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Beyond Digital Literacy: An Integrative Review of AI-Era Digital Citizenship Competencies for Elementary Students

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Abstract
The rapid development of generative artificial intelligence (AI) has changed the way children access information, create content, communicate, and participate in the digital environment. owever, digital literacy and AI literacy are still studied separately, leaving basic education without a competency framework that integrates technological capabilities with responsible digital participation. This research aims to review, critique, and synthesize the literature on digital literacy, AI literacy, digital citizenship, and AI education to reconceptualize the literacy competencies of elementary school students. An integrative literature review was conducted through a structured multi-source search of publications in 2021–2026. After full-text verification and assessment of the role of evidence, 27 publications were selected as the main analytical corpus, while four additional publications were used as conceptual and contextual sources. The data were analyzed through critical comparison and thematic synthesis. The results of the study show that AI literacy does not replace digital literacy,and but expands transforms it. The foundations of digital literacy include information and data investigation, media and multimodal literacy, digital communication and creation, and safety, privacy, identity, and rights. The foundation is extended through conceptual understanding of AI, articulation of intent in human–AI interactions, critical verification and bias evaluation, ethical and social reasoning, human agency and authorship, and AI-assisted problem-solving and creation. The synthesis yields an Integrated Digital Citizenship Framework in the AI Era for Elementary Students, which anchors these competencies within pedagogical support, teachers, families, schools, access, and equity thereby guiding students toward critical, ethical, safe, inclusive, responsible, and agency-driven participation. This framework offers a conceptual basis for curriculum development, teacher professional development, and performance-based assessment in primary education.

Keywords:
AI literacy; Digital literacy; Digital citizenship; Elementary education; Integrative literature review

A. INTRODUCTION

Artificial intelligence, especially generative AI, is changing the way humans access information, produce content, communicate, learn, and participate in a digitally mediated society. Unlike earlier digital technologies that primarily supported the storage, transmission, or retrieval of information, contemporary generative AI systems can produce new content, interact conversationally with users, and increasingly mediate educational and informational practices (UNESCO, 2023). These developments create new educational demands concerning personal data, machine-generated information, human–AI decision-making, and the social and ethical consequences of automated systems (Akgun & Greenhow, 2022; UNESCO, 2023). For children, these concerns extend beyond technical proficiency because AI systems may affect their privacy, safety, autonomy, opportunities,

identities, and participation in digital environments (Akgun & Greenhow, 2022; UNICEF, 2021). Therefore, preparing elementary school students to face the AI era should be understood as part of a broader effort to cultivate digital citizenship—the capacity to participate critically, ethically, safely, inclusively, responsibly, and with agency in a society increasingly mediated by intelligent systems. This orientation is consistent with UNESCO's AI Competency Framework for Students, which emphasizes a human-centered mindset, ethics, human agency and responsible engagement with AI, as well as UNICEF's child-centered guidance that emphasizes children's rights, privacy, safety, inclusion, and meaningful participation in an AI-mediated environment (UNESCO, 2024; UNICEF, 2021).

Digital literacy provides an indispensable foundation for these educational efforts. Contemporary digital competence encompasses information and data literacy, communication and collaboration, digital content creation, safety, and critical and responsible engagement with digital technologies (Vuorikari et al., 2022). DigComp 2.2 has explicitly incorporated more than 250 updated examples of knowledge, skills, and attitudes, including those related to AI-driven and other emerging technologies, demonstrating that digital literacy is not an outdated concept but an evolving competence framework responsive to technological change (Vuorikari et al., 2022). Nevertheless, established digital-literacy frameworks were largely developed before the widespread educational use of generative AI and therefore do not always make explicit the challenges introduced by systems that generate content, infer patterns from data, and interact with users in increasingly autonomous ways (Falloon, 2020; UNESCO, 2023). These characteristics complicate students' interactions with digital information because AI-generated outputs may obscure their underlying sources, data, limitations, and potential biases, thereby increasing the importance of critical evaluation and human judgment (Akgun & Greenhow, 2022; Long & Magerko, 2020). Consequently, information inquiry must increasingly include verification of AI-generated responses; media literacy must address synthetic and manipulated content; digital creation must consider human authorship, attribution, and disclosure of AI assistance; and digital safety must extend to data privacy, algorithmic bias, and responsible human oversight (UNESCO, 2023; Vuorikari et al., 2022). The central question, therefore, is not whether digital literacy should be replaced, but how its foundational competencies should be retained, extended, and transformed for AI-mediated interaction.

AI literacy emerged in response to these new demands. Early conceptual studies defined AI literacy as a set of competencies necessary to understand, interact with, and critically evaluate AI systems. These competencies include the ability to recognize AI, understand data and machine learning, evaluate the strengths and limitations of these systems, and identify the role of humans in its development and use (Long & Magerko, 2020). A subsequent framework categorizes AI literacy into the abilities to know and understand AI, use and apply it, evaluate and create with AI, and consider ethical issues (Ng et al., 2021). More recent K–12 frameworks have expanded this construct to include confidence, collaboration, self-reflection, agency, social impact, and responsible use (Chiu et al., 2024). At the policy level, the AI competency framework for students developed by UNESCO identifies four interrelated domains, namely human-centered mindset, AI ethics, AI techniques and applications, and AI systems design. UNESCO also emphasizes that the implementation of this framework must be tailored to students' prior knowledge, curricular contexts, teacher readiness, and the broader educational environment. These developments indicate that AI literacy is increasingly understood as a multidimensional educational construct, rather than merely a technical ability to program or operate AI devices.

Although the conceptualization of AI literacy continues to evolve, the literature still shows a gap between education levels and discipline traditions. Research on digital literacy and digital citizenship has built a broad foundation that includes critical use of information, media participation, communication, content creation, digital security, and digital rights. In parallel, research on AI literacy has resulted in a variety of models that focus on knowledge about AI, computational thinking, human-AI interaction, critical evaluation, ethics, and systems creation. However, AI literacy education is still largely still developed for secondary and high school levels, or rooted in computer science and engineering perspectives that cannot be applied directly to elementary school students. A review conducted by Yim (2024) suggests that frameworks specifically appropriate for basic education are still not adequately developed and propose a more inclusive understanding of the

interactions between humans and technological agents. A subsequent review of 25 empirical studies in elementary schools found increased integration of constructivist learning, project-based learning, programming, computational thinking, and intelligent agents. However, there is considerable variation in learning content, pedagogical approaches, assessments, learning outcomes, and handling of ethical issues (Yim & Su, 2025). Global initiatives at the primary school level also implement practical and collaborative activities, but their implementation is still hampered by access gaps, limited teacher readiness, and inconsistent curricular and institutional support (Yeter et al., 2024).

Another limitation is the tendency of literature to emphasize the operational and technical dimensions more than the critical, sociocultural, and civic dimensions. A review of AI literacy programs for children and adolescents shows that operational forms of AI literacy are still more dominant, while the critical and sociocultural dimensions receive relatively less attention (Atias & Mawasi, 2025). Teaching children to recognize AI or create simple models is an important step, but it doesn't necessarily prepare them to question whose data is represented, how algorithmic decisions can distribute opportunities, which perspectives are underrepresented, or who should be held accountable for adverse outcomes. Therefore, a critical perspective on AI literacy is critical because it expands learning beyond the ability to use and understand AI to the capacity to question, criticize, and reconsider social, political, cultural, and ethical implications (Veldhuis et al., 2025). At the same time, these expectations must be aligned with the characteristics of the child's development. Research on AI literacy in primary education emphasizes active, hands-on, collaborative, and project-based approaches that enable young learners to engage with abstract AI concepts through concrete, socially mediated experiences (Yeter et al., 2024; Yim & Su, 2025). The development of these competencies is also influenced by parental mediation, school policies, teacher readiness, infrastructure, access and equity (Guo et al., 2025; Yeter et al., 2024). Therefore, AI literacy in primary education must be conceptualized as an architecture of individual competencies and as a development path supported by an ecosystem geared towards responsible participation.

Previous studies have produced several important bodies of knowledge, but they remain fragmented. Existing digital literacy frameworks describe foundational competencies for navigating the digital environment, while AI literacy frameworks formulates new competencies for understanding and interacting with intelligent systems. Reviews focusing on the primary school level provide evidence on age-appropriate pedagogical tools and approaches, while child-centred policy guidelines emphasize rights, protection, participation, and inclusion. However, the field still lacks an integrative conceptualization that simultaneously: (a) maintains the essential foundations of digital literacy; (b) explains the transformation of these foundations through interaction with AI; (c) distinguishes among technical, critical, ethical, creative, and agency-based competencies; (d) considers the developmental and ecological conditions of primary education; and (e) directs all competencies toward digital citizenship in the AI era. Thus, the gap is not the absence of an AI literacy model, but the lack of an integrative architecture tailored to primary education that connects digital foundations, expands AI competencies, and supports both developmental pathways and civic participation.

This fragmentation makes integrative literature review the most appropriate methodological approach. An Integrative review is designed to examine dynamic and rapidly evolving topics, particularly when diverse or partially conflicting literature bust be reviewed, critiqued, and synthesized into new perspectives or conceptual frameworks (Torraco, 2016). Therefore, this study reviews, critically analyzes, and synthesizes the literature on digital literacy, digital citizenship, AI literacy, and AI education in primary schools to address the following questions.

1. What competencies are identified in the literature on digital literacy, digital citizenship, and AI literacy that are relevant to elementary school students?
2. What limitations arise when conventional digital literacy competencies are applied in the context of children's interaction with AI systems?
3. What developmental, pedagogical, and ecological conditions affect the development of literacy in the AI era in basic education?
4. How the foundations of digital literacy and AI-specific competencies can be integrated to support AI-era digital citizenship in elementary school students?

The review mainly focused on elementary school-age students, typically aged 6 to 12 years, as well as on the dimensions of pedagogical literacy, development, ethics, and citizenship, compared to advanced AI system engineering. The main contribution of this research is the Integrated Digital Citizenship Framework in the AI Era for Elementary Students, which is a layered competency architecture that maintains the foundations of digital literacy, expands those foundations through AI-specific competencies, places learning in a supportive developmental and ecological context, and directs competency development towards participation digital that is critical, ethical, safe, inclusive, responsible, and institution-driven. This research positions AI literacy not as a substitute for digital literacy, but as a necessary reconceptualization in an era where children are increasingly involved with an agent and influential technology system.

B. METHODS

1. Research Design and Review Purpose

This study uses an integrative literature review (ILR) to examine how the literacy competencies of elementary school students should be reconceptualized in line with the widespread use of AI, especially generative AI, in education and the daily information environment. This method was chosen because the topics in this review are rapidly evolving, multidisciplinary, and represented by a diverse array of empirical studies, review articles, conceptual frameworks, and ecosystem-oriented research. The review process follows Torraco's (2016) guidance. The operational sequence of this study also adapts the conceptual, empirical, and interpretive phases summarized by Christmals and Gross (2017).

The main goal of this review is to develop a conceptual framework, not just to calculate the magnitude of the impact. Therefore, this review combines the concepts of digital literacy, digital competence, digital citizenship, AI literacy, and AI education, as well as pedagogical conditions and relevant environments for elementary schools. The expected outcome is a framework that describes the enduring foundations of digital literacy, competencies that require transformation in an AI-mediated environment, as well as the development support and ecosystem that enables these competencies to thrive.

2. Search Strategy and Source Identification

Structured multi-source searches were conducted across Google Scholar, SpringerLink, and ScienceDirect. Three members of the research team retrieved the sources using a combination of search terms related to digital literacy, digital competence, AI literacy, AI education, generative AI, children, and primary education. The documented search protocol implemented a 2021–2026 publication year limit and focused on English-language journal articles. Because digital and AI literature often develop in separate streams, the searches were executed through multiple query groups rather than by requiring each publication to mention digital literacy, AI literacy, and primary education simultaneously.

This search strategy is designed to identify the corpus that conceptually represents, not to claim the full scope of the database. The initial search archive doesn't store the total number of results generated by each query or complete deduplication log. Therefore, this study reports the final corpus of successfully verified texts and the analytical role of each source, rather than presenting a conventional PRISMA flowchart detailing the stages from database identification to final inclusion.

Table 1. Documented Search Sources and Query Groups

Source	Search Focus	Documented Query Examples	Operational Note
Google Scholar	Digital literacy, digital competence, AI literacy, AI education, and generative AI	"digital literacy" "primary education"; "digital competence" "elementary school"; "AI literacy"; "artificial intelligence literacy" education; "AI education" children; "generative AI" education	Phrase-based searches; publication filter since 2021.

Source	Search Focus	Documented Query Examples	Operational Note
SpringerLink	Digital literacy and AI literacy in primary/elementary education	"digital literacy" AND "primary education"; "digital competence" AND "elementary school"; "AI literacy"; "artificial intelligence literacy" education; "generative AI" education	Article, English, and 2021–2026 filters were documented.
ScienceDirect	Separate digital-literacy and AI-literacy streams plus child-focused AI education	("digital literacy" OR "digital competence" OR "digital competencies") AND ("primary education" OR "elementary school" OR "primary school"); ("AI literacy" OR "artificial intelligence literacy" OR "AI education" OR "generative AI") AND (education OR learning); ("AI literacy" OR "artificial intelligence education") AND (children OR "young learners")	Article, English, and 2021–2026 filters were documented.

3. Eligibility Criteria and Evidence Boundaries

The feasibility of publication is determined based on the characteristics of the document, its conceptual relevance, the educational context, and the limitations of the use of evidence in synthesis. Empirical studies, article reviews, and conceptual publications are maintained because the integration of diverse forms of evidence is a fundamental goal of the ILR methodology. Evidence obtained from teachers, parents, policy documents, and assessments is used to explain ecosystem conditions or conceptual foundations, rather than as a direct representation of student competencies.

Table 2. Eligibility Criteria

Criterion	Inclusion	Exclusion or boundary rule
Publication period	Publications dated 2021–2026.	Publications outside the documented corpus period; earlier sources were used only for methodological or foundational comparison and were not coded.
Language and format	English-language journal articles, including empirical studies, reviews, conceptual papers, and scholarly commentaries.	Non-English publications and non-scholarly web materials.
Topical relevance	Digital literacy, digital competence, digital citizenship, AI literacy, AI education, generative AI in education, or closely related constructs.	Purely technical AI-engineering studies without literacy, pedagogical, ethical, or citizenship relevance.
Population/context	Elementary/primary students; broader K–12, child, or youth evidence when conceptually transferable; teacher, parent, policy, measurement, and conceptual studies relevant to the elementary ecosystem.	Higher-education-only studies without direct conceptual or contextual relevance to elementary or K–12 education.
Evidence use	Direct primary-school and school-age evidence for competency claims; teacher/parent/conceptual evidence for ecosystem and framework interpretation.	Teacher or parent evidence was not treated as a proxy for students' competencies; adjacent-age studies were not generalized as elementary-only findings.

4. Full-Text Verification and Corpus Construction

The final archive consists of 33 published and accessible full texts of literature. Each publication was matched against a literature inventory and then evaluated for bibliographic details, year of publication, journal outlets, research context or author affiliation, population or research corpus, methodological design, thematic scope, and relevance to the research question. This verification

process aims to correct inaccuracies and misclassifications of the initial metadata, thus establishing the limits of proof that can be proven by each source.

The evidence is further classified according to its analytical role. Core analytical sources provide direct evidence from elementary school students, focused reviews of elementary education, or broader school-age studies that have strong relevance to the constructs being studied. Contextual or supporting resources are aimed at teachers, parents, assessments, policies, conceptual foundations, or adjacent developmental contexts. A total of 27 publications are retained as the main analytical corpus, consisting of 14 core analytical sources and 13 contextual or supporting sources. Four additional publications were used for triangulation and to enrich conceptual interpretations, but these publications were not treated as coding units and were excluded from thematic frequency calculations. Two studies that focused exclusively on higher education were excluded from the study. The flow of the corpus construction is illustrated in Figure 1.

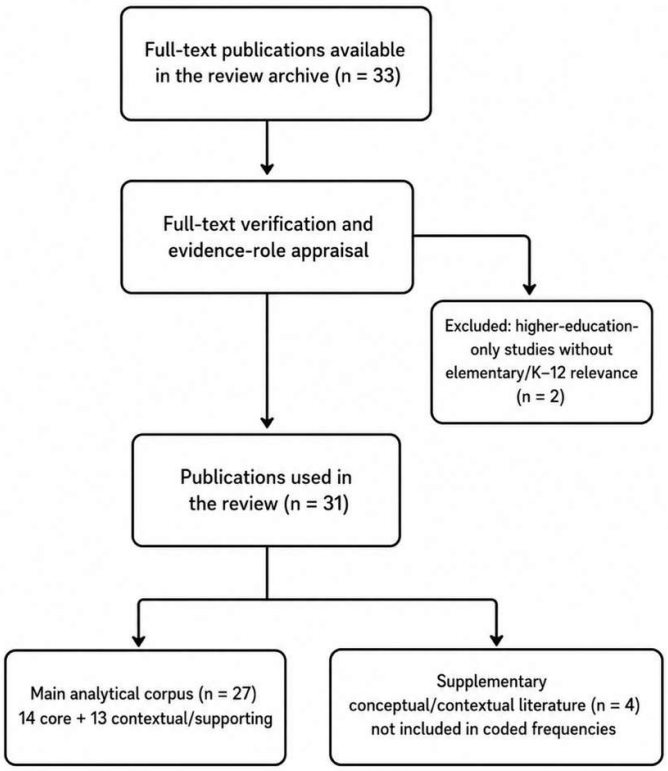


Figure 1. Verified Corpus-Construction Flow

5. Data Extraction, Critical Analysis, and Integrative Synthesis

Data are extracted into a structured matrix containing author details, year of publication, journal outlet, geographic context, thematic focus, research population or corpus, methodological design, and key findings. Early coding uses information literacy, media literacy, communication, AI awareness, rapid literacy, AI ethics, human-AI collaboration, and digital citizenship as sobering concepts. These categories are treated as temporary categories because the initial matrix contains overlapping constructions and some conclusions that require further full-text verification.

Analysis is carried out through repeated data reduction, data presentation, fixed comparison, conclusion drawn, and verification. Each temporary code is cross-checked with its full text; Unsupported codes have been removed, overlapping codes are merged, and clear distinctions are made between student competencies, developmental progress or proficiency, and ecosystem support. Cross-study patterns were then compared to identify the sustainable foundations of digital

literacy, the specific expansion of AI, contradictions, conceptual vacuums, and developmental boundary conditions. The resulting themes are mapped into a conceptual framework, and each construction proposal is traced back to its supporting sources before the framework is finalized.

Critical analysis focused on the contributions and limitations of the reviewed literature. Particular attention was paid to whether the technology was treated as a passive tool or as an interactive AI system; whether the research addressed verification, algorithmic bias, synthetic media, authorship, responsibility, and human agency; and whether the proposed aligned with the developmental stages of primary school students. Studies of teachers and parents were analyzed as evidence of ecosystems, rather than as direct measures of student competencies.

6. Critical Appraisal and Methodological Transparency

A single standardized quality assessment instrument is not applied because the corpus comprised quantitative, qualitative, and mixed-methods research, alongside review articles, conceptual publications, and scientific commentary. Instead, a narrative critical assessment was integrated into the full-text verification and and extraction processes. Each source was evaluated based on its methodological design, study population or corpus, transparency of design, clarity of relevance, and the types of claims that could be substantiated by the evidence. Sources were not treated equally: core analytical evidence was utilized to construct competency and pedagogical themes, while contextual evidence is primarily used to interpret ecosystem conditions, policies, assessments, and conceptual foundations.

Several methodological safeguards were implemented to strengthen interpretive transparency. Additional publications were excluded from thematic frequency calculations; K–12 or adolescent evidence was not reported as primary school student-specific evidence; self-report instruments were explicitly distinguished from performance-based competency measures; and studies on digital literacy or augmented reality were not automatically considered evidence of AI literacy or human–AI collaboration. Because the total number of initial database results was unavailable was unavailable, this study did not claim exhaustive coverage. After the inductive synthesis was completed, the assessment component of the framework was theoretically refined using the SOLO Taxonomy (Biggs & Collis, 1982) to operationalize the requirements for developmentally sensitive and performance-based assessments. The SOLO Taxonomy was not treated as an inductive theme and was excluded from corpus frequency calculations.

C. RESULTS AND DISCUSSION

1. Results

The full-text verification process retained 27 publications as the main analytical corpus. Fourteen publications provided core evidence directly related to primary education or digital literacy and AI among school-age children, while 13 publications provided contextual evidence regarding teachers, parents, assessments, policies, and conceptual foundations. Coding validation replaced the initial binary checkmark system with a distinction between direct and contextual support. From this process, ten cross-study themes were reconstructed regarding the foundations of digital literacy, AI-specific transformations, developmental and ecological conditions, and assessments. Table 3 summarizes these themes and their interpretive functions.

Table 3. Validated Cross-Study Themes

No.	Theme	Core constructs	Interpretive result
1	Digital-literacy foundations remain necessary	Information/data inquiry; media and multimodal literacy; digital communication/creation; safety, privacy, identity, and rights	These capacities are retained rather than displaced by AI literacy.
2	AI literacy adds conceptual understanding of intelligent systems	AI concepts, data, algorithms/models, capabilities, limitations	Learners need to recognize how AI differs from conventional digital tools.

No.	Theme	Core constructs	Interpretive result
3	AI interaction requires intent articulation	Purposeful questioning, age-appropriate prompting, iterative refinement	Prompting is treated as a subcompetency, not a stand-alone literacy.
4	Verification and ethical reasoning become central	Accuracy, sources, hallucination, bias; fairness, transparency, accountability, inclusion	Epistemic checking and normative judgment are related but analytically distinct.
5	Human agency and responsibility must be preserved	Control, judgment, authorship, attribution, accountability	Collaboration with AI should not transfer responsibility to the system.
6	Problem solving and creation extend beyond coding	Computational thinking, model construction, design, testing, creative production	Technical construction is integrated with critical and sociocultural learning.
7	Digital citizenship is the integrative outcome	Safe, ethical, critical, inclusive, responsible, and agentic participation	Literacy is oriented toward participation in an AI-mediated society.
8	Young learners require active and developmentally appropriate pedagogy	Play, projects, construction, STEAM, games, tangible activity, guided inquiry	Abstract concepts become accessible through concrete and socially mediated activity.
9	Teacher and ecological support are boundary conditions	Teacher readiness; parental mediation; school policy; infrastructure; access and equity	These conditions enable competence but are not student competencies.
10	Assessment must distinguish perception from performance	Self-report, performance tasks, scenarios, artifacts, developmental progression	Perceived familiarity cannot substitute for demonstrated competence.

Source: Authors' synthesis based on the validated corpus.

Digital Literacy as the Retained Foundation

The first theme highlights the enduring nature of foundational competencies. Digital literacy studies within primary schools continue to emphasize information inquiry, media interpretation, digital communication and creation, and safe participation. Aprilia (2025) demonstrated that digital literacy in the early grades is embedded in literacy routines, the use of electronic libraries, teacher support, infrastructure, and community involvement. Scholes et al. (2024) associated gaming experiences with students' perceived digital competencies, including media practices, networked learning, collaboration, creativity, and problem-solving, while demonstrating the influence of gender and socio-economic conditions. Nevrelova et al. (2024) found that augmented reality activities could support visualization, motivation, and collaboration, while Mansour et al. (2026) report an increase in digital media literacy through connected STEAM learning. Furthermore, Li et al. (2024) proposed a child-focused measurement structure encompassing digital identity, use, safety, security, emotional intelligence, literacy, and rights.

These findings do not support replacing digital literacy with a completely different AI literacy framework. In contrast, digital literacy serves as a basic prerequisite when children engage with AI systems: they still have to find and interpret information, understand multimodal messages, communicate and create, and protect their privacy, identity, and rights. The limitations of conventional digital literacy are historical and functional, not absolute. Most studies treat technology as a resource, medium, or passive environment, but do not explicitly account for agent systems that generate new content, infer patterns from data, respond conversationally, and influence decisions. Therefore, this synthesis maintains the four core domains of digital literacy while transforming its application in AI-mediated interactions.

AI-Specific Competencies: From Operation to Critical and Sociotechnical Literacy

The second group of themes describes the competencies needed when children interact with agent and generative systems. Reviews focusing on basic education place AI literacy at the intersection of digital literacy, data literacy, computational thinking, ethics, and human-AI interaction (Yim, 2024; Yim & Su, 2025). The corpus analyzed attests to the emergence of six AI-specific domains:

conceptual understanding of AI; interaction and articulation of intentions; critical verification and bias evaluation; ethical and social reasoning; human agency, collaboration, and authorship; and AI-assisted troubleshooting and creation.

Conceptual understanding includes the ability to recognize AI, identify the role of data and models, and understand the capabilities and limitations of systems. This competency is very important because the changing output of natural language can obscure the probabilistic nature of these systems and the human decision-making that underlies their development. Interaction and articulation of intent involves formulating purposeful questions, providing context, and refining interactions over and over again. However, there is still not enough evidence to establish rapid literacy as a stand-alone domain. Rapid practices are emerging only in a subset of the corpus and range from simple question formulation to more systematic rapid design (Feng & Carolus, 2026; Yeter et al., 2024). As a result, impulses are positioned as more enduring subcompetencies, specifically the ability to articulate goals, evaluate responses, and revise interactions.

This synthesis also distinguishes critical verification from ethical reasoning. Verification addresses whether AI-generated outputs are accurate, adequately sourced, logically consistent, transparent regarding their limitations, and free from bias. Ethical and social reasoning evaluates whether AI practices are fair, transparent, accountable, inclusive, and socially responsible. This distinction is crucial because outputs can be factually accurate but ethically problematic, or conversely, designed for ethical purposes but lack epistemic reliability. The current lack of emphasis on these higher-order dimensions is evident in Wu et al. (2024): only 35.71% of the analyzed K–12 classroom videos discussed advanced evaluation or creation, while AI ethics was featured in a mere 5.1%. Atias and Mawasi (2025) also found that operational literacy dominated AI programs for children, while sociocultural and critical literacies were the least represented. Corroborating this, Veldhuis et al. (2025) further emphasized the need for a critical AI literacy that enables children to question, critique, and transform the social, political, cultural, ecological, and ethical implications of AI.

Human-AI collaboration was reconceptualized as an agency-sensitive competency. The core issue extends beyond merely whether students can generate useful outputs, encompassing whether they maintain critical judgment, authorship, accurate attribution, and ultimate responsibility. This domain safeguards against collaboration devolving into uncritical dependency or wholesale delegation. Furthermore, AI-assisted problem-solving and creation were defined more broadly than mere programming. While model construction, computational thinking, design, testing, and creation remain vital, the literature indicates that they must be integrated with critical interpretation, social awareness, and accountable use objectives (Atias & Mawasi, 2025; Yim & Su, 2025; Yu, 2025).

Developmental and Ecological Boundary Conditions

The third group of themes shows that a framework for primary school students cannot be built simply by reducing adult competence or higher education. Age-appropriate AI learning is most often associated with an active, concrete, and socially mediated approach. Project-based learning, constructionism, game-based learning, manipulative activities, STEAM, guided inquiry, storytelling, and collaborative problem-solving allow children to engage with abstract concepts through observable actions and artifacts (Lee, 2026; Wu et al., 2024; Yeter et al., 2024; Yim & Su, 2025). The game-based curriculum developed by Lee (2026) shows that data, simple algorithms, quick choices, fairness, accountability, and security can be effectively operationalized through routines, manipulative objects, storytelling, and guided dialogue. Because this study involved pre-K and kindergarten children, these findings were used as evidence of adjacent developmental stages, rather than as direct evidence for the entire elementary school age range.

Teacher, family, and institutional factors emerged as possible conditions compared to student attributes. Teacher surveys consistently identify a lack of readiness, digital competence, time, resources, infrastructure, confidence, and professional development as significant barriers to implementation (Ábalos-Aguilera et al., 2026; Loureiro et al., 2024; Maulyda et al., 2025; Robandi et al., 2025). However, Yeter et al. (2024) also point to gaps and limited access in teacher preparation as a global challenge. The family dimension has also proven to be an integral part: Guo et al. (2025) found that parents' AI literacy contributes to their self-efficacy in supporting children's education.

Therefore, this framework positions pedagogy, teacher scaffolding, parental mediation, school policy, access, and equality as ecological supports that encompass the competency architecture. This separation prevents the unification of the environmental context with individual traits and reinforces the premise that the achievement of competencies depends on fair learning opportunities.

Assessment and Developmental Progression

The last group of findings relates to the assessment methodology. The AI literacy instruments reviewed were largely characterized by the scale of self-reports. A systematic review conducted by Lintner (2024) identified 13 self-report instruments but only three performance-based instruments, with a limited psychometric evidence record on some of these instruments. For example, the AIL-SAQ developed by Thianwan and Srikoon (2026) for upper primary school students provides a reliable measure of students' perceptions of learning about AI, how AI works, and life with AI; However, the instrument measures self-perception, not actual performance. Consequently, assessment is positioned as a cross-domain principle and not a stand-alone student competence. The corpus demonstrates the need for developmentally sensitive assessments that combine self-reflection with performance tasks such as source verification, scenario evaluation, interaction observation, verbal explanation, and the creation of authentic artifacts. However, the corpus does not reveal a consensus on a single developmental taxonomy. Therefore, the selection of the SOLO Taxonomy as a progression lens is explained in the Discussion section as a refinement of the post-synthesis theory.

Conceptual Integration and Framework Synthesis

The process of conceptual bridging results in three different forms of transformation. First, basic competencies are maintained: information research, media literacy, communication and creation, and safety and human rights remain important. Second, its practical application has undergone a transformation. Information search is evolving into AI-assisted investigations coupled with rigorous source verification; media literacy extends to the interpretation of synthetic content; digital creation includes repeated interactions between humans and AI, transparent disclosure of AI use, and authorship; and digital security extends to data governance, automated decision-making, fairness, and accountability. Third, AI-specific competencies are introduced, such as understanding AI models and their limitations, evaluating biases, maintaining human agency, and solving problems either with or through the development of AI systems.

These transformations are consolidated into the Integrated AI-Era Digital Citizenship Framework for Primary Students. Within this framework, digital citizenship is positioned not merely as an additional skill, but rather as the overarching intended outcome: the ability to participate critically, ethically, safely, inclusively, responsibly, and agencyfully in a society increasingly shaped by AI. The architecture of this framework is illustrated in Figure 2.

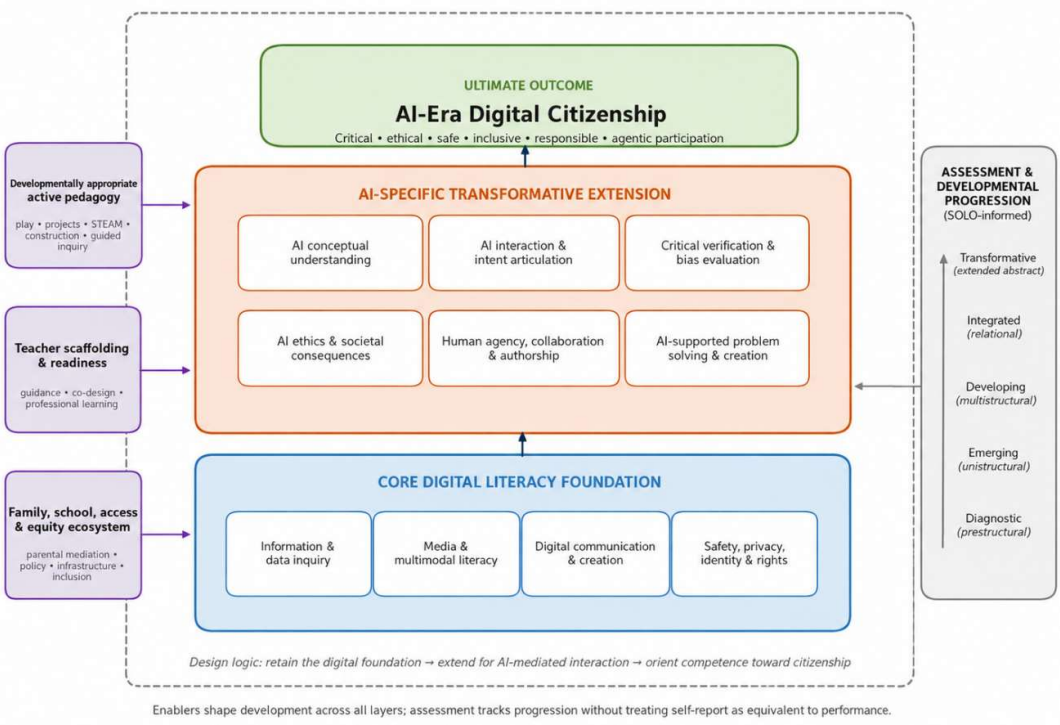


Figure 2. Integrated AI-Era Digital Citizenship Framework for Elementary Students
Note. The framework is an integrative inference from the validated corpus. Student competencies are separated from developmental and ecological enablers, while a SOLO-informed assessment lens tracks progression across all layers.

2. Discussion

The main contribution of this review is the reconceptualization of the relationship between digital literacy and AI literacy in primary education. These findings do not support AI literacy as a simple substitution model or a standalone technical subject. Instead, the relationships observed are cumulative and transformative: basic digital literacy practices are still needed, but their implementation evolves as children interact with systems capable of generating content, inferring patterns, and participating in conversations or decision-making processes. This interpretation is in line with the DigComp 2.2 framework, which maintains the core digital competency domain while integrating AI-related examples and new technologies, rather than replacing the underlying structure (Vuorikari et al., 2022). This is also in line with Falloon's (2020) statement that digital competence must go beyond mere technical skills to include ethical, safe, productive, and context-sensitive participation. The proposed framework extends this conceptual resilience argument to elementary school students and makes the transformation of the AI era more explicit.

Relationship to Established AI-Literacy Frameworks

The proposed framework is aligned with the basic model of AI literacy, but differs in its specific goals and architecture. Long and Magerko (2020) define AI literacy as the competency to critically evaluate AI, communicate and collaborate with AI, and apply AI in daily life. Similarly, Ng et al. (2021) categorize AI literacy into four dimensions: knowing and understanding, using and applying, evaluating and creating, and addressing ethical issues. While these models remain important references, they still emphasize more on the functional and evaluative aspects of AI literacy. For the context of basic education, the framework proposed in this study provides three main improvements, namely: linking AI literacy to the foundations of digital literacy, distinguishing epistemic verification from ethical and social considerations, and placing student agency and authorship as explicit elements in human–AI collaboration.

The latest frameworks further confirm that AI literacy and competence are multidimensional. Chiu et al. (2024), for example, distinguish literacy as mastery of knowledge about AI from competence as the ability to apply this knowledge meaningfully, while incorporating aspects of technology, impact, ethics, collaboration, and self-reflection in the context of K–12 education. In line with that, UNESCO (2024) organizes students' AI competencies into four main domains, namely human-centered mindset, AI ethics, AI techniques and applications, and AI system design, with the development of competencies from the stage of understanding to application and creation. The framework proposed in this study is consistent with this orientation, but offers additional affirmations in the form of a preserved foundation of digital literacy, a final orientation to digital citizenship in the AI era, as well as a clearer distinction between the competencies that need to be developed in students and the supporting conditions that teachers, schools, and families must provide.

To clarify the position and conceptual contribution of the proposed framework, it is necessary to make a comparison with a number of frameworks and guidelines that have been influential in the development of digital literacy and AI literacy. This comparison shows that the framework developed in this study is not intended to replace previous frameworks, but rather to integrate and expand them in the context of basic education. In particular, the framework maintains the foundations of digital literacy, accommodates AI-specific competencies, affirms student agency and authorship, incorporates ecological support, and directs competency development in the digital citizenship of the AI era. The comparison is summarized in Table 4.

Table 4. Comparison with Established Frameworks and Guidance

Reference framework	Primary emphasis	Distinct contribution of the proposed framework
Long & Magerko (2020)	Critical evaluation; communication/collaboration; use of AI; 17 competencies and design considerations	Retains evaluation and collaboration, but adds elementary digital foundations, agency/authorship, ecological enablers, and citizenship outcome.
Ng et al. (2021)	Know and understand; use; evaluate; ethical issues	Disaggregates evaluation into verification/bias and ethics/social consequences; embeds use in developmental pedagogy.
Chiu et al. (2024)	Technology; impact; ethics; collaboration; self-reflection; distinction between literacy and competency	Adds continuity with digital literacy and separates learner competence from family/school conditions.
UNESCO (2024)	Human-centered mindset; ethics; techniques/applications; system design; progression from understanding to creation	Retains the human-centered orientation while adding a citizenship outcome, elementary ecological supports, and a SOLO-informed cross-cutting assessment lens.
DigComp 2.2 (Vuorikari et al., 2022)	Information/data; communication/collaboration; content creation; safety; problem solving, updated for AI	Provides the retained digital foundation that is transformed through AI-specific competencies.
UNICEF (2021)	Child rights, development, inclusion, fairness, privacy, safety, transparency/accountability, preparation, enabling environment	Supplies a child-rights and ecosystem rationale for AI-era digital citizenship.

Theoretical Contribution: Epistemic Responsibility and AI-Era Citizenship

The epistemic-ethical distinction represents a significant theoretical contribution. Broad frameworks usually place "evaluation" and "ethics" alongside technical knowledge, but the basic education curriculum requires clarity regarding the specific nature of the evaluative processes involved. Epistemic responsibility has to do with the ability of students to question AI-generated outputs, look for corroborating evidence, recognize uncertainties, and detect data or model bias. Instead, ethical responsibility addresses broader issues regarding justice, privacy, accountability, inclusion, power dynamics, and social consequences. This demarcation is reinforced by the K-12 ethics literature, which argues that risks related to privacy, oversight, autonomy, bias, and accountability cannot be mitigated through technical instruction alone (Akgun & Greenhow, 2022). These differences are increasingly aligned with UNESCO's emphasis on critical engagement and human-centered ethical judgment (UNESCO, 2024).

Putting digital citizenship as the end product of the framework can expand the scope of Ai literacy beyond just operational proficiency. Atias and Mawasi (2025) study shows that the dominance of operational literacy over critical literacy indicates that a balance between the two dimensions will not be formed automatically in the curriculum. In line with these findings, Veldhuis et al. (2025) defines critical AI literacy as the capacity to question, criticize, and even transform the social and cultural conditions surrounding the use of AI. The framework proposed in this study translates that orientation into broader developmental goals: students not only need to be able to operate and evaluate AI, but also need to be empowered to participate responsibly, recognize represented and ignored interests and perspectives, and hold agencies to reject, correct, or propose fairer uses of AI. Thus, readiness to face the future is not reduced to adaptability to technology, but includes the capacity to assess and shape the way technology is used in social life.

In this context, human agency is an important element to prevent AI literacy from stopping at the ability to interact with interfaces. Generative AI interfaces can make interactions appear to resemble interpersonal communication, while obscuring the decisions of humans, data, labor, and the institutional interests that make up the system. Therefore, Yim (2024) emphasized that AI literacy in elementary schools needs to consider the relationship between human and non-human agents. The framework proposed in this study responds to these needs by placing attribution, decision-making authority, accountability, and authorship as important parts of human–AI collaboration. By implication, the quality of AI-assisted products is judged not only by the quality of their output, but also by the ability of students to explain the contribution of AI, conduct critical verification and revisions, and maintain responsibility for the final decisions and products produced.

Curriculum and Pedagogical Implications

The proposed framework calls for a curriculum shift from isolated technical training to learning that integrates inquiry, creation, critical analysis, and participation. The basics of digital literacy do not have to be limited to informatics classes; Instead, competencies can be developed across disciplines—including language arts, civics, science, mathematics, and the arts. AI-specific competencies can then be integrated into age-appropriate tasks, such as comparing search results to AI-generated responses, observing how simple data changes affect classification results, identifying missing perspectives from recommendations, iteratively refining instructions or prompts when documenting changes, and transparently revealing the use of AI in collaborative work. In this way, learning maintains its disciplinary purpose while transforming the AI workflow into objects that can be observed, investigated, and critically discussed.

The pedagogical approach must also be in harmony with the developmental characteristics of elementary school students. Learning must evolve from concrete experience to more abstract understanding, and from mere application to critical evaluation. The literature supports the use of games, projects, construction activities, STEAM, hands-on assignments, and guided investigations, while UNESCO (2024) emphasizes the progression from understanding to application and creation. However, this development does not mean that ethical considerations should be postponed until students have mastered the technical aspects. Issues of justice, privacy, openness, representation, and responsibility can be introduced early on through scenarios relevant to children's experiences, while technical complexities are introduced gradually. Yang (2022) and Lee (2026) show that AI

concepts can be introduced through stories, concrete coding activities, and routines that children are already familiar with. This kind of approach is especially important because the ability of elementary school students to understand concepts and evaluate the accuracy of their own beliefs is still developing.

This pedagogical implication requires strengthening the capacity of teachers. Falloon (2020) framework for teachers' digital competence and studies in the literature show that teachers need more than just operational knowledge about technology. They need to be able to assess when the use of AI provides educational value, model the verification and transparency process related to the use of AI, protect students' privacy and well-being, and facilitate ethical discussions. Ng et al. (2021) also highlight that school readiness, teacher AI competence, and AI literacy and student ethical awareness are significant challenges in integrating AI into education. Therefore, teachers need support through clear guidelines, access to verified tools, technical assistance, and organizational learning at the school level. In this way, the responsibility for meaningfully integrating AI falls not only on individual teachers but becomes part of a broader institutional readiness framework.

Child Rights, Family Mediation, Access, and Equity

The ecological layer is not just a supporting aspect of implementation, but an important condition that determines whether the development of AI literacy takes place fairly and protects the interests of children. UNICEF's guidance on AI for children places safety and well-being, data protection and privacy, non-discrimination and justice, transparency and accountability, inclusion, and respect for children's rights as key principles for the development and use of AI (UNICEF, 2021). This perspective is relevant to the context of K–12 education because the use of AI also presents a risk of algorithmic bias, privacy violations, surveillance, and reduced student autonomy, especially for underrepresented or underserved groups (Akgun & Greenhow, 2022). At the elementary school student level, identity protection, safety, security, and digital rights have also been positioned as an important part of children's competencies in the digital environment (Li et al., 2024). Thus, education that only requires children to "use AI responsibly" is not adequate if the AI system, school policies, and access conditions surrounding them are not transparent, safe, and fair.

Within the framework of this research, equality can be understood through three interrelated dimensions. First, equality of access, which includes the availability of devices, connectivity, age-appropriate technology, and pedagogical support that allows students to have comparable learning opportunities. The issue of access and readiness for implementation is still an important challenge in AI literacy education at the school level (Yeter et al., 2024), while school readiness and teachers' AI competencies also determine the ability of institutions to integrate AI meaningfully (Ng et al., 2021). Second, equality of representation, namely the ability and opportunity of students to question whose language, culture, group, and experience are represented or not represented in AI data and outputs. This dimension is important because AI systems can reproduce or reinforce biases that are already present in the data and the underlying social structure (Akgun & Greenhow, 2022). Third, participatory equality, namely the availability of opportunities that are appropriate to children's development to express their views, raise concerns, question the use of AI, and participate in the preparation of rules for its use in the learning environment (UNESCO, 2024; UNICEF, 2021). These three dimensions affirm that AI literacy is not only about individual competencies, but also about the opportunities available to every child to learn and participate safely, equally, and meaningfully.

Family mediation is another integral part of the ecosystem because a child's experience with AI extends beyond the classroom through voice assistants, recommendation systems, digital entertainment, search engines, and learning support devices. Empirical evidence suggests that parents' AI literacy is related to their self-efficacy in supporting elementary school children's education (Guo et al., 2025). These findings demonstrate the importance of strengthening school–family communication and providing learning support that allows parents to understand the opportunities, limitations, and risks of AI. At the same time, differences in social and economic conditions can affect children's digital experiences and competencies, so schools cannot assume that all families have equal access, knowledge, and mentoring capacity (Scholes et al., 2024). Therefore, the development of equitable AI literacy needs to be understood as a shared responsibility between students, teachers, families, schools, and the education system, not as an individual responsibility of

children.

Assessment implications

Assessment needs to be aligned with the conceptual differentiation between knowledge, interaction, verification, ethical reasoning, creation, and participation. The self-report scale cannot show whether students are able to verify false citations, recognize unfair classifications, explain model limitations, or maintain authorship during co-creation. Therefore, a balanced assessment system can include brief self-reflection, scenario-based ethical assessments, performance tasks that demand source checks and prompt revisions, AI-assisted product artifacts, and verbal explanations of student decisions. Its main function should be formative and diagnostic, not just classification.

To operationalize these developmental needs, the framework uses the progression informed by the SOLO Taxonomy (Biggs & Collis, 1982). Different from the categories of cognitive processes such as knowing, applying, evaluating, and creating useful ones for designing goals or tasks, SOLO assesses the quality of the visible learning outcome structure. The progression moves from diagnostic (prstructural), emerging (unistructural), developing (multistructural), integrated (relational), to transformative (extended abstract). Thus, students are assessed based on the shift from the introduction of one aspect, towards several aspects that are still separate, the integration of technical-critical-ethical dimensions, and the transfer of understanding to new situations. SOLO is used as a post-synthesis theoretical refinement, not as a theme inductively generated from the corpus. This approach needs to be combined with the methodological caution of (Lintner, 2024) and Thianwan and Srikoon (2026): self-perception is valuable for reflection, but should not be treated as equivalent to performance-based competence.

Policy Implications and Research Agenda

At the policy level, this framework can serve as a curriculum design heuristic, rather than a rigid universal checklist. UNESCO (2024) emphasizes that the global framework needs to be tailored to local readiness, curriculum, teacher competence, and students' initial abilities. The same principle applies to this framework. Education authorities need to determine cross-grade progression, map the integration of competencies into subjects, establish child protection and data governance, provide tools that have been reviewed, and support teacher and parent learning. UNESCO's guidelines on generative AI also emphasize human-centered regulation, data protection, age-appropriateness, and institutional validation of the tools used (UNESCO, 2023). Curriculum reform therefore needs to go hand in hand with governance.

The proposed framework results in five research priorities. First, the structure needs to be validated through expert assessment, child-centered design, and classroom studies at various levels. Second, performance-based instruments and scenarios are needed that complement self-reports. Third, longitudinal research needs to examine how digital foundations support AI-specific competencies and whether epistemic verification and ethical reasoning are evolving at different rates. Fourth, ecological research needs to examine the interaction of teacher readiness, family mediation, school policies, infrastructure, language, and socio-economic conditions with student achievement. Fifth, cross-cultural research needs to examine the meaning of constructs and civic goals in different curricula and communities, especially in contexts that are still underrepresented in the literature.

Interpretive Limitations

Findings need to be interpreted within the limits of the study. The search was conducted in a structured manner on three sources, but it was not a thorough systematic search with a complete record of initial identification and deduplication. The analytical corpus combines empirical studies, review articles, conceptual publications, and contextual evidence; Some school-age studies also cover a wider age range than basic education. Therefore, the framework is an integrative synthesis that is informed by theory, not prevalence estimates or validated developmental models. The external framework used in the Discussion serves for comparison and interpretation, but is not included in the 27 publications encoded. Empirical testing can necessitate the renaming, merging, or separation of constructs, while retaining its core architectures: digital foundations, AI-specific transformations, developmental and ecological support, assessment progression, as well as AI-era digital citizenship.

D. CONCLUSION

This study integrates the literature on digital literacy, AI literacy, digital citizenship, and basic education to formulate relevant competencies for elementary school students in the AI era. The synthesis shows that AI literacy does not replace digital literacy, but expands and transforms it. Information and data investigation, media and multimodal literacy, communication and digital creation, and safety, privacy, identity, and rights remain foundations. Interaction with AI then demands conceptual understanding, articulation of intent, verification of outputs and biases, ethical and social reasoning, maintenance of agency and human responsibility, and AI-assisted problem-solving and creation.

The main contribution of this research is the Integrated AI-Era Digital Citizenship Framework for Elementary Students. The framework connects the foundations of digital literacy with the expansion of AI-specific competencies and directs them to AI-era digital citizenship, namely critical, ethical, safe, inclusive, responsible, and agency participation. This framework goes beyond separate competency mapping by placing child development, teacher scaffolding, family mediation, school support, access, and equality as possible conditions. SOLO-based progressions are used as a cross-domain assessment lens to distinguish fragmented understandings from integrated, transferable understandings.

In practical terms, this framework can serve as a starting basis for curriculum development, learning design, teacher professional development, and AI literacy assessments in elementary schools. Learning is not enough geared towards the skills of using devices, but it needs to equip students to assess the reliability of AI outputs, understand the consequences of their use, protect data and digital rights, and maintain human responsibility in AI-powered decisions.

This research has limitations. Literature search cannot be claimed to be exhaustive because it depends on available sources and archives. The corpus is also heterogeneous in design, population, level, and definition of construction; Some sources provide direct evidence from elementary school students, while others provide conceptual or ecological evidence. In addition, the resulting framework is still conceptual and has not been empirically validated.

Further research needs to examine frameworks in various primary school contexts, develop performance-based assessment instruments and SOLO rubrics, and examine competency development longitudinally. Future research also needs to examine the role of teachers, parents, school policies, and access gaps in shaping AI literacy in children. Cross-cultural and cross-level validation is needed for the framework to be refined into a more adaptive, measurable, and usable model in basic education policies and practices.

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