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Pre-Service English Teachers' AI Literacy: Status, Challenges, and Enhancement Strategies

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Abstract

In the era of educational digital transformation, Artificial Intelligence (AI) literacy has emerged as a critical competence for teacher professional development. This study investigates the status, structural characteristics, and influencing factors of AI literacy among 315 pre-service English teachers—an underexplored context. Drawing on empirical data and employing Partial Least Squares Structural Equation Modeling (PLS-SEM), the research reveals a distinctive "attitude-leading, skills-lagging" pattern: participants demonstrate strong ethical awareness and human-centered educational values but comparatively weak technical application competence. Results indicate that teaching internship experience acts as a catalyst for higher overall AI literacy. Furthermore, the PLS-SEM analysis confirms a developmental trajectory where AI cognition functions as a foundational driver for technical application, while ethical awareness fosters pedagogical innovation, which in turn significantly promotes continuous professional development. These findings suggest that sustainable AI literacy is achieved through an integrated pathway of cognitive understanding, ethical grounding, and practice-mediated innovation, providing empirical evidence for reforming teacher preparation programs in resource-constrained regions.

Keywords

AI Literacy, Pre-Service English Teachers, Teacher Education, TPACK

1. Introduction

Amidst the sweeping wave of global digital transformation in education, artificial intelligence (AI) is reshaping the educational ecosystem with unprecedented depth and breadth. Specifically, the advent of Generative AI (GenAI) technologies has fundamentally altered knowledge production and acquisition, necessitating a paradigm shift from knowledge transmission to higher-order cognitive facilitation.

Teachers' capacity to understand, apply, and critically reflect on AI technologies--commonly conceptualized as AI literacy—thus emerged as a key indicator of professional competence (UNESCO, 2024). In China, the *Digital Literacy Standards for Teachers* issued by the Ministry of Education (2022) emphasizes teachers' responsibilities in digital awareness, technological application, ethical use, and continuous professional development, thereby providing a national benchmark for AI-related competencies. Against this backdrop, GenAI is accelerating a shift in teaching from delivering content to scaffolding students' analysis, evaluation, and creation.

Pre-service teachers represent the future teaching workforce, and their AI literacy development is pivotal for the sustainable implementation of educational digitalization strategies. While often assumed to be "digital natives" due to their immersion in technology, many teacher candidates may possess operational fluency yet lack the pedagogical conceptualization required to navigate complex AI-enhanced classroom environments.

However, existing research in China has primarily focused on in-service teachers or economically developed regions, leaving pre-service teachers in less-developed areas underexplored. This imbalance is particularly evident in western Guangdong, a region experiencing accelerated educational informatization yet facing uneven resource distribution. This geographical disparity threatens to widen the digital divide, making it critical to understand how local contextual factors—distinct from the resource-rich Pearl River Delta—impede or facilitate technology adoption in emerging regions.

Pre-service English teachers warrant special attention due to the discipline's strong affinity with AI applications, such as intelligent language assessment, automated writing feedback, and personalized learning systems. Language education stands at the forefront of this technological disruption, as Large Language Models (LLMs) and neural machine translation challenge traditional definitions of linguistic competence. Beyond standard tools like intelligent language assessment, automated writing feedback, and personalized learning systems, the integration of AI in English Language Teaching (ELT) now demands a re-evaluation of teacher roles in fostering learner autonomy and critical cross-cultural communication in an algorithmic age. Understanding their AI literacy profile is therefore essential for aligning teacher education with both technological advances and disciplinary demands. Accordingly, this study aims to examine the status quo, structural features, and influencing factors of AI literacy among pre-service English teachers in western Guangdong, and to propose context-sensitive strategies for improvement.

2. Literature Review

2.1. AI Literacy in Teacher Education

The notion of digital literacy has evolved from basic technical skills toward a multidimensional construct encompassing critical thinking, creativity, and ethical awareness. The European Commission's *Digital Competence Framework* (DigCompEdu) highlights teachers' abilities to integrate digital technologies into pedagogy, assessment, and professional development (European Commission, 2017). Building on this foundation, AI literacy extends digital literacy by emphasizing understanding of what AI is and how it works, distinguishing it from general ICT competency (Long & Magerko, 2020). Recent frameworks further stress the importance of data ethics, human-machine collaboration, and the ability to interact with generative agents effectively (Ng et al., 2023; UNESCO, 2024).

In the Chinese context, AI literacy is often conceptualized as an integral component of teacher digital literacy, combining technological competence with ethical responsibility and pedagogical application (Zhu & Hu, 2022). For pre-service teachers, AI literacy entails not only personal proficiency with AI tools but also the capacity to transform such tools into meaningful instructional practices. In this study, pre-service English teacher AI literacy is defined as a comprehensive capability encompassing AI cognition, technical application, pedagogical integration intention, ethical awareness, human-centered educational values, and continuous professional development.

2.2. Research Gap

International studies have increasingly demonstrated that pre-service teachers' technology-related competencies are shaped by cognitive understanding, beliefs, and contextual practice opportunities (Güneş & Bahçivan, 2018; List et al., 2020). Specifically, the integration of AI in education requires teachers to move beyond mere usage towards developing AI-TPACK, which synthesizes technological knowledge of AI with pedagogical content knowledge (Chai et al., 2021). Domestically, scholars like Xiao (2021) and Guo (2021) have preliminarily investigated the connotation and composition of normal students' digital literacy, though primarily focusing on general information technology capabilities rather than AI-specific competencies.

A bibliometric visualization of the current research landscape (see **Figure 1**) reveals distinct clustering around three core themes: the theoretical foundations of AI literacy and user acceptance (green cluster), the rapid emergence of generative AI tools like ChatGPT in professional development (red cluster), and the broader integration of digital literacy in teacher education (blue cluster). The prominence of nodes such as "Technology Acceptance Model," "beliefs," and "knowledge" suggests that existing scholarship heavily prioritizes the psychological readiness and cognitive acceptance of teachers. Furthermore, while terms like generative AI and ChatGPT show strong centrality, they are often linked to "general teacher training" or "education" nodes. This indicates a saturation of research on general tool acceptance, but a fragmented landscape regarding how these tools intersect with specific subject matter methodologies.

Despite these insights, three significant gaps remain evident. First, disciplinary specificity is lacking. Insufficient attention has been paid to subject-specific pre-service teachers, particularly English educators. While general models exist, there is limited integration of the Technological Pedagogical Content Knowledge (TPACK) framework to explicitly explore AI-pedagogy fusion paths within the context of language acquisition (Koehler & Mishra, 2009; Yan et al., 2023).

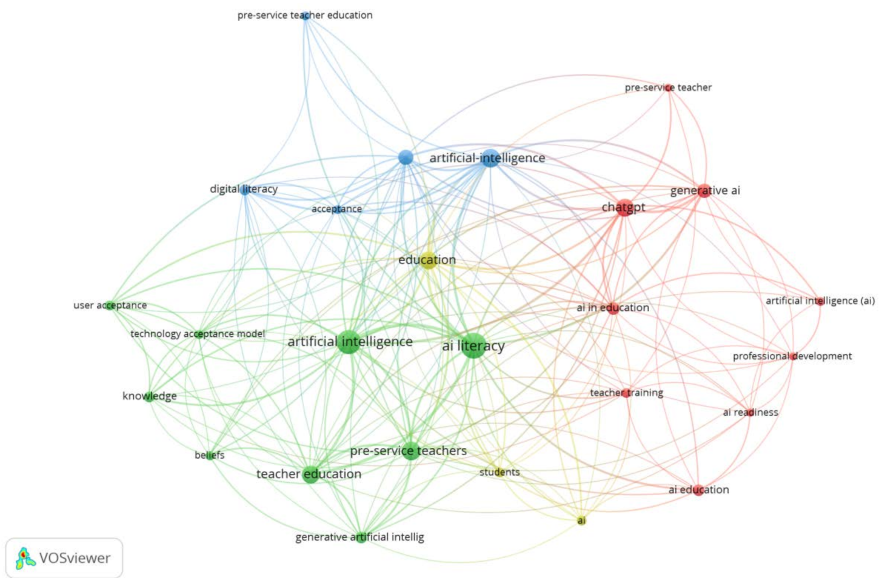

Figure 1. Bibliometric visualization of current research in Pre-service teachers.

Second, regional representation is imbalanced: empirical research overwhelmingly concentrates on eastern coastal developed regions, while rapidly developing yet resource-constrained areas such as western Guangdong remain critically under-examined, despite the likelihood that regional economic, cultural, and educational resource disparities profoundly influence literacy development patterns.

Third, most studies remain descriptive, failing to empirically excavate structural relationships among literacy dimensions, interaction mechanisms, or influencing factors through advanced statistical approaches such as structural equation modeling to reveal internal causal pathways. Therefore, this study seeks to address these gaps through a regionally grounded, discipline-specific, and methodologically integrative approach.

2.3. Research Questions

Based on the conceptualization of AI literacy in teacher education and gaps identified in prior research, this study is guided by the following research questions (RQs):

RQ 1: What is the overall level and structure profile of AI literacy among pre-service English teachers in western Guangdong?

RQ 2: Are there significant differences in AI literacy levels among pre-service English teachers with different background characteristics (e.g., teaching internship experience)?

RQ 3: What are the structural relationships among key dimensions of pre-service English teachers' AI literacy in western Guangdong?

2.4. Research Hypotheses

To address RQ 3 and to provide a clear analytical rationale for the use of structural equation modeling (SEM), the following hypotheses are proposed based on existing theoretical and empirical literature (European Commission, 2017; UNESCO, 2024; Zhu & Hu, 2022):

H1: AI Cognition has a positive influence on Technical Application Competence.

H2: AI Cognition has a positive influence on Integration Intention.

H3: AI Cognition has a positive influence on Continuous Professional Development.

H4: Ethical Awareness has a positive influence on Pedagogical Innovation Ability.

H5: Pedagogical Innovation Ability has a positive influence on Continuous Professional Development.

2.5. Research Significance

This study contributes to the existing literature by providing empirical evidence on the AI literacy of pre-service English teachers in an underexplored regional context. Practically, it focuses on Zhanjiang, the important hub of western Guangdong, to tackle critical challenges regarding undefined AI literacy standards and urban-rural disparities. By aligning with local "Smart Education" initiative, the research aims to narrow quality gap through AI-empowered instruction, ensuring that future educators in resource-constrained areas are equipped to support the region's internalization and digital strategies.

Disciplinarily, this research counters the prevailing imbalances in current literature, which bibliometric analysis reveals is heavily skewed toward in-service teachers in developed eastern regions. It innovates by constructing an interdisciplinary framework that bridges Second Language Acquisition (SLA) theory with AI technology, moving beyond descriptive analysis to establish a structural model of literacy. This approach not only advances the theoretical boundaries of foreign language-IT integration but also facilitates the localized implementation of the *Compulsory Education English Curriculum Standards* (2022), offering a tailored "AI + English" pedagogical paradigm suited to western Guangdong's specific reality.

3. Methodology

3.1. Participants

Participants were 315 undergraduates enrolled in English teacher education major at university in Zhanjiang, Maoming, and Yangjiang. Stratified and convenience sampling methods were combined. The sample predominantly consisted of female students (93.02%), with most participants in their second and third academic years. Approximately 41.9% reported having teaching internship experience. The demographic characteristics of participants are shown in **Table 1**. The data were collected through an online questionnaire platform (https://www.wjx.cn/).

Table 1. Demographic characteristics of participants (N = 315).

Variable	Category	Number	Percentage
Gender	Male	22	6.98%
	Female	293	93.02%
Age	19	108	34.29%
	20	110	34.92%
	21	54	17.14%
	22	26	8.25%
	23	5	1.59%
	24	12	3.81%
Region	Zhanjiang	157	49.84%
	Maoming	83	26.35%
	Yangjiang	75	23.81%
Grade	Year 1	35	11.11%
	Year 2	140	44.44%
	Year 3	107	33.97%
	Year 4	33	10.48%
Internship Experience	Yes	132	41.9%
	No	183	58.1%
Total		**315**	**100%**

As shown in **Table 1**, the sample comprised 93.02% female participants, with the majority (69.21%) aged between 19 and 20 years. The grade-level distribution was predominantly second- and third-year students (78.41%). This demographic structure closely reflects the characteristics of English teacher education students in this region, ensuring adequate representativeness of the target population.

3.2. Instrument

This study developed the *Survey Questionnaire on Artificial Intelligence Literacy of Pre-service English Teachers* by drawing upon the UNESCO AI Competency Framework, China's *Digital Literacy Standards for Teachers*. The questionnaire comprises two sections: the first section collects demographic information; the second section contains the main Likert-scale measuring eight core dimensions: 1) AI Cognition, 2) Technical Application Competence, 3) Integration Intention, 4) Digital Resource Application Competence, 5) Ethical Awareness, 6) Human-Centered Education, 7) Pedagogical Innovation Ability, 8) Continuous Professional Development. A five-point Likert scale was employed (1 = Strongly Disagree, 5 = Strongly Agree). The draft questionnaire underwent expert review and pilot testing to ensure content validity (Table 2).

Table 2. Pre-service teacher AI literacy scale assessment sample questions.

Dimension	Item	Description
AI Cognition	6	I understand the important value of information dissemination, transformation, and application in promoting the growth and development of both teachers and students.
Technical Application Competence	6	I can use at least one AI-driven English teaching tool.
Integration Intention	4	I plan to consciously integrate AI into lesson design and teaching practice in the future.
Digital Resource Application Competence	4	I can use AI tools to develop and adapt existing teaching resources to meet daily instructional needs.
Ethical Awareness	5	I believe teachers should guide students to use AI tools correctly and ethically.
Human-Centered Education	4	I believe that in English teaching, AI tools should always serve students' personalized development needs.
Pedagogical Innovation Ability	4	I will utilize AI technology to explore new forms of future English teaching.
Continuous Professional Development	4	I am willing to continuously reflect upon and improve my methods of applying AI tools in teaching practice.

Initially, the instrument was designed with eight theoretical dimensions. However, during the Exploratory Factor Analysis (EFA), items related to "Digital Resource Application Competence" and "Human-centered Education" were excluded due to low factor loadings (<0.50). The final structure consolidated the items into six distinct latent variables for the SEM analysis.

3.3. Data Collection

This study collected data via the online survey platform *Wenjuanxing* (https://www.wjx.cn/), targeting students enrolled in English teacher education programs at three universities located in Zhanjiang, Maoming, and Yangjiang. A total of 354 responses were collected, and after screening for invalid responses, 315 valid samples were retained, yielding an 88.99% valid response rate. The screening criteria for valid questionnaires were primarily based on completion time. Thirty-six questionnaires were excluded because their completion times were too short to align with the logical duration required for normal reading and thoughtful consideration, thereby ensuring the exclusion of data lacking authenticity and validity. Additionally, three questionnaires were eliminated due to exhibiting patterned response trends (straight-lining), indicating insufficient respondent engagement.

3.4. Data Analysis

Subsequently, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed using SmartPLS 4 software to verify the path relationships. PLS-SEM was selected for this study because it is particularly suitable for exploratory research on theoretical extensions and offers high statistical power even with non-normal data distributions (Hair et al., 2019). The analysis followed a two-step approach: assessing the measurement model for reliability and validity, followed by the structural model to test the hypotheses. Bootstrapping with 5000 subsamples was applied to determine the significance of the path coefficients.

4. Results

4.1. Descriptive Statistics

To address RQ 1, **Table 3** presents the descriptive statistics (means and standard deviations) of each AI literacy dimension, thereby illustrating the overall level and structural profile of pre-service English teachers' AI literacy. Results indicated that Ethical Awareness (M = 4.28, SD = 0.65) and Human-Centered Education (M = 4.25, SD = 0.66) received the highest mean scores, indicating their strong endorsement of ethical norms and student-centered principles regarding AI educational applications. Integration Intention (M = 4.12), Continuous Professional Development (M = 4.20), and Pedagogical Innovation Ability (M = 4.10) also registered relatively high levels, reflecting positive adoption motivations and developmental aspirations. However, Technical Application Competence (M = 3.76, SD = 0.63) and AI Cognition (M = 3.82, SD = 0.62) scored comparatively lower, constituting distinct capability weaknesses. This pattern reflects an "attitude-leading, skills-lagging" profile.

Table 3. Descriptive statistics of AI literacy dimensions (N = 315).

Dimension	Mean	SD	Rank
Ethical Awareness	4.28	0.65	1
Human-Centered Education	4.25	0.66	2
Continuous Professional Development	4.20	0.65	3
Integration Intention	4.12	0.65	4
Pedagogical Innovation Ability	4.10	0.62	5
Digital Resource Application Competence	3.92	0.67	6
AI Cognition	3.82	0.62	7
Technical Application Competence	3.76	0.63	8

4.2. Difference Analysis

In response to RQ 2, **Table 4** reports the results of the independent-samples *t*-test examining differences in overall AI literacy based on teaching internship experience. The overall AI literacy score was calculated as the mean value of all valid items retained after the EFA process. The scale ranges from 1 to 5, where a higher score indicates a higher level of AI literacy. The only demographic variable exerting a statistically significant influence on overall AI literacy was the presence of teaching internship experience ($t = 2.107$, $p = 0.036 < 0.05$). Pre-service teachers who had completed or were currently engaged in educational internships demonstrated significantly higher literacy scores compared to those with no practical experience. This finding suggests that immersion in real-world educational contexts acts as a catalyst for AI literacy, transitioning students from a theoretical understanding of technology to a pragmatic application. The complexities of actual classroom management and lesson preparation likely compel interns to actively seek out and evaluate AI tools (e.g., for material generation or translation assistance), thereby enhancing their operational proficiency and pedagogical intuition.

Table 4. Difference analysis of overall AI literacy score (N = 315).

Variable	Group	Mean	SD	*t*-test	*p*-value
Teaching Internship Experience	Yes (n = 132)	144.80	18.41	$t = 2.107$	0.036*
	No (n = 183)	140.01	21.53		

Note. *$p < 0.05$.

In contrast, differences across gender, age, place of origin, and academic year did not reach statistical significance. The lack of disparity regarding gender and place of origin indicates a leveling effect among "digital natives," suggesting that the university environment may successfully homogenize basic digital access and attitudes, bridging the gap between students from urban centers and western Guangdong. However, the absence of significant growth across academic years is a noteworthy anomaly. It implies that current teacher education programs may lack a vertical, progressive curriculum for AI training; consequently, senior students do not exhibit markedly superior AI competencies compared to their junior counterparts, highlighting a potential structural gap in the four-year training continuum.

Table 5. Hierarchical regression analysis predicting AI literacy (N = 315).

Variable	Model 1	Model 2	Model 3
Internship	4.80*	6.36*	6.31*
Grade (centered)	—	−2.17	−2.63
Internship × Grade	—	—	0.91
R^2	0.014	0.020	0.020

Note. Entries are unstandardized coefficients (B). *$p < 0.05$.

Table 5 presents the hierarchical regression results examining whether internship experience predicts overall AI literacy after controlling for grade. In Model 1, internship experience significantly predicted AI literacy (B = 4.80, $p < 0.05$). After adding grade as a control variable in Model 2, internship remained a significant predictor (B = 6.36, $p < 0.05$), whereas grade itself was not statistically significant. Model 3 further tested the interaction between internship and grade; the interaction term was non-significant, indicating that the positive effect of internship does not vary across academic years. These findings demonstrate that internship experience exerts an independent and robust effect on AI literacy, rather than merely reflecting differences in grade level.

4.3. Correlation Analysis

Based on the theoretical framework and correlation analysis, the model demonstrated good fit indices ($\chi^2/df = 2.12$, RMSEA = 0.06, CFI = 0.95, TLI = 0.94), supporting its validity. Pearson correlation analysis indicated that significant positive correlations existed among all dimensions ($p < 0.01$). The heatmap in Figure 2 visualizes the relationships among the eight dimensions, revealing two distinct structural clusters:

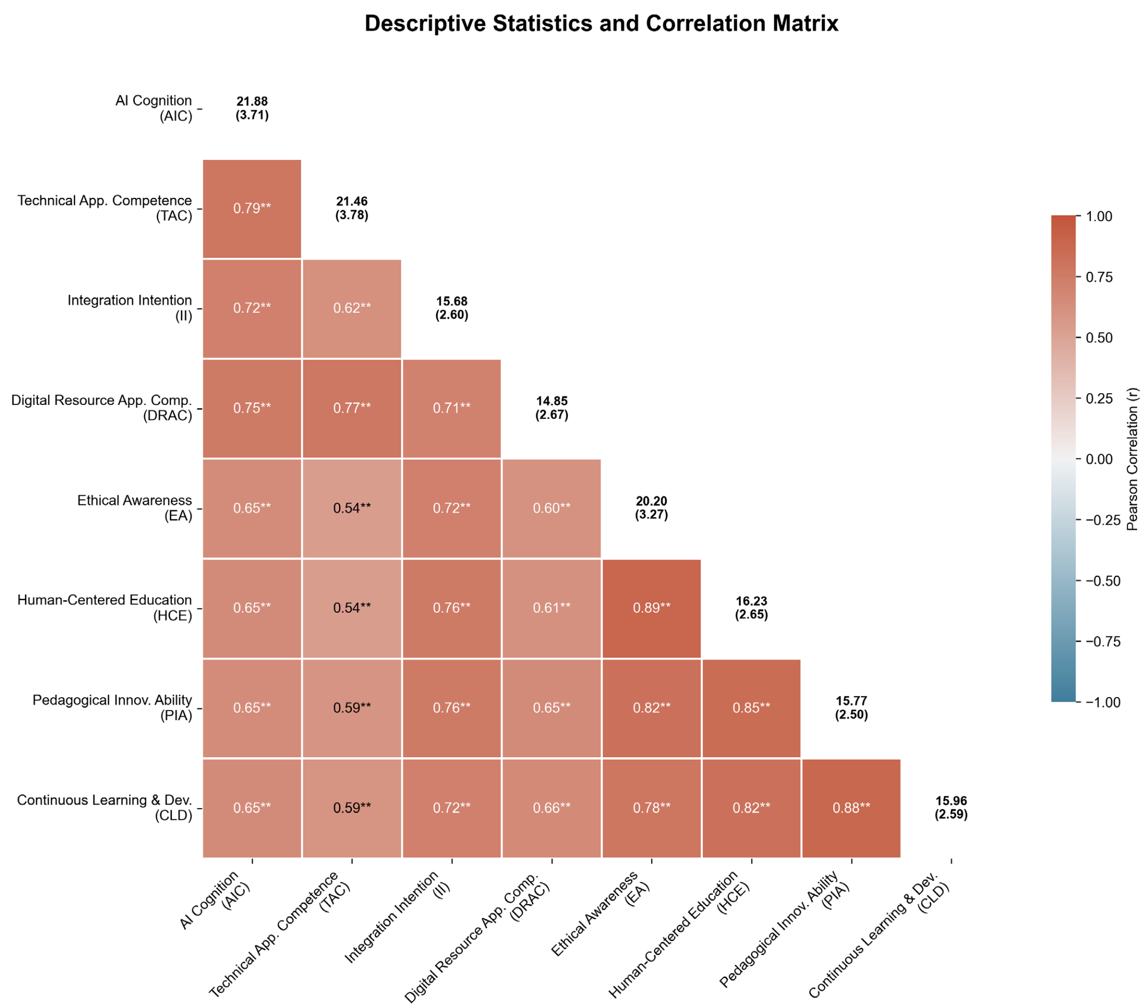

Figure 2. Pearson correlation matrix of the eight AI literacy dimensions.

4.3.1. Ethical-Innovation Cluster (High Correlation)

A strong internal consistency was observed among Ethical Awareness (EA), Human-Centered Education (HCE), Pedagogical Innovation Ability (PIA), and Continuous Professional Development (CPD). The correlation coefficients within this group ranged from 0.78 to 0.89 (specifically, the correlation between HCE and EA was strongest at $r = 0.89$). This indicates that these dimensions form a tightly cohesive psychological construct related to the teacher's value system and professional growth.

4.3.2. Knowledge-Application Cluster (Moderate-High Correlation)

Dimensions related to technical competency—specifically AI Cognition (AIC), Technology Application Capability (TAC), Integration Intention (II), and Digital Resource Application Competence (DRAC)—exhibited robust associations, with coefficients ranging from 0.62 to 0.79. The strongest relationship in this cluster was found between AI Cognition and Technical Application Competence (r = 0.79). This suggests a logical synergy between the theoretical understanding of technology and the practical willingness to apply it.

4.4. PLS-SEM Analysis and Hypothesis Testing

4.4.1. Assessment of the Measurement Model

Reliability analysis in Table 6 indicated that Cronbach's α coefficients for the eight dimensions ranged from 0.945 to 0.977, with all item-total correlations exceeding 0.7, demonstrating excellent internal consistency reliability. EFA results (KMO = 0.958, Bartlett's test $p < 0.001$) supported construct validity, yielding a five-factor structure that integrated related dimensions into broader conceptual modules.

Discriminant validity was evaluated using the Heterotrait-Monotrait ratio of correlations (HTMT), which is considered a more rigorous criterion than the traditional Fornell-Larcker criterion in PLS-SEM analysis (Henseler et al., 2015). As presented in Table 7, all HTMT values fall below the clinically accepted threshold of 0.90. The highest observed value is 0.898 between Ethical Awareness (EA) and Pedagogical Innovation Ability (PIA), while all other ratios are well below the conservative threshold of 0.85. These results indicate that each construct in the model is empirically distinct, thereby establishing adequate discriminant validity for the subsequent structural model analysis.

Table 6. Construct reliability and validity.

Latent Constructs & Items	Outer Loading	Cronbach's Alpha	Composite Reliability (rho_c)	AVE
AI Cognition (AIC)		0.945	0.956	0.785
AIC 1	0.868			
AIC 2	0.891			
AIC 3	0.905			
AIC 4	0.850			
AIC 5	0.899			
AIC 6	0.902			

Continued

Continuous Prof. Dev. (CPD)		0.968	0.977	0.914
CPD 1	0.960			
CPD 2	0.972			
CPD 3	0.919			
CPD 4	0.972			
Ethical Awareness (EA)		0.973	0.979	0.902
EA 1	0.960			
EA 2	0.945			
EA 3	0.943			
EA 4	0.968			
EA 5	0.934			
Integration Intention (II)		0.977	0.983	0.936
II 1	0.977			
II 2	0.959			
II 3	0.961			
II 4	0.972			
Pedagogical Innovation Ability (PIA)		0.950	0.964	0.870
PIA 1	0.900			
PIA 2	0.959			
PIA 3	0.951			
PIA 4	0.921			
Technical Application Competence (TAC)		0.970	0.976	0.869
TAC 1	0.906			
TAC 2	0.900			
TAC 3	0.952			
TAC 4	0.960			
TAC 5	0.931			
TAC 6	0.943			

Table 7. Discriminant validity.

Constructs	AIC	CPD	EA	II	PIA	TAC
AIC						
CPD	0.728					
EA	0.789	0.750				
II	0.856	0.778	0.806			
PIA	0.721	0.771	0.898	0.795		
TAC	0.845	0.653	0.655	0.716	0.660	

4.4.2. Hypotheses Testing

Based on the PLS-SEM algorithm, a structural model was assessed to test the hypothesized relationships using SmartPLS 4.0. Figure 3 illustrates the relationships among key AI literacy dimensions. When the *p*-value is less than 0.05 and the *t*-value exceeds 1.96 (Hair et al., 2019), the path relationships between variables are considered significant, supporting the hypotheses.

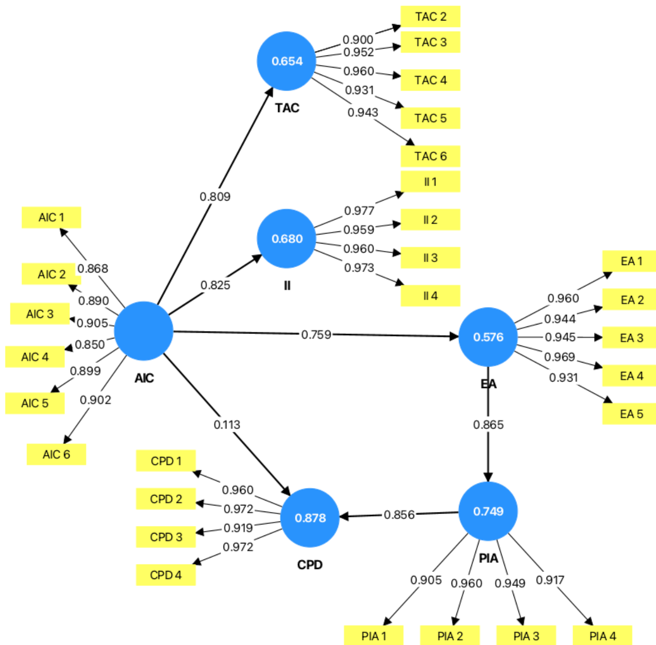

Figure 3. Path diagram of the SEM for pre-service English teachers' AI literacy.

The measurement model demonstrated robust psychometric properties, with observed indicators loading strongly on their respective constructs. The model's predictive power was substantial, as indicated by the coefficients of determination (R^2) for the endogenous constructs: 0.654 for Technical Application Competence (TAC), 0.680 for Integration Intention (II), 0.576 for Ethical Awareness (EA), 0.749 for Pedagogical Innovation Ability (PIA), and 0.878 for Continuous Professional Development (CPD).

Path analysis in Table 8 revealed that AI Cognition (AIC) functioned as a strong foundational driver, exerting significant direct positive effects on Technical Application Competence (TAC) (β = 0.809) and Integration Intention (II) (β = 0.825). AI Cognition also strongly predicted Ethical Awareness (EA) (β = 0.759). However, the direct effect of AI Cognition on Continuous Professional Development (CPD) was relatively weak (β = 0.1133), suggesting that cognitive understanding alone is not the primary driver of sustained professional growth. The model highlights a sequential developmental pathway. Ethical Awareness significantly influenced Pedagogical Innovation Ability (PIA) (β = 0.816). Subsequently, Pedagogical Innovation Ability (PIA) emerged as the strongest predictor of Continuous Professional Development (CPD) (β = 0.856). This structure confirms that while AI cognition provides the necessary foundation, sustainable professional development is most effectively achieved when teachers possess strong ethical awareness that drives pedagogical innovation.

Table 8. Results of hypotheses testing.

Hypotheses	Structural Path	β	*t*	*p*	f^2	Supported
H1	AIC → TAC	0.809	15.022	<0.001	1.888	Yes
H2	AIC → II	0.825	17.603	<0.001	2.126	Yes
H3	AIC → CPD	0.113	1.754	0.080	0.055	No
H4	EA → PIA	0.865	9.807	<0.001	1.130	Yes
H5	PIA → CPD	0.856	14.970	<0.001	3.187	Yes

These values in **Table 9** suggest that the model is particularly effective in explaining developmental and outcome-oriented constructs (PIA, CPD).

Table 9. Explained variance (R^2) and model strength.

Construct	R^2	Interpretation
TAC	0.654	Moderate-high explanatory power
II	0.680	Strong explanatory power
EA	0.576	Moderate explanatory power
PIA	0.749	High explanatory power
CPD	0.878	Very high explanatory power

To summarize the hypothesis testing results, the SEM analysis largely supported the proposed framework. While AI Cognition exerted a strong effect on technical and instructional competencies, its influence on professional development was mediated through ethical and innovative dimensions. Instead, ethical awareness significantly predicts pedagogical innovation ability, which in turn emerges as the strongest predictor of continuous professional development. The results validate a trajectory where AI Cognition (AIC) leads to Ethical Awareness (EA), which fosters Pedagogical Innovation Ability (PIA), ultimately culminating in Continuous Professional Development (CPD). These findings suggest that sustainable AI literacy development is achieved primarily through ethically grounded pedagogical innovation rather than direct cognitive accumulation.

5. Discussion

This study systematically examined the status and internal structure of AI literacy among 315 pre-service English teachers in western Guangdong. Overall, the results reveal a clear pattern in which ethical awareness and human-centered educational values are relatively strong, while technical competence and pedagogical enactment remain weaker. Mapped onto the DigCompEdu framework, participants performed moderately in Area 2 (Digital Resources), indicating basic ability to use existing AI tools (e.g., translation software). However, capacities in Area 3 (Teaching and Learning) were underdeveloped, suggesting difficulty in designing and implementing effective AI-supported instruction. Noticeable gaps also appeared in Area 4 (Assessment) and Area 6 (Facilitating Learners' Digital Competence): despite the ethical grounding aligned with Area 5, participants lacked the technical depth to guide learners in critically evaluating AI-generated content—an essential requirement for empowering students' digital competence.

The SEM findings further clarify the mechanism behind this imbalance. AI cognition emerged as a foundational driver of both technical application and instructional integration intention (path coefficients > 0.68), indicating that conceptual understanding of AI logic is pivotal for translating intention into practice. At the same time, the model points to a value-based motivational pathway: ethical awareness and human-centered educational philosophy jointly foster pedagogical innovation consciousness, which then converts into strong intrinsic motivation for sustained learning. This "Ethics → Humanism → Innovation→ Learning" chain captures a psychological progression from value identification to professional self-development, extending current accounts of how teacher AI literacy matures beyond skills alone.

The significant difference between participants with and without internship experience ($p = 0.036$) underscores that AI literacy is not merely theoretical, but an embodied competence shaped through authentic teaching contexts. This aligns with TPACK and practice-oriented perspectives (List et al., 2020), which emphasize that technological, pedagogical, and content knowledge become actionable only through situated classroom work. Nevertheless, the persistently low technical application scores suggest that internship advantages have not yet translated into subject-specific and sophisticated AI pedagogical competence, highlighting a continuing "practice-to-capability" conversion gap.

Regarding RQ3, the SEM supports a four-stage developmental logic: AI Cognition → Ethical Framing→ Pedagogical Innovation → Sustainable Professional Development. Theoretically, this trajectory repositions ethics from a passive constraint to an active pedagogical catalyst that enables innovation, while also demonstrating that technical competence alone is insufficient for long-term growth. Instead, sustainable AI literacy appears to depend on an integrated pathway in which cognitive understanding, ethical grounding, and practice-mediated innovation reinforce one another. This interpretation resonates with the UNESCO AI Competency Framework and sociocultural views of teacher development, suggesting that professional sustainability in AI-rich education is achieved through the alignment of values, knowledge, and situated action.

6. Conclusion

6.1. Findings

Based on the empirical investigation of AI literacy among 315 pre-service English teachers in western Guangdong, this study advances the following core findings.

First, literacy development exhibits an imbalanced pattern characterized by "high-level value identification but low-level technical competence." While pre-service English teachers demonstrate high levels of endorsement regarding ethical consciousness, humanistic educational philosophy, and pedagogical innovation willingness (means > 4.10)—establishing a robust "ought-to" foundation for development—they possess significant capability deficiencies in AI cognitive depth and practical technical application (means < 3.80). This finding corroborates the "second-order barrier" phenomenon described by Ertmer (2005), where beliefs are established, but operational barriers remain. It also aligns with recent studies on the digital native fallacy, which suggest that students' general digital familiarity does not automatically translate into professional pedagogical competence (Kirschner & De Bruyckere, 2017). Within the specific disciplinary context of English education, technical application often remains at the superficial level of tool consumption (e.g., basic translation software use) rather than advancing to higher-order pedagogical applications such as integration intention, learning analytics, and personalized guidance. This imbalance constitutes the core bottleneck constraining their transformation from AI technology users to AI instructional designers.

Second, AI literacy constitutes a multi-dimensional, dynamically interactive system premised upon cognition as foundation, values as core, and practice as pathway. The structural equation model reveals a sophisticated causal transmission mechanism within literacy: AI cognition not only directly drives technical skill acquisition but indirectly shapes practical behavior through influencing instructional integration intention. Meanwhile, ethical awareness and humanistic educational philosophy function as a value engine, transforming into intrinsic motivation for continuous professional development via the activation of pedagogical innovation consciousness. This structure transcends the traditional linear view of knowledge-skills-attitudes literacy, confirming that in AI educational contexts, value guidance and technological innovation exhibit a deep, mutually constitutive relationship. As noted by Selwyn (2019), technical applications devoid of ethical constraints risk pedagogical alienation, while ethical reflections divorced from technical understanding tend toward empty abstraction. This validates Bandura's (1977) theory of self-efficacy, identifying a critical node for resolving the "knowing-doing gap": only through authentic instructional task performance and the accumulation of successful technology integration experiences can technological anxiety be effectively dissolved, thereby establishing a virtuous cycle of capability development.

Third, immersion in practical contexts serves as the crucial catalyst for transforming literacy into pedagogical capability, while existing teacher preparation systems manifest discontinuities in disciplinary AI cultivation. Comparative analyses demonstrate that pre-service teachers with teaching internship experience exhibit significantly higher overall literacy scores. This provides robust evidence that AI literacy constitutes not "inert knowledge" acquirable through classroom lecturing alone, but rather living capability continuously generated through situated learning in authentic teaching environments (Lave & Wenger, 1991). The absence of AI application scenario training specific to English listening, speaking, reading, writing, and translation skills results in a pronounced disconnect between technical literacy courses and subject-specific pedagogy courses, a challenge frequently cited in TPACK research (Mishra & Koehler, 2006).

6.2. Implications

Building upon these findings above, this study transcends traditional linear gap-filling approaches, instead advocating for systematic support through coordinated efforts across individual, institutional, and regional dimensions, following the progressive logic of cognitive foundation - value internalization - skill integration - practical creation.

6.2.1. Individual Development

We should strengthen pre-service teachers' agency through deep cognition and contextualized practice in AI-supported language teaching and learning. Pre-service teachers should transcend the consumer mentality toward AI tools, transitioning toward the role of critical designers (Tseng et al., 2022). Specifically, they must proactively investigate application principles of natural language processing (NLP) technologies in second language acquisition, developing deeper understanding of technical mechanisms such as AI-assisted writing feedback systems and intelligent speech evaluation algorithms. At the practical level, they should actively participate in "AI + English" Micro-teaching workshops, engaging in micro-research on specific pedagogical problems including virtual scenario creation, intelligent writing feedback, and personalized vocabulary acquisition. Through cycles of "design-implementation-video replay-reflective revision," abstract ethical principles can be transformed into concrete instructional decision-making capabilities, thereby forming transferable intelligent pedagogical knowledge among the pre-service English teachers.

6.2.2. Institutional Training

Stakeholders should establish a spiral curriculum framework that sequentially connects values, knowledge, skills, and practice across stages. Teacher preparation institutions must reconstruct curricula to break the isolation of *Modern Educational Technology Courses*, establishing an AI literacy-infused preparation scheme. At the curricular ethics level, specialized modules such as AI Ethics and English Education should be developed to embed ethical reflection within professional courses through analysis of real cases involving cultural bias in AI translation and data privacy in intelligent assessment, rather than through isolated didactic approaches. At the curricular integration level, core courses including English language pedagogy and curriculum theory should be deeply integrated with AI technologies. Following the AI-TPACK framework (Chai et al., 2021), institutions should design stage-based competency training: Stage 1 focuses on AI-assisted resource curation; Stage 2 trains AI-enabled differentiation; Stage 3 explores generative AI applications in creative writing instruction; Stage 4 conducts instructional diagnosis based on learning analytics data. Simultaneously, tripartite University-Enterprise-School (UES) practical communities should be established, incorporating intelligent classroom observation and AI teaching assistant utilization as compulsory components of educational practicums, implementing dual mentorship systems involving university disciplinary supervisors and front-line technical expert teachers.

6.2.3. Regional Support

A systematic regional support network should be established to integrate standards, resources, and ecosystem-based support for AI literacy development. Educational authorities or stakeholders should play a coordinating role in providing institutional support for AI literacy development. Regarding standards construction, development of Guidelines for Pre-service English Teacher AI Literacy Development is recommended based on the *National Digital Literacy Standards for Teachers Framework*, incorporating western Guangdong's socio-economic development level and English disciplinary characteristics. These should feature clearly defined, tiered competency indicators ranging from "basic cognition - pedagogical application - innovative research" to provide actionable quality standards. Regarding resource provision, a dedicated Western Guangdong Intelligent Education development fund should be established to prioritize support for local institutions in developing AI + English Teaching case libraries, virtual simulation training platforms, and open-source tool kits, with particular emphasis on resource-poor rural-oriented teacher preparation programs. Regarding ecosystem co-construction, a *Four-Party Innovation Alliance* involving local education bureaus, normal universities, exemplary primary/secondary schools, and educational technology enterprises should be constructed. By regularly convening western Guangdong Intelligent English Education Seminars and organizing inter-institutional AI teaching skill competitions, this approach fundamentally addresses the dilemmas of fragmented educational resources and scarce practical scenarios in less-developed regions in the hope of bridging the digital divide.

6.3. Limitations

While this study offers valuable insights into the AI literacy of pre-service English teachers in western Guangdong, several limitations must be acknowledged. First, regarding sampling scope, the participants were drawn exclusively from universities in three cities within western Guangdong. Consequently, their AI literacy levels may be heavily influenced by specific regional educational resource allocations and local curriculum configurations, limiting the generalizability of the findings to other underdeveloped regions or the national context. Second, regarding methodology, the study relied primarily on self-reported questionnaire data. Although validity checks were performed, self-reported measures are inherently susceptible to social desirability bias, where respondents may overestimate their ethical awareness or competencies to align with perceived professional expectations. Finally, this study employed a cross-sectional design, which limits the ability to make strict causal inferences. While PLS-SEM provides evidence of directional structural relationships, future research could employ longitudinal designs to further validate the developmental trajectory of AI literacy over time.

6.4. Directions for Future Research

To address these limitations and further advance the field, future research should focus on three key directions. First, longitudinal tracking studies should be implemented to monitor the developmental trajectory of AI literacy from university entrance through to the induction phase of teaching. This would allow researchers to identify critical tipping points in capability development and evaluate the long-term retention of AI skills acquired during pre-service training. Second, mixed-methods approaches should be adopted to deepen the understanding of the value-skill gap. Integrating qualitative methods such as semi-structured interviews, classroom observations, and stimulating recall protocols would provide richer data on why students struggle to translate high ethical beliefs into concrete technical practices, and how they navigate specific algorithmic challenges in real-time English teaching scenarios. Third, comparative and experimental research should be expanded. Future studies could compare pre-service teachers in western Guangdong with those in the resource-rich Pearl River Delta to empirically quantify the digital divide and isolate the impact of regional economic factors. Additionally, experimental studies testing the efficacy of the proposed Spiral Curriculum or specific AI-TPACK interventions would move the field from descriptive analysis to evidence-based intervention, providing concrete blueprints for teacher education reform.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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