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From Operating Tools to Solving Problems: Reconceptualising Digital Literacy as a Catalyst for Problem-Solving Competency in AI-Enhanced Learning Ecosystems

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Abstract: Digital literacy is widely treated as a strategic competence for learning and work, yet its definitions remain fragmented. The mechanisms through which it develops higher-order competencies are also under-theorised, particularly in learning environments increasingly mediated by generative artificial intelligence (AI). Existing evidence links digital literacy with problem solving through critical thinking. However, this evidence largely predates generative AI, rarely considers self-regulatory and metacognitive pathways, and seldom asks when AI use weakens learning. Adopting a model-type conceptual design, this paper integrates the European Digital Competence Framework (DigComp 2.2), self-regulated learning theory and problem-solving theory, supported by sociocultural, cognitive-flexibility and cognitive-offloading perspectives. It reconceptualises digital literacy as a multidimensional cognitive capability with eight dimensions in four clusters, treating AI literacy as a distinct dimension. It then proposes a framework in which digital literacy develops problem-solving competency through three mechanisms: critical thinking, self-regulated learning and metacognitive monitoring. Seven propositions specify direct, mediated and conditional relationships, including two boundary conditions: the mode of reliance on AI (reflective versus thoughtless) and the interaction between cognitive flexibility and problem structure. The paper contributes a mechanism-based account of how digital literacy may become problem-solving competency and a consistent placement of AI literacy within digital literacy. It also sets out a validation agenda that specifies constructs, candidate instruments and competing structural models. Implications are drawn for curriculum design, AI-integrated pedagogy and digital education policy in higher education.

Keywords: Digital literacy, problem-solving competency, AI literacy, self-regulated learning, metacognition, generative AI

1. Introduction

Generative AI and other intelligent systems have changed what it means to learn with technology. Students can now obtain fluent explanations, worked solutions and draft arguments within seconds. The central educational question has therefore shifted from access to thinking. Learners must now interpret, evaluate, regulate and apply digital and AI-generated information to solve authentic problems, not merely operate the tools that deliver it (Long & Magerko, 2020; Ng et al., 2021). International frameworks reflect this shift. The latest update of the European Digital Competence

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Framework, DigComp 2.2, added more than 250 new examples of knowledge, skills and attitudes, including examples of interaction with AI-driven systems (Vuorikari et al., 2022). It also retains problem solving as one of its five competence areas.

Digital literacy has long been understood as more than technical skill. Gilster (1997) framed it as the ability to understand and use information in multiple formats from diverse sources, and Eshet-Alkalai (2004) described it as a set of cognitive "survival skills" for the digital era. A systematic review of higher education research found that both digital literacy and digital competence have moved from an operational focus on technology use towards cognitive, critical and responsible perspectives (Spante et al., 2018). Definitions still vary according to whether they derive from policy or research. A comparative review across three language contexts likewise found that digital literacy is defined in plural and context-dependent ways (Pangrazio et al., 2020). Even so, the same review found that most higher education publications mentioned digital literacy or digital competence without reference to research or policy definitions (Spante et al., 2018). Recent integrative frameworks also describe it chiefly as a set of competence areas, not as a capability that works through identifiable cognitive mechanisms (Ramdana et al., 2026).

These questions apply directly to Malaysian higher education. A study of generative AI use among Malaysian university users examined patterns of over-engagement and excessive use and recommended promoting self-regulation and strengthening AI literacy (Al-Kumaim et al., 2025). Among undergraduates at a Malaysian public university, AI literacy predicted students' productivity (Yusnilzahri et al., 2025). A recent review in this journal concluded that future work should develop frameworks that balance AI assistance with the promotion of critical thinking (Guo & Zaini, 2024). What remains missing is a theoretically grounded account of *how* digital and AI literacies are converted into higher-order competencies such as problem solving.

Problem-solving competency is a core educational outcome and has been assessed internationally as a domain in its own right (OECD, 2014). Evidence linking it to digital literacy is growing. Among 714 undergraduates, Koçak et al. (2021) found that critical thinking mediated the relationship between digital literacy and problem solving. Greene et al. (2014) treated self-regulated learning and epistemic cognition as core components of digital literacy and related both to learning gains in online study. Recent studies also associate digital and AI literacies with academic outcomes (Wicaksana et al., 2025; Zakir et al., 2025), in one case through metacognitive self-regulation (Ko, 2026). In Malaysia, Zhang and Adnan (2026) reported that generative AI and mobile learning were positively associated with human–AI interaction and mobile-assisted language learning, which in turn were linked to university students' higher-order thinking skills.

1.1 Conceptual Issues Motivating the Study

Three limitations nevertheless remain. *First*, mechanism evidence comes mostly from environments that predate generative AI and typically examines one mediator at a time. Competence frameworks describe what digital literacy contains. For example, van Laar et al. (2017) distinguish core skills, such as information management and problem solving, from contextual skills, such as ethical awareness and self-direction. Such frameworks say little about the cognitive processes through which digital literacy becomes problem-solving competency.

Second, generative AI introduces a counter-mechanism: the technology can perform cognitive work on the learner's behalf. In a randomised study, students supported by ChatGPT improved their essay scores but did not differ from other groups in knowledge gain or transfer (Fan et al., 2025). The authors described this pattern as "metacognitive laziness". Survey evidence also links frequent AI use with lower critical thinking through cognitive offloading (Gerlich, 2025), whereas critical thinking channels AI literacy towards reflective rather than thoughtless use of generative AI during problem solving (Hou et al., 2025b). Frameworks that predict only positive effects of digital literacy are therefore incomplete. A credible framework should specify when digital literacy is converted into problem-solving competency and when it is not.

Third, the position of AI literacy relative to digital literacy is unsettled. Long and Magerko (2020) define AI literacy as a set of competencies that enable individuals to evaluate AI critically, communicate and collaborate with AI, and use it as a tool. Ng et al. (2021) organise it into four aspects: knowing and understanding, using and applying, evaluating and creating, and AI ethics. Some frameworks treat it as a separate literacy, whereas recent reviews position digital literacy as the foundational concept that encompasses data and AI literacy (Polomoshnov et al., 2026). Without a clear decision, models risk logical inconsistency, for example by treating AI literacy simultaneously as a component of digital literacy and as a moderator of its effects. Table 1 summarises these gaps and how the present framework responds.

Table 1. Conceptual gaps and the responses of the proposed framework

Gap in existing literature	Evidence	Response in this framework
Digital literacy conceptualised as an operational or list-based construct	Plural, policy-driven definitions (Spante et al., 2018; Pangrazio et al., 2020); competence-area frameworks (Ramdana et al., 2026)	Digital literacy reconceptualised as a cognitive capability with eight dimensions in four clusters, mapped to DigComp 2.2 (Section 3.1)
Mechanism evidence limited to single mediators and pre-generative-AI settings	Critical thinking as mediator (Koçak et al., 2021); SRL and epistemic cognition in digital learning (Greene et al., 2014)	Three mediating mechanisms, including a serial metacognitive-to-self-regulatory path (P2–P4)

Gap in existing literature	Evidence	Response in this framework
Positive-only assumptions about learning with AI	Metacognitive laziness (Fan et al., 2025); cognitive offloading (Gerlich, 2025); reliance behaviours (Hou et al., 2025b)	AI reliance mode specified as a boundary condition (P6)
Ambiguous status of AI literacy	Separate versus integrated conceptualisations (Ng et al., 2021; Polomoshnov et al., 2026)	AI literacy treated as a distinct dimension of digital literacy with incremental explanatory power (P5), not as a moderator
Problem solving treated as a generic, undifferentiated outcome	Well- versus ill-structured problems (Jonassen, 2000); process-based assessment (OECD, 2014)	Process-based outcome; problem structure and cognitive flexibility as a boundary condition (P7)
Frameworks proposed without a measurement or testing plan	Conceptual frameworks rarely specify validation designs	Validation agenda with candidate instruments and competing structural models (Section 4.2)

Note. SRL = self-regulated learning; P = proposition.

1.2 Purpose and Research Questions

This conceptual paper addresses these limitations through two research questions. **RQ1:** How should digital literacy be conceptualised so that its link with problem-solving competency in AI-enhanced learning ecosystems can be explained rather than asserted? **RQ2:** Through which higher-order mechanisms, and under which conditions, does digital literacy develop problem-solving competency?

In answering them, the paper (a) reconceptualises digital literacy as a multidimensional cognitive capability, (b) proposes a framework with three mediating mechanisms and two boundary conditions, (c) derives seven testable propositions, and (d) sets out an agenda for empirical validation. Section 2 explains the conceptual methodology; Section 3 develops the reconceptualisation, theoretical foundations, framework and propositions; Section 4 discusses contributions, the validation agenda, implications and limitations; and Section 5 concludes.

2. Methodology

2.1 Research Paradigm and Design

The paper adopts a pragmatic–constructivist position. Consistent with constructivism, knowledge is understood as actively constructed through learners' interaction with digital technologies, AI systems, authentic tasks and other people. Learning is therefore an active process of inquiry, reflection and adaptation rather than the passive receipt of information. Consistent with pragmatism, theories are selected for their explanatory usefulness and their capacity to generate propositions that can be tested empirically.

Methodologically, the paper follows the *model* template for conceptual articles described by Jaakkola (2020). Jaakkola argues that a conceptual paper needs an explicit research design, in which the choice of theories and the role of each in the analysis are stated and justified. A model-type paper builds a framework that predicts relationships between constructs and explains the mechanisms behind them. Following Cornelissen (2017), these relationships are expressed as propositions: statements about how and why constructs are related, which differ from hypotheses in that they are not yet tied to specific measures.

2.2 Source Base and Scope

The conceptual synthesis draws on an integrative, purposive review of four bodies of work: (a) conceptual and systematic reviews of digital literacy and digital competence; (b) AI literacy frameworks; (c) empirical studies linking digital or AI literacy with critical thinking, self-regulated learning, metacognition and problem solving; and (d) foundational learning theories. Peer-reviewed work published between 2014 and 2026 was prioritised, including studies conducted in Malaysia. The review is not systematic; sources were selected for their contribution to theory building. No new data were collected or analysed.

The framework is specified at the level of the individual learner in higher education. Institutional and policy-level factors, which Ramdana et al. (2026) address in a multilevel framework, are treated as context rather than modelled.

3. Proposed Framework and Propositions

3.1 Reconceptualising Digital Literacy

Building on the cognitive tradition in digital literacy research (Eshet-Alkalai, 2004; Gilster, 1997) and on DigComp 2.2, this paper defines digital literacy as follows:

> *Digital literacy is a multidimensional cognitive capability that enables learners to access, evaluate, synthesise, create, communicate and ethically use digital and AI-generated information, and to regulate*

their own thinking while doing so, so that they can understand and solve authentic, complex and ill-structured problems.

Three features distinguish this definition. First, it locates digital literacy in cognition rather than in tool operation, while recognising that operational skill is a necessary foundation. Second, it explicitly includes AI-generated information, which differs from other digital content because its sources are often opaque and its fluency can be mistaken for accuracy. Third, it names problem solving as the purpose of digital literacy without making it a component, so that the relationship between the two can be tested rather than assumed. For the same reason, DigComp 2.2's fifth competence area, *problem solving*, is not treated as a dimension of digital literacy here; including it would make the framework circular (Cornelissen, 2017).

The reconceptualisation implies five shifts in how digital literacy is understood (Table 2).

Table 2. Five conceptual shifts in the reconceptualisation of digital literacy

From	To	Implication
Technical competence	Cognitive competence	Assessment moves from whether learners can operate tools to how they reason, judge and decide in digital environments.
Information access	Knowledge construction	Value lies in analysing, synthesising and creating meaning from information, not in retrieving it.
Technology use	Informed decision-making	Learners use digital tools and data strategically, including deciding when not to rely on them.
Individual operation	Collaborative problem solving	Digital platforms become spaces for co-constructing solutions with peers and, increasingly, with AI systems.
Digital fluency	AI-enabled adaptive expertise	Learners continuously adapt to changing AI tools while retaining agency over their own reasoning.

The reconceptualised construct comprises eight dimensions organised into four clusters (Table 3). The clusters are theoretically motivated and are intended to be tested as first-order factors loading on a higher-order digital literacy factor (Section 4.2).

Table 3. Dimensions of digital literacy, working definitions and alignment with DigComp 2.2

Cluster	Dimension	Working definition	DigComp 2.2 alignment
Informational–analytical	D1 Information literacy	Locating, organising and applying online information for a defined purpose	Area 1: Information and data literacy
	D2 Data literacy	Reading, analysing and interpreting digital data to support decisions	Area 1 (managing data, information and digital content)
	D3 Critical digital evaluation	Judging the credibility, bias and reliability of digital sources and AI outputs	Competence 1.2: Evaluating data, information and digital content
AI-specific	D4 AI literacy	Understanding how AI systems work, what they can and cannot do, and how to use, evaluate and question them (Long & Magerko, 2020; Ng et al., 2021)	Cross-cutting; AI examples added in DigComp 2.2
Social–communicative	D5 Digital communication	Sharing ideas clearly and appropriately across digital platforms and formats	Area 2: Communication and collaboration
	D6 Digital collaboration	Working with others in virtual spaces to achieve shared goals	Competence 2.4: Collaborating through digital technologies
Creative–ethical	D7 Digital content creation	Producing, adapting and integrating digital content, including with AI tools, while acknowledging sources	Area 3: Digital content creation
	D8 Digital ethics	Acting responsibly with respect to privacy, intellectual property, academic integrity and transparent use of AI	Competence 2.5 (netiquette) and Area 4: Safety

Note. DigComp 2.2 Area 5 (problem solving) is deliberately excluded because problem-solving competency is the outcome of the framework.

This placement treats AI literacy as a distinct dimension rather than as a separate construct or a moderator. It follows reviews that position digital literacy as a foundational concept, within which data and AI literacy require more specialised knowledge (Polomoshnov et al., 2026). It also preserves a testable claim: if AI literacy is a distinct dimension, it should explain variance in AI-mediated problem solving beyond the informational–analytical cluster (Proposition 5).

3.2 Theoretical Foundations

Following Jaakkola (2020), each theory is assigned an explicit role. Three anchor theories define the antecedent, the mechanisms and the outcome; four complementary lenses explain specific paths and boundary conditions (Table 4).

DigComp 2.2 provides the structural blueprint for the antecedent construct. It offers an internationally recognised specification of digital competence areas and, in its 2022 update, examples relating to interaction with AI systems (Vuorikari et al., 2022). Its role is definitional: it anchors the dimensions in Table 3 and supports content validity in later measurement.

Self-regulated learning (SRL) theory explains the mechanisms. Zimmerman (2000) describes self-regulation as a cyclical process of forethought, performance and self-reflection, and Winne and Hadwin (1998) model learners as monitoring their progress against standards and adapting their tactics accordingly. Flavell's (1979) account of metacognition distinguishes metacognitive knowledge from metacognitive monitoring, which provides the basis for treating monitoring as a mechanism that triggers regulation. Together these theories explain how digitally literate learners convert access to information into goal-directed, monitored problem-solving activity.

Problem-solving theory specifies the outcome. Jonassen (2000) argues that problems vary in structuredness, complexity and domain specificity, and that ill-structured problems, which have multiple solution paths and criteria, demand different cognitive processes from well-structured ones. Drawing on this view and on international assessment frameworks (OECD, 2014), problem-solving competency is conceptualised as a process comprising problem representation, information exploration, solution generation, and evaluation and monitoring. Transfer to novel problems is treated as its strongest expression.

Four complementary lenses support specific paths. **Sociocultural theory** (Vygotsky, 1978) explains why the social–communicative cluster matters: higher mental functions develop through mediated social interaction, and digital collaboration extends the settings in which such interaction occurs. **Cognitive flexibility theory** (Spiro et al., 1991) explains why the benefits of digital literacy should be greatest for ill-structured problems, which require learners to restructure knowledge across cases and perspectives. **Cognitive load theory** (Sweller, 1988) and research on **cognitive offloading** (Risko & Gilbert, 2016) account for both the benefit and the risk of AI. External tools can free working memory for higher-order processing, but they can also remove the effortful processing through which learning occurs. **Connectivism** (Siemens, 2005) frames knowledge as distributed across networks of people and tools, which motivates the framework's attention to how learners navigate and evaluate networked and AI-generated information.

Table 4. Theories, their roles in the framework and the propositions they inform

Theory	Role in the framework	Constructs / propositions
DigComp 2.2 (Vuorikari et al., 2022)	Anchor: defines the dimensions of the antecedent	D1–D8; content validity
Self-regulated learning and metacognition (Flavell, 1979; Winne & Hadwin, 1998; Zimmerman, 2000)	Anchor: explains how digital literacy is converted into goal-directed, monitored activity	M2, M3; P3, P4a, P4b
Problem-solving theory (Jonassen, 2000; OECD, 2014)	Anchor: specifies the outcome and its process stages	Outcome; P7
Sociocultural theory (Vygotsky, 1978)	Lens: explains the role of the social–communicative cluster	D5–D6; P1
Cognitive flexibility theory (Spiro et al., 1991)	Lens: explains why effects vary with problem structure	P7
Cognitive load and cognitive offloading (Risko & Gilbert, 2016; Sweller, 1988)	Lens: explains when AI support helps or substitutes for learning	P6
Connectivism (Siemens, 2005)	Lens: frames knowledge as distributed across networks and AI tools	D3–D4; M1; P2, P5

3.3 The Proposed Conceptual Framework

Fig. 1 presents the framework. Digital literacy, the multidimensional antecedent, develops problem-solving competency mainly through three higher-order mediating mechanisms.

Critical thinking (M1) refers to purposeful, self-regulatory judgement involving interpretation, analysis, evaluation and inference (Facione, 1990). In AI-enhanced ecosystems it includes evaluating the accuracy, provenance and relevance of AI-generated information. Information evaluation is therefore treated as a core component of critical thinking to avoid construct overlap. **Self-regulated learning (M2)** refers to setting goals, selecting and adapting strategies, managing time and seeking help, including deciding when and how to use AI as a source of help (Zimmerman, 2000). **Metacognitive monitoring (M3)** refers to the ongoing judgement of one's own understanding and of the adequacy of information and AI outputs. This judgement signals when verification or a change of strategy is needed (Flavell, 1979; Winne & Hadwin, 1998).

Two boundary conditions qualify these paths. The **AI reliance mode** (reflective versus thoughtless) conditions whether digital literacy activates the mediating mechanisms or is bypassed by AI. **Cognitive flexibility**, in interaction with **problem structure**, conditions how strongly the mechanisms translate into problem-solving competency. Creativity is treated as part of the solution-generation stage of the outcome rather than as a separate mechanism, to keep the model parsimonious.

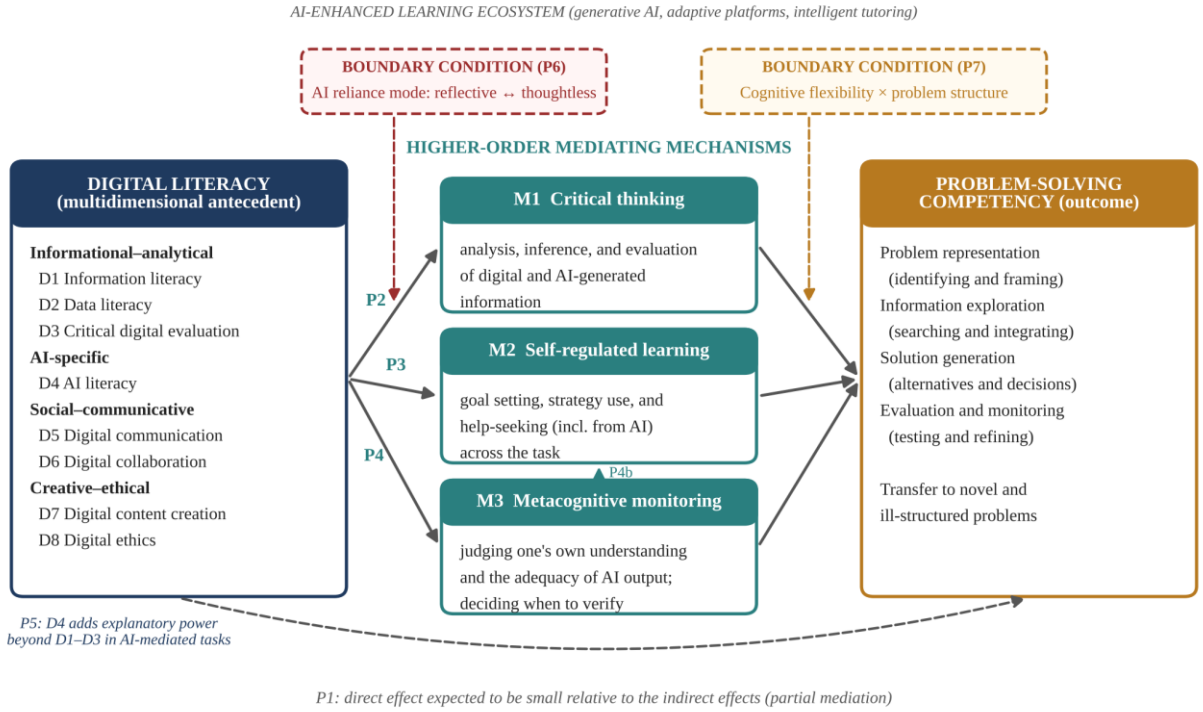


Fig. 1. Proposed conceptual framework of digital literacy and problem-solving competency in AI-enhanced learning ecosystems

Solid arrows denote mediated paths; the dashed curved arrow denotes the direct path; dashed vertical arrows denote moderation. D = dimension; M = mediating mechanism; P = proposition.

3.4 Research Propositions

3.4.1 The overall relationship

Prior studies report positive associations between digital literacy and problem solving, but they also show that much of this association runs through other variables. In Koçak et al. (2021), critical thinking mediated the effect of digital literacy on problem solving, and Zakir et al. (2025) found that digital competence, informal digital learning and digital self-efficacy partially mediated the relationship between digital literacy and academic performance. Sociocultural and SRL perspectives similarly imply that digital capability matters through what learners do with it. Digital literacy is therefore expected to retain a positive but modest direct effect once the mechanisms are taken into account.

> **Proposition 1.** *Digital literacy is positively related to problem-solving competency, and this relationship is predominantly indirect: once critical thinking, self-regulated learning and metacognitive monitoring are taken into account, the direct effect will be small (partial mediation).*

3.4.2 Critical thinking

Digitally literate learners have more practice locating, comparing and evaluating information, which exercises the analytical and evaluative processes that constitute critical thinking. Critical thinking in turn supports problem representation and solution evaluation. Koçak et al. (2021) reported this mediation before generative AI became widespread. The framework extends it to AI-mediated environments, where evaluating AI-generated content becomes part of critical thinking. Hou et al. (2025b) showed that AI literacy predicted critical thinking skills and disposition among 808 undergraduates, and that critical thinking channelled AI literacy towards reflective, cautious and collaborative use of generative AI during problem solving.

> **Proposition 2.** *Critical thinking, including the evaluation of digital and AI-generated information, mediates the relationship between digital literacy and problem-solving competency.*

3.4.3 Self-regulated learning

Digital environments offer abundant information but little external structure, so learning in them depends on learners' ability to plan, monitor and adapt (Greene et al., 2014). Digitally literate learners are better equipped to set goals, choose appropriate tools and manage their workflows, and these self-regulatory processes support persistence and strategic adjustment during problem solving. Recent evidence shows that metacognitive self-regulation shapes how digital learning competence is converted into productive learning engagement and achievement (Ko, 2026).

> **Proposition 3.** *Self-regulated learning mediates the relationship between digital literacy and problem-solving competency.*

3.4.4 Metacognitive monitoring

Metacognitive monitoring is treated as a mechanism rather than as a factor that merely "strengthens" digital literacy, which would conflate mediation with moderation. Digital literacy, particularly critical digital evaluation and AI literacy, sharpens learners' sensitivity to the limits of information and of AI outputs, which improves monitoring. Monitoring, in turn, triggers regulation. Learners who notice a gap in their understanding or a weakness in an AI-generated answer are more likely to change strategy, seek further evidence or verify (Winne & Hadwin, 1998). This implies both a direct mediating path and a serial path through self-regulated learning.

> **Proposition 4a.** *Metacognitive monitoring mediates the relationship between digital literacy and problem-solving competency.*

> **Proposition 4b.** *Metacognitive monitoring and self-regulated learning operate in sequence: digital literacy enhances metacognitive monitoring, which enhances self-regulated learning, which in turn enhances problem-solving competency.*

3.4.5 The distinct contribution of AI literacy

If AI literacy is a distinct dimension of digital literacy rather than a renamed form of information literacy, it should matter most when problems are solved with AI. Learners who understand how generative systems produce output, what they can and cannot do, and how their outputs may be biased have a basis for evaluating AI suggestions (Long & Magerko, 2020; Ng et al., 2021). General information skills do not supply this basis. Evidence that AI literacy predicts critical thinking in generative-AI problem solving (Hou et al., 2025b) and that digital and generative-AI literacies jointly relate to academic performance (Wicaksana et al., 2025) supports this expectation.

> **Proposition 5.** *In AI-mediated problem-solving tasks, AI literacy explains variance in critical thinking and problem-solving competency beyond that explained by the informational–analytical dimensions of digital literacy.*

3.4.6 Boundary condition 1: AI reliance mode

Digital literacy does not guarantee that learners will think with AI rather than let AI think for them. Cognitive offloading can free capacity for higher-order work, but it can also remove the effortful processing through which competence develops (Risko & Gilbert, 2016). Students supported by ChatGPT improved immediate task performance without corresponding gains in knowledge or transfer (Fan et al., 2025), and frequent AI use has been associated with lower critical thinking through offloading (Gerlich, 2025). Hou et al. (2025b) distinguished reflective, cautious and collaborative use from thoughtless use and found that trust in AI predicted thoughtless use. The mode of reliance is therefore expected to condition whether digital literacy activates the mediating mechanisms. Under thoughtless reliance, digital literacy may even be associated with better task products that do not translate into transferable competence.

> **Proposition 6.** *The AI reliance mode moderates the paths from digital literacy to critical thinking, self-regulated learning and metacognitive monitoring: these paths are stronger under reflective reliance and weaker under thoughtless reliance. Under thoughtless reliance, digital literacy will be associated with improved task performance more than with transferable problem-solving competency.*

3.4.7 Boundary condition 2: cognitive flexibility and problem structure

Well-structured problems can often be solved by applying a known procedure, so the advantage conferred by higher-order mechanisms is limited. Ill-structured problems, by contrast, require learners to construct a representation, integrate multiple perspectives and evaluate competing solutions (Jonassen, 2000). Cognitive flexibility is the capacity to restructure knowledge in response to changing situational demands (Spiro et al., 1991). It should therefore shape how fully critical thinking, self-regulation and monitoring translate into effective solutions when problems are ill-structured.

> **Proposition 7.** *Cognitive flexibility moderates the paths from critical thinking, self-regulated learning and metacognitive monitoring to problem-solving competency, and this moderating effect is stronger for ill-structured than for well-structured problems.*

Table 5 summarises the seven propositions, their relationship types and their principal support.

Table 5. Summary of propositions

P	Relationship type	Statement (abbreviated)	Principal support
P1	Direct (partial mediation)	DL → PSC; direct effect small once M1–M3 are included	Koçak et al. (2021); Zakir et al. (2025)
P2	Mediation	DL → critical thinking → PSC	Koçak et al. (2021); Hou et al. (2025b)
P3	Mediation	DL → self-regulated learning → PSC	Greene et al. (2014); Ko (2026); Zimmerman (2000)
P4a	Mediation	DL → metacognitive monitoring → PSC	Flavell (1979); Winne & Hadwin (1998)
P4b	Serial mediation	DL → monitoring → SRL → PSC	Winne & Hadwin (1998)
P5	Incremental validity	AI literacy adds explanation beyond D1–D3 in AI-mediated tasks	Hou et al. (2025b); Ng et al. (2021); Wicaksana et al. (2025)
P6	Moderated mediation	Reliance mode moderates DL → M1–M3; thoughtless reliance yields performance without transfer	Fan et al. (2025); Gerlich (2025); Risko & Gilbert (2016)
P7	Moderation (three-way)	Cognitive flexibility moderates M1–M3 → PSC, more strongly for ill-structured problems	Jonassen (2000); Spiro et al. (1991)

Note. DL = digital literacy; PSC = problem-solving competency; SRL = self-regulated learning; M1–M3 = mediating mechanisms.

4. Discussion

4.1 Theoretical Contributions

The framework makes four theoretical contributions. (i) **A mechanism-based account of digital literacy.** Where competence frameworks describe what digital literacy contains (van Laar et al., 2017; Vuorikari et al., 2022), this framework proposes how it becomes problem-solving competency through three specified mechanisms. (ii) **An extension of mediation evidence into AI-enhanced ecosystems.** It builds on the single-mediator finding of Koçak et al. (2021) by adding self-regulatory and metacognitive pathways, including a serial path, and by specifying how they operate when learners work with generative AI.

(iii) **A conditional rather than positive-only theory.** The framework specifies AI reliance mode and problem structure as boundary conditions. It thereby builds evidence of metacognitive laziness and cognitive offloading (Fan et al., 2025; Gerlich, 2025) into the theory instead of treating it as an anomaly. This also responds to the call, made in this journal, for frameworks that balance AI assistance with the promotion of critical thinking (Guo & Zaini, 2024). (iv) **A coherent placement of AI literacy.** Treating AI literacy as a distinct dimension with incremental explanatory power offers a way to resolve inconsistencies in how it is related to digital literacy (Ng et al., 2021; Polomoshnov et al., 2026).

4.2 Methodological Contributions and Agenda for Empirical Validation

The propositions call for a sequence of designs. A cross-sectional survey of higher education students can establish the measurement model and test P1 to P5 using structural equation modelling (SEM). Mediation implies temporal ordering, so a three-wave longitudinal design is needed, similar to recent longitudinal work on students' digital literacy (Liu et al., 2025). Such a design can test whether changes in digital literacy precede changes in the mechanisms and in problem-solving competency. P6 and P7 are best tested experimentally. For example, learners could be assigned to AI-supported tasks that require either critique of AI output (reflective reliance) or completion by AI (thoughtless reliance), with problem structure varied across tasks.

Table 6 lists candidate instruments. Self-reports of digital literacy may not match actual performance, so performance-based measures of critical thinking and problem solving should complement self-report wherever possible. Instruments developed in other cultural contexts should also be adapted and tested for measurement invariance before use with Malaysian students.

Table 6. Constructs and candidate measures for empirical validation

Construct	Candidate measures	Notes
Digital literacy (D1–D3, D5–D8)	DigComp 2.2-based self-assessment items adapted to higher education (Vuorikari et al., 2022)	Test four first-order clusters and a higher-order factor
AI literacy (D4)	AI literacy scale (Wang et al., 2023); AI literacy questionnaire (Ng et al., 2024)	Include evaluation and ethics subscales
Critical thinking (M1)	Critical thinking disposition and skills measures informed by Facione (1990); performance task requiring evaluation of AI-generated claims	Combine self-report with performance
Self-regulated learning (M2)	Motivated Strategies for Learning Questionnaire, learning-strategies scales (Pintrich et al., 1993)	Add items on help-seeking from AI

Construct	Candidate measures	Notes
Metacognitive monitoring (M3)	Metacognitive Awareness Inventory, regulation subscale (Schraw & Dennison, 1994); calibration indices	Calibration reduces self-report bias
AI reliance mode (W1)	Generative-AI reliance behaviour scale (Hou et al., 2025a)	Reflective, cautious, collaborative and thoughtless use
Cognitive flexibility (W2)	Cognitive Flexibility Inventory (Dennis & Vander Wal, 2010)	Moderator for P7
Problem-solving competency (Y)	Problem Solving Inventory (Heppner & Petersen, 1982); scenario-based well- and ill-structured tasks scored with rubrics (OECD, 2014)	Include a transfer task

The analysis should proceed in four steps. First, confirmatory factor analysis should test whether the eight dimensions load on four clusters and on a higher-order digital literacy factor, and whether AI literacy is empirically distinct from the informational–analytical cluster. Second, a set of competing structural models should be compared: (a) a direct-effect model; (b) a single-mediator model with critical thinking, replicating Koçak et al. (2021); (c) a parallel three-mediator model; (d) a model adding the serial path from metacognitive monitoring to self-regulated learning; and (e) a moderated-mediation model adding the reliance mode. Third, indirect and conditional indirect effects should be estimated with bias-corrected bootstrap confidence intervals (Hayes, 2018). Fourth, measurement invariance should be tested across disciplines and countries, and procedural and statistical remedies for common-method bias should be applied. Both covariance-based and partial least squares SEM are suitable; covariance-based SEM is preferred when the aim is theory confirmation.

4.3 Practical Implications

For **curriculum developers**, the framework implies that digital literacy programmes should explicitly teach critical evaluation of AI output, data interpretation and ethical use alongside operational skills. For **educators**, it implies designing tasks that keep the cognitive work with the learner. Students might, for example, represent a problem themselves before consulting AI, use AI to critique rather than complete their work, and justify when they accepted or rejected AI suggestions. Assessment should capture the problem-solving process, not only the final product.

For **policymakers**, including those shaping digital education agendas in Malaysia and China, the framework suggests supplementing indicators of access and tool use with indicators of critical, self-regulatory and metacognitive capability. Malaysian evidence of over-engagement with generative AI among university users (Al-Kumaim et al., 2025) adds weight to such indicators. Barriers that limit students' development of digital literacy, documented in Malaysian higher education among international students (Anthonysamy et al., 2026), also need institutional attention.

4.4 Limitations

Several limitations should be acknowledged. First, the framework is conceptual; its propositions require empirical testing, and some may not be supported. Second, the integrative review was purposive rather than systematic. Other bodies of literature could yield different emphases, such as sociocultural literacy studies that treat digital literacies as situated social practices (Pangrazio et al., 2020). Third, the framework is specified at the individual level in higher education and does not model institutional, teacher or policy factors, which multilevel frameworks address (Ramdana et al., 2026). Teachers' own digital literacy, for instance, may influence student outcomes (Quillopa, 2026). Fourth, the anchor framework, DigComp 2.2, was developed in a European policy context, and its applicability in Malaysian and wider Asian higher education should be examined rather than assumed. Finally, AI technologies are changing rapidly, so the content of the AI literacy dimension will need periodic revision even if the mechanisms prove stable.

5. Conclusions

This paper has argued that, in AI-enhanced learning ecosystems, digital literacy is better understood as a multidimensional cognitive capability than as the ability to operate tools. Its value lies in what it enables learners to do with digital and AI-generated information. The proposed framework sets out how digital literacy may develop problem-solving competency through critical thinking, self-regulated learning and metacognitive monitoring. It also specifies when this conversion is expected to fail: when learners rely on AI thoughtlessly, or when problems demand more flexibility than the learner can supply. The framework places AI literacy within digital literacy, separates mediation from moderation and sets out an agenda for validation. Once tested, it can support cumulative research and pedagogical designs that help learners think with AI rather than let AI think for them.

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Conflict of Interest

The authors declare no conflicts of interest.

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