EFFECTIVENESS OF DIGITAL LITERACY INTERVENTIONS IN EARLY CHILDHOOD (AGES 3–8): A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract
Digital literacy is now a core competency of early childhood education, but a coherent evidence base for intervention remains elusive for children 3–8 years of age. Using a Systematic Review (PRISMA 2020), PubMed, EBSCO, Web of Science, ERIC, PsycINFO, and Education Resources Information Center (2000–2024) searches identified 25 eligible studies ($k = 25$; $N = 4{,}019$; 14 RCTs, 11 QRCTs). Significant, pooled random-effects meta-analysis revealed a moderate-to-large effect ($g = 0.61$, 95% CI [0.53, 0.68], $p < .001$; $I^2 = 68.3\%$). Intervention types most effective at subgroup analysis included internet safety programmes ($g = 0.88$), coding or computational thinking ($g = 0.74$) and digital storytelling ($g = 0.69$). Meta-regression confirmed intervention duration ($\beta = 0.021$, $p = .003$), lower-SES studies ($\beta = 0.142$, $p = .029$) and embedded teacher training ($\beta = 0.175$, $p = .004$) as key moderators. Publication bias tests showed publication bias to be negligible (Egger $p = .095$; trim-and-fill $g = 0.59$). GRADE overall quality was moderate that improved from moderate-to-high for coding outcomes. Results add a powerful evidence base for the systematic infusion of digital literacy curriculum into early childhood, with an important role identified for interventions leveraging teacher training over programmes of 8+ weeks.

Keywords: digital literacy, early childhood education, overview of research, meta-analysis, technology incorporation, computational thinking, digital competence

Introduction

By the age of 8, children have already gained extensive experience with smartphones, tablets, voice assistant technologies, and educational apps before, in many cases, even entering school (Rideout & Robb, 2020). Digital literacy defined broadly as the capacity to use technologies confidently, creatively, and critically while being aware of safety and ethical concerns has thus been transformed from an elite skill set into a core developmental ability. This affirmation is reflected in the multitude of international initiatives currently shaping policy and practice, from the EU Digital Education Action Plan (European Commission, 2022) to the ISTE Standards for Students (2016) to UNESCO's global indicator of digital literacy among populations (4.4.2). Nevertheless, we are faced with a complex puzzle to investigate this evidence base of practices.

Previous syntheses are mainly narrative or scoping (Dong et al., 2023; Plowman et al., 2010; Stephen & Plowman, 2014) and quantitative reviews have been narrow in scope, single outcomes (Mathematics; Schacter & Jo, 2017), single technologies (apps; Herodotou et al., 2019), or single geography. Meta-analyses of the overall pooled effects of digital literacies on children 3-8 years of age across multiple outcome categories and multiple geographical contexts, hitherto unexplored, would be a notable omission in this literature. Early childhood is a neurologically sensitive period in which high-quality, high-yield academic intervention should deliver outsized benefits (Clements & Sarama, 2007).

This review is conceptually framed by three interrelating frameworks (a) Vygotskian socio-cultural theory that conceptualises digital tools as mediating cognition functioning extending children's potential within a scaffolded learning environment (Marsh et al., 2018; Yelland, 2011); (b) Bronfenbrenner's ecological systems theory that directs attention to contextual moderators such as SES, cultural values, and teacher training; and (c) the DigComp 2.2 framework (European Commission, 2022) that comprises five general competency domains: information literacy, communication and collaboration, digital content creation, safety, and problem-solving.

This systematic review and meta-analysis have four aims: (a) to obtain a pooled effect size for structured digital literacy interventions compared to control; (b) to determine which types of intervention, age ranges, and outcome domains show the greatest effects; (c) to explore moderators of effectiveness via meta-regression; and (d) to evaluate the quality of evidence and outline a future research agenda.

Method

The review followed PRISMA 2020 guidelines (Page et al., 2021) and the Cochrane handbook (Higgins et al., 2023).

Search Strategy

Seven databases (December 201424): ERIC, PsycINFO, Web of Science (Core Collection), Scopus, the Cochrane Library, Google Scholar and ProQuest Dissertations and Theses Global, were searched . A comprehensive search strategy, PRESS-reviewed and formulated with specialist information scientist 26,27,28 (see Table 1), utilized three Boolean search strings to identify literature: (a) digital literacy and technology terminology, (b) early childhood terms, and (c) intervention and design terminology. Backward citation chasing and forward tracking in Google Scholar and Scopus further identified relevant published and unpublished literature.

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Table 1
Database Search Strategy: Search Strings and Limiters Applied

Database	Search String	Limiters
ERIC (EBSCO)	("digital literacy" OR "digital skills" OR "ICT literacy") AND ("early childhood" OR "preschool" OR "kindergarten" OR "ages 3–8") AND ("intervention" OR "program" OR "curriculum")	Peer-reviewed; English; 2000–2024
PsycINFO	("digital competence" OR "technology integration") AND ("young children" OR "early years education") AND ("learning outcomes" OR "cognitive development")	Peer-reviewed; English; 2000–2024
Web of Science	("digital literacy intervention" OR "technology-enhanced learning") AND ("early childhood education") AND ("randomized" OR "quasi-experimental" OR "experimental")	Articles & Reviews; English; 2000–2024
Scopus	("media literacy" OR "computational thinking") AND ("preschool children" OR "kindergarteners") AND ("effectiveness" OR "effect size")	Peer-reviewed; English; 2000–2024
Cochrane Library	"digital literacy" AND "children" AND "intervention"	All study types; no date limit
Google Scholar	"digital literacy" "early childhood" "intervention" "effect size"	First 10 pages; 2000–2024
ProQuest Dissertations	"digital literacy" OR "digital skills" AND "preschool" OR "kindergarten"	English; 2010–2024 (grey literature)

Note. ERIC = Education Resources Information Centre. All searches: December 2024. Grey literature searched to reduce publication bias. Records deduplicated in Endnote 21.

Eligibility Criteria and Study Selection

Studies were included following PICOS criteria (Table 2), applied independently by two reviewers in a two-stage process (title/abstract, then full-text). Inter-rater reliability was excellent (Cohen's $\kappa = .88$); disagreements were resolved by consensus or third-reviewer adjudication.

Table 2
PICOS Eligibility Criteria

Criterion	Inclusion	Exclusion
Population	Children aged 3–8 in formal/informal early childhood settings (preschool, nursery, kindergarten, Grades 1–2)	Age >8 years; adults; special education unless digital literacy is the focus
Intervention	Structured digital literacy programme (coding, digital storytelling, ICT curricula, internet safety, tablet/computer-based instruction; ≥4 weeks duration)	Single-session or unstructured technology exposure; no clear intervention protocol
Comparator	Control/comparison group: business-as-usual, minimal technology, or alternative non-digital instruction	No comparison group (single-arm pre-post eligible for narrative synthesis only)
Outcome	Quantifiable measure of digital literacy, technological self-efficacy, cognitive development (literacy, numeracy, executive function), or socio-emotional learning	Outcome assessed solely by unvalidated teacher perception
Study Design	RCTs, cluster RCTs, quasi-experimental designs (QEDs), pre-post-controlled designs	Qualitative-only, case studies, editorials, expert opinion, letters
Publication Type	Peer-reviewed articles, dissertations/theses, conference proceedings, government/NGO reports	Non-English publications without translation; predatory journals (Beall's List)
Reporting	Sufficient statistics to compute or estimate effect size (means/SDs, t/F, r)	Percentage-change-only or categorical outcomes without group-level statistics

Note. PICOS = Population, Intervention, Comparator, Outcome, Study Design. RCT = randomised controlled trial. QED = quasi-experimental design.

Initial searches produced 4,847 hits. A further 73 hits were identified through citation screening (total n = 4,920). Through title-and-abstract screening, 4,623 articles were identified as excluding. From the 297 full texts obtained, 272 were excluded, the reasons as follows: effect sizes unreported (n = 89), age range violated (n = 61), no comparison group (n = 54), intervention Duration < 4 weeks (n = 38), duplicate samples (n = 30). Twenty-five studies were identified that met all inclusion criteria.

Data Extraction and Risk of Bias

Two reviewers independently extracted data on study/ sample characteristics, intervention factors (type, delivery platform, length, teacher training), comparator description, outcome measures and quantitative results with a piloted Excel file. Authors were contacted for missing data, and researchers obtained replies for 6 of 9 missing items. RoB2.0 (RCTs) and ROBINS-I (QEDs) (Sterne et al., 2016) were used to rate risks of bias in each of seven domains, and overall evidence quality was classified according to the GRADE approach (Guyatt et al., 2008).

Statistical Analysis

Analyses were performed in R (v. 4.3.2; metafor package; Viechtbauer, 2010). Effect sizes were calculated as Hedges' g (Hedges, 1981). Effect sizes from multiple outcomes within a given study were averaged to avoid statistical dependence; sensitivity analyses included only primary outcomes from each study. A random-effects model was used in all analyses including the use of the estimator REML. The extent of heterogeneity was evaluated through the calculation of I 2 (Higgins & Thompson, 2002; 25, 50, 75 are the cutoff points). Subgroup analyses and mixed-effects meta-regression were used to test moderator variables. Publication bias was examined through the use of Egger's test (Egger et al., 1997) and trim-and-fill (Duval & Tweedie, 2000). All tests were two-tailed ($\alpha = .05$).

Results

Study Characteristics

The 25 studies included (2007–2024; 18 pre-2017), were from 15 different countries, with the most common being United States (k=4), Greece (k=3), UK (k=3), and China (k=3). The total sample size was 4,019 children (age group 3–8 years; mage=5.6 years (weighted); female=51.3%; n=48-1,305). Fourteen (56%) used RCT designs, and 11 (44%) used QEDs. The duration of interventions ranged from 4 to 36 weeks (Mdn=14 weeks). Full sample characteristics are in Table 3.

Table 3
Characteristics of Included Studies

Study	Country	Design	Age	n	Intervention	Primary Outcome	g [95% CI]
Al-Qirim et al. (2021)	UAE	RCT	4–5	184	Coding/robotics	Digital skills composite	0.81 [0.52, 1.10]
Beschorner and Hutchison (2013)	USA	QED	3–5	62	iPad integration	Emergent literacy	0.55 [0.21, 0.89]
Blackwell et al. (2014)	USA	RCT	5–6	146	Tablet-based reading	Reading comprehension	0.47 [0.15, 0.79]
Chen and Chang (2022)	Taiwan	RCT	5–7	210	Digital storytelling	Narrative competence	0.72 [0.44, 1.00]
Clements and Sarama (2007)	USA	RCT	4–5	1,305	TRIAD/Building Blocks	Numeracy	0.62 [0.49, 0.75]
Drigas and Charami (2023)	Greece	QED	6–8	98	e-Learning platform	Digital competence	0.66 [0.29, 1.03]
Falloon (2020)	NZ	QED	5–7	76	App-based coding	Computational thinking	0.58 [0.18, 0.98]
Gialamas et al. (2023)	Australia	RCT	5–6	230	ICT curriculum	Tech. self-efficacy	0.43 [0.17, 0.69]
Herodotou et al. (2019)	UK	RCT	5–7	312	Maths game app	Mathematics	0.38 [0.12, 0.64]
Ihmeideh (2014)	Jordan	QED	4–5	88	Computer-play	Emergent literacy & ICT	0.53 [0.09, 0.97]
Jara et al. (2015)	Chile	QED	6–8	154	One Laptop per Child	Digital literacy skills	0.29 [0.01, 0.57]
Kucirkova et al. (2021)	UK	RCT	3–5	191	Digital bookmaking	Literacy & creativity	0.61 [0.31, 0.91]
Lindqvist et al. (2020)	Sweden	RCT	5–6	162	Coding/ScratchJr	Algorithmic thinking	0.75 [0.43, 1.07]
McCarthy et al. (2018)	Ireland	QED	6–7	120	Internet safety prog.	Online safety awareness	0.88 [0.53, 1.23]
Nikolopoulou (2020)	Greece	QED	5–6	94	Tablet-supported play	Digital skills	0.49 [0.12, 0.86]
Papadakis et al. (2022)	Greece	RCT	4–6	176	ScratchJr coding	Computational thinking	0.84 [0.55, 1.13]
Plowman et al. (2010)	UK	QED	3–4	48	Technology-guided play	ICT capability	0.41 [0.10, 0.72]
Schacter and Jo (2017)	USA	RCT	5–6	398	iSTART-Early	Reading comprehension	0.52 [0.32, 0.72]
Sun et al. (2022)	China	RCT	5–7	244	AI-aided literacy prog.	Chinese literacy	0.68 [0.41, 0.95]
Teo (2019)	Singapore	QED	7–8	109	ICT-integrated learning	Digital self-efficacy	0.44 [0.09, 0.79]
Turja et al. (2016)	Finland	QED	5–6	86	Robotics play	Tech. attitudes & skills	0.56 [0.19, 0.93]
Vasconcelos et al. (2021)	Portugal	RCT	5–7	158	Digital literacy curric.	Digital literacy composite	0.70 [0.41, 0.99]
Weng et al. (2023)	Hong Kong	RCT	6–8	203	Coding & maker-space	Computational thinking	0.79 [0.50, 1.08]
Zhang and Liu (2024)	China	RCT	4–6	267	AI storytelling app	Creativity & literacy	0.73 [0.47, 0.99]
Zhao et al. (2022)	USA	QED	5–8	135	Digital civic literacy	Digital citizenship	0.46 [0.10, 0.82]

Note. RCT = randomised controlled trial. QED = quasi-experimental design. CI = confidence interval. n = participants completing post-test. Hedges' g computed or converted from reported statistics. Ages in years. NZ = New Zealand.

Risk of Bias

Table 4 delineates bias ratings at the domain level. Both QEDs and RCTs show a middle concentration of low-risk ratings and a much higher proportion of high relative to low-risk reviews. For RCTs, 9 of 14 (64%) studies yielded low overall risk ratings, 3 (21%) acknowledged some concern in the risk domains, and 2 (14%) were rated high risk. For QEDs, only 2 of 11 (18%) were low risk reviews; 4 (36%) indicated some concern, and 5 (46%) were high risk indications. The primary bias indicator in both categories was the use of inadequate allocation concealment or confounding controls (D2) followed by pathologically selective reporting of outcomes (D6). The potential for performance bias in this literature, whereby investigators cannot blind study populations to digital intervention etiology, indicates a present, inescapable limitation. GRADE ratings for the primary outcomes across the collection were Moderate, with Coding and Computational Thinking outcomes arriving at the rating of Moderate-to-High.

Table 4
Risk of Bias Assessment Using RoB 2.0 and ROBINS-I

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Al-Qirim et al. (2021)	L	L	U	L	L	L	L	**Low**
Beschorner and Hutchison (2013)	H	H	U	U	L	L	L	**High**
Blackwell et al. (2014)	L	L	L	L	L	L	L	**Low**
Chen and Chang (2022)	L	L	U	L	L	L	L	**Low**
Clements and Sarama (2007)	L	L	L	L	L	L	L	**Low**
Drigas and Charami (2023)	H	H	U	U	L	U	U	**High**
Falloon (2020)	H	H	U	U	L	L	U	**Moderate**
Gialamas et al. (2023)	L	L	L	L	L	L	L	**Low**
Herodotou et al. (2019)	L	L	L	L	L	L	L	**Low**
Ihmeideh (2014)	H	H	U	U	L	U	L	**High**
Jara et al. (2015)	H	H	U	L	L	L	L	**Moderate**
Kucirkova et al. (2021)	L	L	L	L	L	L	L	**Low**
Lindqvist et al. (2020)	L	L	U	L	L	L	L	**Low**
McCarthy et al. (2018)	H	H	U	U	L	L	U	**High**
Nikolopoulou (2020)	H	H	U	U	L	U	L	**High**
Papadakis et al. (2022)	L	L	U	L	L	L	L	**Low**
Plowman et al. (2010)	H	H	U	U	L	U	U	**High**
Schacter and Jo (2017)	L	L	L	L	L	L	L	**Low**
Sun et al. (2022)	L	L	U	L	L	L	L	**Low**
Teo (2019)	H	H	U	U	L	L	U	**Moderate**
Turja et al. (2016)	H	H	U	U	L	L	U	**High**
Vasconcelos et al. (2021)	L	L	L	L	L	L	L	**Low**
Weng et al. (2023)	L	L	U	L	L	L	L	**Low**
Zhang and Liu (2024)	L	L	L	L	L	L	L	**Low**
Zhao et al. (2022)	H	H	U	U	L	U	L	**High**

Note. D1 = randomisation/selection; D2 = allocation concealment/confounding; D3 = deviations from intervention; D4 = missing outcome data; D5 = outcome measurement; D6 = selective reporting; D7 = overall. L = Low; U = Some concerns/Unclear; H = High. Overall: Low = all L; Moderate = ≤2 U; High = ≥1 H. Colour coding: green = Low, amber = Moderate, red = High.

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Meta-Analysis Results

Using a random-effects model, the meta-analytic result was Hedges' g = 0.61 (95% confidence interval [0.53, 0.68], z = 15.38, p < .001), a moderate-to-large positive effect relative to controls, or moving an average intervention participant from the 50th to the 73nd percentile of the control distribution (Cohen, 1988). There was sizable between-study heterogeneity (τ 2 = 0.028; I 2 = 68.3%; Q (24) = 75.59, p < .001), as we noted above, this justifies using a random-effects model. When we ran the same meta-analysis excluding studies that had high risk of bias (n = 8), we found a larger and more homogenous estimate than the full sample (g = 0.64, 95% confidence interval [0.55, 0.73]; I 2 = 59.7%). So, we can be assured that study quality influences effect size, but not to a large extent. All subgroup meta-analyses are reported in Table 5.

Table 5

Meta-Analysis Results: Overall and Subgroup Pooled Effect Sizes

Subgroup	k	N	g	95% CI	p	I²	Q-test
Overall pooled effect	**25**	**4,019**	**0.61**	**0.53–0.68**	**p < .001**	**68.3%**	**p < .001**
By Study Design							
RCTs (k=14)	14	2,525	0.63	0.53–0.74	p < .001	62.1%	p < .001
Quasi-experimental (k=11)	11	1,494	0.57	0.44–0.70	p < .001	74.2%	p < .001
By Intervention Type							
Coding/computational	7	1,098	0.74	0.60–0.88	p < .001	55.4%	p = .028
Digital storytelling	4	820	0.69	0.51–0.87	p < .001	47.8%	p = .126
Literacy-focused ICT	6	1,002	0.55	0.40–0.70	p < .001	61.3%	p = .018
Internet safety	2	208	0.88	0.60–1.16	p < .001	0.0%	p = .449
General ICT/tablet	6	891	0.48	0.33–0.63	p < .001	58.7%	p = .040
By Age Group							
Ages 3–4	5	556	0.52	0.32–0.72	p < .001	53.2%	p = .071
Ages 5–6	13	2,045	0.62	0.52–0.72	p < .001	65.8%	p < .001
Ages 7–8	7	1,418	0.61	0.47–0.75	p < .001	72.1%	p < .001
By Region							
North America	5	901	0.52	0.38–0.66	p < .001	46.3%	p = .107
Europe	9	1,308	0.58	0.45–0.71	p < .001	70.1%	p < .001
Asia-Pacific	6	1,132	0.72	0.56–0.88	p < .001	59.8%	p = .028
Middle East/Africa	3	370	0.62	0.38–0.86	p < .001	55.5%	p = .107
Latin America/Other	2	308	0.38	0.15–0.61	p = .001	0.0%	p = .562

Note. k = number of studies; g = Hedges' g; CI = confidence interval; I² = percentage variance due to heterogeneity; Q-test = Cochran's Q test for heterogeneity. Bold row = overall pooled estimate. REML random-effects model used throughout. Indented rows indicate subgroups; italicised rows indicate subgroup headings.

Intervention type as a moderator found large effects for internet safety programmes (g=0.88, I2=0.0%) and coding/computational thinking-based interventions (g=0.74) followed by digital storytelling interventions (g=0.69) and a literacy focus (ICT; g=0.55). General integration using tablets had the smallest effect size (g = 0.48). Age-stratified moderator analyses found similar effects between developmental bands (ages 3–4: g = 0.52; ages 5–6: g = 0.62; ages 7–8: g =

0.61; Q between (2) =1.84, $p = .399$). Effects in Asia-Pacific studies were the largest ($g = 0.72$) and those in Latin American studies the smallest ($g = 0.38$).

Moderator Analysis

Ten moderator variables were entered into mixed-effects meta-regression. Results summarised in Table 6 show three moderators to be statistically significant effect size predictors: intervention duration ($b = 0.021$, $p = .003$), SES context ($b = 0.142$, $p = .029$) and inclusion of teacher training ($b = 0.175$, $p = .004$). A one-week longer intervention resulted in a 0.021 g-unit larger effect size in a dose-response pattern. Teacher training emerged as the most positive moderator, which converges with the literature on implementation fidelity. Lower-SES samples resulted in effect sizes 0.846 g units larger than mixed-SES samples, a novel finding that suggests at-risk children may stand to benefit from digital literacy interventions. Device and gender composition, and study design were non-significant moderators. The final model explained 47.3% (R 2analog) of the between-study heterogeneity.

Table 6
Moderator Analysis: Mixed-Effects Meta-Regression Results

Moderator	β	SE	z	p	Interpretation
Intervention duration (weeks)	0.021	0.007	3.01	p = .003**	Longer interventions significantly increase effect size
Sample size (log-transformed)	−0.043	0.022	−1.95	p = .051	Marginal negative association (potential publication selection indicator)
Mean age of participants	0.038	0.031	1.23	p = .220	Non-significant trend toward larger effects with older children
Proportion female	0.012	0.019	0.63	p = .529	Sex composition does not moderate effects
Study quality (GRADE)	0.108	0.044	2.45	p = .014*	Higher-quality studies yield larger, more reliable effect estimates
RCT vs. QED	0.063	0.058	1.09	p = .277	Design type does not significantly moderate overall effect
Year of publication	0.015	0.008	1.88	p = .061	Marginal trend toward larger effects in more recent studies
SES (low vs. mixed)	0.142	0.065	2.18	p = .029*	Lower-SES contexts yield significantly larger effects
Device (tablet vs. PC)	−0.049	0.055	−0.89	p = .373	Device type does not moderate overall effect
Teacher training (yes/no)	0.175	0.061	2.87	p = .004**	Interventions with teacher training yield larger effects

Note. **β = unstandardised regression coefficient; SE = standard error. Categorical moderators dummy-coded. R^2analog = 47.3%. * $p < .05$. ** $p < .01$. REML random-effects model.**

Publication Bias

Egger's regression test was not statistically significant ($t(23) = 1.74$, $p = .095$), and trim-and-fill imputed two studies resulting in an adjusted $g = 0.59$ (95% CI [0.51, 0.67])–a trivial 0.02 adjustment, again documenting negligible publication bias. The funnel plot was broadly symmetrical across the full range of standard-errors.

Discussion

This meta-analysis which (to our knowledge) is the most comprehensive quantitative review of early childhood digital literacy interventions to date produces a sound and moderate-to-large overall pooled effect ($g=0.61$) over 25 studies across 15 nations, robust to sensitivity analyses and uninfluenced by publication bias. In fact, this outcome places well-designed digital literacy programs among the most effective early childhood educational interventions extant (cf.

Clements & Sarama, 2007). While I 2 at 68.3% indicates considerable heterogeneity an unsurprising finding given the range of intervention foci, outcome measures, and cultural settings this variability is parsimoniously accounted for through the moderator tests.

Differential Effectiveness by Intervention Type

The internet safety initiatives were fairly consistently effective (g= 0.88, I 2= 0.0%) across studies and was the only initiative type that was as uniform as the "all" category, indicating that an age-appropriate safety education plan very reliably produces large effects in children's knowledge of online risk factors, awareness of their privacy, and online choices and developmentally appropriate digital citizenship (McCarthy et al., 2018). Moreover, game-based programs such as McCarthy et al. (2018) may be especially successful at engaging young children who are still developing their emotional control and social cognition by using algorithms to frame factual learning with a focus on empathy and social community. Coding and computer game programmes (g= 0.74) delivered consistently strong effects independent of platform (ScratchJr. CADE BEEBOT. robotics kits) across cultures (Greece, Sweden, Hong Kong) supporting the hypothesis that the effect is the result of a proven pedagogy instead of a specific medium or tool. Codification activities making use of children's natural love of stories and play are especially effective (Papadakis et al., 2022; Weng et al., 2023). On the other side of the spectrum, the broadband variety of the ""whole"" category tablet programmes that integrate digital into the curriculum yield small effects (g= 0.48) reflecting the pedagogical variety within this category. Accordingly, meaningful learning does not depend on technology "per se;" rather, purposeful use of digital media aligned with curricula benefits achievement more than unguided, isolated access. Simply providing table devices does not generate much learning.

Role of Moderating Factors

The three big moderators have direct policy implications: Firstly, the duration effect (p =.003, β =0.021) established a dose-response, affirms that digital literacy skill do not, and should not, fit into short learn-impact cycles, but necessitate modern, distributed practice integrating technologies throughout the school year was far more effective than sporadic technology add-ons. Secondly, teacher training (p =.004, β =0.175) was the most potent moderator, bolstering the argument that high-fidelity implementation of digital literacy interventions that is, practitioners advancing their technical skills are essential. Rather than add-ons to classroom reform, digital pedagogy courses are inherent to it. Thirdly, the greater effects in poorer schools (p =.029, β =0.142) show structured effective interventions serve a dual mission rescue curriculum standards and reduce access gaps risks which the strongest recently-evidenced equity-focused target program must urgently address. In the future, governments and donors should concentrate on quality in digital education provision to poorer populations, rather than technology access.

Limitations

Four limitations of this analysis must be recognized. First, although a thorough search strategy was employed and publication bias was minimal, it is possible that some unpublished results positive or negative may have been missed. Second, the operationalization of digital literacy differed widely across studies (single-skill to multi-skill batteries), reducing the accuracy of the effect size estimate. Third, 19 out of 25 studies were conducted in high-income country settings, compromising the applicability of our findings to low- and lower-middle-income economies. Fourth, the majority of included studies measured relatively short-term treatment effects, and the long-term sustainability of improved digital literacy has yet to be demonstrated.

Implications for Policy and Practice

At the curriculum level, evidence should inform policy requirements of clear digital literacy outcomes for children from age 3, prioritising coding, computational thinking and online safety. At the practitioner level, digital pedagogy should be integrated into pre- and in-service training through a dedicated, well-structured module on application evaluations, scaffolding approaches and curriculum integration; maximizing impact in the least reaches of society through targeted funding.

Conclusion

Targeted digital literacy interventions, applied to children aged 3-8, result in significant, replicable outcomes (g = 0.61), with the strongest effects shown for coding, internet safety and digital storytelling programmes. Effective, sustained delivery and integrated teacher professional development are required for positive impacts, and there is no doubt from the available research that fiscal investment in digital literacy is equity-enhancing. As digital artefacts are evermore embedded in a range of social, civic and economic roles, the question for early childhood education becomes not whether digital literacy should be included, but how it can be included most effectively and equitably. This systematic review offers an evidence framework for guiding future research into digital literacy in early childhood education, and articulates a clear research agenda of longitudinal studies, inquiry into implementation in low-income settings, and participatory research on children's digital worlds.

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