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Developmental Paths of Digital Literacy among Pre-service English Teachers in Human–AI Collaborative Contexts

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Abstract

Against the backdrop of educational digital transformation and the growing use of generative artificial intelligence in teacher education, the development of digital literacy among pre-service English teachers deserves closer attention. Drawing on the course English Curriculum Standards and Instructional Design for Secondary Schools at a university in southern China, this study employed a mixed-methods design combining questionnaires and interviews to examine changes in pre-service English teachers' digital literacy in AI-assisted instructional design. The findings show that participants generally demonstrated a moderately high level of digital literacy and improved through course-based learning. Their development diverged into three paths: active, steady, and constrained. These differences were shaped mainly by their understandings of the educational value of AI, their capacity for human–AI collaboration, and their ability to integrate AI into subject-specific pedagogical work. The study contributes to a more dynamic understanding of digital literacy among pre-service English teachers and offers implications for course design and the integration of AI into teacher education.

Keywords

digital literacy, human–AI collaboration, pre-service English teachers, English instructional design, developmental paths

1. Introduction

With the ongoing digital transformation of education and the increasing incorporation of artificial intelligence into educational settings, teachers' digital literacy has become a foundational issue in both teacher professional development and instructional change. In China, the Key Priorities of the Ministry of Education for 2022 called for the implementation of a national strategy for educational digitalization, while the industry standard Digital Literacy of Teachers systematically specified the core competencies

expected of teachers in the new era, including digital awareness, digital knowledge and skills, digital application, digital social responsibility, and professional development (Ministry of Education, 2022a, 2022b). These policy developments suggest that the focus of teacher education is shifting from technology use per se to teachers' ability to employ technology appropriately and effectively in specific pedagogical contexts.

This shift is particularly salient for pre-service English teachers. As generative AI becomes increasingly embedded in English instructional design, the key issue is no longer simply whether to use AI, but how to mobilize it in ways that serve disciplinary aims, evaluate AI-generated content critically, and sustain professional judgment throughout the design process. In this sense, what pre-service English teachers need in the age of AI extends beyond operational competence with digital tools. It also includes more deeply rooted forms of digital literacy, such as information discernment, ethical awareness, risk management, and the capacity for human–AI collaboration.

Against this backdrop, the present study is situated in the course English Curriculum Standards and Instructional Design for Secondary Schools offered in an English teacher education program at a university in southern China. It investigates how pre-service English teachers actually used AI tools during the course and examines the developmental paths of their digital literacy, together with the factors shaping those paths. This course was selected because it is directly oriented toward the practice of English instructional design and thus provides a concentrated setting in which students' interactions with AI in authentic pedagogical tasks can be observed. It therefore offers a useful lens through which to explore how digital literacy takes shape in real course-based contexts.

The significance of this study is twofold. Theoretically, it seeks to move research on teachers' digital literacy beyond macro-level policy discussion and general competency frameworks into the concrete domain of subject-specific coursework in English teacher education. It also approaches digital literacy as a developmental rather than static construct, highlighting how it is gradually formed and differentiated through situated tasks and human–AI interaction. Practically, by examining the developmental paths of pre-service English teachers' digital literacy and the reasons behind them, the study presents a more grounded account of their developmental needs in AI-mediated contexts and provides a basis for improving English teacher preparation, refining course design, and strengthening guidance on AI use in teacher education (Ministry of Education et al., 2018).

To address these concerns, the study employs a mixed-methods design that combines quantitative questionnaires with semi-structured interviews. By comparing pre- and post-course data, it identifies the developmental paths of digital literacy among pre-service English teachers and further explores the factors underlying those paths. Two research questions guide the inquiry: First, what developmental paths characterize pre-service English teachers' digital literacy before and after taking the course English Curriculum Standards and Instructional Design for Secondary Schools? Second, how do these different paths emerge? Compared with previous studies, this study extends existing work by focusing on a disciplinary group of pre-service English teachers, drawing on an authentic course-based setting,

and examining not only patterns of development but also the mechanisms through which different paths are formed.

2. Literature Review

2.1 Research on Teachers' Digital Literacy

Existing research on teachers' digital literacy has focused primarily on two areas: conceptual clarification and framework construction. By tracing the evolution of the concept of digital literacy and reviewing relevant international frameworks, Wu et al. (2023) argue that teachers' digital literacy should not be understood simply as technical operational ability; rather, it refers to a comprehensive set of competencies through which teachers use digital technologies appropriately in educational settings, address pedagogical problems, and assume corresponding responsibilities (Wu et al., 2023). From the perspective of educational digital transformation, Zhou et al. (2023) further emphasize that teachers' digital literacy is significant not only for instructional innovation but also for the restructuring of teacher professional development (Zhou, L., Zhang, M., & Zhang, C., 2023). Building on this line of work, Yang et al. (2024), drawing on the Chinese standard Digital Literacy of Teachers, developed a framework for normal university students' digital literacy consisting of five first-level dimensions, thereby extending research from in-service teachers to the preparation of future teachers (Yang, Meng, & Wang, 2024).

Taken together, these studies have provided relatively clear answers to such foundational questions as what teachers' digital literacy is, what dimensions it includes, and how it may be assessed. They have also established an important basis for subsequent inquiry. At the same time, however, most existing studies remain at the macro level of standards interpretation and framework construction, while paying comparatively limited attention to how digital literacy is actually formed in specific subject areas and authentic task-based contexts.

2.2 Research on Pre-service Teachers' Digital Literacy

In recent years, discussion of digital literacy has increasingly moved from teachers in general to the population of pre-service teachers. Relevant studies suggest that pre-service teachers' digital literacy is generally at a medium or moderately high level, though marked differences exist across dimensions. Typically, digital awareness and basic technical skills appear relatively strong, whereas digital application and sustained professional development tend to be weaker (Dai, 2023; Wang & Xu, 2025). In relation to teacher preparation, Wang et al. (2025), from the perspective of model construction, point out that pre-service teachers' digital literacy encompasses knowledge, application, awareness, values, and innovation, and is characterized by clear developmental and hierarchical features.

Once the discussion enters the field of foreign language education, the disciplinary specificity of digital literacy becomes more evident. Lai et al. (2023) argue that the integration of digital resources into the design of foreign language teaching activities has become a new normal, and that the key to foreign language teachers' digital literacy lies not in the number of tools they command, but in whether they

can integrate technology meaningfully in relation to instructional goals, learning tasks, and the characteristics of available resources (Lai, Lü, & Gong, 2023). Similarly, Bian et al. (2024) and Yan (2024), respectively from the perspectives of current training conditions and competence framework construction, reveal the subject-specific nature of digital literacy among pre-service foreign language teachers. These studies have thus advanced discussion from teachers in general to pre-service teachers and have begun to attend to the context of foreign language education.

Even so, most of the existing research remains dominated by cross-sectional surveys. As a result, there is still insufficient understanding of how the same group of learners changes over time in concrete task contexts, and how the divergence in their development can be explained.

2.3 Research on Teacher Education in Human–AI Collaborative Contexts

With the entry of generative AI into teacher education, human–AI collaboration has become a rapidly emerging area of inquiry over the past two years. Based on an empirical study of pre-service teachers' instructional design in human–AI collaborative settings, Wu et al. (2024) note that instructional design supported by generative AI is not a matter of simply invoking a tool; rather, it unfolds through a series of interconnected stages, including knowledge retrieval, structural reconstruction, and plan generation, throughout which teachers continue to play a central role in goal setting, content evaluation, and instructional refinement. Shi and Liu (2025) further contend that, in AI-empowered educational contexts, pre-service teachers' digital literacy has expanded beyond conventional digital technology use to encompass more complex capacities such as human–machine collaboration, intelligent judgment, and responsibility awareness (Wu, Wang, & Dong, 2024).

Similar observations can be found in international scholarship. Studies show that pre-service English teachers generally recognize the value of AI in brainstorming, improving lesson preparation efficiency, and tailoring instructional materials in AI-assisted teaching practice, while at the same time facing such challenges as overreliance, ethical risks, and content distortion (Wulandari & Purnamaningwulan, 2024). Related research also suggests that whether AI can genuinely promote teacher professional growth depends on teachers' ability to formulate effective prompts, evaluate and revise generated output, and exercise sound pedagogical judgment (Moorhouse et al., 2024). These findings indicate that research on teachers' digital literacy has moved beyond general digital technology use toward human–AI collaborative contexts.

Nevertheless, current studies tend to focus more on the functional support provided by AI tools, users' attitudes toward such tools, or the short-term effects of intervention. Comparatively less is known about how different students, working on authentic course tasks, arrive at different developmental outcomes through AI use, and what mechanisms underlie such differences.

In sum, previous research has laid a solid foundation for the present study, yet three limitations remain. First, insufficient attention has been paid to how digital literacy is formed in specific subject areas and authentic task-based contexts. Second, research on pre-service teachers' digital literacy has largely remained at the level of cross-sectional description, with relatively little dynamic observation. Third,

the developmental paths of digital literacy and the factors shaping them in human–AI collaborative contexts have yet to be adequately explored. In response to these gaps, the present study takes the course English Curriculum Standards and Instructional Design for Secondary Schools as its focal context to examine pre-service English teachers' use of AI tools and to analyze the developmental paths of their digital literacy as well as the factors that shape them. In so doing, it seeks to address two central questions: how does the digital literacy of pre-service English teachers develop, and why do different developmental paths emerge?

3. Key Concepts, Theoretical Foundations, and Research Design

3.1 Key Concepts

3.1.1 Human–AI Collaboration

Human–AI collaboration does not imply that machines replace human beings; rather, it refers to a mode of task completion in which humans and intelligent systems work together by drawing on their respective strengths (Licklider, 1960). In educational contexts, human–AI collaboration is primarily manifested in teachers' interactions with intelligent technologies around instructional goals and in the ongoing optimization of tasks through iterative feedback (Fang et al., 2022). In this study, human–AI collaboration is defined as the process by which pre-service English teachers, while retaining primary responsibility for pedagogical judgment, make use of generative AI for information retrieval, idea development, content generation, and instructional plan refinement in the context of English instructional design. Its core lies in teacher-led collaborative support rather than technological substitution.

3.1.2 Pre-service English Teachers

In this study, pre-service English teachers refers to students enrolled in English teacher education programs who have not yet formally entered the teaching profession but intend to pursue careers in English language teaching in basic education (Chen, 2019). This group is at a critical transitional stage between student identity and teacher identity, and their digital literacy is gradually formed through coursework, instructional design training, and preparation for teaching practice (Vallente, 2020; Li & Peng, 2024).

3.1.3 Digital Literacy

Digital literacy is not a single technical skill. Rather, it refers to a composite capacity through which individuals acquire, understand, evaluate, and use information in digital environments and employ digital tools to solve problems (Gilster, 1997; Martin & Grudziecki, 2006). In educational research, digital literacy places greater emphasis on teachers' ability to integrate digital technologies into concrete pedagogical contexts (Wu et al., 2023). In the present study, digital literacy refers specifically to pre-service English teachers' ability to use digital technologies and AI tools in the process of English instructional design for resource acquisition, information evaluation, instructional planning, and pedagogical decision-making.

3.2 Theoretical Foundations

3.2.1 Teacher Professional Development Theory

Teacher professional development is not a static end state; rather, it is a continuing process through which teachers construct professional competence through learning, practice, and reflection (Fuller, 1969). Subsequent research has further shown that teacher development does not proceed in a simple linear fashion, but deepens through the interaction between teaching practice and self-adjustment (Conway & Clark, 2003). For pre-service teachers in particular, this stage is not only a period of accumulating disciplinary knowledge and pedagogical skills, but also a crucial phase in the gradual formation of teacher identity, professional judgment, and practical competence (Wang & Zhang, 2023). In relation to the present study, the development of digital literacy among pre-service English teachers in AI-assisted instructional design should not be understood merely as improved technical proficiency. Rather, it is part of a broader process in which professional competence is continuously shaped through course-based learning, human–AI interaction, and pedagogical reflection (Ministry of Education of the People’s Republic of China, 2022a; Ministry of Education et al., 2018). Teacher professional development theory therefore provides an overarching explanatory framework for analyzing both the formation of digital literacy and the differences in its developmental paths among pre-service English teachers.

3.2.2 Constructivist Theory

Constructivism holds that knowledge is not a fixed body of content transmitted directly from the outside world to the learner; instead, it is actively constructed by learners on the basis of prior experience through interaction with environments, tasks, and other people (Piaget, 1970; Vygotsky, 1978). This perspective emphasizes the situated, interactive, and agentic nature of learning and highlights learners’ meaning-making processes in concrete tasks (Taber, 2024). From the perspective of the present study, constructivism offers an important lens for understanding how digital literacy develops among pre-service English teachers. Digital literacy is not an abstract competence formed independently of pedagogical activity; rather, it is gradually constructed through course participation, human–AI interaction, and task-based practice. Constructivist theory thus provides theoretical support for examining both the developmental process of digital literacy and the divergence of its paths.

3.3 Research Design

3.3.1 Research Context and Participants

This study was conducted in the course English Curriculum Standards and Instructional Design for Secondary Schools offered in an English teacher education program at a university in southern China. The course is directly oriented toward future secondary school English teaching and covers such core tasks as interpreting curriculum standards, analyzing teaching materials, setting instructional objectives, designing classroom activities, and planning assessment. As such, it provides a concentrated setting in which students’ use of digital technologies, especially AI tools, during instructional design can be observed. Using this course as the research context made it possible to examine changes in pre-service

English teachers' digital literacy in the course of situated learning.

The participants were 48 undergraduate students majoring in English teacher education who were enrolled in the course. As a group, they were at an important stage in the formation of professional teacher identity and had already begun to receive relatively systematic training in subject-specific instructional design. They therefore offered a realistic picture of pre-service English teachers' learning conditions, patterns of technology use, and digital literacy development in digitally mediated and AI-supported contexts.

3.3.2 Research Instruments and Procedures

(1) Questionnaire Design

A pre-test/post-test questionnaire design was adopted in this study. The questionnaire was developed primarily on the basis of the five-dimensional framework of the Chinese standard Digital Literacy of Teachers, with reference to the DigCompEdu framework, and was moderately adapted in line with Zhou's (2025) design and measurement structure for a digital literacy questionnaire for normal university students (Redecker, 2017; Zhou, 2025). The questionnaire consisted of three parts: basic information, AI use, and a core digital literacy scale. The core scale covered five dimensions—digital awareness, digital knowledge and skills, digital learning, digital teaching application, and digital social responsibility—and included 32 items in total, rated on a five-point Likert scale. Pilot testing indicated that the scale demonstrated satisfactory reliability and validity.

The pre-test was administered at the beginning of the course to identify students' baseline levels of digital literacy and their existing patterns of AI use. The post-test was conducted at the end of the course. While retaining the core scale, the post-test also included additional course-related items to capture changes after course participation. In the formal investigation, both the pre-test and the post-test were administered to the same class of 48 undergraduate students majoring in English teacher education. After data collection, invalid responses were removed, and the remaining data were coded and analyzed statistically.

(2) Interview Design

Interviews were used as a supplement to the questionnaire data in order to further explain differences among students in their ways of using AI, the depth of their participation in instructional design, and the development of their digital literacy. Semi-structured interviews were conducted, focusing mainly on the specific stages at which AI entered the instructional design process, how students evaluated and handled AI-generated output, the difficulties and concerns they encountered in use, and their perceptions of change after course participation.

Participants for the interviews were selected purposively on the basis of questionnaire results and observed AI use. One representative case was chosen from each of the three developmental types—active development, steady development, and constrained development—for in-depth interviews. Each interview lasted approximately 20 to 30 minutes. With participants' consent, the interviews were audio-recorded and later transcribed for analysis. To protect participants' privacy,

pseudonyms are used throughout the paper.

(3) Data Analysis

Quantitative and qualitative data were analyzed separately and then triangulated. The quantitative data were processed mainly using SPSS 27.0, including frequency statistics for basic information and AI use, descriptive statistics for each dimension of digital literacy and for the overall score, and the classification of developmental paths based on changes between the pre-test and post-test. The qualitative data were analyzed using thematic analysis. Interview transcripts were organized, coded, and categorized, with particular attention to differences across student types in their understanding of the value of AI, depth of use, evaluation of AI-generated results, and transformation of course support into practice. In the final analysis, the quantitative data were used primarily to present the overall level, changes, and path types of digital literacy among pre-service English teachers, whereas the qualitative data were used mainly to explain why different developmental paths emerged.

3.3.3 Research Process

The study was carried out in three stages. The first stage was a baseline survey, in which the pre-test questionnaire was administered before the course began to identify the initial level of digital literacy and prior AI use among the 48 undergraduate students majoring in English teacher education. The second stage involved path identification. After the course ended, the post-test questionnaire was administered, and changes across dimensions were examined by comparing pre-test and post-test scores. These results were then considered together with the frequency, breadth, and depth of AI tool use in order to classify students' digital literacy development into distinct path types. The third stage involved case selection and analysis of contributing factors. Based on the path classification results, three typical cases were selected for semi-structured interviews. These interview data, together with course materials such as slides and lesson plans, were used to analyze the internal factors shaping different developmental paths.

4. Results and Discussion

This section addresses the first research question, namely, what developmental paths characterized pre-service English teachers' digital literacy before and after the course English Curriculum Standards and Instructional Design for Secondary Schools. To answer this question, the study first describes the digital literacy profile and AI use reported in the pre-test so as to establish the participants' baseline status prior to the course. It then compares the pre-test and post-test results to identify different patterns of development and to summarize the main characteristics of the three path types.

4.1 *Developmental Paths of Digital Literacy among Pre-service English Teachers*

4.1.1 Overall Characteristics of Pre-service English Teachers' Digital Literacy

As shown in Table 1, the overall level of digital literacy among the 48 undergraduate students majoring in English teacher education was moderately high, although development across dimensions was uneven. In particular, digital awareness and digital social responsibility were relatively strong, whereas

digital knowledge and skills and digital teaching application were comparatively weaker. This finding is broadly consistent with previous research suggesting that pre-service teachers' digital literacy tends to be at a moderately high level overall while remaining imbalanced across dimensions (Dai, 2023). It suggests that most participants had already developed a certain degree of digital awareness and a sense of responsibility, but still had room to improve in transforming digital technologies into pedagogically meaningful design capacity.

Table 1. Current Levels of Digital Literacy among Pre-service English Teachers

Dimension	N	Minimum	Maximum	Mean	SD
<i>Digital awareness</i>	48	1.80	5.00	3.9542	0.60809
<i>Digital knowledge and skills</i>	48	1.63	5.00	3.5000	0.75838
<i>Digital learning</i>	48	2.20	5.00	3.6500	0.56342
<i>Digital teaching application</i>	48	1.86	5.00	3.6756	0.56665
<i>Digital social responsibility</i>	48	3.33	5.00	4.3299	0.47576
<i>Overall digital literacy</i>	48	2.52	4.97	3.7977	0.49875

A closer look at the distribution of total scores suggests that baseline differences also existed within the sample. Based on the distribution of the overall mean scores, participants with mean scores below 3.00 were classified as the low-score group, those with scores from 3.00 to below 4.00 as the medium-score group, and those with scores of 4.00 or above as the high-score group. As shown in Table 2, students were not evenly distributed across these groups. Bian et al. (2024), in their discussion of digital literacy among pre-service foreign language teachers, likewise note that students differ substantially in prior experience with digital tools, in their capacity to integrate technology into pedagogy, and in the support conditions available to them. Viewed in this light, the group differences identified in the present study reflect not merely variations in score level, but also differences in students' starting points in terms of digital foundations, understanding of English instructional design, and ability to translate technology into pedagogical practice. These differences constituted an important precondition for the subsequent divergence of developmental paths during the course.

Table 2. Distribution of Digital Literacy Levels among pre-service English Teachers

Group	Frequency	Percentage	Valid Percentage	Cumulative Percentage
<i>Low-score group</i>	5	10.4	10.4	10.4

Group	Frequency	Percentage	Valid Percentage	Cumulative Percentage
<i>Medium-score group</i>	28	58.3	58.3	68.8
<i>High-score group</i>	15	31.3	31.3	100.0
<i>Total</i>	48	100.0	100.0	

The pre-test also showed that the AI tools most frequently used by students were general-purpose large language models, especially Doubao, DeepSeek, and ERNIE Bot. Overall, participants tended to prioritize general-purpose tools. In terms of frequency and purpose, AI had already entered some students' learning routines and instructional design preparation, mainly for information search, idea generation, language polishing, and improving task efficiency. Its involvement was much more limited, however, in stages requiring stronger professional judgment, such as interpreting curriculum standards or designing assessment. This suggests that, at present, AI primarily functions for pre-service English teachers as an efficiency-enhancing and auxiliary resource rather than as a deeply embedded component throughout the whole instructional design process.

When the pre-test results are considered together, a certain relationship can be observed between students' digital literacy levels and their AI use. Students with stronger foundations in digital literacy tended to be more active in terms of frequency, range, and initiative of AI use, and were also more likely to regard AI as a pedagogical support resource rather than a simple information-generation tool. By contrast, students with weaker digital literacy foundations were more likely to remain at a low-frequency, surface-level, or cautious mode of use. Ji and Li (2025) similarly argue that the development of digital literacy among pre-service English teachers is closely related to their understanding of technology and the degree to which they engage with professional tasks^[31]. In the present study, this means that digital literacy is reflected not only in technical awareness and responsibility, but also in the depth with which students are able to employ AI in instructional design tasks.

4.1.2 Identification of Developmental Paths of Digital Literacy

Building on the pre-test analysis, the study next compared changes in digital literacy before and after the course. As shown in Table 3, the course as a whole had a positive effect on students' digital literacy development, with more substantial gains appearing in dimensions more closely tied to task practice, especially digital knowledge and skills and digital teaching application. This pattern is broadly in line with previous findings that digital literacy develops gradually through participation in authentic tasks (Wang & Xu, 2025).

Table 3. Descriptive Statistics for Changes in Digital Literacy among Pre-service English Teachers

Dimension of Change	N	Minimum	Maximum	Mean	SD
<i>Change in digital awareness</i>	48	0.00	2.00	0.3083	0.35957
<i>Change in digital knowledge and skills</i>	48	-0.13	1.50	0.4557	0.37764
<i>Change in digital learning</i>	48	-0.60	1.00	0.2917	0.34011
<i>Change in digital teaching application</i>	48	-0.29	1.43	0.3899	0.31566
<i>Change in digital social responsibility</i>	48	-0.17	0.83	0.1771	0.21582
<i>Change in overall digital literacy</i>	48	-0.19	1.03	0.3367	0.23479
<i>Valid cases (listwise)</i>	48				

On the basis of the pre-test/post-test change scores, the present study classified the sample into three developmental types—constrained development, steady development, and active development—primarily according to the magnitude of change in overall digital literacy, while also taking students' AI use into account. More specifically, participants whose change in overall digital literacy was below 0.20 were classified as the constrained development type, those whose change scores fell between 0.20 and 0.40 as the steady development type, and those whose change scores reached or exceeded 0.40 as the active development type. These classifications were then cross-checked against students' frequency of AI use, stages of AI involvement, and degree of initiative in use. The distribution is presented in Table 4. The results indicate that the development of digital literacy among pre-service English teachers did not follow a single uniform path; rather, it gradually differentiated into distinct developmental patterns over the course of the learning process.

Table 4. Distribution of Developmental Path Types of Digital Literacy

Path Type	Frequency	Percentage	Valid Percentage	Cumulative Percentage
<i>Constrained development</i>	15	31.3	31.3	31.3
<i>Steady development</i>	16	33.3	33.3	64.6
<i>Active development</i>	17	35.4	35.4	100.0
<i>Total</i>	48	100.0	100.0	

4.1.3 Specific Manifestations of Different Developmental Paths

During the course, the most salient feature of students in the active development group was that they were able to incorporate AI into key instructional design tasks at an early stage and to establish a relatively stable interaction between AI use and the improvement of their own digital literacy. For these students, AI was no longer merely a tool for collecting information or polishing language; it entered more central stages such as interpreting curriculum standards, analyzing teaching materials, and shaping instructional plans. Their digital literacy development thus showed a shift from simple technological engagement toward pedagogical transformation. This finding is broadly consistent with Wu et al.'s (2024) argument that human–AI collaborative instructional design does not consist in simply invoking tools, but in allowing AI to enter the core stages of pedagogical planning.

By contrast, students in the steady development group also used AI in course tasks, but tended to treat it more as a supplementary or supportive tool, mainly for building lesson-plan frameworks, organizing materials, and polishing language. Their use had not yet led to any substantial restructuring of their instructional design thinking. For this group, changes in digital literacy were more often manifested as limited integration rather than deep transformation.

Students in the constrained development group, in turn, were characterized by a relatively narrow range of AI use, and AI had not truly entered the core stages of course tasks. Even when they did use AI, their engagement was mostly confined to low-risk stages such as information search, translation, and language polishing, while its involvement in more professionally demanding dimensions—such as interpreting curriculum standards, judging learner needs, organizing classroom activities, and designing assessment—remained limited. As a result, the changes observed in this group largely remained at the level of technological contact, and improvements in digital literacy were comparatively modest.

4.2 Factors Shaping Different Developmental Paths

This section turns to the second research question, namely, what factors contributed to the emergence of different developmental paths. To address this question, the study draws on interview data to compare three representative cases and, in light of relevant factors identified in the literature review, offers a further explanation of the logic through which different paths took shape. To protect participants' privacy, the three interviewees are referred to as A, B, and C, representing the active development, steady development, and constrained development types, respectively.

4.2.1 Comparison of the Three Cases

To present more clearly the differences among the three representative students in their understandings of AI, depth of use, evaluation of outputs, and transformation of course support, the interview transcripts were subjected to thematic coding. The results are shown in Table 5.

Table 5. Thematic Coding Results from Interviews with Students across Different Developmental Paths

Parent Theme	Subtheme	Typical Manifestation	Path Type
Understanding of the educational value of AI	Collaborative understanding	AI is viewed as a collaborative resource in instructional design, used not only to improve efficiency but also to broaden ideas and identify problems.	Active development
	Instrumental understanding	AI is understood mainly as a tool for saving time, providing frameworks, and supporting expression.	Steady development
Depth of AI involvement in instructional design	Risk-oriented understanding	Greater attention is paid to such risks as distortion in AI output, weakened thinking, and overdependence; reservations remain about its educational value.	Constrained development
	Deep involvement across multiple stages	AI enters multiple stages, including learner analysis, formulation of instructional objectives, design of classroom activities, language refinement, and post-class reflection.	Active development
Judgment of AI output and collaborative capacity	Involvement in peripheral stages	AI is used mainly for information collection, generation of lesson-plan frameworks, and polishing of instructional language.	Steady development
	Involvement in low-risk stages	AI use is largely confined to low-risk stages, such as information search, language polishing, and revision of objective statements.	Constrained development
Judgment of AI output and collaborative capacity	Selection, revision, and reconstruction	AI output is filtered and further revised or reconstructed in light of textbook content, student level, and classroom feasibility.	Active development
	Partial adoption with limited	Students make a preliminary judgment about whether the output is usable, but	Steady development

Parent Theme	Subtheme	Typical Manifestation	Path Type
	revision	usually retain only part of it and revise it in a limited way.	
	Distrust and cautious abandonment	Students often discontinue use because they cannot determine whether AI output is reliable or worry that it may not fit real classroom situations.	Constrained development
	Effective transformation of support	Teacher modelling, assignment requirements, and peer communication are effectively transformed into more active and more in-depth strategies for using AI.	Active development
Course support and developmental conditions	Limited uptake of support	Teacher modelling and peer experience can be accepted, but they are not easily transformed into deeper integration strategies.	Steady development
	Insufficient support for judgment	Students generally hope for more concrete cases, demonstrations, and evaluative criteria in order to strengthen their confidence in using AI.	Constrained development

Taken together, the differences among the three types of students were mainly reflected in three aspects. First, they differed in how they understood the educational value of AI. Students in the active development group were more likely to view AI as a collaborative resource in instructional design; those in the steady development group tended to understand it primarily as an efficiency-enhancing support tool; and those in the constrained development group placed greater emphasis on distortion, dependence, and risk. Second, they differed in the depth with which AI entered instructional design. Students in the active development group were able to allow AI to participate in multiple key stages, whereas students in the steady development group largely remained at the level of peripheral tasks, and those in the constrained development group used AI only to a limited extent in low-risk stages. Third, they differed in how they handled AI-generated output. Students in the active development group typically selected, revised, and reconstructed AI output; students in the steady development group tended to adopt it only partially and make limited revisions; students in the constrained development group often abandoned it because they lacked confidence in their own judgment. By comparison,

differences in course support were more likely to amplify or reinforce these three dimensions of divergence.

A similar pattern of differentiation has also been noted in previous research. Wulandari and Purnamaningwulan (2024) point out that pre-service English teachers often hold both expectations of value and concerns about risk in relation to AI. Moorhouse et al. (2024), meanwhile, emphasize that whether AI can genuinely support teacher professional growth depends not simply on exposure to the tool itself, but on teachers' capacity to evaluate, revise, and pedagogically judge generated output. In light of the present study, the differences among the three path types should therefore not be reduced to differences in technical proficiency alone; they also reflect students' differing understandings of AI's role, differing ways of involving it in professional tasks, and differing levels of pedagogical judgment.

4.2.2 Analysis of the Factors Behind Path Formation

Differences in how students understood the educational value of AI constituted the starting point of path divergence. Teachers' digital literacy is not simply a matter of knowing how to use tools; it also concerns how teachers understand the relationship between technology and pedagogy (Zhou et al., 2023). Students in the active development group were more willing to regard AI as a participant in instructional design, and were therefore more likely to experiment actively and continue revising their use in practice. Students in the steady development group accepted AI, but positioned it more as an efficiency tool. Students in the constrained development group, by contrast, placed greater emphasis on such risks as distortion, dependence, and loss of judgment, making it difficult for them to sustain motivation for continued use. As participant A put it, AI was "more like someone I could discuss things with," whereas participant C repeatedly stressed that she had "always been somewhat guarded against it." These cases suggest that students' basic understanding of AI's educational value directly shaped their subsequent willingness to use it and the depth of that use.

Differences in the capacity to collaborate with AI were another key factor driving further divergence. With the entry of generative AI into teacher education, what affects the quality of use is not merely whether one can operate the tool, but whether one can ask appropriate questions and make effective judgments about the output (Wu et al., 2024; Celik et al., 2026). Students in the active development group were generally able to refine prompts, filter responses, and adjust AI output in line with instructional goals. Participant A noted that she later came to realize that "I needed to make the textbook content, the students' grade level, and the teaching objectives as explicit as possible; only then would it give me something a bit more reliable." Although students in the steady development group were also aware that questioning strategies mattered, they usually remained at the stage of initial experimentation. Participant B commented, "My biggest difficulty is actually that I don't know how to make my questions more specific." Students in the constrained development group often stopped using AI because they did not know how to follow up. Participant C stated candidly: "Another problem is that I don't know how to ask follow-up questions. If the first answer isn't right, I usually don't feel like continuing." This indicates that differences in prompting, follow-up questioning, and filtering ability

constituted an important mechanism underlying path divergence.

Differences in the degree of subject-specific integration also played a crucial role. For pre-service English teachers, whether digital literacy is genuinely enhanced depends less on how many tools they command than on whether technology can enter the core tasks of English instructional design (Wu et al., 2024). Students in the active development group were able to bring AI into key stages of English instructional design and achieve relatively deep integration in activity organization and post-class reflection. Reflecting on the design of a reading lesson, participant A remarked that AI had helped her realize that “there wasn’t enough progression between the activities in my original plan.” Students in the steady development group, by contrast, remained more at the level of framework building and language polishing. As participant B put it, “Its role is more like helping me get past the initial hurdle. When it comes to how to develop the lesson further and how to connect everything, I still have to rely on myself.” Students in the constrained development group found it more difficult to turn AI output into instructional plans suited to English classrooms. Participant C admitted that “many of the activities it suggested were too general. They didn’t really seem suitable for secondary school students, or they looked fine on paper, but I didn’t know how to carry them into the classroom.” This suggests that the ability to move from tool use to subject-specific integration marked an important dividing line among the three path types (Lai et al., 2023; Ji & Li, 2025).

4.2.3 Discussion

Overall, the development of digital literacy among pre-service English teachers did not proceed as a single linear process of improvement. Rather, under the combined influence of students’ understandings of the value of AI, their capacity for collaboration with AI, the degree of integration between technology and subject pedagogy, and the extent to which course support could be transformed into practice, their development gradually differentiated into three paths: active development, steady development, and constrained development. On the surface, the differences among these paths were reflected in the magnitude of improvement in digital literacy and the depth of AI use. At a deeper level, however, they reveal different understandings of the relationship among technology, pedagogy, and one’s own professional role in human–AI collaborative contexts.

5. Implications for Pre-service English Teacher Education

5.1 *Embedding Digital Literacy Development in English Instructional Design Tasks*

The development of digital literacy among pre-service English teachers should be anchored more firmly in the work of English instructional design itself. Interpreting curriculum standards, analyzing teaching materials, understanding learners, designing classroom activities, and revising lesson plans are not only core components of pedagogical training; they are also important sites in which digital literacy is formed. For this reason, digital literacy development in teacher education should not remain at the level of tool introduction or technical skills training. Instead, digital technologies—and AI tools in particular—need to be situated within authentic pedagogical tasks so that student teachers can

gradually understand the scope, value, and limits of technological intervention in practice and move from general tool use toward meaningful pedagogical integration.

5.2 Moving beyond Tool Training toward Human–AI Collaborative Competence

As AI becomes part of teacher education, the key issue is not whether pre-service teachers use it, but whether they are able to develop a stable capacity for human–AI collaboration. AI can support idea generation, material integration, and linguistic refinement, but the appropriateness of instructional goals, the alignment of activities with learners’ needs, and the feasibility of classroom implementation still depend on teachers’ professional judgment. Future course design should therefore place greater emphasis on such capacities as prompt construction, output evaluation, content revision, and pedagogical reworking. In this way, student teachers can strengthen their professional agency while using AI, rather than allowing their digital literacy to remain at the level of superficial invocation or simple dependence.

5.3 Providing Differentiated Support for Different Developmental Paths

The existence of different developmental paths suggests that the cultivation of digital literacy among pre-service English teachers should not follow a one-size-fits-all model. For students in the active development group, more complex tasks may be used to promote deeper integration of AI into such areas as assessment design, reflective revision, and instructional refinement. For those in the steady development group, the priority is to help AI use move beyond information gathering and language polishing into the core stages of instructional planning. For students in the constrained development group, teacher modelling, case-based scaffolding, and peer discussion are especially important for reducing hesitation and building basic confidence and judgment in AI use. The point of differentiated support is not to rank students, but to ensure that each group receives developmentally appropriate opportunities for further growth.

6. Conclusions

Drawing on the course English Curriculum Standards and Instructional Design for Secondary Schools, this study employed a combination of pre- and post-course questionnaires and semi-structured interviews to examine how pre-service English teachers’ digital literacy developed in AI-assisted instructional design contexts. The findings suggest that digital literacy did not improve in a uniform or synchronous manner. Rather, it evolved through the combined influence of course tasks, human–AI interaction, and individual differences, resulting in visible developmental divergence among participants.

Overall, the participants demonstrated a moderately high level of digital literacy, although the development of different dimensions was uneven. Course-based learning contributed positively to its growth, with more evident gains in dimensions more closely connected to practical task engagement. Further analysis identified three developmental paths—active development, steady development, and constrained development. These paths were shaped mainly by participants’ understandings of the

educational value of AI, their capacity for human–AI collaboration, and the extent to which they were able to integrate AI into subject-specific pedagogical work. The findings therefore indicate that the development of digital literacy among pre-service English teachers is not simply a matter of becoming more proficient with tools. Instead, it is a process that takes shape—and gradually differentiates—through engagement in authentic instructional design tasks.

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