS

A meta-analysis encompassing 83 studies provides compelling evidence for the significant impact of educational media on students' early numeracy skills. This research highlights several critical factors that warrant consideration in the selection and implementation of such media. Notably, computer-assisted instruction demonstrates superior efficacy compared to tablet-based and traditional media approaches, underscoring the importance of media type. Geographical context also plays a crucial role, with educational media showing particularly high effectiveness in America and Europe. These findings emphasize the need for a nuanced, context-sensitive approach to educational media deployment in early numeracy instruction. Interestingly, the study reveals that certain factors commonly presumed to be influential do not significantly affect outcomes. Neither the duration of media utilization (programs lasting 10 weeks or less versus those exceeding 10 weeks) nor the form of the media (game-based versus non-game-based) produced statistically significant differences in effectiveness. These results suggest that the quality and relevance of content may be more critical than program duration or form when designing interventions. As such, educators and policymakers should prioritize computer-based approaches and consider regional variability while focusing on content quality.

Future research in this field should focus on several key areas to enhance our understanding and improve the efficacy of educational media in early numeracy instruction. Firstly, longitudinal studies are needed to assess the long-term impacts of these interventions on students' mathematical development. Secondly, researchers should investigate the specific features of computer-based instruction that contribute to its superior effectiveness, potentially leading to the development of more targeted and efficient educational technologies. Additionally, cross-cultural studies should be conducted to identify the underlying factors contributing to regional differences in efficacy, which could inform the adaptation of successful strategies to diverse educational contexts. Finally, future research should explore the potential of adaptive learning systems and artificial intelligence in

personalizing early numeracy instruction, potentially addressing individual learning needs more effectively than current one-size-fits-all approaches.

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