

Pre-service English teachers' Artificial Intelligence literacy and its learning solution—A mixed-methods research

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Abstract. In the context of generative-AI-driven educational transformation, pre-service English as a Foreign Language (EFL) teachers' GenAI literacy is vital for future professional competency. This convergent parallel mixed-methods study administered a 34-item Generative Artificial Intelligence (GenAI) Literacy Questionnaire and conducted semi-structured interviews with 88 pre-service EFL teachers from southeast China and five outstanding peers. Guided by Bronfenbrenner's Ecological Systems Theory, we examined the overall status, dimensional structure, and learning pathways of GenAI literacy. Quantitative results showed generally positive self-evaluations, with prominent ethical awareness but weak theoretical mastery and offline instructional-design capacity. Exploratory factor analysis verified a five-dimensional construct. Qualitative analysis revealed dual learning channels and grade-differentiated demands. Synthesizing evidence, we propose a dual-channel staged progressive learning pathway integrating university-based formal training with autonomous informal practice. This study offers empirical evidence for optimizing pre-service EFL teacher education and AI-related professional training.

Keywords: pre-service EFL teachers, generative AI literacy, mixed-methods research, ecological systems theory, learning pathway

1. Introduction

Artificial Intelligence (AI) has emerged as a transformative force across various industries in recent years, driven by advances in natural language processing and large-scale datasets [1]. This trend implies extensive applications of AI tools in English as a Foreign Language (EFL) education, reshaping teaching, learning, and assessment practices [2]. It is increasingly critical for English teachers to understand how to integrate AI into language instruction and pedagogical design [3]. Generative AI (GenAI) tools—such as ChatGPT, DeepSeek, and Doubao—can offer individualized feedback, real-time interaction, creative idea generation, and abundant relevant resources, potentially enhancing student engagement and classroom efficiency [4, 5]. Consequently, as future EFL educators, pre-service English teachers must develop fundamental AI literacy, broadly defined as the adaptive capacity to incorporate AI tools into instructional design and language teaching, build foundational understanding of AI concepts, and critically examine AI-related ethical considerations [6].

Existing scholarship has primarily examined GenAI applications in EFL education and second language acquisition. Within educational settings, this body of research has accumulated substantial data on in-service

teachers' perceptions of AI literacy [7-9]. However, studies focusing on pre-service teachers' AI literacy and competency—particularly in EFL contexts—remain scarce. This gap is significant, as pre-service teachers constitute the future teaching workforce, and their AI-related preparedness will directly shape forthcoming EFL classroom practices [6]. Moreover, most existing studies adopt a single-method design, predominantly quantitative questionnaire surveys, which lack in-depth qualitative exploration of pre-service EFL teachers' perceived AI literacy and targeted learning solutions [2].

To address these gaps, this study adopts Bronfenbrenner's Ecological Systems Theory (EST) as its core analytical framework [10]. Unlike single-factor perspectives that isolate individual or environmental variables, EST offers a multi-layered analytical logic that encompasses internal psychological mechanisms and multilevel external supports—a lens particularly suited to pre-service EFL teachers navigating the critical formative stage of AI literacy development. Applying EST enables this study to systematically identify multi-dimensional barriers to AI competency growth and derive coherent, tiered learning pathways. Against this theoretical foundation, this study selects pre-service English majors from comprehensive and normal universities as participants and addresses two central research questions:

What is the overall status and dimensional distribution of AI literacy among pre-service EFL teachers?

What systematic learning pathways can be developed to enhance their comprehensive AI competency?

Methodologically, this study employs a mixed-methods design: quantitative data are collected via an AI literacy questionnaire adapted from Wang [2], and qualitative evidence is obtained through one-on-one semi-structured interviews. By triangulating statistical outcomes with participants' authentic subjective perceptions, this paper systematically identifies multi-layered constraints on pre-service teachers' AI literacy and proposes corresponding targeted improvement solutions.

This study is expected to contribute to the theoretical refinement of EFL teacher digital literacy in the AI era. By systematically analyzing the current status of pre-service EFL teachers' AI literacy development, the research unpacks multi-dimensional influencing factors that constrain or facilitate AI literacy acquisition in authentic teaching contexts. Empirically, the findings offer practical implications for teacher education and training systems, providing educational institutions with targeted guidance for designing scientifically grounded, context-sensitive, AI-oriented professional development programs. Additionally, the results enable pre-service and in-service EFL teachers to identify their own competency gaps, strengthen their ability to integrate diverse AI tools into English instruction, and develop a more comprehensive understanding of AI literacy—thereby supporting their sustainable professional growth in increasingly intelligent educational environments.

2. Literature review

2.1. Theoretical framework: Ecological Systems Theory

Bronfenbrenner's Ecological Systems Theory (EST) provides a multi-layered analytical framework for understanding individual development, positing that human competence emerges from dynamic interactions between individuals and their nested environmental systems, rather than from isolated personal factors alone [10]. The framework delineates four interconnected ecological tiers: the microsystem, encompassing immediate daily interaction settings; the mesosystem, comprising linkages across micro-level environments; the exosystem, involving indirect institutional influences; and the macrosystem, representing overarching socio-cultural and educational policy norms. Within this nested structure, individual psychological characteristics continuously interact with each environmental layer to jointly shape learners' competency formation.

Within EFL education research, Ghiasvand et al. adopted EST to examine teachers' AI readiness and demonstrated its advantages over single-factor analytical models that treat individual and contextual indicators in isolation [11]. For pre-service EFL teachers, AI literacy development is shaped by a full set of interwoven ecological factors: classroom learning and internship practice fall within the microsystem; university-internship school cooperation belongs to the mesosystem; curriculum policies and educational technology resource allocation constitute the exosystem; and national digital education strategies and industry AI standards form the macrosystem. Despite these theoretical affordances, existing scholarship has predominantly applied EST to in-service teachers or general student populations, with few customized frameworks designed specifically for pre-service EFL cohorts. Most prior studies address only one or two environmental dimensions in isolation, failing to systematically disentangle cross-layer interactions. To address this gap, the present study adopts EST as its core analytical lens, develops a comprehensive multi-level ecological framework tailored to pre-service English teachers, and employs both questionnaires and semi-structured interviews to capture the interactive effects of each ecological factor.

2.2. General AI literacy among pre-service teachers

Originating from digital and information literacy research, AI literacy is broadly defined as a multidimensional competency encompassing technical cognition, practical operation, critical evaluation, and ethical reflection [12]. From a socio-technical perspective, the construct extends beyond the narrow conception of programming skills for computer science majors and comprises four interrelated core competency clusters: understanding the basic logic and technical boundaries of AI systems, mastering standardized human-AI collaborative practices, maintaining critical and ethical stances toward algorithmic outputs, and analyzing the long-term societal implications of intelligent technology diffusion. This interdisciplinary conceptualization moves beyond the technology-centric bias of early literacy research and establishes a universal competency framework applicable to learners across all disciplines.

In recent years, scholars have developed multiple AI literacy measurement scales based on this dimensional framework. Wang et al. and Pan and Wang subdivided teaching-oriented AI competency indicators according to educators' actual classroom demands [2, 13], while Gong et al. further incorporated internal psychological variables—including technology acceptance and learning self-efficacy—into the literacy measurement system [14]. Concurrently, qualitative research by Kohnke et al. captured a dimension rarely addressed by quantitative scales: pre-service teachers' subjective emotional perceptions of AI tools, such as anxiety and over-dependence risks [3]. Despite the proliferation of dimensional frameworks and measurement instruments, the majority of existing scales have been designed and validated for in-service teachers with substantial teaching experience. Few researchers have adjusted the weighting of practical teaching indicators or established targeted evaluation standards for pre-service teachers, who remain in the competency accumulation and professional identity formation stage. Moreover, most prior empirical studies rely solely on static, one-off questionnaire data to describe literacy levels, rarely integrating quantitative results with in-depth qualitative interview narratives to uncover the underlying causes of uneven competency development. To address these limitations, the present study adapts a set of AI literacy indicators for pre-service English majors and employs a mixed-methods design to collect both structured scale data and open-ended interview materials.

2.3. EFL-specific AI literacy for pre-service teachers

When generic AI literacy frameworks are applied to EFL teaching contexts, they require reconstruction and localization centered on the distinctive characteristics of language instruction. Wang et al. developed a discipline-specific GenAI literacy framework for EFL educators, comprising five mutually reinforcing

dimensions: GenAI Knowledge, GenAI Use, GenAI Design, GenAI Evaluation, and GenAI Ethics [2]. This contextualized framework foregrounds the disciplinary attributes of foreign language teaching, requiring educators to align diverse AI functions with listening, speaking, reading, and writing objectives, and to possess the critical capacity to identify grammatical errors, logical flaws, and implicit cultural biases in machine-generated language texts [13]. Kohnke et al. further enriched this practical perspective through qualitative interviews, observing that even when student teachers possess basic AI knowledge, they often struggle to flexibly integrate intelligent tools into differentiated language activities due to the absence of targeted curriculum training and authentic internship experiences [3].

A substantial body of empirical research has yielded complementary findings through both quantitative surveys and qualitative interviews. Large-scale questionnaire data indicate that pre-service EFL teachers' overall GenAI literacy remains at a moderate level, with the GenAI Design dimension, which covers lesson planning and multimodal resource development, consistently scoring lowest [2]. Semi-structured interview studies further capture trainees' ambivalent attitudes toward AI tools: they generally recognize AI's value in reducing repetitive teaching tasks, yet hold only vague awareness of core ethical risks such as data leakage and algorithmic bias in language learning platforms [3]. Affective factors, including technology-related learning anxiety, also serve as significant barriers that hinder pre-service teachers' sustained AI engagement in language classrooms [15]. Nevertheless, current EFL-contextualized AI literacy research exhibits two notable deficiencies. First, most scholars discuss disciplinary competency indicators in isolation, without embedding these EFL-specific dimensions into EST's four-layer ecological system to analyze how internal psychological factors and multi-level environmental forces jointly shape trainees' language-oriented AI competence. Second, most existing improvement strategies are proposed on the basis of single-dimensional data analysis, lacking tiered learning pathways aligned with the full set of EFL AI literacy indicators. To address these gaps, this study embeds the five EFL GenAI dimensions within the multi-level ecological framework, examines the interactive relationships between disciplinary competency demands and internal or external ecological factors, and further develops systematic, actionable tiered learning pathways for pre-service English majors.

3. Methodology

This research was situated within the Chinese EFL educational context and aimed to systematically investigate the current status of pre-service EFL teachers' AI literacy and practical competency, as well as to explore potential pathways for its development and optimization. A robust mixed-methods design was adopted to achieve holistic and rigorous outcomes, integrating both quantitative and qualitative data collection and analytical procedures for a multidimensional understanding of the research topic. Quantitative questionnaire data were utilized to outline the overall developmental level and general perceptual characteristics of pre-service EFL teachers' AI literacy across a relatively large sample, providing macro-level statistical evidence for prevalent trends. Qualitative interview data, in contrast, enabled in-depth exploration of the complex underlying influencing factors, individual learning experiences, and distinctive developmental patterns regarding AI literacy acquisition. Collecting and analyzing both forms of empirical data concurrently facilitated methodological triangulation and effective cross-validation of the final results, which greatly enhanced the credibility, comprehensiveness, and interpretive depth of the overall findings [16].

3.1. Participants

This study adopted a convergent parallel mixed-methods design, incorporating two distinct participant groups for quantitative questionnaire surveys and qualitative semi-structured interviews, respectively. The quantitative

participants were pre-service EFL students majoring in English-related disciplines at comprehensive and normal universities in southeast China. Initially, 90 questionnaire responses were collected. After screening, two responses with extremely short completion durations were eliminated as invalid, yielding a final valid sample of 88 participants. The questionnaire data provided macro-level statistical evidence illustrating the overall status and influencing factors of students' AI literacy development. The demographic profiles of questionnaire participants are presented in Table 1.

Table 1. Demographic characteristics of participants ($N = 88$)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	18	20.5
	Female	70	79.5
Grade	Undergraduate	81	92.0
	Postgraduate	7	8.0
Teaching Practicum Experience	No practicum experience	39	44.3
	Short-term observation (< 1 month)	16	18.2
	Full teaching practicum (1–3 months)	8	9.1
	Full-time teaching experience (3 months)	25	28.4
Generative AI Tool Exposure	Within 1 year	22	25.0
	More than one year	66	75.0

Note. Percentages are valid percentages and may not sum exactly to 100 due to rounding.

Table 1 displays participant demographic information. The sample included 18 male and 70 female students. A total of 81 respondents were undergraduates, and 7 were postgraduates. No teaching-related practicum experience was reported by 44.3% of participants, whereas 28.4% accumulated more than 3 months of full-time teaching practice. Generative AI tools have been used for over one year by 75% of participants, with 25% having less than one year of exposure.

Qualitative data were collected from five outstanding undergraduate students majoring in English-related disciplines through purposive sampling. Their background information is presented in Table 2.

Table 2. Participant demographics

No.	Gender	University	Relevant EFL Teaching Background
1	Female	Soochow University	Major GPA ranked in the top 10% First prize in the Pre-service Teacher Basic Skills Competition Micro-teaching experience
2	Female	Soochow University	Major GPA ranked in the top 10% Over two years of tutoring experience
3	Female	Soochow University	Over one year of tutoring experience Strong performance in educational coursework
4	Female	Soochow University	Major GPA ranked in the top 10% Over one year of teaching and classroom observation practice
5	Male	South China Normal University	Extensive volunteer teaching experience Strong performance in educational coursework

All interviewees demonstrated outstanding academic credentials: either their major GPAs ranked within the top 10% of their cohort, or they had won first prizes in pre-service teacher teaching skills competitions. Purposive sampling was adopted to recruit these exemplary participants, who possessed robust EFL teaching expertise and extensive relevant learning experience. Such informants were capable of offering nuanced, in-depth insights into the development of GenAI literacy among foreign language pre-service teachers. The qualitative interview data supplemented, contextualized, and interpreted the numerical trends derived from the questionnaire survey, achieving data triangulation and enhancing the trustworthiness of the overall mixed-methods results. All participants took part voluntarily, and oral informed consent was obtained from each individual before the interviews.

3.2. Instruments

3.2.1. *Pre-service EFL teachers' AI literacy questionnaire*

This study adopted a revised questionnaire to measure pre-service EFL students' GenAI literacy, encompassing their knowledge, practical operational skills, critical evaluation competence, and ethical awareness regarding GenAI tools widely used in foreign language education. The core Likert-scale items were adapted from Wang et al.'s validated GenAI literacy scale for in-service EFL teachers, whose five-dimensional framework was grounded in Ng et al.'s AI literacy framework and Bloom's taxonomy of educational objectives [2, 17, 18]. The finalized scale contained 34 items distributed across five latent factors: GenAI Knowledge (8 items), GenAI Use (9 items), GenAI Design (6 items), GenAI Evaluation (5 items), and GenAI Ethics (6 items).

The questionnaire consisted of two distinct sections. The first collected demographic and AI usage background information, including gender, academic level, teaching-related practicum experience, foreign language teacher certification status, and length of exposure to GenAI tools. The second comprised the five-dimensional GenAI literacy measurement items. The questionnaire was administered in Chinese and employed a 5-point Likert scale ranging from 1 (completely disagree) to 5 (completely agree). Internal consistency of the overall scale and each subdimension was examined via Cronbach's alpha coefficients, all of which reached acceptable reliability thresholds. A sample item reads: "I can design targeted generative AI application schemes to facilitate foreign language classroom learning activities."

3.2.2. *Semi-structured interviews*

Semi-structured interviews served as the core qualitative instrument, complementing questionnaire data to capture in-depth, contextualized perspectives on pre-service EFL students' GenAI literacy that quantitative measurements could not fully reflect. Five outstanding pre-service English undergraduates were selected via purposive sampling, with their demographic and academic backgrounds summarized in Table 2. All participants held competitive academic rankings or had received awards in the Normal Students' Basic Teaching Skills Competitions, ensuring substantial practical experience in lesson planning and micro-teaching for rich case analysis.

The semi-structured interview guide was adapted from the framework designed by Kohnke et al., with substantial revisions to fit the context of Chinese pre-service foreign language teacher education and the central research questions of this study [3]. The final protocol consisted of open-ended questions organized into five thematic sections: practical usage of GenAI tools, evaluation of AI application effects, attitudes toward AI integration in EFL instruction, the connotation and constituent dimensions of pre-service teachers' GenAI literacy, and channels and demands for AI-related learning and training.

3.3. Data collection and analysis

This study adopted a parallel mixed-methods design, collecting quantitative and qualitative data independently before integrating the two datasets for triangulation during the analysis stage.

All questionnaire items employed a 5-point Likert scale ranging from 1 (completely disagree) to 5 (completely agree), and the survey collected participants' demographic information and self-reported GenAI literacy levels. SPSS 24.0 was used for quantitative statistical processing. Descriptive statistics were first calculated to summarize participants' demographic characteristics and overall GenAI literacy performance. Reliability tests and EFA were then conducted to validate the scale's dimensional structure, followed by group comparative analyses to explore differences in GenAI literacy across participants with varied backgrounds.

Prior to large-scale questionnaire distribution, a pilot test with 30 pre-service EFL students was conducted to test the reliability of the 34-item GenAI literacy scale. After reliability verification, formal questionnaires were administered, and 88 valid responses were obtained for Exploratory Factor Analysis (EFA). Principal Component Analysis with Varimax rotation was adopted, and factors with eigenvalues greater than 1.0 were retained, yielding a five-factor solution. Cronbach's alpha coefficients for the overall scale and five subdimensions are displayed in Table 3. All coefficients were well above the critical threshold of 0.70, indicating excellent internal consistency.

Table 3. Reliability statistics of the GenAI literacy scale

Dimension	Number of Items	Cronbach's Alpha
GenAI Design	6	0.931
GenAI Use	9	0.909
GenAI Knowledge	9	0.910
GenAI Ethics	5	0.900
GenAI Evaluation	5	0.878
Full Overall Scale	34	0.973

The suitability test results for factor analysis are shown in Table 4. The KMO value reached 0.877, and Bartlett's Test of Sphericity presented significant statistical results ($\chi^2 = 2830.776$, $df = 561$, $p < .001$), which proved the dataset was appropriate for factor extraction.

Table 4. KMO and Bartlett's test

Index	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.877
Bartlett's Test: Approx. Chi-Square	2830.776
df	561
Sig.	< .001

Principal Component Analysis with Varimax rotation was adopted, and factors with eigenvalues greater than 1 were retained. As presented in Table 5, five latent factors were extracted, jointly explaining 72.179% of the total variance of all items, which meets the standard of over 60% cumulative explained variance in social science and verifies good construct validity of the scale.

Table 5. Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	18.246	53.664	53.664	18.246	53.664	53.664	6.321	18.590	72.179
2	2.364	6.952	60.617	2.364	6.952	60.617	6.146	18.077	36.667
3	1.618	4.759	65.376	1.618	4.759	65.376	5.337	15.698	52.366
4	1.266	3.723	69.099	1.266	3.723	69.099	4.385	12.897	65.263
5	1.047	3.080	72.179	1.047	3.080	72.179	2.351	6.916	72.179

Extraction Method: Principal Component Analysis.

Although the sample size $N = 88$ is relatively modest for exploratory factor analysis, methodological literature suggests that sample size requirements are contingent upon several interrelated factors, including communality levels, factor-to-item ratios, and the strength of the underlying factor structure [19-21]. In the present study, the Kaiser-Meyer-Olkin measure (0.877) confirmed sampling adequacy, and all item communalities exceeded 0.50 (ranging from 0.556 to 0.847), indicating that a substantial proportion of variance in each observed variable was captured by the extracted factors. Furthermore, the scale items were adapted from a theoretically grounded and empirically validated framework [2, 17], and the five-factor solution exhibited strong item loadings (all > 0.50) with minimal cross-loadings. Under these conditions—high communalities, clear factor structure, and theory-driven item development—a sample size of around 100 is considered adequate for stable factor extraction [19, 21, 22]. Thus, the current sample size is defensible for the primary analytical purpose of validating the dimensional structure of the GenAI literacy scale within this specific population.

Following the questionnaire survey, qualitative data were collected via six semi-structured interviews, one of which served as a pilot. Revisions were made to the interview protocol after the pilot session to enable more thorough investigation and obtain more accurate information. Before each interview, participants were informed of the research purpose, anonymization procedures, and audio recording arrangements, and oral informed consent was obtained prior to the start of each conversation.

All interviews were conducted synchronously via Tencent Meeting, with each session lasting approximately 25 to 35 minutes. Standard core questions ensured consistent inquiry logic across all five interviewees, while flexible follow-up probes were reserved to elicit detailed personal learning and lesson-design experiences. Data saturation was reached upon completion of all five interviews; no new core themes or unique perspectives emerged from subsequent dialogue, indicating sufficient qualitative material for thematic analysis. All audio recordings were transcribed verbatim into complete text files for systematic coding and cross-case comparison. Thematic analysis was then applied to the transcribed texts, employing a three-level coding framework (open coding, axial coding, and selective coding) to extract core themes corresponding to the research questions.

4. Results

4.1. Quantitative findings

This section reports quantitative results based on valid questionnaires collected from 88 pre-service foreign language teachers, including item-level descriptive statistics and Exploratory Factor Analysis (EFA) outcomes. Reliability test procedures detailed in the Data Collection and Analysis section are not repeated here.

4.1.1. Descriptive statistics of questionnaire items

All questionnaire data were processed with SPSS. Mean values and standard deviations were calculated for each item of the GenAI literacy scale. Consistent with Isae and Barjesteh, a five-tier classification standard based on fixed Likert score intervals was adopted to interpret respondents' self-reported attitudes toward GenAI competence: 1.00–1.80 = strongly disagree, 1.81–2.60 = disagree, 2.61–3.40 = neutral, 3.41–4.20 = agree, and 4.21–5.00 = strongly agree [16].

Table 6. Descriptive statistics of questionnaire items

Item	Mean	Std. Deviation	Interpretation
Q9 Design AI application schemes and classroom activities independently	3.57	0.881	Neutral-Agree
Q10 Design AI prompts and lesson plans	3.51	0.922	Neutral-Agree
Q11 Design AI schemes to assist instructional design and evaluation	3.57	0.92	Neutral-Agree
Q12 Design offline AI hands-on activities without electronic devices	3.17	0.973	Neutral
Q13 Design age-appropriate AI schemes to enhance participation	3.55	0.909	Neutral-Agree
Q14 Design rubrics for evaluating foreign language writing	3.57	0.894	Neutral-Agree
Q15 Collect and organize foreign language teaching resources	3.85	0.941	Agree
Q16 Select AI tools according to students' proficiency levels	3.47	0.946	Neutral-Agree
Q17 Use AI to interpret teaching data and adjust design	3.69	0.914	Agree
Q18 Use AI to sort and categorize teaching content	3.68	0.904	Agree
Q19 Use AI for self-directed professional learning and improvement	3.64	0.973	Agree
Q20 Use AI to summarize foreign language reading materials and literature	3.95	0.909	Agree
Q21 Use AI to provide targeted learning feedback	3.81	0.856	Agree
Q22 Use AI to create and edit teaching documents	3.5	0.971	Neutral-Agree
Q23 Use AI to conduct foreign language skills teaching and assessment	3.6	0.941	Agree
Q24 Understand various generative AI software and tools	3.35	1.006	Neutral-Agree
Q25 Clearly understand the role of pre-service teachers in AI-enhanced teaching	3.75	0.834	Agree
Q26 Master AI lesson plan design and implementation methods	3.59	0.905	Neutral-Agree

Table 6. Continued

Q27 Judge the quality of students' AI-assisted assignments	3.55	1.038	Neutral-Agree
Q28 Master the principles of applying AI to foreign language education	3.45	0.909	Neutral-Agree
Q29 Possess basic computer knowledge and computational thinking	3.36	0.961	Neutral-Agree
Q30 Understand the impact of AI on academic learning and society	3.81	0.771	Agree
Q31 Understand the core foundational theories of AI	3.25	1.02	Neutral
Q32 Be aware of AI-sensitive issues and potential risks	3.99	0.78	Agree
Q33 Pay attention to bias issues in AI-generated content	3.88	0.855	Agree
Q34 Consider educational equity, privacy, and academic integrity	4.0	0.773	Agree—Strongly agree
Q35 Remind students of AI plagiarism and manipulation risks	4.26	0.703	Strongly agree
Q36 Cultivate students' ethical and standardized use of AI	4.15	0.796	Agree—Strongly agree
Q37 Consider data security and usage risks	4.07	0.77	Agree—Strongly agree
Q38 Evaluate the reliability and classroom suitability of AI tools	3.92	0.761	Agree
Q39 Judge whether AI tools can achieve teaching objectives	3.75	0.834	Agree
Q40 Verify the authenticity and quality of AI outputs	3.83	0.761	Agree
Q41 Evaluate the value and impact of integrating AI into teaching	3.61	0.877	Agree
Q42 Design AI application schemes and learning activities	3.73	0.881	Agree

Valid N (listwise) = 88. All items were measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Table 6 reveals clear hierarchical disparities across all survey items. Q35, which concerns reminding students of AI plagiarism risks, obtained the highest mean score ($M = 4.26$) and fell into the "Strongly agree" bracket. Multiple items measuring AI ethical literacy recorded means above 4.00, including Q34 ($M = 4.00$) and Q37 ($M = 4.07$). Their standard deviations were all below 0.80, demonstrating consistent high awareness of AI ethics and risk prevention among respondents. Most items related to routine AI-assisted teaching operations, such as Q20 ($M = 3.95$), were classified as "Agree," reflecting participants' self-perceived proficiency in basic tool operation for instructional support. In stark contrast, only two items remained at the neutral level: Q12 on offline AI activity design ($M = 3.17$) and Q31 covering fundamental AI theories ($M = 3.25$). These two items also presented larger standard deviations (0.973 and 1.020, respectively), indicating substantial individual gaps in theoretical reserves and offline AI teaching design capacity. Such uneven distribution of self-reported competence preliminarily suggests that pre-service teachers' generative AI literacy comprises multiple differentiated latent dimensions, which is further verified via exploratory factor analysis in the following section.

4.1.2. Exploratory factor analysis results

Principal Component Analysis was adopted for factor extraction, and Varimax orthogonal rotation with Kaiser normalization was applied to simplify the factor structure and enhance interpretability. Following the Kaiser

criterion (eigenvalues > 1.0), five latent common factors were extracted. These five factors jointly explained 72.179% of the total variance, exceeding the 60% threshold for adequate explanatory power in social science research. Rotation converged after eight iterations, indicating a stable and interpretable factor structure. All item communalities ranged from 0.556 to 0.847, demonstrating that each item was sufficiently explained by the five extracted latent constructs.

Table 7. Rotated component matrix

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Q15 Collect and organize foreign language teaching resources	0.734				
Q11 Design AI schemes to assist instructional design and evaluation	0.733				
Q14 Design rubrics for evaluating foreign language writing	0.702				
Q13 Design age-appropriate AI schemes to enhance participation	0.679				
Q17 Use AI to interpret teaching data and adjust design	0.667				
Q9 Design AI application schemes and classroom activities independently	0.62				
Q10 Design AI prompts and lesson plans	0.606				
Q30 Understand the impact of AI on academic learning and society	0.568		0.515		
Q16 Select AI tools according to students' proficiency levels	0.557				
Q26 Master AI lesson plan design and implementation methods	0.526				
Q12 Design offline AI hands-on activities without electronic devices	0.51				
Q29 Possess basic computer knowledge and computational thinking		0.788			
Q31 Understand the core foundational theories of AI		0.759			
Q24 Understand various generative AI software and tools		0.754			
Q22 Use AI to create and edit teaching documents		0.698			
Q23 Use AI to conduct foreign language skills teaching and assessment		0.666			
Q20 Use AI to summarize foreign language reading materials and literature		0.644			
Q28 Master the principles of applying AI to foreign language education		0.589			
Q21 Use AI to provide targeted learning feedback		0.565			
Q36 Cultivate students' ethical and standardized use of AI			0.862		
Q35 Remind students of AI plagiarism and manipulation risks			0.858		
Q37 Consider data security and usage risks			0.757		
Q34 Consider educational equity, privacy, and academic integrity			0.657		
Q32 Be aware of AI-sensitive issues and potential risks			0.58		
Q33 Pay attention to bias issues in AI-generated content			0.535		
Q41 Evaluate the value and impact of integrating AI into teaching				0.686	
Q39 Judge whether AI tools can achieve teaching objectives				0.663	

Table 7. Continued

Q42 Design AI application schemes and learning activities		0.61
Q38 Evaluate the reliability and classroom suitability of AI tools	0.542	0.565
Q18 Use AI to sort and categorize teaching content		0.501
Q25 Clearly understand the role of pre-service teachers in AI-enhanced teaching		0.744
Q19 Use AI for self-directed professional learning and improvement		0.724

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 8 iterations. Factor loadings below 0.50 are omitted.

Table 7 presents the rotated component matrix of all survey items; factor loadings lower than 0.50 are omitted for conciseness. Every item exhibited a dominant loading above 0.50 on only one single factor with trivial cross-loadings, which indicated satisfactory discriminant validity of the scale's internal structure. The item grouping of each extracted factor was largely consistent with the five theoretical dimensions preset in the questionnaire design, detailed as follows:

Factor 1: Generative AI Instructional Design Competence

This factor comprised 11 items corresponding to the theoretical dimension of GenAI design capacity. These items focus on designing differentiated AI lesson plans, developing tailored prompts, constructing writing assessment rubrics, and designing offline AI practice activities matched to student characteristics, reflecting pre-service teachers' core ability to customize GenAI solutions for diverse foreign language classroom activities.

Factor 2: Generative AI Knowledge and Operational Competence

Nine items loaded prominently on this factor, integrating the original theoretical dimensions of GenAI use ability and GenAI knowledge reserve. It covers two core areas: foundational AI theories and computational thinking, and practical operational skills such as collecting teaching resources, organizing curriculum content, editing instructional documents, and supporting personal professional development. Statistically, theoretical knowledge reserves and daily AI operational proficiency naturally converged into an integrated competency domain.

Factor 3: Generative AI Ethical Literacy

Six items formed this factor, fully corresponding to the theoretical dimension of AI ethical literacy. Items under this factor centre on identifying AI bias, safeguarding academic integrity, protecting student privacy and data security, and guiding students to use GenAI in standardized, ethical ways. The high loadings of ethical items echo the descriptive statistical finding that respondents held strong self-perceived awareness of educational AI ethics.

Factor 4: Generative AI Teaching Evaluation Competence

Five items constituted this factor, aligning with the theoretical dimension of GenAI evaluation ability. Relevant items measure participants' capacity to assess the reliability and classroom suitability of AI tools, judge whether GenAI can achieve preset teaching objectives, verify the authenticity of AI-generated outputs, and evaluate the long- and short-term educational value of AI integration.

Factor 5: Vocational Role Cognition and Self-development

Two items loaded independently on this factor, reflecting pre-service teachers' clear recognition of their vocational roles within AI-enhanced foreign language classrooms and their initiative to utilise generative AI for personal professional growth.

Overall, the EFA results strongly validate the five-dimensional theoretical framework of pre-service foreign language teachers' generative AI literacy proposed in this study. The five latent factors extracted statistically correspond well to the item classification designed in the original scale, confirming satisfactory construct validity of the 34-item questionnaire. The distinct differentiation of item loadings across factors provides quantitative evidence to interpret the unbalanced developmental characteristics of participants' generative AI literacy reflected in the foregoing descriptive statistics. The group-level patterns and structural features identified via questionnaire analysis will be complemented by individual experiential insights from interview data to fully unpack the root causes of uneven literacy development and corresponding learning pathways.

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 8 iterations. Factor loadings below 0.50 are omitted.

4.2. Qualitative findings

To complement the questionnaire-based quantitative portrait, semi-structured interview data from five pre-service foreign language teachers were analysed through a three-level thematic coding procedure (open coding, axial coding, and selective coding). Four interrelated themes emerged from the data, collectively illuminating the lived experiences underlying the statistical patterns identified in the quantitative phase.

Table 8. Three-level thematic coding framework for interview data

1st-order theme	2nd-order category	3rd-order open code
Mixed AI Attitudes and Universal Risk Awareness	Positive recognition of generative AI	Recognise teaching auxiliary value; improve work efficiency; facilitate lesson preparation; support personalised teaching
	Negative & neutral perceptions	AI output inaccuracy; over-reliance risk; rigid thinking; weakened teacher agency; neutral wait-and-see stance
	Risk vigilance	Algorithm bias; academic integrity risks; privacy concerns; misuse of generative AI by students
Instrumental AI Usage, Insufficient Offline Design Capacity	Instrument-oriented practical application	Collect teaching resources; summarise literature; generate feedback; assist lesson-plan drafting; routine teaching document editing
	Lack of complex instructional design	Rare offline AI-activity design; limited student-centered AI-driven classroom design; insufficient practice of non-digital AI-related activities
Unbalanced Literacy Structure: Strong Ethics, Weak Theory	Ethical awareness & normative awareness	Identify AI-generated bias; pay attention to educational equity; guard academic integrity; focus on data security; clarify teacher responsibilities in AI-empowered teaching
	Insufficient theoretical knowledge reserve	Poor understanding of underlying AI principles; vague cognition of computational thinking; difficulty explaining core AI logic
Dual Learning Paths and Grade Differences	Formal learning channels	University-offered courses; thematic lectures & training; academic reading; systematic curriculum learning
	Informal learning channels	Online self-exploration; peer observation; self-directed trial-and-error; community-based informal exchange
	Grade-related differences in learning demand	Lower-grade exploratory evaluation; demand for structured support; upper-grade stable cognition; preference for flexible independent learning

Note. 1st-order themes correspond to four thematic findings; open codes were abstracted from interview transcripts of five pre-service foreign-language teachers (P1–P5).

Mixed AI Attitudes and Universal Risk Awareness

All five interviewees held mixed attitudes toward GenAI teaching tools, with positive evaluations dominant. P3 registered the highest share of positive codes (40.5%), followed by relatively positive perceptions (38%). "Attitudes and reflection" stood as a core coding node for P4 (35%) and P5 (18.5%). P1 and P2 also assigned the largest coding weight to AI attitudes and AI evaluation, indicating that pre-service foreign language teachers generally recognize GenAI's instructional value.

Meanwhile, participants widely identified potential risks of AI application. P1's transcripts contained 15% risk-related codes, covering algorithmic bias, over-reliance on AI, and rigid thinking; P2 repeatedly pointed to inaccurate AI outputs and weakened teacher agency. Despite overall positive tendencies, neutral and negative viewpoints remained prevalent: P3 exhibited negative (28%), relatively negative (15.5%), and highly negative (12.5%) codes; P4 held 15% negative content, and P5 recorded 5.5% neutral perspectives. Such consistent risk perception aligns with the quantitative finding that ethical items earned the highest mean scores, exemplified by Q35 ($M = 4.26$).

Instrumental AI Usage, Insufficient Offline Design Capacity

Coding results revealed that participants mainly adopted GenAI for routine auxiliary teaching tasks. P1 devoted 11.5% of codes to AI operation and 8.5% to assisted lesson planning, relying on AI to collect teaching resources and summarize literature. P2 prioritized efficiency improvement and personalized feedback as core usage purposes; P3 identified daily AI application and teaching practice as key nodes (14.5% and 12.5%). P4 and P5 also demonstrated frequent instrumental use, with relevant codes accounting for 17% and 18%, respectively.

In contrast, few participants designed offline AI hands-on activities without digital devices. The proportion of instructional design codes reached only 2.5% for P4 and 1% for P5. This pattern corresponds to the descriptive statistics showing that Q12 (offline AI activity design, $M = 3.17$) and Q31 (core AI theory mastery, $M = 3.25$) remained at the neutral level, indicating that participants mastered basic tool operation but lacked theoretical reserves and innovative offline design abilities.

Unbalanced Literacy Structure: Strong Ethics, Weak Theory

Three-level coding uncovered the unbalanced composition of participants' GenAI literacy. In terms of ethical cognition, multiple interviewees were able to identify AI risks and abide by academic norms. P3's codes for ethical risk perception occupied 7.5%, and AI value boundary cognition accounted for 4%; P4 recorded 8.5% and 8% for the two nodes; P5's awareness of teachers' AI responsibilities reached 7.5%. Combined with P1's reflections on academic integrity and data security, participants demonstrated clear ethical norms for classroom AI use.

However, participants' understanding of underlying AI theories was limited. The coding proportion of AI theoretical cognition stood at 7.5% (P3), 11.5% (P4), and 4% (P5). Few participants could elaborate on the core operating logic of GenAI during interviews. This pattern aligns with the EFA results: the ethical dimension carried higher factor loadings, while theoretical knowledge and practical operations converged into a single integrated factor, suggesting that participants' ethical awareness developed far earlier than systematic theoretical cognition.

Dual Learning Paths and Grade Differences

All participants summarized two types of approaches to improving GenAI literacy: formal learning and informal learning. Formal learning included university courses, specialized training lectures, and academic reading; informal learning referred to self-exploration on online platforms and peer classroom observation.

The node of literacy promotion paths appeared frequently across transcripts, with coding proportions of 15.5% (P3), 18.5% (P4), and 17% (P5). P4 and P5 both mentioned formal curriculum learning (6.5% and 9.5%), and P5 added self-directed informal learning (4.5%). Some participants, such as P1, held reserved views on mandatory specialized courses and preferred flexible independent learning.

Grade-based cross-group data further reflected differentiated learning characteristics. Grade 2 students contributed 61.21% of all learning-path-related interview content, higher than Grade 3's 38.79%. For AI evaluation cognition, Grade 2 students accounted for 56.98%, exceeding Grade 3's 43.02%; Grade 3 students showed a higher proportion of positive attitudes (55.83%) than Grade 2 (44.17%). The data indicate that lower-grade pre-service teachers are in an exploratory stage with a stronger demand for systematic learning support, while upper-grade students have formed stable positive cognition after extended AI exposure.

Collectively, the interview data document pre-service foreign language teachers' actual cognitive and behavioral conditions regarding GenAI use and provide individual experiential evidence to interpret the overall group characteristics reflected in the questionnaire statistics.

5. Discussion

This study adopted a convergent parallel mixed-methods design to investigate GenAI literacy among pre-service EFL teachers, combining questionnaire data from 88 participants and semi-structured interview evidence from five purposively selected informants. Drawing upon Bronfenbrenner's Ecological Systems Theory, the research examined the overall status, internal dimensional structure, and feasible learning pathways of pre-service teachers' GenAI literacy. The key empirical findings are discussed in dialogue with existing literature below.

First, both quantitative and qualitative data consistently revealed that pre-service EFL teachers demonstrated comparatively well-developed AI ethical awareness, whereas their theoretical knowledge of AI and capacity for offline AI-oriented instructional design remained relatively insufficient. On the questionnaire, items concerning AI academic integrity, data security, and risk warning obtained the highest mean values—a pattern further corroborated by interview coding showing widespread risk vigilance among participants. This outcome resonates with prior research on teacher AI literacy, which reports that student teachers can readily recognize ethical risks in AI-assisted teaching yet struggle to translate such awareness into theory-driven instructional practice [6, 9]. One plausible explanation lies in the publicized discussions surrounding AI academic misconduct on university campuses: pre-service teachers are repeatedly exposed to ethical reminders about AI plagiarism and algorithmic bias, which cultivates their normative awareness at the perceptual level. Nevertheless, teacher education curricula have not yet delivered systematic instruction covering underlying AI principles or non-digital AI classroom activities. Consequently, participants are capable of identifying which risks should be avoided, but remain less confident in understanding how AI functions and how to design offline AI-related learning experiences for students. Moreover, substantial individual variation was observed in theoretical and design-related items, indicating uneven developmental trajectories across different pre-service teachers.

Second, exploratory factor analysis confirmed a five-factor latent structure for the self-developed GenAI literacy scale. Notably, theoretical knowledge and practical operational skills statistically converged into a single factor, rather than forming two fully independent dimensions as originally hypothesized in the questionnaire design. This empirical pattern suggests that for current Chinese pre-service EFL teachers, hands-on tool operation and theoretical cognition are tightly intertwined in their real-world experience. Most student teachers acquire AI tool competence through trial-and-error practical use, while theoretical conceptual learning

remains fragmentary and supplementary. This finding signals an important practical implication for teacher education: theoretical instruction ought not to be completely isolated from hands-on AI teaching practice. Knowledge lectures decoupled from authentic EFL teaching scenarios may fail to produce meaningful improvements in pre-service teachers' overall AI literacy.

Third, interview themes uncovered dual-track learning pathways consisting of formal institutional learning and informal self-directed exploration, alongside grade-related discrepancies in learning demands. Lower-grade pre-service teachers exhibited stronger exploratory motivation and a greater need for structured support, while upper-grade participants formed more stable and positive attitudes toward GenAI after accumulating more teaching-relevant experience. Such differences align with the logic of Bronfenbrenner's Ecological Systems Theory. Within the microsystem, individual pre-service teachers' evolving learning experiences and changing cognitive states shape their acceptance of AI tools. At the mesosystem level, interactions between coursework, micro-teaching practice, and self-directed online resource consumption jointly determine the actual effect of AI literacy development. However, existing university-based training cannot fully satisfy diverse needs across different training stages. Some participants expressed reservations about compulsory specialized AI courses and preferred flexible, context-embedded learning modes. Accordingly, drawing on quantitative group-level characteristics and individual interview experiences, this study proposes a context-adapted feasible learning pathway tailored for Chinese pre-service EFL teachers, which integrates staged formal institutional training with autonomous informal practice. This tiered dual-channel solution responds to their imbalanced literacy structure and grade-differentiated learning needs.

Taken together, this study shows that pre-service EFL teachers have formed positive basic perceptions of GenAI and possess sound ethical awareness, but their literacy development exhibits a prominent structural imbalance. Ethical cognition outpaces theoretical mastery and innovative instructional design competence. Both formal and informal learning channels contribute to literacy growth, yet institutional support remains insufficiently targeted to address grade-specific developmental demands.

6. Conclusion

6.1. Main findings

This mixed-methods study investigated GenAI literacy among pre-service EFL teachers. Three major conclusions can be drawn from the integrated quantitative and qualitative evidence. First, pre-service EFL teachers generally hold positive self-evaluations of their GenAI literacy. Their AI ethical awareness stands out as a relative strength, while core AI theory mastery and offline AI activity design capacity constitute obvious weak points, accompanied by noticeable individual disparities. Second, pre-service teachers' GenAI literacy presents a five-dimensional latent structure: GenAI instructional design competence, GenAI knowledge and operational competence, GenAI ethical literacy, GenAI teaching and evaluation competence, and vocational role cognition and self-development. In practical developmental reality, theoretical knowledge and operational skills are closely integrated. Third, pre-service teachers improve AI literacy via both formal learning (university courses, thematic training, academic reading) and informal self-directed learning (online exploration, peer observation). Learning demands differ across grades: lower-grade pre-service teachers are in the exploratory phase and call for more structured support, whereas upper-grade participants hold more stable attitudes toward AI-enhanced language teaching.

6.2. Integrating findings through bronfenbrenner's ecological systems theory

Synthesizing the convergent evidence through Bronfenbrenner's Ecological Systems Theory explains why the observed structural imbalances emerge and how the dual learning channels and grade-differentiated demands are systemically produced. At the microsystem level, grade-related disparities in learning demands become theoretically meaningful: lower-grade participants' stronger exploratory motivation reflects their ongoing formation of proximal cognitive schemas about AI, whereas upper-grade students' more stable attitudes stem from accumulated practicum experiences. At the mesosystem level, the convergence of theoretical knowledge and operational proficiency into a single factor suggests a weak or fragmented synergy between formal coursework and informal trial-and-error learning; the two settings operate in parallel without productive cross-fertilization. At the exosystem level, current AI training is delivered predominantly as one-off, decontextualized sessions rather than as vertically integrated, grade-phased curricula, creating a systemic bottleneck that fails to address differentiated developmental needs. At the macrosystem level, the disproportionately strong AI ethical awareness reflects a broader cultural emphasis on academic integrity, data security, and risk prevention, which has been internalized more readily than theoretical or pedagogical dimensions. These systemic diagnoses validate the proposed dual-channel staged learning pathway, which aims not to add more content but to recalibrate the mesosystemic bridge and restructure the exosystemic arrangement.

6.3. Practical implications: a dual-channel staged learning pathway

Drawing upon the five-dimensional factor structure, the interview-coded themes of dual learning channels and grade-differentiated demands, and the integrative logic of Ecological Systems Theory, this study proposes a dual-channel staged progressive learning pathway for Chinese pre-service EFL teachers. On the formal institutional track, universities implement grade-differentiated, progressive training modules embedded within existing EFL teacher education curricula. For lower-grade undergraduates, the priority is foundational conceptual grounding: short-term thematic workshops introduce core generative-AI principles, common tool functions, and essential ethical norms—an emphasis empirically justified by the EFA results, which identified AI ethics as the most coherently developed dimension. For upper-grade students who have completed micro-teaching or formal practicum, training transitions to scenario-oriented application, with guided practice in prompt engineering, AI-assisted lesson planning, output quality evaluation, and offline, non-digital AI-related classroom activity design. This design explicitly targets the two weakest competency dimensions identified in the EFA: Generative AI Instructional Design Competence and Generative AI Teaching Evaluation Competence. On the informal autonomous track, pre-service teachers supplement institutional training through self-directed exploration, leveraging open online resources, peer lesson-planning communities, and teaching observations. This track is not an additional burden but a formalization of existing practices, since interview coding revealed that informal learning already accounts for a substantial share of AI-related activities. The two tracks are mutually reinforcing: formal courses supply a normative framework and staged milestones, while informal practice affords flexibility for personalized consolidation. This integrated pathway aligns with the developmental characteristics of Chinese pre-service EFL teachers and is systematically grounded in the multi-systemic diagnoses derived from Bronfenbrenner's EST.

6.4. Limitations and future research directions

This study has several limitations. First, questionnaire participants were recruited from universities in southeast China, which limits the generalizability of conclusions to pre-service EFL teachers in other regions. Additionally, the modest sample size ($N = 88$) for EFA, while methodologically defensible given the high

communalities and clear factor structure, warrants cautious interpretation; future research with larger, more diverse samples is encouraged to cross-validate the five-dimensional structure. Second, qualitative interview participants were selected via purposive sampling and represented academically outstanding pre-service teachers whose learning experiences may not fully reflect the conditions of average-level student teachers. Third, the cross-sectional design can only describe the status quo of generative-AI literacy; it cannot capture dynamic longitudinal changes throughout teacher-training programmes. Future research could adopt larger-scale sampling covering broader geographical areas, conduct longitudinal tracking to observe how GenAI literacy evolves across coursework, micro-teaching, and practicum, and design quasi-experimental intervention studies to empirically test the effectiveness of the proposed learning pathway.

Data availability statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical approval

Ethical review and approval were not required for the study on human participants. The participants provided their oral informed consent to attend this study.

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