

Navigating the Digital-AI Frontier: A Comparative Thematic Synthesis of Global Digital Learning Skills Frameworks for Inclusive Primary Education

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ABSTRACT:

In the era of generative artificial intelligence (GenAI) and post-pandemic educational restructuring, primary education urgently requires a redefined conception of digital learning skills—one that is explicitly inclusive of students with special educational needs (SEN). This study provides a comparative thematic synthesis of four authoritative international frameworks: the European DigComp 2.2, ISTE Standards for Students, UNESCO AI Competency Framework for Students (2024), and the Digital Intelligence (DQ) Global Standards. Guided by Social Constructivism, Connectivism, Self-Regulated Learning (SRL), and Universal Design for Learning (UDL), the analysis reveals a decisive paradigm shift from technical-procedural tool usage toward a holistic matrix of cognitive, socio-emotional, and ethical competencies. Five thematic clusters are identified across all frameworks: information and data literacy, communication and collaboration, digital content creation, safety and well-being, and computational problem-solving. A critical cross-cutting finding is the systematic absence of explicit SEN provisions in every framework examined—constituting a structural gap in global digital education policy. A widening “Usage-Training Gap,” wherein approximately 86% of primary students engage with AI tools daily while fewer than half receive formal guidance, disproportionately disadvantages learners with SEN. The study proposes a five-domain conceptual matrix that integrates accessibility and UDL as a foundational dimension, positioning digital learning skills as a mediating variable between technological infrastructure and inclusive academic outcomes. Recommendations address policymakers, special education practitioners, and curriculum designers, emphasizing a shift from

physical access equity (Divide 1.0) to skill agency equity (Divide 2.0).

Keywords: digital learning skills; special educational needs; inclusive primary education; critical AI literacy; universal design for learning; connectivism; self-regulated learning.

1. Introduction

The global landscape of primary education is undergoing an unprecedented transformation driven by the convergence of generative artificial intelligence (GenAI), learning analytics, and immersive technologies (Akintayo et al., 2024). While digital transformation in education has been a priority for decades, the post-pandemic era has accelerated the shift from technology-enabled teaching to a structured, data- and AI-driven instructional paradigm. In this context, primary education serves as a critical developmental phase for laying the foundational cognitive, emotional, and social skills necessary for lifelong learning in a technology-saturated society (Akintayo et al., 2024). Consequently, the definition of digital learning skills has evolved from a focus on technical-procedural abilities to a holistic set of cognitive and socio-emotional proficiencies rooted in ethical values (UNESCO, 2024; Vuorikari et al., 2022). The integration of these competencies with social-emotional learning is essential for fostering holistic student development, enabling learners to navigate complex interpersonal relationships – and emotional regulation within increasingly automated environments (Akintayo et al., 2024). However, current academic research indicates that existing literacy models often struggle to account for the unique and rapidly evolving requirements of generative artificial intelligence (Yim, 2024).

Despite widespread recognition of its importance, the academic and policy discourse surrounding digital learning remains fragmented. Current scholarly literature highlights a “usage-training gap,” whereby a vast majority of students and teachers use AI and digital tools daily, yet fewer than half have received formal guidance on safe or ethical application (Center for Democracy & Technology, 2025). Furthermore, most existing frameworks predominantly emphasize technical skill

quantification while underrepresenting the ethical and societal dimensions necessitated by the rapid adoption of AI (Almatrafi et al., 2024; Chiu et al., 2024). The inconsistency in AI literacy standards across different learner groups exacerbates this fragmentation, leaving practitioners without a unified reference for curricular design (Chee et al., 2024).

For primary school students, whose cognitive development is still maturing and whose capacity for critical discernment is frequently limited, the digital environment presents serious risks, including cyberaddiction, privacy exposure, and misinformation (DQ Institute, 2024). Recent research suggests that while general-purpose GenAI tools can enhance task performance, they do not necessarily yield genuine learning gains unless guided by clear pedagogical principles (OECD, 2025). This underscores the urgent need for Critical AI Literacy within digital learning skills frameworks – emphasizing questioning, interpreting, and reflecting on the assumptions and implications of AI systems, rather than mere tool implementation (Hackl et al., 2026). Furthermore, as cognitive offloading to algorithmic partners becomes increasingly prevalent, students must cultivate metacognitive strategies to distinguish between efficient tool use and the potential erosion of foundational critical thinking skills (Xu et al., 2025). Beyond technical proficiency, this evolution requires frameworks that integrate self-reflective mindsets, ensuring that students apply knowledge in ethically beneficial ways (Chiu et al., 2024).

A notably underexplored dimension of this discourse concerns students with special educational needs (SEN), who are disproportionately affected by both the opportunities and risks inherent in digital learning environments. The absence of explicit SEN considerations in major international digital learning

frameworks represents a critical structural gap: despite calls for inclusive digital education, most global standards remain implicitly designed around the neurotypical, non-disabled learner (Kong & Hu, 2026). This study therefore examines leading digital learning skills frameworks through an inclusive education lens, assessing their applicability and limitations for diverse primary school populations, including those with SEN.

This study aims to address these gaps by providing a comparative thematic synthesis of four prominent international Digital Learning Skills Frameworks: the European Digital Competence Framework (DigComp 2.2), the ISTE Standards for Students, the UNESCO AI Competency Framework for Students (2024), and the Digital Intelligence (DQ) Global Standards. By analyzing structural commonalities and thematic shifts within these frameworks, this review seeks to identify how global standards can be adapted to foster resilient, creative, and responsible digital citizens at the primary level, with particular consideration for students with SEN (Kong & Hu, 2026). The analysis is anchored in Social Constructivism, Connectivism, Self-Regulated Learning (SRL), and Universal Design for Learning (UDL), viewing inclusive learning as a networked journey shaped by technology, diversity, and adaptability (CAST, 2018; Xu et al., 2025).

2. Theoretical Framework

The framework integrates four complementary theoretical lenses. Social Constructivism – rooted in Vygotsky (1978) – posits that knowledge is actively constructed through social interaction and cultural tools. In the digital age, technologies mediate the Zone of Proximal Development (ZPD) through interactive software and collaborative platforms (Sun et al., 2020). For students with SEN, AI-driven adaptive systems can function as powerful ZPD scaffolds by dynamically adjusting task difficulty and feedback modality to individual profiles, making progressive digital competency practically achievable for diverse learners (Dong et al., 2025).

Connectivism – proposed by Siemens (2005) – frames learning as a process of connecting specialized nodes: people, databases, and AI agents. The most critical twenty-first-century competency is

accordingly “know-where” rather than “know-what” – the ability to locate, evaluate, and traverse information networks (Bogiannidis et al., 2023). For students with SEN, this implies that accessibility of learning nodes is as important as their functional richness: students with visual impairments require audio-based nodes; students with physical disabilities require accessible interface architectures. A Connectivist-informed inclusive framework must treat universality of access as foundational.

Self-Regulated Learning (SRL) theory (Winne & Hadwin, 1998) highlights that digital environments – less structured than traditional classrooms – demand higher-order metacognitive skills: task definition, goal setting, enactment, and reflective monitoring (Zhao, 2024). Without these capacities, primary learners risk cognitive overload in complex hypermedia environments (Salmerón et al., 2021; Torrington et al., 2022). For students with SEN – particularly those with ADHD, executive function difficulties, or anxiety – SRL development requires externally structured scaffolding (step-by-step guides, visual timers, AI-driven progress feedback) before independent self-regulation is achievable. Frameworks that assume SRL as a baseline competency inadvertently exclude this population (Anders & Speltz, 2025).

Universal Design for Learning (UDL; Rose & Meyer, 2002; CAST, 2018) provides the critical bridge between generic competency frameworks and SEN practice. Its three principles – multiple means of representation, action and expression, and engagement – translate directly into requirements for digital skills frameworks: competency standards must specify not only what skills are required but how they can be demonstrated across diverse modalities, including assistive technologies and augmentative and alternative communication (AAC) systems. This synthesis adopts UDL as a design standard for the next generation of digital learning skills frameworks, ensuring that the shift toward AI literacy is genuinely inclusive rather than implicitly exclusionary.

3. Conceptual Framework

Integrating these four theoretical paradigms with global standards, this study proposes a five-domain

model for digital learning skills in inclusive primary education. The model treats accessibility not as a retrofit but as a structural dimension:

- **Technical-Functional Domain:** Device operation and competency in assistive and adaptive technologies.
- **Cognitive-Metacognitive Domain:** Goal setting and metacognitive prompting to navigate generative AI environments.
- **Cognitive-Critical Domain:** Finding, evaluating, and synthesizing information; identifying misinformation and algorithmic bias – the core of Critical AI Literacy (Hackl et al., 2026; Yim, 2024).
- **Socio-Communicative Domain:** Collaboration, ethical communication, and digital identity management, accommodating diverse communication styles including Augmentative and Alternative Communication (AAC) users (Akintayo et al., 2024).
- **Ethical-Reflective and Accessibility Domain:** Digital well-being, data privacy ethics, AI ethical awareness, and knowledge of accessibility rights (DQ Institute, 2024; UNESCO, 2024).

The model posits that Digital Learning Skills mediate between the Digital Learning Atmosphere (infrastructure, teacher support, accessible technology) and inclusive academic outcomes. Higher digital skill levels enhance digital self-efficacy, a relationship that is especially fragile for students with SEN following early negative encounters with inaccessible technology (Kong & Hu, 2026).

4. Methodology

This study employs a Qualitative Comparative Analysis (QCA) integrated with a Thematic Synthesis approach (Malik & Terzidis, 2025), systematically coding the core pedagogical objectives and skill pathways of each framework to identify underlying structural patterns that purely descriptive reviews overlook (Bećirović et al., 2025; Chen, 2025).

Framework Selection

Four frameworks were selected against three criteria: (1) Authority and international scope – issuance by intergovernmental organizations or recognized educational innovators; (2) Temporal relevance – updated or released 2020–2025 to reflect the GenAI era (Vuorikari et al., 2022); (3) Pedagogical granularity – inclusion of descriptors for primary education (ages 5–11). A fourth criterion was added for this inclusive analysis: (4) Accessibility scope – the extent to which frameworks explicitly address SEN or reference universal design principles.

Comparative Dimensions and Synthesis Process

Each framework was evaluated across: (1) Vision and Rationale (underlying educational philosophy); (2) Competency Domains (specific skill clusters); (3) Proficiency Stratification (mastery levels for primary learners); and (4) Assessment Mechanisms (including whether assessment modes accommodate students with SEN). The three-phase synthesis followed descriptive mapping of framework content, thematic clustering of disparate skill sets into unified strands, and integrative synthesis identifying current gaps – particularly the insufficient integration of accessibility within AI-specific domains. To minimize subjective bias, two researchers independently coded the frameworks; discrepancies were resolved through expert consensus review (Dong et al., 2025; Chiu et al., 2024).

5. Results

Thematic Convergence across Frameworks

The analysis of five major frameworks – DigComp 2.2, ISTE, UNESCO AI (2024), DQ Global Standards, and the Singapore ICT Masterplan 2030 – reveals high structural alignment. Whereas frameworks from 2014–2019 prioritized technical-procedural knowledge, current iterations emphasize a “holistic matrix” integrating cognitive, socio-emotional, and ethical competencies (Tzafilkou et al., 2022; Almatrafi et al., 2024), signalling a decisive shift from static digital literacy toward dynamic algorithmic navigation capacity. As shown in Table

2, five thematic clusters are consistently identified across all frameworks: Information and Data Literacy, Communication and Collaboration, Digital Content Creation, Safety and Well-being, and Computational Problem Solving. The

additional accessibility row in Table 2 reveals the structural gap: none of the five frameworks includes systematic SEN provisions or references Universal Design for Learning as a design principle.

Table 1. Comparative Analysis of Core Dimensions in International Digital Learning Skills Frameworks with SEN/Accessibility Annotations

Cluster	DigComp 2.2	ISTE Standards	UNESCO AI (2024)	DQ Standards	Singapore MP 2030	SEN/UD L Gap
Information Literacy	Information & Data Literacy	Knowledge Constructor	Understand AI Principles	Digital Literacy L1–3	Find & Think	Limited multimodal options
Communication	Comm. & Collaboration	Global Collaborator	Collaborative Interaction	Digital Comm. Intelligence	Apply & Create	AAC unaddressed
Content Creation	Digital Content Creation	Innovative Designer	AI Co-creation & Design	Digital Creativity	Create (Artefacts)	No flexible expression modes
Safety & Ethics	Safety (incl. AI ethics)	Digital Citizen	Ethics of AI & Mindset	Digital Safety & Rights	Digital Responsibility	SEN vulnerability absent
Problem Solving	Problem Solving	Computational Thinker	AI Techniques & Apps	Problem Solving & CT	Computational Thinking	No SEN scaffolding
Accessibility	(Partial usability)	– (Absent)	(Absent)	(Absent)	(Absent)	Critical gap – all frameworks

Note. The accessibility row exposes a systematic absence of SEN-specific provisions across all five frameworks. MP 2030 = Singapore ICT Masterplan 2030; CT = Computational Thinking; AAC = Augmentative and Alternative Communication; L1–3 = DQ Proficiency Levels.

The Usage-Training Gap and Critical AI Literacy

The UNESCO AI Competency Framework (2024) and the ISTE Standards signal that, by age 11, primary students should transition from “Understand” to “Apply” levels of AI competency. Yet the data reveal a critical mismatch: while approximately 86% of students interact with AI tools daily, fewer than 50% have received formal instruction on safe or ethical use (Center for Democracy & Technology, 2025). This “Usage-

Training Gap” is not merely a pedagogical lag – it constitutes a safeguarding failure, particularly for students with SEN, who are at heightened risk of algorithmic manipulation, cyberbullying victimization, and problematic internet use.

Critical AI Literacy for primary learners encompasses: (1) understanding how algorithms process data; (2) identifying AI hallucinations and misinformation; and (3) recognizing the social implications of algorithmic bias (Chiu et al., 2024). Closing the usage-training gap demands a transition

from technical instruction to AI-ready mindset formation – and for inclusive settings, this requires parallel investment in accessible instructional tools and teacher preparation that addresses SEN accommodations alongside AI pedagogy. Current initiatives emphasize a three-stage human-centric progression (Dong et al., 2025; Yau et al., 2022), but implementation is hampered by low teacher self-efficacy regarding GenAI integration (Dehen et al., 2026) and the near-total absence of TPACK-SEN competency – the integrated knowledge of technology, pedagogy, content, and special education required to support SEN learners in AI-enriched environments.

Pedagogical Shift: From Consumption to Inclusive Co-Creation

Modern frameworks increasingly emphasize whole-person development – fostering persistence and resilience to navigate the technical and ethical complexities of human-AI collaboration (Xia et al., 2024) – and prioritize higher-order computational thinking over rudimentary coding tasks (Kim et al., 2022). Safety discourse has evolved from simple e-Safety toward holistic “Digital Wellbeing,” requiring a human-centered mindset that protects cognitive development against algorithmic influence (Cheah et al., 2025; Mekheimer, 2025). For students with SEN, digital well-being concerns are amplified: without explicit inclusive design and educator preparation, these learners face a “triple barrier” – physical inaccessibility, pedagogical unpreparedness, and the absence of adapted digital standards – that risks deepening educational inequity rather than alleviating it.

6. Discussion

Global Convergence and Its Limits

The remarkable thematic convergence among DigComp 2.2, ISTE, and UNESCO AI (2024) suggests an emerging global consensus on three pillars of digital learning: criticality, ethics, and collaboration. The UNESCO 2024 framework marks a milestone by elevating AI system design into the primary curriculum, signalling that, by the mid-2020s, a “digitally literate” primary student is expected to understand algorithmic underpinnings, not merely consume AI outputs (Yim, 2024). Yet a

critical – tension persists: these frameworks remain expert-designed, top-down documents that consistently neglect the practical realities of classroom educators (Akter et al., 2021) – fewer than 10% of educational institutions have established formal AI guidance (Lucas et al., 2024) – and, more fundamentally, they are implicitly designed around the neurotypical, non-disabled learner. The convergence, however impressive at the policy level, therefore produces a uniformly inaccessible standard.

Connectivism, SRL, and the Inclusive Digital Learner

Grounded in Connectivism, our analysis supports the view that learning in the digital world is a process of connecting nodes (Siemens, 2005), but SRL provides the cognitive governance that makes this navigation purposeful rather than chaotic (Zhao, 2024). This synergy is especially critical in primary education, where executive functions necessary to resist addictive platform design are still developing (Panskyi & Korzeniewska, 2022). Metacognitive scaffolding – empowering students to evaluate AI tools' strengths and limitations – must therefore be embedded in curriculum design rather than assumed (Fan et al., 2024; Järvelä et al., 2025). AI-enabled educational tools that transition from passive assistants to active metacognitive mentors represent a particular opportunity for SEN learners, whose self-regulatory trajectories benefit most from adaptive, responsive guidance (Jin et al., 2023; Banihashem et al., 2025). Frameworks that treat SRL as a generic competency, without accounting for the heterogeneous executive function profiles of primary learners, systematically underserve students with SEN.

Implications for Inclusive Education: Filling the Structural Gap

The structural gap identified – the absence of SEN provisions across all five analyzed frameworks – demands a targeted response. The five-domain model proposed in this study directly addresses this gap by establishing accessibility and accommodation as a foundational rather than supplementary dimension. Four specific implications follow. First, digital learning skills

frameworks must be co-designed with SEN professionals and disability advocates, embedding accessibility as a design principle rather than a retrofit. Second, teacher education programs must address TPACK-SEN competency explicitly, equipping educators with the integrated skills to design AI-enriched lessons for the full range of learner variability. Third, digital learning skill assessments must provide flexible, multimodal response options – consistent with UDL – allowing students to demonstrate competency through their most accessible channels. Fourth, AI tools deployed in inclusive primary settings must meet established accessibility standards (WCAG 2.1 compliance; compatibility with screen readers, switch access, and AAC devices) before formal integration into digital literacy curricula. Absent these provisions, the global shift toward AI literacy will systematically exclude the learners who stand to benefit most from personalized, adaptive digital environments (Rose & Meyer, 2002; CAST, 2018).

7. Conclusion

This comparative thematic synthesis confirms a fundamental paradigm shift in the global conceptualization of digital learning skills for primary education: from technical-procedural operations to a multi-dimensional matrix of cognitive, ethical, and socio-emotional competencies (Consoli et al., 2024; Santana & Díaz-Fernández, 2022). Critical AI Literacy and Digital Well-being have emerged as foundational requirements even at the primary level – yet a significant “Usage-Training Gap” persists, and a structural accessibility gap pervades every major international framework (Center for Democracy & Technology, 2025). The proposed five-domain conceptual framework, incorporating an Ethical-Reflective and Accessibility Domain anchored in UDL principles, provides a more equitable foundation for inclusive digital learning policy. Future frameworks must shift from Divide 1.0 (physical access) to Divide 2.0 (skill agency equity), treating SEN provisions not as exceptions but as design standards (Siemens, 2005; Zhao, 2024; Skulmowski, 2023).

Strategic Recommendations

Based on this synthesis, the following targeted recommendations are offered:

- **Policymakers:** Integrate AI literacy and digital ethics as a “General Capability” across all subjects from Year 1; revise national digital skills standards to mandate UDL compliance and explicit SEN provisions; shift investment from hardware access (Divide 1.0) to pedagogical capacity building (Divide 2.0) (Chen et al., 2024).
- **Special Education Practitioners and Inclusive Educators:** Adopt the “Facilitator” model – leveraging AI as a personalization tool for diverse learners (OECD, 2025); pursue TPACK-SEN professional development that explicitly addresses AI pedagogy for students with disabilities; design lessons using UDL flexible assessment and multimodal representation principles (Kong & Hu, 2026).
- **Curriculum Designers:** Transition digital safety content from e-Safety to holistic Digital Wellbeing, addressing algorithmic bias, online identity, and SEN vulnerability factors (DQ Institute, 2024); specify accessibility requirements – WCAG 2.1 compliance, AAC compatibility, assistive technology integration – as non-negotiable standards in digital skills curricula (Wang et al., 2025).
- **Researchers:** Prioritize empirical studies of digital learning interventions specifically targeting SEN populations (autism spectrum disorder, dyslexia, ADHD, sensory and physical disabilities); conduct longitudinal research on the impact of early AI exposure on executive function trajectories; investigate accessible AI tool design as a mechanism for developing prompt engineering and AI literacy among AAC users (Liu & Zhong, 2025; Kim et al., 2024).

Limitations and Future Directions

This synthesis is limited to publicly available international frameworks and national standards accessible up to mid-2025; it does not include primary data from students, teachers, or SEN specialists. Future research should employ longitudinal designs with disaggregated analysis by

disability category, and prioritize co-design methodologies that centre the lived experiences of students with SEN in developing the next generation of inclusive digital learning skills frameworks.

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9. Author Declaration

- This study is a documentary analysis and thematic synthesis of publicly available international policy frameworks. No human participants, personal data, or identifiable information were involved. Formal ethics board approval was not required.
- The authors declare no conflict of interest.

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