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Leveraging Local and Global EdTech Ecosystems to Strengthen Digital Literacy and Learning: A Systematic Review and Meta-Analysis

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Abstract
Background: Educational technology (EdTech) is commonly evaluated through adoption, access, or platform use, although these indicators do not establish digital-literacy development or improved learning. Evidence is also fragmented between locally contextualized platforms, globally scaled services, critical governance research, and intervention studies. Objective: This study synthesized how local or national and global EdTech ecosystems support digital literacy and learning, with particular attention to Indonesia, Malaysia, and Thailand, and quantitatively examined whether hardware- and software-focused interventions differed in their association with learning outcomes in low- and middle-income settings. Methods: A three-layer evidence synthesis was conducted in accordance with PRISMA 2020 principles. A supplied Scopus corpus of 78 records published from 2020 to 4 August 2026 was screened alongside 23 sources from the revised source manuscript and 15 intervention reports identified through citation chasing. Ninety-eight records were retained in the systematic evidence map, 38 sources informed the critical full-text or authoritative-source synthesis, and 30 hardware/software effect-size contrasts from 13 unique reports were included in a secondary random-effects meta-analysis. Effects were aggregated within publication using generalized least squares with an assumed within-publication correlation of 0.50, then pooled using restricted maximum likelihood and modified Hartung-Knapp intervals. Results: The qualitative evidence consistently supported a conditional hybrid-ecology model: local platforms contributed curricular, linguistic, and cultural alignment, while global platforms expanded content, authoring, interoperability, and collaboration. Digital-literacy gains depended on purposeful tasks, teacher competence, equitable access, accessibility, institutional support, and data governance. At publication level, hardware-focused interventions produced a near-zero pooled effect ($d = -0.055$, 95% CI -0.251 to 0.141; $I^2 = 94.2\%$), whereas software-focused interventions showed a positive but imprecise effect ($d = 0.217$, 95% CI -0.024 to 0.458; $I^2 = 90.7\%$). The modality difference was not definitive in meta-regression ($p = 0.096$). Contrast-level sensitivity analysis favored software ($d = 0.245$, 95% CI 0.092 to 0.397), but this estimate was less conservative because correlated outcomes were treated as independent. Conclusions: EdTech contributes through mediated practices rather than technological presence. The convergent evidence favors investment in pedagogically integrated software, teacher capacity, accessibility, and governance over hardware distribution alone. Because the quantitative evidence was highly heterogeneous, secondary, and indirect for digital literacy, the pooled estimates should be interpreted as directional rather than causal.

Keywords: digital literacy; educational technology; platform ecosystems; Southeast Asia; digital equity; teacher digital competence; meta-analysis

1. Introduction

Digital technology is now embedded in education policy, school administration, classroom instruction, assessment, communication, and professional learning. The COVID-19 disruption accelerated this expansion, but it also demonstrated that nominal access to a platform is not equivalent to a reliable opportunity to learn. Across Southeast Asia, the value of technology has depended on device availability, connectivity, adult support, language, accessibility, teacher preparedness, and the capacity of institutions to organize coherent learning experiences (Global Education Monitoring Report Team & SEAMEO, 2023; Jeon et al., 2021; UNICEF East Asia and Pacific Regional Office, 2021). These conditions remain consequential after emergency remote teaching because platform use has become a durable component of education systems rather than a temporary response.

Digital literacy should therefore not be reduced to operational fluency. It includes the ability to identify an information need, search strategically, evaluate evidence and provenance, create and communicate digital content, protect privacy and well-being, solve technical and intellectual problems, and regulate one's own learning (Law et al., 2018; Reichert et al., 2020; Audrin & Audrin, 2022). A student who can open an application or submit an assignment may still be unable to distinguish credible sources, explain how an algorithm shaped a result, attribute digital material lawfully, or make a defensible decision about data disclosure. The relevant outcome is situated competence expressed in authentic practice, not exposure to a branded platform.

A recurring policy distinction separates local or nationally oriented EdTech platforms from global platforms. Local platforms may align with national curricula, languages, assessment systems, cultural examples, and public-sector priorities. Global platforms may offer larger content libraries, mature authoring tools, cloud infrastructure, analytics, and cross-border networks. In actual classrooms, however, these categories are interdependent. Local student data can move through transnational infrastructures; national repositories can depend on global identity and productivity services; and teachers often combine search engines, messaging applications, learning management systems, video repositories, office suites, and local content services within one task (Kerssens & van Dijck, 2024; Kerssens & van Dijck, 2021; Ortegón et al., 2024). The relevant unit of analysis is consequently an ecosystem or learning sequence, not an isolated application.

This ecosystem perspective also reveals asymmetries. Global providers benefit from scale, network effects, technical capacity, and capital, while local providers and public systems often carry the burden of curricular adaptation, inclusion, and accountability. Platformization can blur the boundary between public education and commercial data infrastructures, creating concerns about surveillance, dependency, interoperability, and the distribution of benefits and risks (Jarquín Ramírez, 2023; Ramírez & Gutiérrez, 2023; Vetter & McDowell, 2023; Verelst et al., 2025; Díez-Gutiérrez, 2021). Privacy decisions are especially complex in schools because educators and institutions frequently select technologies on behalf of students, although students bear substantial disclosure and profiling risks (Keith et al., 2025).

The evidence on educational impact is equally unsettled. Platform adoption, login frequency, satisfaction, perceived usefulness, and self-reported confidence are commonly treated as outcomes even though they are intermediate indicators. Longitudinal evidence has identified circumstances in which EdTech use was associated with negative or gap-widening achievement patterns, while research in low-resource contexts emphasizes that children do not learn autonomously in a social vacuum (Ahn, 2022; Huntington et al., 2023). Conversely, well-designed computer-assisted and personalized-learning interventions have produced meaningful gains in some settings (Banerjee et al., 2007; Muralidharan et al., 2019; Major et al., 2021). These apparently conflicting findings are logically compatible: technology can amplify strong pedagogy and support, but it can also scale weak design, unequal access, or inappropriate substitution.

The source manuscript provided a critical integrative review of local and global EdTech ecosystems in Indonesia, Malaysia, and Thailand. Its substantive argument was strong, but its method explicitly did not constitute an exhaustive systematic review and did not estimate pooled effects. The present study retains that argument while strengthening the evidentiary architecture in three ways. First, it converts a supplied Scopus export into a transparent systematic evidence map. Second, it integrates the source manuscript's verified conceptual, empirical, and policy literature into a structured critical synthesis. Third, it conducts an exploratory secondary meta-analysis of hardware- and software-focused intervention effects reported for girls in low- and middle-income countries (Jordan & Myers, 2022).

The review addressed four questions: (1) Which complementary affordances are associated with local or national and global EdTech platforms? (2) Through which pedagogical mechanisms can platform ecosystems support digital literacy? (3) Which infrastructural, professional, institutional, accessibility, and governance conditions shape implementation? and (4) Do hardware- and software-focused EdTech interventions show different pooled associations with learning outcomes? The fourth question concerns learning achievement rather than digital literacy itself. It was included as a quantitative test of a central proposition arising from the qualitative literature: educational value is more likely to arise from structured instructional design and feedback than from hardware presence alone.

2. Conceptual Framework

2.1 Digital literacy as situated and multidimensional competence

The UNESCO framework organizes digital literacy into device and software operations, information and data literacy, communication and collaboration, digital-content creation, safety, problem solving, and context-specific competence (Law et al., 2018). This multidimensional conception is consistent with authentic application-based assessment and with national or regional studies that include cognitive, technical, managerial, ethical, and safety-related dimensions (Reichert et al., 2020; Harmawati et al., 2024; Techataweewan & Prasertsin, 2018). The framework prevents a category error in EdTech evaluation: a platform feature is an affordance, whereas digital literacy is a demonstrated capability. A search box affords retrieval, but information literacy is shown when learners formulate a query, compare sources, assess evidence, and justify selection.

Digital literacy is also relational. The same learner may perform differently across languages, devices, subjects, and institutional contexts. Accessibility barriers, limited data packages, shared devices, inaccessible multimedia, or unfamiliar terminology can suppress performance even when underlying capability is present. Conversely, repeated use of a familiar interface may inflate confidence without supporting transfer to new tools or tasks. Evaluations should therefore measure authentic performance, transfer, and the reasoning embodied in digital artefacts rather than relying solely on self-report.

2.2 The conditional hybrid-ecology model

The proposed model treats local relevance and global reach as potentially complementary resources. Local or national platforms can reduce linguistic and curricular distance, represent local knowledge, and connect activities to domestic assessment and safeguarding arrangements. Global platforms can provide diverse information, advanced production tools, international collaboration, and interoperable services. Neither category is educationally sufficient on its own. The contribution of each depends on how teachers and institutions combine tools within a learning sequence.

The model is conditional because five cross-cutting requirements determine whether affordances become learning opportunities: equitable and reliable access; teacher digital competence; coherent pedagogical design; usability and accessibility; and accountable governance. These requirements are not implementation details external to learning. They shape who can participate, what actions are possible, what evidence is produced, and whose interests are protected. Critical research on platformization and commercial influence reinforces the need to analyze ownership, data flows, procurement, and exit arrangements alongside pedagogy (Williamson et al., 2021; Kerssens & van Dijck, 2024; Verelst et al., 2025).

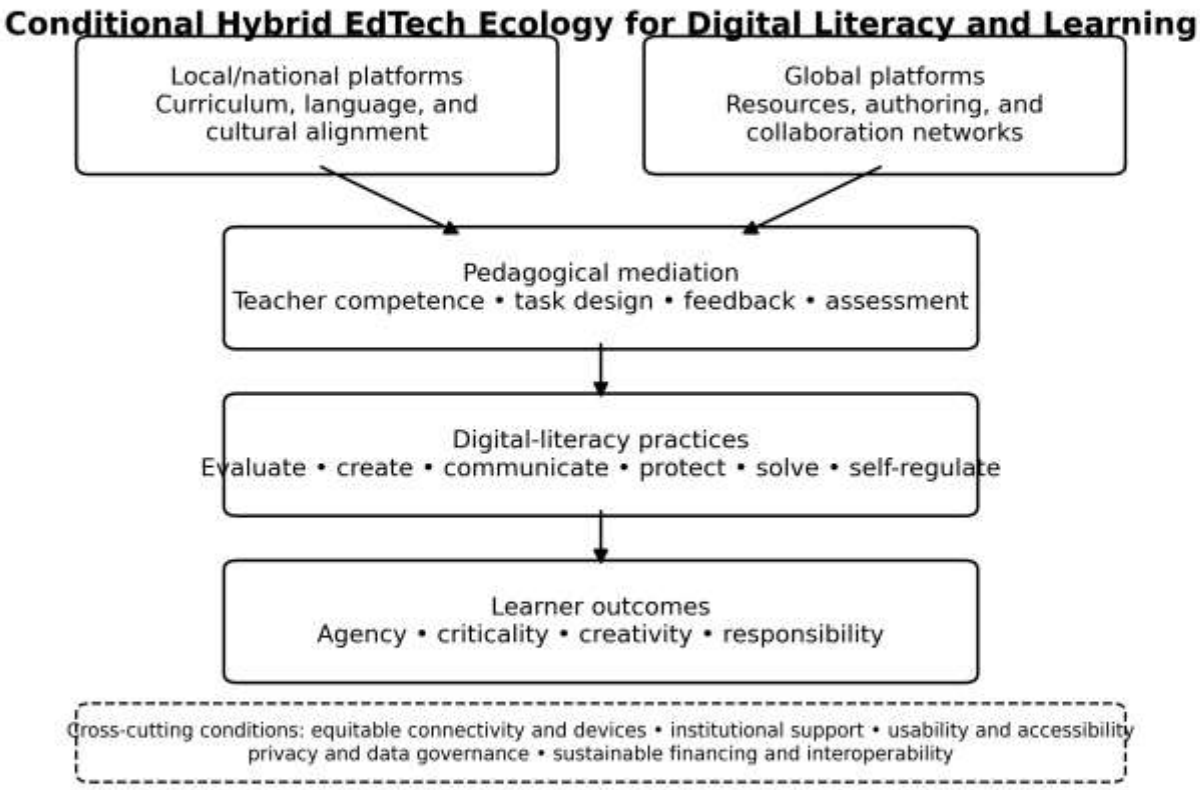

Figure 1. Conditional hybrid EdTech ecology for digital literacy and learning. Local and global platforms contribute affordances that are converted into digital-literacy practices through pedagogical mediation; learning depends on cross-cutting conditions.

2.3 Pedagogical mediation and teacher digital competence

The Technological Pedagogical Content Knowledge framework explains why adding a tool to an unchanged lesson does not constitute meaningful integration (Mishra & Koehler, 2006). Teacher digital-competence frameworks extend this reasoning to professional engagement, assessment, inclusion, learner empowerment, ethics, and reflective practice (Redecker, 2017; Falloon, 2020). In the present model, pedagogical mediation includes tool selection, task sequencing, scaffolding, source-evaluation prompts, orchestration of interaction, feedback, accessibility adaptation, and assessment of both disciplinary understanding and digital practice.

This mediation is particularly important in AI-enabled systems. Personalization may increase practice opportunities or adapt difficulty, but it can also obscure curricular assumptions, reduce teacher autonomy, or turn prediction into an unexamined decision rule. Studies of teacher-AI collaboration and human-in-the-loop personalization suggest that professional judgment remains necessary for contextualization, error detection, and responsible use (Dennison et al., 2026; Bhutoria, 2022). Ethical implementation additionally requires reliability, transparency, safety, and practical guidance that educators and providers can operationalize (Kousa & Niemi, 2023).

3. Methods

This study used a mixed evidence-synthesis design comprising a systematic evidence map, a critical integrative synthesis, and a secondary meta-analysis, with reporting organized according to PRISMA 2020 principles (Page et al., 2021). This design was selected because the available evidence included empirical platform studies, policy analyses, conceptual frameworks, measurement research, systematic reviews, institutional reports, and intervention effect sizes, whereas a conventional meta-analysis alone could not address the full research questions because most studies on digital literacy and platform governance did not report comparable quantitative outcomes. The review was not prospectively registered, and the supplied materials were treated as a fixed evidence corpus. This decision, together with the absence of a preserved historical Scopus query, is reported transparently to avoid presenting a retrospectively reconstructed search as the original database syntax. Three evidence sources were combined: a Scopus CSV export retrieved on 4 August 2026 containing 78 unique records published from 2020 to that date; 23 substantively integrated and bibliographically verified sources from the revised manuscript, including seminal frameworks, national studies, and institutional reports; and 15 primary intervention reports published between 2003 and 2019, identified through backward citation chasing from the quantitative review of EdTech interventions for girls (Jordan & Myers, 2022). DOI and normalized-title checks identified no duplicates between the Scopus export and the manuscript reference set. Because the original Scopus query was not embedded in the export, the corpus was treated as the reproducible input object. Its content broadly corresponded to concept blocks covering educational technology, EdTech, digital learning, learning platforms, artificial intelligence, platformization, and digital transformation, combined with digital literacy, digital competence, pedagogy, learning outcomes, equity, inclusion, governance, privacy, accessibility, and local, national, global, regional, or low-resource contexts. The reconstructed syntax is provided in Appendix A and should be replaced with an exact rerun and database log when required by the target journal.

Scopus records were eligible when they were journal articles, review articles, or conference papers that addressed education as the primary domain; examined an EdTech platform, digitally mediated learning practice, AI-enabled educational system, digital-inclusion issue, platform-governance process, or education-system transformation; and used an empirical, systematic-review, conceptual-analytic, or policy-research method with identifiable implications for learners, teachers, institutions, or public governance. Books, book chapters, and editorials were excluded from the Scopus evidence-map branch to maintain a consistent publication-type boundary, although seminal reports and frameworks verified in the source manuscript were retained in the critical synthesis. Records were excluded when their primary focus was health, finance, market forecasting, entrepreneurship, commercial strategy, or general political commentary without a specific educational-technology analysis, or when titles and abstracts lacked sufficient methodological or outcome information. Eligibility for quantitative pooling additionally required an EdTech intervention conducted in a low- or middle-income country, a learning outcome reported for girls, an effect estimate accompanied by a confidence interval or standard error, and a modality classifiable as hardware or software. Mixed interventions categorized as “other” were retained in the narrative synthesis but excluded from the hardware–software comparison. All 78 Scopus records were screened using titles, abstracts, and metadata, resulting in 60 inclusions and 18 exclusions. The 23 manuscript sources and 15 citation-chained intervention reports contributed to the critical and quantitative branches. The adapted evidence flow therefore comprised 116 screened records, 98 records included in the systematic evidence map, 38 full-text or authoritative sources included in the critical synthesis, and 13 unique primary reports contributing hardware or software estimates to the meta-analysis. Two additional primary reports evaluated interactive learning-tool or satellite-instruction packages that could not be classified unambiguously as either hardware or software.

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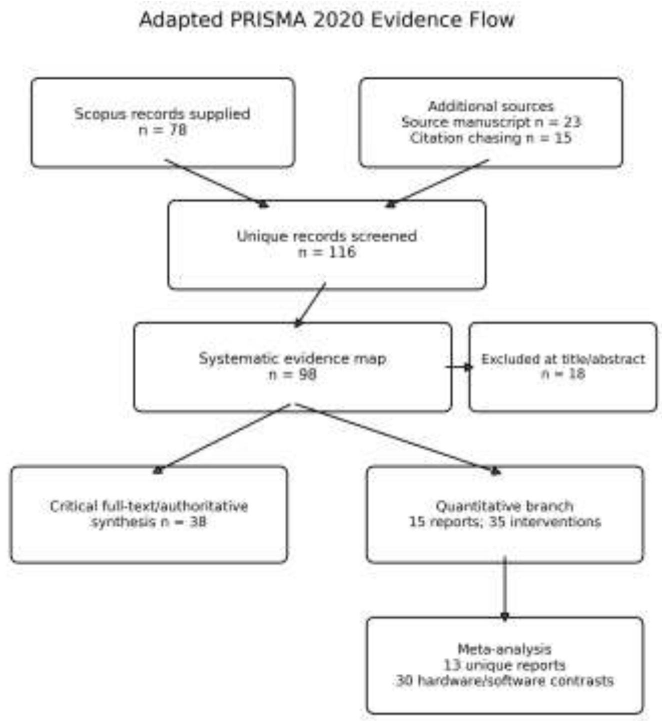

Figure 2. Adapted PRISMA 2020 evidence flow. Eighteen Scopus records were excluded because they were outside education, used an ineligible publication type, or lacked sufficient methodological or outcome detail. The evidence-map layer is based on supplied metadata and abstracts; the critical and quantitative layers use the source manuscript and citation-chained reports.

3.5 Data extraction and qualitative synthesis

For each included Scopus record, the extraction sheet recorded bibliographic information, publication year, document type, decision, exclusion reason where applicable, and a primary thematic category. The five categories were governance, platformization, and political economy; pedagogy, learning, and teacher mediation; AI, personalization, and ethics; equity, access, and inclusion; and system transformation and policy. Coding was deductive, based on the review questions, and was manually checked against each title and abstract. The complete audit trail is supplied as a CSV supplement.

The critical synthesis used a framework method. Claims were mapped to digital-literacy dimensions, local or global platform affordances, pedagogical mechanisms, and enabling or constraining conditions. Country evidence for Indonesia, Malaysia, and Thailand was analyzed comparatively. Numerical claims were retained only when traceable to a study or institutional report; platform adoption and satisfaction were not treated as equivalent to learning impact.

3.6 Quantitative data extraction

The quantitative source reported 35 interventions from 15 publications and displayed standardized effects and 95% confidence intervals in modality-specific forest plots (Jordan & Myers, 2022). Thirteen hardware contrasts from five publications and 17 software contrasts from nine publications were eligible for pooling. One publication contributed both hardware and software interventions, yielding 13 unique reports but 14 modality-specific publication units. Five 'other' contrasts from interactive learning-tool and satellite-instruction studies were not pooled because their hardware and software components were inseparable.

Point estimates and confidence-limit positions were digitized from the published forest plots and calibrated to the horizontal axes. Standard errors were calculated as (upper limit - lower limit)/(2 x 1.96). Study labels, modality, subtype, extracted effect, standard error, and confidence limits are supplied in the quantitative supplement. Digitization was checked by reproducing the approximate location and pooled direction shown in the source figures. The source's software pooled label was closely reproduced; the hardware diamond was located near zero, consistent with the extracted estimates.

3.7 Statistical analysis

Multiple outcomes from the same publication are statistically dependent. The primary analysis therefore aggregated contrasts within each publication and modality using generalized least squares. Because outcome correlations were not reported, a common within-publication correlation of rho = 0.50 was assumed. Sensitivity analyses used rho = 0 and rho = 0.80. Publication-level effects were pooled with a random-effects model using restricted maximum likelihood. Confidence intervals used the modified Hartung-Knapp method, which is more conservative than a normal approximation when the number of studies is small (Hartung & Knapp, 2001).

Heterogeneity was summarized with tau-squared, Cochran's Q, and I-squared (Higgins et al., 2003). Ninety-five percent prediction intervals were calculated to show the range of effects expected in a new comparable setting. A random-effects meta-regression tested modality as an exploratory moderator. A contrast-level analysis that treated all 30 estimates as independent was retained only as a sensitivity analysis because it understates within-publication dependence. Publication-bias tests were not conducted: each modality contained fewer than 10 publication units, the effects were secondary and digitized, and heterogeneity was substantial.

3.8 Confidence appraisal

No item-level risk-of-bias judgments were inferred from titles or abstracts. For the quantitative branch, confidence was appraised narratively across design limitations reported in the secondary source, indirectness to the present digital-literacy question, inconsistency, dependence among multiple outcomes, and digitization. The certainty of pooled hardware and software estimates was judged low. This judgment limits interpretation but is more defensible than fabricating study-level ratings without complete primary reports.

4. Results

4.1 Evidence selection and descriptive profile

The Scopus branch retained 60 of 78 records. The included evidence increased over time: three records were published in 2020, four in 2021, five in 2022, nine in 2023, 12 in 2024, 15 in 2025, and 12 during the partial 2026 period ending 4 August. The document set comprised 51 journal articles, five conference papers, and four reviews. This temporal pattern indicates rapid expansion, but the partial 2026 count should not be interpreted as a full-year decline.

Governance, platformization, and political economy was the largest primary theme (23 records; 38.3%), followed by pedagogy, learning, and teacher mediation (15; 25.0%), AI, personalization, and ethics (10; 16.7%), equity, access, and inclusion (eight; 13.3%), and system transformation and policy (four; 6.7%). The distribution demonstrates that contemporary EdTech research is not solely an effectiveness literature. A substantial share examines public-private relations, data infrastructures, teacher autonomy, commercialization, and the political assumptions embedded in digital transformation (Mateluna-Estay, 2025; Mertanen et al., 2022; Forsler, 2025; Kerssens & van Dijck, 2024; Verelst et al., 2025).

Table 1. Evidence-base profile and analytical contribution.

Component	Records	Date range	Analytical role
Scopus evidence map	78 screened; 60 included	2020-August 2026	Abstract-level mapping of contemporary EdTech themes
Source-manuscript literature	23	2006-2025	Verified conceptual, country, measurement, and policy synthesis
Citation-chained intervention reports	15	2003-2019	Quantitative branch on girls' learning outcomes in LMICs
Included Scopus document types	51 articles; 5 conference papers; 4 reviews	2020-August 2026	Descriptive evidence profile
Primary Scopus themes	Governance 23; pedagogy 15; AI 10; equity 8; policy 4	2020-August 2026	Framework synthesis and gap identification

4.2 From a platform binary to an orchestrated ecology

The evidence supported a distinction between local or national and global platforms, but not a rigid binary. Local platforms reduced linguistic and curricular distance, offered nationally recognizable examples, and could connect learning to domestic assessment and teacher-development systems. Their limitations included uneven technical maturity, restricted interoperability, limited independent evaluation, and vulnerability to short funding cycles. Global platforms expanded resource diversity, authoring capacity, identity services, and collaboration, but could be weakly aligned with national curricula, demanding in low-bandwidth contexts, and governed through terms that schools and families did not meaningfully negotiate.

The strongest configuration was an orchestrated sequence. A learner might receive a locally contextualized problem, search global and national sources, analyze data in a spreadsheet, collaborate in a shared document, create a bilingual multimedia explanation, conduct a privacy and accessibility check, and submit the artefact through a school platform. Digital literacy arises from the coordinated practices required by this sequence. Exposure to any single platform is neither necessary nor sufficient.

Platform ecology is also a governance relation. Research from Europe and Latin America illustrates how local educational activity becomes integrated into transnational data infrastructures and commercial ecosystems (Jarquín Ramírez, 2023; Ramírez & Gutiérrez, 2023; Kerssens & van Dijck, 2024; Kerssens & van Dijck, 2021). Studies of EdTech brokering show that schools, governments, universities, and firms do not interact directly in a neutral market; intermediaries translate claims, standards, and evidence across sectors (Ortegón et al., 2024). These findings make interoperability, data portability, transparent procurement, and exit provisions integral to educational quality.

Table 2. Complementary platform functions, learning tasks, and principal risks.

Digital-literacy dimension	Local/national contribution	Global contribution	Illustrative task and principal risk
Information and data literacy	Curriculum-specific questions, national-language sources, and local datasets	Diverse sources, international databases, and advanced search or analysis tools	Compare local and international accounts and justify credibility judgments. Risk: misinformation, language barriers, and ranking bias.
Communication and collaboration	Culturally familiar interaction and school-community participation	Cross-school or cross-border synchronous and asynchronous teamwork	Co-author a bilingual explanation with evidence-based peer feedback. Risk: unequal participation, harassment, and blurred boundaries.
Digital-content creation	Local examples, culturally relevant media, and curriculum-aligned templates	Mature multimedia, coding, publishing, and visualization tools	Create a licensed infographic, podcast, simulation, or data story. Risk: copyright violations and template-driven superficiality.
Safety, ethics, and well-being	Local regulation, school safeguarding, and contextualized norms	Identity management, security controls, and global-citizenship resources	Conduct a privacy and accessibility audit. Risk: surveillance, data extraction, cyberbullying, and excessive screen time.
Problem solving and self-regulation	Guided progression and locally relevant feedback	Adaptive resources, tutorials, planning tools, and dashboards	Set a goal, select tools, document decisions, troubleshoot, and reflect. Risk: automation dependence and inequitable support.

4.3 Pedagogical pathways to digital literacy

Information and data literacy was the most consistently supported pathway. Platforms can increase opportunities to search, filter, compare, and organize information, but retrieval becomes literacy only when learners examine authorship, evidence, date, relevance, and bias. Indonesian evidence linking ICT literacy with reading-literacy patterns indicates that digital competence interacts with academic literacy rather than operating as an isolated technical skill (Annisawati & Oktora, 2024). Assessment should capture the reasoning behind source selection and interpretation, not only successful navigation.

Digital-content creation provided a second pathway. Multimedia production, coding, simulations, data visualization, and collaborative documents can move learners from consumption to authorship. The cognitive value depends on disciplinary purpose: creating a video or infographic is not automatically higher-order learning. It becomes substantive when students transform evidence, make explainable design choices, attribute sources, revise after feedback, and communicate to an authentic audience.

Communication and collaboration formed a third pathway. Global platforms can connect learners across institutions and countries, while local platforms can support interaction in familiar languages and social contexts. Productive collaboration requires explicit roles, participation records, feedback criteria, and safeguards. Without such design, online group work can reproduce unequal participation, blur boundaries, or divide a task into disconnected fragments.

Safety, ethics, and well-being were integral rather than supplementary. Malaysian digital-citizenship research links online learning, safety, and well-being, while privacy scholarship emphasizes that student disclosure frequently occurs under institutional mandate rather than individual choice (Mahadir et al., 2021; Keith et al., 2025). Learners need repeated practice with secure authentication, privacy settings, data minimization, copyright and licensing, respectful communication, AI disclosure, and responses to harmful content.

Self-regulation and problem solving could be supported through flexible pacing, tutorials, dashboards, planning tools, and iterative feedback. However, autonomy should not be equated with absence of support. Research with remote out-of-school learners found that technology remained embedded in community relations, cultural context, and accessibility constraints (Huntington et al., 2023). Hybrid-learning evidence similarly indicates that organizational and pedagogical challenges are as important as technical availability (Prihadi et al., 2021).

4.4 Equity, accessibility, and the full access chain

Access was multidimensional. Reliable electricity, affordable data, bandwidth, device quality, screen size, accessibility features, repair, and sufficient time on a non-shared device all affected participation. Household-level ownership could conceal unequal control over a device or data package. Evidence from Indonesia and regional reviews documents persistent digital divides by geography, socioeconomic position, gender, and institutional capacity (UNICEF Indonesia, 2021; International Telecommunication Union, 2023; Liang et al., 2023).

Accessibility required more than technical compliance. Neurodiverse learners, students with disabilities, users of older phones, and learners working in a second language could encounter interface complexity, inaccessible multimedia, inconsistent terminology, or excessive cognitive load (Anapey et al., 2025). Place-based research in India further challenged standardized claims that platform scale automatically produces empowerment, showing that access and autonomy, in-person relationships, and perceived quality shaped actual use (Pathak-Shelat & Bhatia, 2024).

Usability evidence from a major Indonesian commercial platform identified actionable interface concerns but did not establish learning effectiveness (Kusuma et al., 2024). This distinction is important: usability is a prerequisite for reaching a task, not proof that the task develops digital literacy. Evaluation should separately test accessibility, usability, pedagogical quality, and learning outcomes.

4.5 Teacher competence, institutional coherence, and AI governance

Teacher competence was the principal mechanism connecting platform affordances to learning. Professional development limited to one-off technical workshops was insufficient. Teachers needed subject-specific design knowledge, accessible-content practices, online safeguarding, assessment of digital artefacts, interpretation of analytics, and opportunities to review student work with colleagues (Falloon, 2020; Redecker, 2017). Research on AI-assisted lesson curation likewise positioned teacher judgment as necessary for customization in low-resource settings (Dennison et al., 2026).

Institutional coherence influenced whether teachers could exercise that judgment. Schools often accumulated overlapping applications without a clear architecture for identity management, technical support, data retention, procurement, interoperability, or evaluation. Fragmentation increased cognitive load and generated multiple data trails. A defensible selection process begins with learning outcomes and user needs, then examines accessibility, privacy, evidence quality, interoperability, total cost, and the ability to migrate content and records.

AI intensified these requirements. Companies reported difficulty translating fragmented ethical expectations into reliable, transparent, safe, and equitable product practices (Kousa & Niemi, 2023). Personalization research identified potential advantages but also reinforced the need for human-in-the-loop oversight (Bhutoria, 2022). Algorithmic recommendations, automated assessment, and generative content should therefore be treated as contestable inputs to professional decisions, not as self-validating outputs.

4.6 Comparative synthesis: Indonesia, Malaysia, and Thailand

Indonesia combined public digital resources, commercial mobile platforms, school-level learning management systems, and global productivity tools. The strongest evidence concerned conditions rather than isolated platform effects. National and international reports identified gaps between connectivity supply and educational demand, while empirical work operationalized digital literacy across media use, platform management, ethics, and safety (International Telecommunication Union, 2023; UNICEF Indonesia, 2021; Harmawati et al., 2024). Spatial evidence connected ICT literacy with reading-literacy variation but did not identify a causal platform effect (Annisawati & Oktora, 2024).

Malaysia provided longer-standing evidence on a nationally scaled virtual learning environment. Teacher perceptions, technical support, and pedagogical integration shaped implementation, and a mathematics study found positive potential in a specific context (Ramli & Saleh, 2019; Phoong et al., 2020). Digital-citizenship evidence emphasized safety and well-being, and comparative digital-library research showed that intention, habit, and context influenced sustained use (Mahadir et al., 2021; Habibi et al., 2022). These results support continued teacher and institutional support rather than assuming that national scale guarantees classroom value.

Thailand contributed strong measurement work. Validated indicators emphasized cognitive, technical, and social-emotional dimensions of digital literacy (Techataweewan & Prasertsin, 2018). Direct independent comparisons of Thai local and global platform configurations remained limited in the verified source set. Regional policy evidence consequently supports competence frameworks and evaluation capacity while leaving important causal questions unresolved (Global Education Monitoring Report Team & SEAMEO, 2023).

Across the three systems, evidence was more consistent about enabling conditions than platform superiority. A regional survey of policy makers also suggested that system capacity and learning priorities may not align automatically with enthusiasm for EdTech investment (Yarrow et al., 2024). The appropriate policy question is not which platform category is universally best, but which combination of tools, tasks, support, and safeguards produces verifiable and equitably distributed learning.

Table 3. Comparative synthesis for Indonesia, Malaysia, and Thailand.

Country	Evidence emphasized	Most defensible conclusion	Priority evidence gap
Indonesia	Digital divide and connectivity; multidimensional digital literacy; ICT and reading literacy; platform usability	Benefits depend on reliable access, broad competence development, teacher mediation, and usable interfaces	Longitudinal and quasi-experimental studies linking specific platform practices to authentic digital-literacy growth
Malaysia	Teacher implementation of Frog VLE; subject-specific platform use; digital citizenship; digital-library adoption	Technical support and pedagogical integration are central; safety and well-being must accompany access	Representative school-level outcome studies across subjects, locations, and learner groups
Thailand	Validated digital-literacy indicators and regional policy evidence	Competence frameworks can guide curriculum and assessment, but platform-level outcome evidence remains thin	Independent comparisons of local-global configurations, including equity and accessibility effects

4.7 Secondary meta-analysis of learning outcomes

The quantitative branch included 30 eligible contrasts: 13 hardware estimates from five publications and 17 software estimates from nine publications. Hardware interventions included computers, interactive whiteboards, and One Laptop per Child programs. Software interventions included educational games, electronic worksheets, multimedia packages, and personalized adaptive learning. The source review reported highly heterogeneous effects and did not conduct a full meta-analysis (Jordan & Myers, 2022). The present analysis therefore used random effects and conservative small-sample intervals.

At publication level with rho = 0.50, hardware-focused interventions produced a pooled effect of d = -0.055 (95% CI -0.251 to 0.141; tau-squared = 0.022; I-squared = 94.2%). The 95% prediction interval was -0.513 to 0.403. Software-focused interventions produced d = 0.217 (95% CI -0.024 to 0.458; tau-squared = 0.088; I-squared = 90.7%), with a prediction interval of -0.510 to 0.944. The overall pooled effect was d = 0.117 (95% CI -0.051 to 0.286; I-squared = 95.1%). These prediction intervals show that both benefit and harm remain plausible in a new setting.

Meta-regression estimated a software-versus-hardware difference of 0.268 standard deviations (95% CI -0.055 to 0.591; p = 0.096). The point estimate favored software, but the moderator did not reach conventional statistical significance under the conservative publication-level model. Results were sensitive to the assumed within-publication correlation. With rho = 0, the software estimate was 0.234 (95% CI 0.018 to 0.450); with rho = 0.80, it was 0.178 (95% CI -0.122 to 0.478). Hardware remained near zero across assumptions.

The less conservative contrast-level sensitivity analysis treated the 30 effects as independent. It estimated d = -0.054 for hardware (95% CI -0.149 to 0.042), d = 0.245 for software (95% CI 0.092 to 0.397), and d = 0.106 overall (95% CI 0.001 to 0.212). This analysis reproduced the directional pattern in the source figures but should not be preferred because it ignores correlation among outcomes reported by the same publication.

Study-level effects varied substantially. Positive software results were reported in educational-game, multimedia, and personalized-adaptive-learning studies, including trials in India, China, and Malawi (Banerjee et al., 2007; Lai et al., 2015; Mo et al., 2015; Muralidharan et al., 2019; Pitchford et al., 2019). However, one electronic-worksheet configuration was negative, and hardware studies ranged from positive to negative (Barrera-Osorio & Linden, 2009; Berlinski & Busso, 2013; Cristia et al., 2010; Sharma, 2014). The quantitative evidence therefore supports a conditional, not deterministic, interpretation of modality.

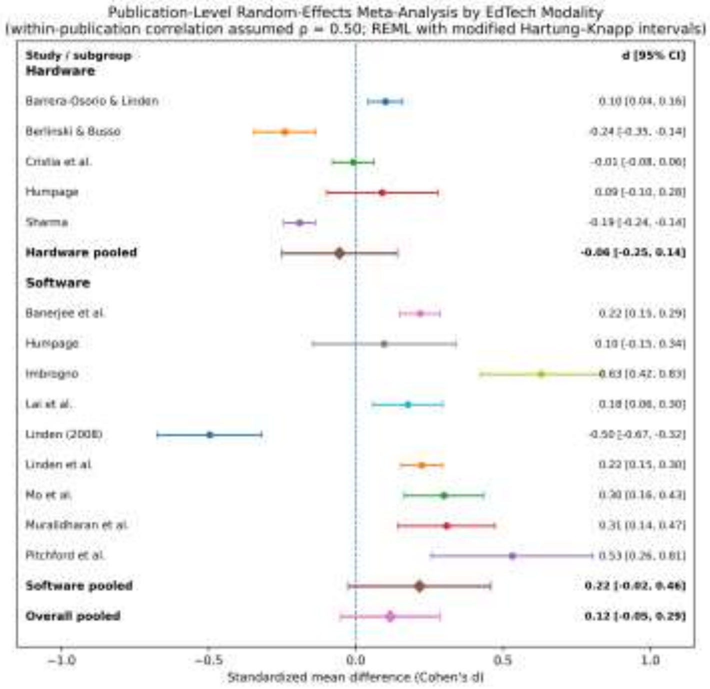

Figure 3. Publication-level random-effects meta-analysis by EdTech modality. Multiple contrasts were aggregated within publication and modality assuming rho = 0.50. Pooled estimates use restricted maximum likelihood and modified Hartung-Knapp confidence intervals.

Table 4. Primary publication-level random-effects meta-analysis (rho = 0.50).

Model	Publication units	Pooled d	95% CI	I^2	tau^2	95% prediction interval
Hardware	5	-0.055	-0.251 to 0.141	94.2%	0.022	-0.513 to 0.403
Software	9	0.217	-0.024 to 0.458	90.7%	0.088	-0.510 to 0.944
Overall	14 modality-specific units; 13 unique reports	0.117	-0.051 to 0.286	95.1%	0.077	-0.505 to 0.739

5. Discussion

5.1 Principal findings

The systematic review and meta-analysis converge on a central conclusion: EdTech contributes through practices, support, and governance rather than through technological presence. Local and global platforms offered complementary affordances, but those affordances became educationally valuable only when teachers organized meaningful tasks and when institutions secured equitable access, usability, accessibility, and responsible data practices. The evidence does not support a simple claim that more platform adoption produces more digital literacy.

The quantitative results reinforce this conclusion without proving it. Hardware distribution alone had a pooled effect close to zero, whereas software-focused interventions had a more positive average direction. The publication-level software confidence interval crossed zero, the modality moderator was not definitive, and heterogeneity was extreme. Nevertheless, the pattern is coherent with prior evidence that personalized or instructionally structured technology can support learning in some low- and middle-income contexts (Major et al., 2021; Muralidharan et al., 2019). It is equally coherent with evidence that poorly integrated technology can have negative or gap-widening effects (Ahn, 2022).

5.2 Why software is not a sufficient explanation

The hardware-software distinction should not be reified. 'Software' in the included studies represented different pedagogies: practice games, electronic worksheets, multimedia packages, and adaptive learning. Their effects depended on content quality, feedback, pacing, alignment, implementation, and the relationship between technology and teacher instruction. Similarly, hardware programs varied in deployment, training, content, and opportunity cost. Modality is therefore a proxy for design features rather than a causal mechanism.

A more useful interpretation is that hardware is enabling infrastructure, while learning requires an instructional system. Devices, connectivity, and electricity are necessary for many digital practices, but they do not specify what learners will do, what feedback they will receive, or how misconceptions will be addressed. Investment decisions should accordingly budget for content, teacher learning, accessibility, technical support, evaluation, and maintenance rather than treating device procurement as a complete intervention.

5.3 Local relevance, global reach, and public value

Local-global complementarity is asymmetric. Global platforms can supply mature infrastructure and broad resources, but they may externalize curricular adaptation, accessibility work, privacy risk, and dependency to local institutions. Local providers may understand national language and curriculum but lack scale, interoperability, or independent evidence. Public policy should coordinate these capacities rather than assuming that market competition will produce an optimal ecology.

Open standards, portable content, federated identity where appropriate, transparent service levels, and enforceable data-exit provisions can reduce dependency. Procurement should require evidence of accessibility and pedagogical value, not only feature lists or user counts. Platform governance should clarify ownership, lawful processing, retention, consent, advertising, algorithmic decision making, intellectual property, and procedures for contesting automated outputs.

5.4 Implications for curriculum, assessment, and professional learning

Curricula should define observable digital-literacy practices before specifying technologies. Examples include verifying a source, documenting search decisions, creating licensed content, collaborating with traceable contributions, protecting personal data, disclosing AI assistance, troubleshooting a workflow, and reflecting on tool selection. These outcomes can be assessed through artefacts, performance tasks, process logs, oral justification, and transfer to an unfamiliar platform.

Teacher professional learning should be continuous, subject-specific, and evidence-generating. Teachers need structured opportunities to design a task, test it with diverse learners, examine artefacts, identify accessibility and misconception patterns, revise the sequence, and share results in professional communities. This approach integrates technical capability with pedagogy, content knowledge, ethics, and assessment rather than separating them into a one-time software tutorial.

Institutions should evaluate the full access chain. Connectivity indicators should distinguish nominal coverage from reliable bandwidth and affordable use. Device indicators should account for sharing, age, repair, accessibility, and sustained availability. Learning indicators should be disaggregated by location, gender, disability, language, and socioeconomic position. Average adoption can otherwise conceal systematic exclusion.

5.5 Research agenda

Future studies should evaluate platform configurations rather than isolated brands. Intervention reports should document teacher preparation, task design, content, dosage, feedback, platform settings, access conditions, implementation fidelity, and assessment. Longitudinal and quasi-experimental designs should use authentic digital-literacy performance measures and report transfer across tools. Mixed-method studies are needed to explain why the same configuration benefits one group while burdening another.

Quantitative syntheses require better reporting of sample sizes, group means, standard deviations, intraclass correlations, and covariance among multiple outcomes. Researchers should distinguish hardware provision, content, teacher support, adaptive logic, and communication functions rather than coding a complex intervention as simply 'technology.' Data and analysis code should be made available when ethically permissible.

Regional collaboration through ASEAN and SEAMEO could support shared accessibility protocols, privacy templates, evaluation instruments, open educational resources, and repositories of independently evaluated learning tasks. Cooperation should preserve national and local adaptation while reducing duplicated technical work. The objective should be interoperable public value, not uniform platform dependence.

6. Limitations

This study has six principal limitations. First, the supplied Scopus export did not preserve the original search string. The corpus and screening log are reproducible, but a prospective database rerun is required to reproduce identification from first principles. Second, the 60-record Scopus evidence map was based on titles, abstracts, and metadata. Detailed causal or quality judgments were not inferred from records that were not available as full text.

Third, the critical synthesis relied on 23 sources already integrated in the source manuscript and 15 citation-chained intervention reports. Where primary reports were unavailable, claims were limited to information reported in the verified source or secondary review. Fourth, effect sizes were digitized from published forest plots rather than reconstructed from participant-level or complete summary data. Digitization adds measurement uncertainty that is not represented in the reported standard errors.

Fifth, multiple effects within publications required an assumed correlation. Sensitivity analyses showed that the software confidence interval depended partly on this assumption. The contrast-level analysis was intentionally labeled less conservative. Sixth, the meta-analysis concerned girls' learning outcomes in low- and middle-income countries, not direct measures of digital literacy and not specifically Indonesia, Malaysia, or Thailand. It provides an indirect quantitative test of the pedagogy-over-presence proposition and should not be generalized as a regional causal estimate.

Finally, heterogeneity was very high and prediction intervals were wide. The pooled estimates summarize a distribution of diverse interventions rather than a single stable effect. Risk-of-bias ratings and certainty judgments should be updated after complete retrieval of primary reports if the manuscript is prepared for a journal that requires formal RoB 2, ROBINS-I, or GRADE tables.

7. Conclusion

Local or nationally oriented and global EdTech platforms can jointly support digital literacy and learning, but their contribution is neither automatic nor uniform. Local platforms can strengthen curricular, linguistic, and cultural relevance; global platforms can broaden resources, production capabilities, interoperability, and collaborative reach. Educational value emerges when teachers orchestrate these affordances through tasks that require learners to evaluate information, create and communicate responsibly, protect data and well-being, solve problems, and regulate learning.

The secondary meta-analysis provides cautious quantitative support for the same logic. Hardware-focused interventions were near zero on average, while software-focused interventions had a more positive but heterogeneous and statistically imprecise publication-level effect. The result favors investment in instructional design, teacher capability, feedback, accessibility, and governance rather than device distribution alone. It does not justify a universal claim that software is effective.

For Indonesia, Malaysia, Thailand, and comparable education systems, the strategic priority is not to maximize platform adoption. It is to build coherent, equitable, and governable digital-learning ecologies in which local relevance, global connectivity, professional judgment, and learner protection reinforce one another, and in which value is verified through authentic assessment and independent evaluation.

Appendix A. Reconstructed Search Concept Blocks

The historic Scopus query was not embedded in the supplied export. The following syntax is an auditable reconstruction of the concepts represented in the fixed corpus and is not claimed to be the exact original query: TITLE-ABS-KEY(("educational technology" OR edtech OR "digital learning" OR "learning platform" OR "learning management system" OR "artificial intelligence" OR platformization OR "digital transformation") AND ("digital literacy" OR "digital competence" OR pedagogy OR "learning outcome*" OR equity OR inclusion OR accessibility OR governance OR privacy) AND (local OR national OR global OR ecosystem* OR "low-resource" OR "low- and middle-income" OR "Southeast Asia" OR Indonesia OR Malaysia OR Thailand)). A final submission should rerun and date the search in Scopus and, where required, at least one additional database.

Appendix B. Meta-analytic Sensitivity Summary

Table 5. Sensitivity analyses for dependence and analysis level.

Analysis	Modality	k	Pooled d	95% CI
Publication-level, rho = 0.0	Hardware	5	-0.055	-0.252 to 0.143
Publication-level, rho = 0.0	Software	9	0.234	0.018 to 0.450
Publication-level, rho = 0.5	Hardware	5	-0.055	-0.251 to 0.141
Publication-level, rho = 0.5	Software	9	0.217	-0.024 to 0.458
Publication-level, rho = 0.8	Hardware	5	-0.054	-0.246 to 0.139
Publication-level, rho = 0.8	Software	9	0.178	-0.122 to 0.478
Contrast-level; independence assumed	Hardware	13	-0.054	-0.149 to 0.042
Contrast-level; independence assumed	Software	17	0.245	0.092 to 0.397
Contrast-level; independence assumed	Overall	30	0.106	0.001 to 0.212

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