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RESEARCH ARTICLE

AI LITERACY BEYOND STEM: RETHINKING TEACHER EDUCATION FOR THE AI ERA

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ABSTRACT – Artificial Intelligence (AI) is rapidly transforming education, demanding that educators possess a multidimensional literacy extending beyond technical skills to include affective, behavioural, cognitive, and ethical competencies. This study systematically investigates these four dimensions of AI literacy among 265 pre-service teachers (124 STEM, 141 non-STEM) at Institut Pendidikan Guru Kampus Pendidikan Teknik (IPGKPT) using the validated AI Literacy Questionnaire (AILQ) grounded in the ABCE framework. Results reveal that Ethical Learning (EL) and Affective Learning (AL) scored highest, indicating strong ethical awareness and motivation, while Cognitive Learning (CL) lagged, highlighting a persistent gap in foundational understanding. Notably, independent samples t-tests showed no significant differences between STEM and non-STEM groups in AL and BL, but a moderate advantage for STEM participants in CL and EL. These findings challenge the notion that AI literacy is exclusive to technical fields, underscoring the need for equitable, cross-disciplinary integration of AI literacy within teacher education. Building on previous research, the study identifies a disconnect between awareness and application, particularly in cognitive and behavioural domains. It recommends embedding hands-on, ethics-anchored, and discipline-inclusive AI training into teacher education curricula, aligned with the values of Education 5.0. The study further advocates for institutionalising a comprehensive AI literacy framework as a national competency model, ensuring that future educators are not only AI-literate but also equipped to lead ethical, inclusive, and transformative AI integration in Malaysian classrooms and beyond. This research offers actionable recommendations for curriculum reform and policy, aiming to empower educators with agency, adaptability, and ethical judgment in post-pandemic learning environments.

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INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) is fundamentally transforming education worldwide, redefining not only what students learn but also how teachers teach and educational institutions operate. From adaptive learning platforms to intelligent assessment tools, AI has permeated classrooms across all disciplines, making AI literacy an essential competency for educators in the 21st century. As AI technologies become increasingly embedded in teaching and learning, the expectation for teachers to move beyond basic digital skills toward a nuanced, multidimensional understanding of AI is more urgent than ever. AI literacy extends far beyond technical proficiency; it encompasses affective, behavioural, cognitive, and ethical dimensions that collectively empower educators to critically evaluate, thoughtfully apply, and responsibly lead the integration of AI in diverse educational contexts. Recent global research underscores significant disparities in AI literacy among pre-service and in-service teachers, often shaped by discipline, experience, and access to professional development (Bohari et al., 2024; Zawacki-Richter et al., 2019). While policy initiatives and institutional investments have primarily targeted STEM educators, the reality is that AI's impact transcends subject boundaries, affecting language arts, social sciences, and the arts as much as mathematics and science. This calls for a paradigm shift in teacher education: AI literacy must be cultivated as a universal, cross-disciplinary competency.

In the wake of the COVID-19 pandemic, the urgency for digital transformation in education has accelerated. AI literacy is now recognised as a cornerstone of teacher adaptability, digital leadership, and ethical stewardship in increasingly complex learning environments. As argued by Ng et al. (2023b), educators must not only learn to use AI tools but also develop the critical, reflective, and ethical capacities necessary to harness AI for equitable, learner-centred outcomes. To address these challenges, the ABCE framework, encompassing Affective, Behavioural, Cognitive, and

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Ethical learning, offers a holistic lens for understanding and measuring AI literacy among educators. This model recognises that effective AI integration requires not only knowledge and skills but also positive attitudes, proactive engagement, and firm ethical grounding.

This study investigates the levels of AI literacy across these four domains among pre-service teachers at Institut Pendidikan Guru Kampus Pendidikan Teknik (IPGKPT), with a specific focus on comparing STEM and non-STEM cohorts. By identifying patterns, strengths, and gaps, this research challenges the misconception that AI literacy is the exclusive domain of STEM fields and advocates for inclusive, cross-disciplinary strategies in teacher preparation. The findings aim to inform the restructuring of teacher education curricula in Malaysia and beyond, aligning with the human-centric, values-driven vision of Education 5.0, where every educator is empowered as a critical thinker, ethical leader, and innovator in the AI era.

Research Objectives

This study specifically aims to:

1) Identify the levels of AI literacy among pre-service teachers in STEM and non-STEM fields.
2) Compare differences between STEM and non-STEM pre-service teachers in Affective, Behavioural, Cognitive, and Ethical Learning.

LITERATURE REVIEW

The concept of Artificial Intelligence (AI) literacy has undergone rapid evolution in recent years, reflecting the increasing integration of AI technologies into educational environments worldwide. AI literacy is now recognised as a multidimensional competency, encompassing not only technical skills but also affective, behavioural, cognitive, and ethical domains, an understanding that is crucial for preparing educators to lead in the AI era (Ng et al., 2023a; Bohari et al., 2024).

Theoretical Foundations of AI Literacy

The ABCE model (Affective, Behavioural, Cognitive, and Ethical learning), as articulated by Ng et al. (2023a), provides a comprehensive structure for conceptualising and measuring AI literacy among educators. Each dimension is grounded in established educational and psychological theories:

- Affective Learning (AL): This dimension encompasses educators' attitudes, interests, and self-efficacy related to AI. The Self-Determination Theory (Deci & Ryan, 1985) and Social Cognitive Theory (Bandura, 1986) emphasise the significance of intrinsic motivation and self-belief in promoting openness to technology adoption.
- Behavioural Learning (BL): BL reflects active engagement, practical use, and collaborative learning with AI tools. The Theory of Planned Behaviour (Ajzen, 1991) and Experiential Learning Theory (Kolb, 1984) underpin this domain, emphasising the role of intention and hands-on experience in shaping behaviour.
- Cognitive Learning (CL): This domain focuses on the acquisition of AI knowledge, encompassing conceptual understanding and problem-solving. Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001) provides a framework for mapping cognitive development from basic recall to higher-order thinking skills.
- Ethical Learning (EL): EL is becoming increasingly vital as educators confront issues such as data privacy, algorithmic bias, and the responsible use of AI. Kohlberg's Moral Development Theory (Mathes, 2021) and Digital Citizenship models (Ribble, 2011) inform this dimension, emphasising the need for principled, value-driven decision-making.

Expanding the Scope: AI Literacy as a 21st-Century Competency

Recent scholarship positions AI literacy as a core enabler of adaptability, innovation, and ethical leadership in education (Ng et al., 2023b; Zawacki-Richter et al., 2019). The COVID-19 pandemic accelerated digital transformation, underscoring the need for educators to move beyond operational skills and develop critical, reflective, and ethical capacities for integrating AI. This shift aligns with the vision of Education 5.0, which advocates for human-centric, values-driven, and future-ready learning environments.

Gaps in Research and Practice

While much of the existing literature focuses on AI literacy among STEM educators and higher education faculty, there is a notable paucity of research examining pre-service teachers, particularly those in non-STEM disciplines (Bohari et al., 2024; Guan et al., 2025). Studies have identified significant disparities in AI literacy associated with demographic factors, including gender, age, and academic background. This suggests the need for targeted interventions and equitable opportunities in teacher education programs. Furthermore, frameworks such as the Technology Acceptance Model (TAM) (Davis, 1989; Tahar et al., 2020) and Diffusion of Innovations Theory (Rogers, 2003; Scherer et al., 2021) offer additional insight into how educators adopt and adapt to emerging technologies. These models emphasise the significance of perceived usefulness, ease of use, and the impact of early adopters in promoting widespread technology adoption.

Towards Inclusive and Ethical AI Literacy

Effective AI integration in education requires more than technical know-how; it demands a comprehensive understanding, critical engagement, and ethical reflection qualities that must be cultivated early in teacher preparation. Embedding the ABCE model and related frameworks systematically into teacher education can ensure that future educators are not only proficient users of AI but also critical evaluators, ethical leaders, and innovators in their fields.

Contribution of the Present Study

This study addresses a critical gap in the literature by examining AI literacy across both STEM and non-STEM pre-service teachers, using the ABCE model as an analytical lens. By identifying strengths and weaknesses across affective, behavioural, cognitive, and ethical domains, the research provides actionable insights for curriculum transformation and policy development. Ultimately, it supports the creation of inclusive, practical, and ethically grounded teacher education programs that prepare educators for leadership in AI-enhanced, post-pandemic classrooms.

METHODOLOGY

Research Design

This study employed a quantitative, cross-sectional survey design to systematically assess the levels of AI literacy among pre-service teachers at Institut Pendidikan Guru Kampus Pendidikan Teknik (IPGKPT), Malaysia. The research focused on four key dimensions of AI literacy: Affective Learning (AL), Behavioural Learning (BL), Cognitive Learning (CL), and Ethical Learning (EL) as articulated in the ABCE framework (Ng et al., 2023a). This design enabled the researchers to capture a comprehensive snapshot of participants' competencies, attitudes, and ethical considerations related to AI at a single point in time.

Participants and Sampling

The target population comprised pre-service teachers enrolled in both STEM and non-STEM programs at IPGKPT. To ensure diverse and representative participation, stratified random sampling was used, with strata defined by academic specialisation (STEM vs. non-STEM). The final sample consisted of 265 participants (124 STEM, 141 non-STEM), reflecting the overall demographic and disciplinary distribution of the institution. This approach enhanced the validity of comparisons between groups and minimised sampling bias.

Instrumentation

Data were collected using the AI Literacy Questionnaire (AILQ), a validated instrument grounded in the ABCE model. The AILQ is designed to measure:

- Affective Learning (AL): Items assessing attitudes, intrinsic motivation, self-efficacy, and interest in AI.
- Behavioural Learning (BL): Items capturing engagement, participation, and behavioural intentions regarding AI use.
- Cognitive Learning (CL): Items evaluating knowledge, conceptual understanding, and application of AI concepts.
- Ethical Learning (EL): Items addressing awareness of ethical principles, responsible AI use, and digital citizenship.

The AILQ demonstrated high construct validity and reliability, with Cronbach's alpha coefficients exceeding 0.80 for all subscales. Minor contextual adaptations were made to ensure cultural and linguistic relevance for Malaysian pre-service teachers, including clarifying examples and adjusting terminology to enhance understanding.

Data Collection Procedures

The survey was administered electronically via Google Forms, maximising accessibility and convenience for participants. Prior to participation, informed consent was obtained, and participants were assured of the confidentiality and anonymity of their responses. Data collection was conducted over a two-week period, ensuring a high response rate and data integrity.

Data Analysis

Descriptive statistics (means, standard deviations) were computed to summarise AI literacy levels across the four ABCE dimensions. To compare AI literacy between STEM and non-STEM groups, independent samples t-tests were conducted for each dimension, with statistical significance set at $p < 0.05$. Effect sizes were calculated to interpret the magnitude of observed differences. To aid interpretation, Table 1 shows a modified mean score scale based on Asio (2024), which categorises proficiency levels for each dimension.

Table 1. Interpretation of mean scores for AI literacy (Asio, 2024)

Mean Score Range	Interpretation
1.00 – 1.79	Very Low
1.80 – 2.59	Low
2.60 – 3.39	Moderately High
3.40 – 4.19	High
4.20 – 5.00	Very High

Ethical Considerations

The study adhered to rigorous ethical standards throughout all phases. Ethical approval was obtained from the institutional review board. Participants provided informed consent, and all data were handled with strict confidentiality and anonymity. The research design and reporting align with the principles of responsible conduct in educational research.

RESULTS AND DISCUSSION

Demographic Profile of Participants

A total of 265 pre-service teachers from IPGKPT participated in this study. The demographic variables considered include gender, age, ethnicity, and academic major, providing a well-rounded profile of the participants. Table 2 summarises the demographic characteristics.

Table 2. Demographic profile of participants

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	74	27.8
	Female	192	72.2
Age	18-19	105	39.5
	20-24	99	37.2
	25-29	37	13.9
	30-34	23	8.6
	35-39	2	0.8
Ethnicity	Malay	178	66.9
	Chinese	61	22.9
	Indian	13	4.9
	Indigenous	14	5.3
Academic Major	STEM	121	45.5
	Non-STEM	145	54.5

Of the 265 respondents, 191 (72.1%) identified as female, while 74 (27.9%) identified as male. This gender distribution reflects broader trends within teacher education programs in Malaysia, where female enrolment typically outweighs male participation. Participants were predominantly young adults, consistent with the demographics of pre-service teachers. The most significant proportion of respondents was aged 18–19 (39.6%), followed closely by those aged 20–24 (37.0%). Smaller proportions were observed in the 25–29 age group (14.0%), the 30–34 age group (8.7%), and the 35–39 age group (0.8%). This age distribution underscores the early-career status of the majority of respondents. In terms of ethnicity, the sample was primarily composed of Malay participants (66.8%), followed by Chinese (23.0%), Indigenous (5.3%), and Indian (4.9%). This distribution reflects Malaysia's multicultural demographic, ensuring the perspectives captured are inclusive and broadly representative. Regarding academic specialisation, 144 participants (54.3%) were enrolled in non-STEM programs, while 121 participants (45.7%) were from STEM disciplines. This near-balanced representation supports robust comparative analysis across academic backgrounds about AI literacy dimensions.

Levels of AI Literacy Among Pre-Service Teachers

Descriptive statistics were computed to determine the overall AI literacy levels of pre-service teachers across the four ABCE domains: AL, BL, CL, and EL. These dimensions reflect Ng et al.'s (2023) ABCE framework, which conceptualises AI literacy as a holistic integration of emotional, behavioural, cognitive, and ethical competencies, each playing a critical role in how future educators engage with AI meaningfully and responsibly.

Table 3. Descriptive statistics of AI literacy dimensions

Dimension	Mean (M)	Standard Deviation (SD)	Interpretation
AL	4.20	0.53	Very High
BL	4.03	0.64	High
CL	3.83	0.72	Moderately High
EL	4.35	0.59	Very High

Table 3 shows that the mean scores for each dimension were classified as follows: EL (M = 4.35) and AL (M = 4.20) fall within the Very High range, indicating that pre-service teachers exhibit a strong awareness of AI's societal impact and demonstrate positive attitudes, motivation, and confidence toward learning AI. The prominence of EL aligns with Kohlberg's Moral Development Theory, reflecting higher-order ethical reasoning, a key outcome envisioned in the ABCE model's goal of cultivating responsible AI users and critical thinkers. Similarly, the high affective scores support principles from Self-Determination Theory (Deci & Ryan, 1985) and Social Cognitive Theory (Bandura, 1986), emphasising that motivation and self-efficacy are vital precursors to active engagement in technology-enhanced learning.

BL (M = 4.03) is interpreted as High, suggesting that while participants show an intention and effort to engage with AI tools and activities, there remains potential for greater practical exposure and collaboration. This finding supports the Theory of Planned Behaviour (Ajzen, 1991), which explains how behavioural attitudes and perceived control shape intention, underscoring the importance of providing structured and socially supported AI learning opportunities.

CL (M=3.83), categorised as Moderately High, was the lowest among the four dimensions. This reveals a critical gap in participants' conceptual understanding of AI principles, mechanisms, and applications. Within the ABCE model, CL occupies the higher cognition spectrum, requiring learners to move beyond passive knowledge toward application, evaluation, and creation. As reflected in Bloom's Revised Taxonomy, the current findings indicate that while interest and ethical awareness are strong, many trainees have yet to develop the depth of understanding necessary for the sophisticated integration of AI in pedagogical contexts.

Taken together, the results depict a cohort that is emotionally engaged and ethically aware yet still developing in cognitive and applied domains. This imbalance, when viewed through the ABCE framework, emphasises the need for scaffolded AI literacy instruction that transitions learners from interest (AL) to action (BL) toward deep understanding (CL), governed by critical ethical reflection (EL). Aligning with the transformative goals of Education 5.0, teacher education curricula must embed AI literacy across all domains to ensure future educators are equipped with the knowledge, judgment, and creativity to lead AI-enhanced learning in inclusive, human-centred ways.

Comparison of AI Literacy Between STEM and Non-STEM Pre-Service Teachers

To address the second research objective, this study examined differences in AI literacy between STEM and non-STEM pre-service teachers across four key domains of the ABCE framework: Affective Learning, BL, CL, and EL. These domains, conceptualised by Ng et al. (2023), form a holistic model of AI literacy that progresses from emotional readiness and engagement to higher-order cognitive understanding and ethical reasoning. Independent samples t-tests were conducted to compare group means, supported by effect size analysis using Cohen's d (see Table 4).

Table 4. Comparison of AI literacy based on STEM and non-STEM

Dimension	Academic Major Mean (SD)		t (df)	p-value	Cohen's d	Interpretation
	STEM	Non-STEM				
AL	4.24 (0.50)	4.17 (0.55)	1.069	0.286	0.13	Not significant; small effect
BL	4.09 (0.61)	3.99 (0.67)	1.218	0.224	0.15	Not significant; small effect
CL	3.92 (0.67)	3.75 (0.75)	2.024	0.044	0.25	Significant; Small moderate effect
EL	4.42 (0.57)	4.29 (0.59)	1.796	0.074	0.22	Approaching significant; small effect

The results reveal that CL was the only domain with a statistically significant difference (p = .044) between STEM and non-STEM participants. STEM students demonstrated a higher conceptual understanding of AI principles, applications, and problem-solving. The moderate effect size (d = 0.25) further suggests a meaningful gap in this higher-order literacy skill. This is consistent with the ABCE framework's hierarchy, which positions CL at the upper end of the cognitive spectrum, involving tasks such as evaluating and creating AI solutions. The finding also aligns with Bloom's Revised Taxonomy, highlighting the importance of applying and synthesising knowledge in developing 21st-century competencies.

While not statistically significant, EL also showed a trend favouring STEM students ($p = 0.074$, $d = 0.22$). Since EL is closely linked to responsible AI use, which encompasses issues such as data bias, algorithmic fairness, and transparency, this result suggests a slight advantage for STEM learners, likely due to their greater exposure to ethical considerations embedded in technical coursework. This pattern reinforces the ABCE framework's emphasis on ethical reasoning as a capstone of AI literacy and Kohlberg's Moral Development Theory, which explains how structured learning environments can enhance ethical judgment.

Interestingly, no significant differences were found in AL and BL, with small effect sizes in both domains. This suggests that pre-service teachers share similar levels of interest, confidence, and engagement with AI regardless of academic background. In the ABCE framework, these dimensions reflect foundational emotional and participatory readiness for learning with AI. The comparable results across both groups support the theoretical premise of Self-Determination Theory (Deci & Ryan, 1985) and Social Cognitive Theory (Bandura, 1986), highlighting that motivation and perceived self-efficacy depend not solely on technical background but also on psychological needs and environmental support.

Overall, the results underscore the need for targeted interventions in cognitive and ethical domains, especially for non-STEM pre-service teachers. While both groups demonstrate readiness to engage with AI (AL & BL), the ability to critically understand and apply AI (CL), as well as to navigate its societal implications (EL), remains uneven. These findings validate the ABCE framework's progression logic from emotional engagement to ethical reasoning and affirm that for AI literacy to be truly equitable and transformative, teacher education programs must embed scaffolded, discipline-inclusive approaches that support cognitive growth and ethical formation in line with Education 5.0.

RECCOMENDATION

Integrating Multidimensional AI Literacy into the National Teacher Education Curriculum

To ensure that all Malaysian pre-service teachers, regardless of their discipline, are equipped for the AI era, AI literacy must be embedded as a core component across all teacher education programs. This integration should not be limited to STEM subjects but extended to language, humanities, and arts education, reflecting the cross-disciplinary impact of AI (Bohari et al., 2024; Ng et al., 2023a). The curriculum should be scaffolded, beginning with foundational AI concepts and progressing to advanced applications, ensuring that every graduate possesses a working knowledge of AI's potential, limitations, and classroom relevance. Collaborative, interdisciplinary modules and project-based assignments can help contextualise AI for Malaysian classrooms, making the learning authentic and meaningful.

Advancing Experiential and Ethics-Centred Professional Development

Given the study's findings that ethical awareness and affective engagement are high, but cognitive and behavioural competencies lag, teacher education must prioritise experiential, hands-on learning and robust ethics training. Teacher preparation programs should include workshops, micro-credentials, and practicum experiences that enable pre-service teachers to use fundamental AI tools and platforms to design, deliver, and reflect on AI-enhanced lessons (Ng et al., 2023b). Ethics modules should be anchored in Malaysian and global case studies, prompting critical reflection on issues such as data privacy, algorithmic bias, and the responsible use of AI in diverse school settings (Kohlberg, 2021; Ribble, 2011). This approach will cultivate reflective, principled educators who can lead ethically in the digital age.

Institutionalising a National AI Literacy Framework and Continuous Upskilling

To ensure consistency and sustainability, the Ministry of Education should adopt and institutionalise a multidimensional AI literacy framework, such as the ABCE model, as a national standard for teacher competencies (Ng et al., 2023a). This framework should guide curriculum development, teacher accreditation, and ongoing professional learning. All teacher education institutions should offer continuous AI literacy upskilling for both pre-service and in-service teachers, using blended and online formats to maximise accessibility. Micro-credentialing and certification in AI literacy will incentivise lifelong learning and ensure the Malaysian teaching workforce remains agile and future-ready (Zawacki-Richter et al., 2019).

Fostering Interdisciplinary Collaboration and Systematic Impact Evaluation

Maximising the impact of AI literacy initiatives requires a collaborative, whole-institution approach. Teacher education programs should facilitate partnerships between STEM and non-STEM faculties, encourage joint projects, and promote peer mentoring to share best practices and resources (Bohari et al., 2024). Interdisciplinary seminars, innovation challenges, and knowledge-sharing platforms can further foster a collaborative culture around AI integration. Equally important is the establishment of robust mechanisms for monitoring and evaluating AI literacy outcomes. Regular assessment, using both quantitative and qualitative data, will inform iterative improvements, ensure responsiveness to technological advances, and help align teacher preparation with the evolving needs of Malaysian classrooms (Asio, 2024). By implementing these recommendations, Malaysia can lead the region in preparing a new generation of educators who are not only AI-literate but also ethical, adaptable, and empowered to drive transformative, inclusive learning in the AI era. These actions will support the vision of Education 5.0 and position Malaysian education at the forefront of global digital innovation.

CONCLUSION

Empowering Malaysian educators with multidimensional AI literacy is essential for building a future-ready, equitable education system that transcends traditional disciplinary boundaries. The persistent gaps in foundational AI understanding and practical application, particularly among non-STEM pre-service teachers, highlight the urgent need for teacher education programmes to move beyond basic digital skills and embrace a holistic approach that integrates affective, behavioural, cognitive, and ethical competencies. Embedding hands-on, ethics-driven, and inclusive AI training throughout the teacher preparation journey will not only equip future educators to harness AI effectively but also foster critical thinking, adaptability, and principled leadership in the classroom. By institutionalising comprehensive AI literacy frameworks and prioritising continuous professional development, Malaysia can position its teachers at the forefront of educational transformation, ensuring they are prepared to lead, innovate, and inspire in an increasingly complex, AI-driven world.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTIONS

A. Bohari served as the corresponding author, led the conceptual framework design, and coordinated the research and manuscript writing

A. Kaliappan contributed to data collection, analysis, and interpretation

S. L. Loh reviewed and edited the manuscript, providing critical insights to enhance its academic rigour

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