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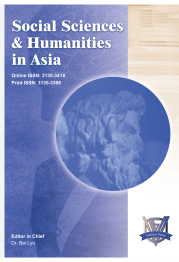

RESEARCH ARTICLE

Digital Self-Regulation and Critical Thinking: The Imperceptible Attrition of Deliberative Rationality in the 5.0 Era

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ABSTRACT

Background and Purpose: Higher education is progressively shifting toward a human-centred Education 5.0 paradigm. This shift raises critical questions about students' digital self-regulation with artificial intelligence (AI) tools. Understanding how such self-regulation influences critical-thinking habits is essential. This study draws on Self-Regulated Learning theory and the 21st-century skills framework. It examines associations between dimensions of digital self-regulation and discrete critical-thinking dispositions. The participants were 42 pre-service teachers from a central university in Delhi, India.
Methods: Two validated instruments were administered to all participants. The first was an 18-item scale capturing six facets of AI-mediated digital self-regulation. These facets included goal planning, prompt and tool strategies, and AI output quality monitoring. The second was an 18-item scale measuring six critical-thinking dispositions. Facet-level analyses explored specific links between individual self-regulation dimensions and thinking dispositions. Comparisons were also conducted among low, medium, and high AI-usage groups.
Results: No meaningful link emerged between overall self-regulation scores and general critical-thinking profiles. However, facet-level inspection revealed important nuances across dimensions. Learners who refined prompts and chose appropriate AI platforms displayed higher inquisitiveness. Those who verified AI answers against external sources demonstrated more systematic reasoning. Highly prescriptive goal planning appeared to dampen curiosity, though this trend lacked statistical decisiveness. Comparisons among AI-usage groups produced no significant differences in critical-thinking dispositions.
Conclusion: These findings highlight prompt refinement and output verification as key instructional leverage points. Teacher-education programmes can use these strategies to foster curiosity and organised analysis. Integrating targeted digital self-regulation practices may strengthen critical thinking in AI-rich learning environments.

KEYWORDS

Digital Self-Regulation, Critical Thinking, Education 5.0, Pre-Service Teachers, Cognitive Dispositions

1. INTRODUCTION

Educational concepts have evolved alongside successive generations of the web. Read-only Education 1.0 mirrored the mid-1990s Web 1.0 era. Learners browsed static websites. Schools seldom integrated digital tools (Sharma, 2019). Web 2.0 shifted the paradigm to read–write–publish through blogs in 1999. This transition increased learner involvement. Yet classrooms remained largely lecturer-centred (Newby, 2003). Web 3.0 introduced semantic, read-write-execute services. Applications began to interact intelligently with users and data. Education 4.0 is aligned with Industry 4.0's cyber-physical systems. It gained widespread academic acceptance across institutions. However, shortages of certified personnel hindered the development of fully immersive learning environments (Maria et al., 2018). Artificial intelligence (AI), robotics, and analytics became central to this phase (Galatro et al., 2025).

Education 5.0 adopts Industry 5.0's human-centredness (Heikkilä, 2026; Amaral et al., 2026). Students now choose what, where, when, how, and with whom to study (Mustafa Kamal et al., 2019; Universiti Teknologi MARA, 2019). Institutions embed innovative technologies into learning designs. These designs foster cooperation, creativity, communication, and criticality (Galatro et al., 2025). This paradigm also requires learners to plan, monitor, and manage digital behaviours. Academic and ethical objectives guide these self-regulatory processes. Recent research confirms that AI-integrated environments support self-regulatory capacity when properly scaffolded (Huang et al., 2025; Rasheed et al., 2026; Xu, 2025; Tomisu & Yamanaka, 2025). Many students use digital tools intentionally. Yet a sizeable group succumbs to algorithm-driven distractions (Hairiyanto et al., 2024; Martin et al., 2025). This discrepancy in self-regulation widens what scholars call the deep-structure innovation gap. Institutions invest heavily in hardware and digital platforms. Yet they overlook the metacognitive abilities that turn access into genuine advantage (Adnan, 2020; OECD, 2026).

Traditional curricula sometimes include coding or cybersecurity modules. However, they rarely teach attention management, online ethics, or data triage (Adnan, 2020). Pre-service teachers face particularly high stakes. They design tomorrow's classrooms. They must manage complex, screen-rich learning environments daily. This responsibility requires them to model responsible digital behaviours. They must also transmit those behaviours to future learners. Despite growing scholarly discussion, few empirical studies link digital self-regulation to higher-order thinking. Most studies address digital literacy or digital intelligence instead. They leave the self-regulatory component theoretically underspecified (Zheng & Zhang, 2025; Flanigan & Kim, 2025). Few studies examine how Education 5.0's twin pillars, collaboration and creativity, interact with self-regulation.

This study uses Zimmerman's (1989) self-regulated learning (SRL) model as its theoretical foundation. The model emphasises self-directed learning, personal responsibility, and strategic use of digital resources. Digital resources in this context include AI tools. Recent scholarship extends Zimmerman's model into AI-enhanced learning contexts (Tomisu & Yamanaka, 2025; Xu, 2025). AI systems can scaffold metacognitive monitoring when instructional design preserves human agency (Xia et al., 2025; Flanigan & Kim, 2025). This investigation examines how far digital self-regulation predicts pre-service teachers' critical-thinking abilities. Critical thinking defines 21st-century skills frameworks (Trilling & Fadel, 2009) and underpins Education 5.0 goals. This study surveyed 42 pre-service teachers at a central university in Delhi, India. It pursues two objectives:

- To assess prevailing levels of digital self-regulation and critical-thinking skills among pre-service teachers;
- To examine how pre-service teachers' digital self-regulation relates to their critical-thinking dispositions.

This study makes several distinct contributions to the existing literature. First, it moves beyond broad digital literacy constructs. It examines fine-grained, AI-specific self-regulatory behaviours as predictors of critical-thinking dispositions. These behaviours include prompt engineering, tool selection, and output verification. Second, it situates this inquiry within the Indian higher-education context. Global studies on Education 5.0 have underrepresented this setting. Third, it employs a purpose-built digital self-regulation in learning scale. Rather than repurposing instruments designed for earlier digital technologies, the researcher validated this scale specifically for AI-mediated environments. Fourth, the facet-level analytical approach reveals differential associations across dimensions. Aggregate-score analyses would obscure these important distinctions. This approach yields actionable, dimension-level findings for curriculum designers and teacher educators. Together, these features address a convergent gap in existing research. This gap lies at the intersection of AI-mediated self-regulation and critical-thinking dispositions. It also encompasses pre-service teacher preparation in a developing-country context.

2. LITERATURE REVIEW

2.1 Digital Self-Regulation in Technology-Mediated Learning

The popular belief that young people inherently master digital tools by virtue of birth has persisted despite substantial counter-evidence (Prensky, 2001; Bennett et al., 2008; Jones et al., 2010; Kennedy et al., 2008). Technological integration has shifted pedagogy toward learner-centred models. These models demand robust SRL competencies. Web-based note-taking functions predict stronger SRL behaviors (Kaufman, 2004). Revisiting and reorganising online materials further enhances autonomy, planning, and strategy revision (Cosnefroy, 2014). A broad spectrum of research confirms that technology-enhanced environments regularly elicit goal-setting, progress monitoring, and reflection (Bartolomé et al., 2007; Wong et al., 2018; Alkhasawnh & Alqahtani, 2019; Hsu, 2020; Min & Nasir, 2020; Urbina & Villatoro, 2021).

Specific digital artefacts further scaffold self-regulation. Constructing e-portfolios elevates both motivational engagement and strategic cognition across all SRL phases (Alexiou & Paraskeva, 2010). Effective environments provide planning tools such as personal blogs and embedded monitoring prompts. They also offer clear performance criteria through feedback-rich e-portfolios (Bartolomé & Steffens, 2011). Students who frequently consulted a grade-monitoring application tracked progress more accurately and achieved higher exam scores (Barber et al., 2011). Interactive digital classrooms have produced clearer task comprehension, improved planning, and stronger self-monitoring (Johnson & Davies, 2014).

System quality mediates these effects. Information quality, communication quality, and user satisfaction together channel platform benefits into enhanced self-regulation (Zhao & Chen, 2016). Weekly e-journal reflections boost planning and self-monitoring (Fung et al., 2019). In language learning, information and communication technology tools support goal commitment, resource management, and active regulation (Kizil & Savran, 2016; Onivehu et al., 2018; Khampirat, 2021; Su et al., 2021). More recent investigations confirm that AI-powered platforms introduce new regulatory demands. Students must now manage not only their own cognitive processes but also the quality and appropriateness of AI-generated outputs (Huang et al., 2025; Lin & Chang, 2026).

Not all findings are uniformly positive. SRL gains occur primarily among students who consciously exploit online platforms. Others remain passive consumers (Chelghoum, 2017). Two distinct learner profiles emerge from the literature. The first comprises frequent technology users who lack regulatory tactics. The second is a smaller group that integrates digital tools with deliberate SRL strategies (Domínguez & Marcelo, 2017). These results underscore an important instructional principle. Technology-enhanced environments must embed explicit SRL supports to be effective. Such supports include planning aids, monitoring dashboards, and transparent criteria. These elements help translate digital access into autonomous and strategic learning.

2.2 Critical Thinking Dispositions

Critical thinking is perceived as a high-level cognitive ability. It is vital for individuals making decisions in their careers and life (Hale, 2012). The ability to think critically is consistently listed among the desired outcomes of education (Halpern, 1993; Moore, 2013). Nurturing critical thinking requires focusing on the learning process rather than on outcomes alone, moving from learning to thinking (Perkins & Murphy, 2006). According to Bloom's taxonomy, thinking abilities range from the concrete to the abstract: knowledge, understanding, application, analysis, synthesis, and evaluation. The final three categories encompass higher-order thinking skills.

Critical thinking is a process for deciding the truth, accuracy, or value of something. It is characterised by the ability to find reasons and make choices, observe situations thoroughly, and change one's opinion based on evidence. Ennis (1996) maintains a conception of critical thinking rooted in specific skills, observing, inferring, generalising, reasoning, and evaluating reasoning. For him, critical thinking is the correct assessment of statements and, more broadly, reasonable reflective thinking. Ennis (1992) argues that critical-thinking skills can be learned independently of specific disciplines and transferred across domains. He does, however, recognise that a certain minimum competence in a discipline is essential before those skills can be applied within it.

Paul (1994) similarly emphasises the skills and processes of critical thinking. He distinguishes between a weak sense and a strong sense of critical thinking. The weak sense refers to the ability to think critically about others' positions. The strong sense involves thinking critically about one's own position and arguments. It also includes examining one's own assumptions and worldview. For Paul, critical thinking requires deep self-knowledge. It demands both intellectual courage and intellectual humility. A strong critical thinker grasps the larger picture holistically and evaluates entire worldviews rather than merely critiquing isolated argumentative steps. Contemporary researchers have extended these foundational accounts by linking critical-thinking dispositions to AI literacy and media evaluation competencies (Rahimi & Yadollahi, 2025; Setiawan et al., 2026).

2.3 21st-Century Skills Framework

Ten of the fourteen major 21st-century skills frameworks explicitly mention critical thinking. These include the KSSLTM Framework (2020), the CBSE Handbook for 21st-Century Skills (2020), the Center for Curriculum Redesign (2019), the HUN School of Education profile

(2019), Roslaniec (2018), the Van Laar et al. digital-skills model (2017), the ISTE/NETS student standards (2016), the World Economic Forum taxonomy (2015), and the Assessment and Teaching of 21st-Century Skills (ATC21S) initiative. Their shared emphasis on critical thinking suggests widespread agreement that disciplined reasoning drives contemporary learning.

Critical analysis dominates these frameworks for several reasons. The World Economic Forum's (2015) Ways of Thinking list stresses the need to examine sources and assertions regularly, as information now grows faster than memorisation can accommodate. Rationality also underpins creativity, cooperation, and communication. Innovative ideas only generate value when subjected to rigorous testing (HUN School of Education, 2019). Digital fluency alone is insufficient in a disinformation age. Van Laar et al. (2017) include critical assessment within their digital-skills model precisely to help students distinguish authentic from manipulated information. Citizenship frameworks, such as the European Key Competencies for Lifelong Learning (2018), treat reflective judgment as a safeguard for democratic debate.

Most frameworks describe critical thinking as deliberate, self-regulated judgment comprising analysis, inference, assessment, and explanation. The CBSE Handbook (2020) defines it as the ability to 'analyse complex, real-world challenges'. The Centre for Curriculum Redesign recommends moving from topic-based to performance-based understanding, which demands disciplined reasoning (CCR, 2019). The ATC21S initiative designates critical thinking as Competency 7 and emphasises evidence-based decision making (ATC21S, 2012). ISTE (2016) embeds the concept in a standard that ties data management to informed conclusions. Educational guidance across frameworks converges on explicitly teaching argument mapping, hypothesis testing, and counter-example production rather than assuming these competencies develop implicitly.

2.4 Research Gap

Despite substantial inquiry into both digital self-regulation and critical thinking, significant gaps remain. The majority of existing studies treat digital self-regulation as a unitary construct, obscuring the differential effects of its constituent facets. In particular, the specific regulatory behaviours associated with AI-mediated learning, prompt formulation, tool selection, and output verification have received limited empirical attention. Most instruments for measuring SRL were developed before generative AI became prevalent and may not capture the distinct demands of AI-assisted study environments.

A second gap concerns the population studied. Pre-service teachers occupy a dual role in education systems. They are simultaneously learners who must develop strong self-regulatory and critical-thinking competencies. They are also future educators who will model these behaviours for their students. Yet the literature contains few studies on this group within AI-mediated contexts. The Indian higher-education setting remains especially underrepresented in this area. This gap persists despite the rapid expansion of digital learning platforms in the country. India's National Education Policy (2020) also mandates critical-thinking integration across curricula.

No prior empirical study has simultaneously investigated AI-specific digital self-regulation and critical-thinking dispositions among pre-service teachers in India. This research addresses that gap. It surveys 42 teacher candidates and examines how AI-supported self-regulatory strategies, measured at the facet level, predict critical-thinking dispositions. The findings are intended to inform Education 5.0-aligned curriculum development and pedagogical practice in teacher-education programmes.

2.5 Conceptual Framework

This research applies Zimmerman's (2000) cyclical SRL model. Zimmerman defines self-regulated learners as motivated, metacognitively aware, and proactive. His model comprises three interconnected stages. In the forethought phase, learners assess the task, evaluate their motivation and ability, set objectives, and plan tactics. Self-efficacy, intrinsic motivation, and positive outcome expectancies enhance effort intensity and persistence (Zimmerman, 2000).

In the performance phase, students apply and track their chosen tactics. Self-control strategies include self-instruction, help-seeking, and self-imposed consequences to sustain attention and effort (Dabbagh & Kitsantas, 2013). Self-monitoring involves comparing actions or products against internal standards and collecting observations for subsequent assessment. Accurate self-monitoring helps students identify performance gaps and adjust their tactics or resource allocation (Dabbagh & Kitsantas, 2013; Zimmerman & Moylan, 2009).

In the self-reflection phase, learners compare results with objectives and attribute outcomes to effort, strategy use, task difficulty, or external factors. Self-judgment and self-reaction shape emotions and motivation. Positive assessments reinforce effective methods and boost self-efficacy. Negative evaluations may prompt strategy change, renewed effort, or disengagement (Zimmerman & Moylan, 2009). These reflective insights feed into the next forethought stage, making self-regulation iterative and self-correcting.

Pintrich (2004) extended this framework with a Four-Phase Process Model. Phase one covers planning and activation; phase two, monitoring; phase three, control; phase four, response and reflection. Pintrich identified five regulatory domains: metacognitive, cognitive, motivational, behavioural, and environmental. Winne (1995) added four decision nodes at which regulation may succeed or fail: task interpretation, goal setting, strategy implementation, and progress appraisal. Failure at any node disrupts the regulatory loop. Clear performance criteria and timely feedback help learners navigate each node successfully. The integration of these theoretical perspectives provides the scaffolding for the present study's instrument design and analytical approach.

3. METHODOLOGY

3.1 Research Design

The present study adopted a survey design situated within a cognitive-behavioural paradigm. This approach enabled the investigation of concurrent relationships between digital self-regulation and critical-thinking dispositions among pre-service teachers. Theoretical guidance was drawn from established models of SRL (Zimmerman, 2000) and cognitive-behavioural theory.

3.2 Sample

The research was conducted at a central university in Delhi, India. The sample comprised 42 pre-service teachers (25 females, 17 males). All were enrolled in the 4th semester of their teacher-education programme. Participants were selected through purposive sampling to ensure balanced digital usage representation. The low-usage group included 9 participants (21.4%). The medium-usage group was the largest with 23 participants (54.8%). The high-usage group comprised 10 participants (23.8%).

3.3 Instruments

3.3.1 Digital Self-Regulation in Learning Scale (DSR-L)

A DSR-L, developed based on Zimmerman's SRL framework, was administered. The instrument consisted of 18 items distributed across six sub-dimensions. These included Goal Planning, Strategic Resource Use, and Monitoring and Metacognitive Tracking. The remaining three were Help-Seeking and Networked Support, Self-Control and Distraction Management, and Self-Reflection and Adaptation. Each item was scored on a 5-point Likert scale (Strongly Disagree = 1, Strongly Agree = 5). Cronbach's alpha values ranged from 0.74 to 0.85 across sub-dimensions, indicating good internal consistency.

3.3.2 Critical Thinking Dispositions Inventory (CTDI)

Critical thinking was assessed using an 18-item CTDI, adapted from Facione (1992). This instrument measures six core constructs: Truth-Seeking, Open-Mindedness, Analyticity, Systematicity, Critical Self-Confidence, and Inquisitiveness. A 5-point Likert response format was used. Cronbach's alpha coefficients ranged from 0.76 to 0.88 across constructs, confirming reliability and construct validity for the sample.

3.4 Data Collection Procedures

Data were collected using a secure online survey platform. All participants received a Google Form containing an informed consent statement. This ensured that participation was voluntary, confidential, and anonymous.

3.5 Data Analysis Strategies

The analytical workflow comprised two stages. Descriptive statistics, means, standard deviations, and frequency distributions were computed for all study variables, including demographic and digital-usage profiles. Pearson's correlation coefficients were then calculated to explore relationships between digital self-regulation facets and critical-thinking dispositions. A one-way analysis of variance (ANOVA) examined differences in critical-thinking scores across digital-usage groups, and independent-samples t-tests assessed gender differences.

4. RESULTS

This section presents the findings in four stages. The first covers participant demographics. The second reports descriptive statistics for the key constructs. The third examines Pearson correlations between DSR-L facets and CTDI subscales. The fourth explores between-group comparisons by AI-usage level. Table 1 summarises the demographic composition of the sample. Table 2 reports means and standard deviations for the main variables. Table 3 presents the full Pearson correlation matrix, and Table 4 reports the one-way ANOVA results.

As shown in Table 1, the sample was majority female (59.5%). Digital usage was predominantly at the medium level, accounting for 54.8% of participants. Low users comprised 21.4% of the sample. High users made up the remaining 23.8%.

Table 2 presents the central tendency and dispersion for the main constructs. Participants rated themselves above the scale midpoint of 3.00 on both measures. Digital self-regulation scored moderately high ($M = 3.49$, $SD = 0.21$). Critical thinking scored slightly higher ($M = 3.68$, $SD = 0.24$). These scores indicate moderate-to-positive self-appraisal on both dimensions across the sample.

As shown in Table 3, only two pairwise associations reached statistical significance. Strategic Resource Use correlated positively with Inquisitiveness ($r = 0.36$, $p < 0.05$). Self-Control correlated positively with Systematicity ($r = 0.30$, $p < 0.05$). Goal Planning and Inquisitiveness showed a negative link that approached medium strength ($r = -0.33$). However, this trend fell short of statistical significance ($p = 0.07$).

Table 4 reports the one-way ANOVA comparing CTDI scores across the three AI-usage groups. The result, $F(2, 39) = 1.27$, $p = 0.29$, was not statistically significant. Critical-thinking dispositions did not vary by AI-usage category.

5. FINDINGS

The aggregate digital self-regulation score showed a negligible and non-significant link with overall critical thinking ($r = -0.08$, $p = 0.61$). This means that general self-regulatory ability does not predict critical-thinking tendencies among pre-service teachers. Simply being better at

Table 1 Participant Demographics: Gender Distribution and Digital Usage Density Categories

Variable	Category	n	%
Gender	Female	25	59.5
	Male	17	40.5
Digital Usage	Low	9	21.4
	Medium	23	54.8
	High	10	23.8

Table 2 Descriptive Statistics for Key Study Variables

Measure	Mean	SD
DSR-L	3.49	0.21
CTDI	3.68	0.24

Table 3 Pearson Correlation Matrix: DSR-L Facets × CTDI Subscales

DSR-L \ CTDI	Truth-Seeking	Open-Mindedness	Analyticity	Systematicity	Self-Confidence	Inquisitiveness
Goal Planning	-0.24	-0.09	0.06	-0.03	0.04	-0.33
Strategic Resource Use	0.16	0.03	0.08	0.13	-0.07	**0.36***
Monitoring & Tracking	0.07	0.13	0.07	-0.11	0.19	-0.01
Help-Seeking & Support	0.06	0.15	-0.04	-0.20	0.06	-0.19
Self-Control	0.11	-0.05	-0.17	**0.30***	-0.18	0.01
Reflection & Adaptation	-0.02	0.07	0.11	-0.05	0.22	0.05

*Note. * p < 0.05; N = 42. Bold values denote statistically significant correlations.*

Table 4 One-Way ANOVA of CTDI Scores by AI-Usage Group

Source	df	SS	MS	F	p
Between Groups	2	0.175	0.087	1.27	0.29
Within Groups	39	2.680	0.069	--	--
Total	41	2.855	--	--	--

regulating one's use of AI tools does not automatically sharpen critical thinking. The relationship between these two constructs appears more nuanced than a simple overall connection.

Facet-level inspection yielded more nuanced results. A moderate, positive correlation emerged between Strategic Resource Use and Inquisitiveness ($r = 0.36$, $p = 0.02$). Learners who adeptly refined prompts and selected appropriate AI platforms displayed greater intellectual curiosity and a stronger willingness to pursue knowledge beyond prescribed requirements. A comparable positive association appeared between Self-Control and Systematicity ($r = 0.30$, $p = 0.04$). In this instrument, Self-Control measures the monitoring of AI-output quality. Individuals who rigorously verified AI outputs against external sources engaged in more structured, sequential problem-solving approaches. These two significant correlations point to prompt refinement and output verification as the most consequential regulatory behaviours for critical-thinking development.

The relationship between Goal Planning and Inquisitiveness was moderately negative ($r = -0.33$, $p = 0.07$). Although this association did not reach statistical significance, its magnitude is noteworthy. The trend suggests that overly prescriptive, rigid planning of AI-mediated tasks may constrain open-ended inquiry. When learners follow a highly structured plan, they may forgo the exploratory, curiosity-driven engagement with AI tools that fosters inquisitiveness. Further research is required to substantiate this effect and to identify the threshold at which goal planning shifts from enabling to constraining. The one-way ANOVA revealed no significant differences in critical-thinking dispositions across AI-usage groups. Low, medium, and high usage groups showed similar profiles, $F(2, 39) = 1.27$, $p = 0.29$. This rules out a simple dosage effect. Using AI more often does not automatically strengthen critical-thinking dispositions. What matters is the quality of self-regulatory engagement, not the quantity of use. Independent-samples t-tests also confirmed no significant gender-based differences. Males and females scored similarly on the AI-Mediated Self-Regulation scale, $t(40) = 0.42$, $p = 0.68$. They also showed comparable results on the critical-thinking disposition scale, $t(40) = 0.35$, $p = 0.73$. These findings support the measurement invariance of both instruments across genders.

6. IMPLICATIONS

The findings carry direct implications for teacher-education curriculum design. Prompt refinement shows an empirically supported relationship with inquisitiveness. This argues for dedicated modules on advanced prompt engineering in teacher preparation. Such modules would guide pre-service candidates through iterative cycles of prompt design and testing. They would also include structured opportunities for refining and improving prompts. Making the reasoning behind prompt choices explicit helps build stronger thinking habits. These modules cultivate the habit of intellectual questioning, a core component of inquisitiveness.

The link between output verification and systematicity is equally important for curriculum planning. It argues for scaffolded activities that require learners to carefully triangulate sources. Learners should also practise systematic fact-checking of AI-generated outputs in class settings. Structured focus intervals can be dedicated to cross-referencing AI responses against primary sources. These intervals directly support the development of organised and step-by-step analytical reasoning. Such activities train learners to evaluate evidence actively rather than passively accept AI content.

The present study did not find a direct statistical effect of self-reflection on thinking dispositions. However, fostering metacognitive adaptation remains essential for deep and transferable learning. Teacher-education programmes should include reflective seminars or guided journaling after AI tasks. These practices prompt candidates to examine what AI tools produced during the activity. They also encourage learners to reflect on how they evaluated or rejected those outputs. This process nurtures a stronger sense of metacognitive awareness over time.

At the policy and accreditation level, course syllabi need thoughtful revision. Professional-development frameworks should also be updated alongside these syllabi. Both should explicitly merge AI self-regulation training with critical-thinking objectives. This alignment ensures that graduates develop both technological fluency and cognitive sophistication. It also embeds Education 5.0 competencies throughout teacher preparation as core requirements. These competencies should not be treated as optional or supplementary additions to the curriculum.

7. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

7.1 Limitations

Several limitations must be acknowledged when interpreting these findings. First, the sample size of 42 participants from a single central university in Delhi, India, restricts the generalisability of the results. The purposive sampling strategy, while appropriate for the exploratory goals of the study, introduces potential selection bias. Participants were all drawn from the fourth semester of one teacher-education programme, which limits the diversity of educational contexts represented. Second, both instruments relied on self-report measures. Participants' assessments of their own self-regulatory behaviours and critical-thinking dispositions may reflect social desirability biases or inaccurate self-perceptions rather than actual behaviour. Observed correlational patterns cannot establish causal direction; dispositional curious learners may be simply more inclined to refine their prompts, rather than prompt refinement causing heightened inquisitiveness. Third, the study was conducted at a single point in time. It does not capture how digital self-regulation and critical-thinking dispositions co-evolve over time. This limitation applies both across a teacher-education programme and in response to specific instructional interventions.

7.2 Future Research Directions

Future researchers are encouraged to replicate this study with larger and more diverse samples. These samples should span multiple institutions, regions, and educational levels. Such replication would test the generalisability of the facet-level associations identified here. Longitudinal designs tracking the same cohort across semesters would strengthen causal claims. Researchers could then determine whether prompt engineering instruction produces measurable growth in inquisitiveness. They could also assess whether output verification training improves systematicity over time. Experimental or quasi-experimental studies would add further value to this line of inquiry. These studies could introduce specific AI-regulation training programmes in classroom settings. Researchers could then measure their effects on critical-thinking dispositions against control conditions. Qualitative methods would offer richer and more process-level insights into learner behaviour. Think-aloud protocols and reflective interviews could capture how learners engage with AI tools. Digital trace data from learning management systems could reveal real-time self-regulation patterns. Researchers should also explore whether these associations hold across different disciplinary contexts. These contexts include science, technology, engineering, and mathematics, social sciences, social sciences, and the arts. AI tool use and self-regulatory demands may differ substantially across these domains. Finally, future studies should revisit the non-significant negative trend found in this study. Goal planning showed a potential dampening effect on inquisitiveness. Larger samples or specific conditions may reveal whether this trend becomes statistically robust. Such findings could uncover the boundary conditions under which structured planning inhibits curiosity-driven learning.

8. CONCLUSION

This study reveals important associations among pre-service teachers in Delhi, India. Two facets of AI-mediated digital self-regulation stand out in their connection to critical thinking. Prompt refinement is positively linked with the disposition of inquisitiveness. Output verification shows a meaningful connection with systematic reasoning. These findings suggest that targeting specific self-regulatory behaviours matters more than general training. Broad digital literacy instruction alone is unlikely to nurture these thinking dispositions.

These findings point toward four practical and actionable curriculum components. The first part involves teaching learners how to craft clear and effective prompts. The second focuses on cultivating the habit of verifying AI-generated content against reliable sources. The third introduces reflective seminars, where learners critically assess their own thinking and learning strategies. The fourth aligns the course design with the broader goals of Education 5.0 and sustainability. When combined, these elements create a comprehensive framework for teacher education. Each component reinforces the others, contributing to a richer learning experience.

Taken together, this study provides a useful blueprint for rethinking teacher-education programmes. It seeks to prepare future educators with strong digital competencies and sharp cognitive abilities. It also nurtures the sense of ecological responsibility needed to lead meaningful learning communities. Such communities should reflect sustainability in their everyday practices and long-term goals. Embedding these strategies across the entire curriculum ensures steady growth in self-regulation and critical thinking. Graduates of such programmes will carry technological confidence and intellectual depth into their classrooms. They will also bring the ethical awareness that Education 5.0 demands of tomorrow's teachers.

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