

Examining the Effects of AI-Enhanced Teaching on Pre-Service Teachers' Instructional Application Competence in Digital-Intelligent Literacy: A Case Study of the Course AI-Enhanced Instructional Design Innovation and Application

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Abstract: Investigating how AI-enhanced teaching influences pre-service teachers' instructional application competence in digital-intelligent literacy is of substantial value for optimizing teacher education curricula, improving instructional management in teacher preparation programs, and enhancing the quality of future teachers' digital-intelligent development. Taking the course AI-Enhanced Instructional Design Innovation and Application as an example, this study employed a self-developed questionnaire to examine changes in pre-service teachers' digital application competence and practical AI application competence before and after course participation. A total of 299 valid responses were collected from students enrolled at a normal university in Yunnan Province, China. Drawing on the digital application competence dimension in the Teacher Digital Literacy framework and the practical application dimension in the AI Literacy Framework for Primary and Secondary School Teachers in Guangdong Province (Trial), this study conducted a pre-post comparative analysis of pre-service teachers' instructional application competence in digital-intelligent literacy. The findings indicate that participation in the course significantly improved students' competence, particularly in digital instructional design, digital instructional implementation, intelligent resource development, and intelligent instructional implementation. However, relatively limited gains were observed in digital academic assessment, intelligent instructional evaluation, and collaborative education.

Keywords: AI-enhanced teaching; Pre-service teachers; Digital-intelligent literacy; Instructional application competence; Teacher education

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1. Introduction

In recent years, China has issued a series of policy documents, such as the *Opinions on Comprehensively*

Deepening the Reform of Teacher Development in the New Era and the *Action Plan for Revitalizing Teacher Education (2018–2022)*, to strengthen teacher workforce development ^[1]. These policies emphasize that teachers should improve their digital-intelligent literacy, master digital and intelligent teaching tools, actively engage with technological innovation, and explore new forms of intelligent education ^[2]. More recently, the *Opinions on Accelerating the Advancement of Educational Digitalization*, jointly released by the Ministry of Education and eight other departments in 2025, further highlighted the need to develop digital literacy standards and AI application guidelines for teachers and students, and to promote practical activities and evaluation related to digital and AI literacy.

Against the backdrop of rapid advances in artificial intelligence, the education sector is undergoing a profound digital-intelligent transformation. The ability to integrate AI technologies effectively into instructional practice has become an essential component of future teachers' professional competence ^[3]. Empirical studies have shown that AI-enhanced teaching can significantly improve teaching effectiveness across educational stages ^[4], with particularly strong effects reported in higher education and in disciplines such as computer science, mathematics, English, and biology ^[5]. This new context requires teachers to rethink instructional design from the perspectives of generation, feedback, adjustment, and iteration. Using real-time learning data and dynamically generated learner profiles, teachers are increasingly expected to adapt instructional goals, content, activities, and assessment in flexible ways, thereby overcoming the limitations of traditional instructional design and creating seamless online-offline learning experiences characterized by adaptability, generativity, and creativity.

2. Research overview

Digital-intelligent literacy refers to the comprehensive set of awareness, knowledge, competence, and ethical understanding that individuals need in the digital-intelligent era. Although the term may appear to combine digital literacy and AI literacy, its connotations go beyond a simple aggregation of the two. In essence, digital-intelligent literacy can be understood as an advanced and integrated form of literacy that reflects the demands of technology-rich and AI-mediated environments ^[6].

Research on teachers' digital-intelligent literacy has gradually expanded in recent years. Some scholars have argued that teachers' digital-intelligent literacy and their instructional application competence are central indicators of teacher preparation quality ^[7]. In 2022, China's Ministry of Education issued the Teacher Digital Literacy industry standard, which provides important guidance for teacher development in this area. At its core is teachers' digital application competence, understood as the comprehensive ability to conduct a range of digital teaching activities, including digital instructional design, digital instructional implementation, digital academic assessment, and digital collaborative education ^[8].

Other researchers have examined teacher digital-intelligent literacy from a human-AI collaboration perspective and have conceptualized it as a fusion of data literacy and AI literacy, involving multiple dimensions such as knowledge and skills, higher-order thinking, and beliefs and ethics ^[9]. Existing studies also suggest that some teachers still demonstrate insufficient digital-intelligent literacy, limited familiarity with emerging technologies, and a tendency to remain at the level of basic operational use ^[10]. As a result, they may struggle to design and implement rich technology-supported instructional activities, particularly in areas such as virtual simulation, intelligent resource development, and data-informed teaching ^[11].

In response to these challenges, future teachers need to strengthen both their digital-intelligent literacy and their ability to apply such literacy in authentic instructional contexts ^[12]. To address this issue, the present study combines the dimensions outlined in the Teacher Digital Literacy framework and the AI Literacy Framework

for Primary and Secondary School Teachers in Guangdong Province (Trial) to examine how AI-enhanced teaching supports the development of pre-service teachers' instructional application competence.

3. Research design

3.1. Research framework

AI-Enhanced Instructional Design Innovation and Application is a compulsory public course for pre-service teachers at the university level. The course is built around three major goals. First, it aims to help students understand the logic of applying AI tools, including generative AI, in instructional design and classroom practice. Second, it seeks to cultivate evidence-based instructional improvement, encouraging students to optimize teaching on the basis of evidence rather than using technology merely for its own sake. Third, it emphasizes critical thinking by guiding students to examine the educational appropriateness and ethical risks of AI technologies.

Rather than training students to become technical operators of AI systems, the course aims to develop educational innovators who can use technology meaningfully and responsibly. Based on the course content, the Teacher Digital Literacy framework, and the AI Literacy Framework for Primary and Secondary School Teachers in Guangdong Province (Trial), this study adapted the questionnaire, distributed it to participants, and analyzed the resulting data.

The research focused on two aspects. The first was pre-service teachers' digital application competence within the Teacher Digital Literacy framework, examined through a comparison of students' competence before and after taking the course. The second was the practical application dimension of AI literacy, analyzed across five dimensions: intelligent instructional design, intelligent resource development, intelligent instructional implementation, intelligent instructional evaluation, and intelligent collaborative education. Through these two strands of analysis, the study explored whether participation in the course contributed to improvements in pre-service teachers' instructional application competence in digital-intelligent literacy.

3.2. Instruments and methods

This study partially drew on the AI literacy scale developed by Professor Zhong Baichang's research team^[13]. The questionnaire consisted of four sections. The first section collected students' basic demographic information. The second section focused on learning diagnostics for sophomore pre-service teachers, including entry-level competence, learning styles and preferences, information literacy, and related background characteristics. The third section measured self-reported digital application competence, covering four dimensions: digital instructional design competence, digital instructional implementation competence, digital academic assessment competence, and digital collaborative education competence. The fourth section assessed practical AI application competence for primary and secondary school teaching, including 45 items across five dimensions: intelligent instructional design, intelligent resource development, intelligent instructional implementation, intelligent instructional evaluation, and intelligent collaborative education.

The overall reliability of the questionnaire was strong, with a Cronbach's alpha coefficient of 0.977 and a split-half reliability coefficient of 0.914, both exceeding 0.80. The KMO value was 0.829, and Bartlett's test of sphericity was significant ($P = 0.000$), indicating good construct validity and suitability for factor analysis. Both the digital application competence section and the practical AI application competence section adopted a five-point Likert scale ranging from 1 ("not at all competent") to 5 ("highly competent").

The collected data were analyzed using SPSS 27.0. The main analytical procedures included descriptive

statistics, standard deviation analysis, and difference analysis. In addition, Python was used to support data processing and visualization.

3.3. Participants

The participants were students enrolled in the course AI-Enhanced Instructional Design Innovation and Application at University Y. Following the principle of voluntary participation, the questionnaire was distributed online through the Wenjuanxing platform. A total of 320 responses were collected. After removing duplicate and invalid responses, 299 valid questionnaires were retained, yielding an effective response rate of 93.43%.

As the course was offered in the first semester mainly to humanities-oriented pre-service teachers, the sample primarily consisted of first-semester students from humanities and social science teacher education programs. The gender ratio was approximately 2:8 (male to female). This participant profile should be taken into account when interpreting the findings.

4. Data collection based on the scales of digital application competence and practical AI application competence

4.1. Scale for digital application competence

Digital application competence is a core dimension in the Teacher Digital Literacy framework and represents a key leverage point for digitally empowered teacher development ^[14]. In this study, digital application competence refers to teachers’ ability to use digital technological resources to support educational activities. It includes four dimensions: digital instructional design, digital instructional implementation, digital academic assessment, and digital collaborative education (Figure 1).

This part of the questionnaire employed a five-point Likert scale ranging from 1 (“not at all competent”) to 5 (“highly competent”). It examined students’ self-reported competence across the four dimensions mentioned above.

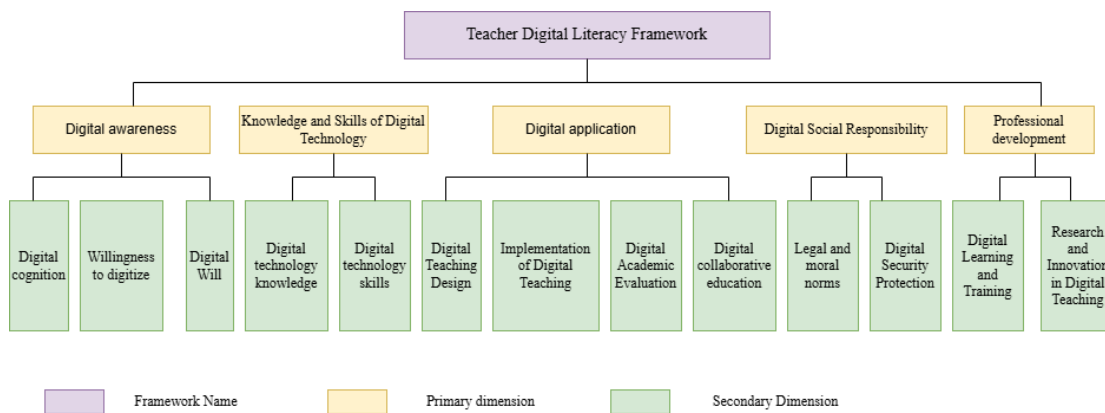


Figure 1. Teacher Digital Literacy Framework

4.2. Scale for practical AI application competence

This study also adopted the practical application dimension of the AI Literacy Framework for Primary and Secondary School Teachers in Guangdong Province (Trial), which aligned closely with the course content of AI-Enhanced Instructional Design Innovation and Application. In this framework, practical application competence refers to teachers’ active use of AI in educational scenarios such as teaching, learning, assessment, diagnosis, management, and holistic student development. It includes five dimensions: intelligent instructional design,

intelligent resource development, intelligent instructional implementation, intelligent instructional evaluation, and intelligent collaborative education (Figure 2).

The course was designed to support the overarching educational goal of fostering student development through ethically grounded and pedagogically meaningful uses of AI. For pre-service teachers who were not majoring in educational technology, the course aimed to strengthen their information-based instructional design and application competence through the integration of AI technologies. Based on the alignment between the course content and the intelligent instructional design dimension of the AI literacy framework, this study developed a practical AI application competence questionnaire for pre-service teachers.

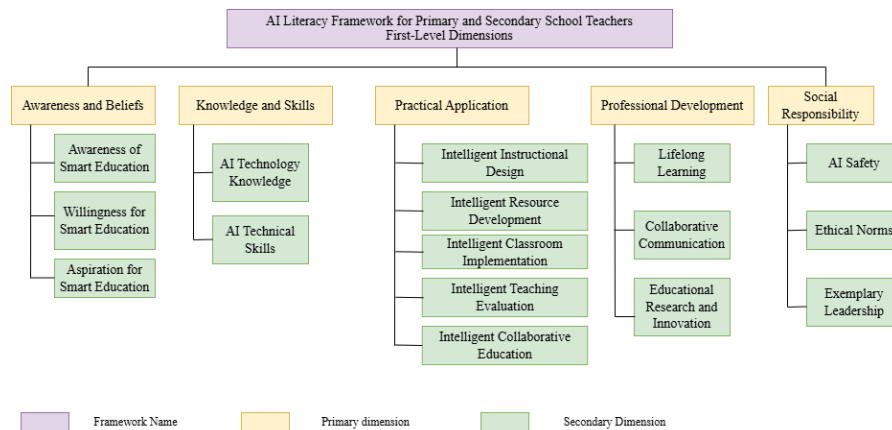


Figure 2. AI Literacy Framework for Primary and Secondary School Teachers

5. Multidimensional data analysis

5.1. Analysis of the digital application competence dimension

5.1.1. Overall descriptive analysis

Descriptive analysis was first conducted to summarize the overall characteristics of the dataset and to provide a foundation for further analysis. The main indicators included mean values, reflecting central tendency, and standard deviations, reflecting dispersion.

Because the digital application competence scale employed a five-point Likert format, its theoretical midpoint was 3. As shown in the analysis (Table 1), the overall pre-course mean score for digital application competence was 2.86, which was lower than the theoretical midpoint. This indicates that sophomore pre-service teachers had developed a certain level of digital application competence, but their overall competence remained relatively limited.

Across the four dimensions, the mean scores ranked as follows: digital collaborative education competence, digital instructional implementation competence, digital instructional design competence, and digital academic assessment competence. Although digital collaborative education competence showed the highest mean score among the four, it still remained below 3, suggesting that there was considerable room for improvement. Digital academic assessment competence had the lowest mean score, indicating that it was the most difficult area for students. This result suggests the need to cultivate data thinking, strengthen multidimensional assessment literacy, reinforce the practical use of digital tools, and optimize support systems for assessment. More broadly, it points to the importance of helping students shift from a tool-oriented approach to a data-driven instructional decision-making mindset.

The standard deviation for overall digital application competence was relatively small (0.681), indicating that the mean score was reasonably representative of the sample as a whole.

Table 1. Overall pre-course status of digital application competence

Dimension	Mean	Standard deviation
Digital instructional design competence	2.89	0.65
Digital instructional implementation competence	2.91	0.68
Digital academic assessment competence	2.69	0.74
Digital collaborative education competence	2.95	0.66
Digital application competence	2.86	0.68

5.1.2. Pre- and post-course differences in digital application competence

To examine differences before and after course participation, an independent-samples *t*-test was conducted, and radar charts were used for visual comparison.

The results indicate a statistically significant difference in digital application competence between the pre-course and post-course conditions (**Table 2**). The *P*-value was below 0.05, suggesting that students' digital application competence differed significantly before and after taking the course. Overall, post-course scores were higher than pre-course scores. Significant gains were particularly evident in overall digital application competence and digital instructional implementation competence.

At the dimensional level, digital instructional design competence showed a highly significant difference, with $t = 10.389$ and $P < 0.001$. The post-course mean for digital instructional design competence was 3.629 (SD = 0.573), whereas the pre-course mean was 2.892 (SD = 0.647). This clearly indicates substantial improvement after course participation.

Comparing the *t*-values across the dimensions ($10.398 > 9.363 > 2.086 > 0.082$), the rank order of improvement was as follows: digital instructional design competence > digital instructional implementation competence > digital academic assessment competence > digital collaborative education competence. These findings suggest that the course had a strong positive effect on improving pre-service teachers' digital application competence.

However, the *P*-value for digital collaborative education competence was 0.935, which exceeded 0.05. This means that no statistically significant difference was found between the pre-course and post-course conditions for this dimension. In other words, the course contributed little to improving students' competence in digital collaborative education, indicating that this area should be strengthened in future teaching.

Table 2. *t*-test analysis of pre- and post-course differences in digital application competence

Dimension	Status	<i>n</i>	Mean (SD)	<i>t</i>	<i>P</i>	Difference
Digital instructional design	Post-course (A)	144	3.629 (0.573)	10.398	<0.001***	Post > Pre
	Pre-course (B)	155	2.892 (0.647)			
Digital instructional implementation	Post-course (A)	144	3.569 (0.536)	9.363	<0.001***	Post > Pre
	Pre-course (B)	155	2.908 (0.682)			
Digital academic assessment	Post-course (A)	144	2.868 (0.752)	2.086	0.038*	Post > Pre
	Pre-course (B)	155	2.688 (0.737)			
Digital collaborative education	Post-course (A)	144	2.958 (0.756)	0.082	0.935	Post = Pre
	Pre-course (B)	155	2.952 (0.657)			

The visual comparison in **Figure 3** further shows that students’ overall digital application competence improved substantially after the course, with the largest increase observed in digital instructional design competence. Although digital academic assessment competence also improved, its post-course level remained relatively low, suggesting that assessment-related content remained a learning difficulty. By contrast, digital collaborative education competence showed almost no change, further indicating that this area received insufficient attention in the course.

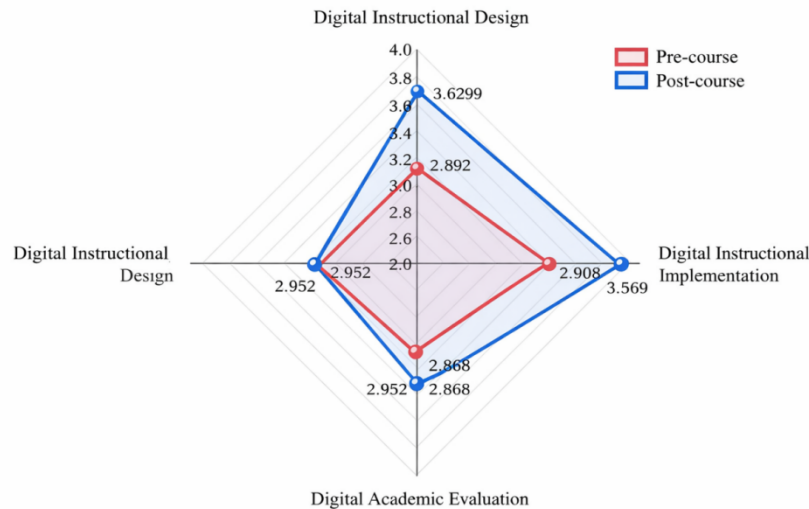


Figure 3. Comparison of improvements in digital application competence

5.2. Analysis of practical AI application competence

5.2.1. Overall descriptive analysis

The practical application competence scale also employed a five-point Likert format, and its theoretical midpoint was therefore 3. The overall pre-course mean score for practical application competence was 2.865 (**Table 3**), which was also below the theoretical midpoint. This suggests that sophomore pre-service teachers’ practical AI application competence for school teaching was at a moderately low level.

Among the five dimensions, intelligent collaborative education competence showed the highest mean score, whereas intelligent resource development competence showed the lowest. This result suggests that, prior to the course, students were less prepared to develop AI-supported educational resources than to engage in AI-related collaborative education scenarios.

Table 3. Overall pre-course status of practical application competence

Dimension	Pre-course mean	Post-course mean	Change
Digital instructional design competence	2.892	3.629	0.737
Digital instructional implementation competence	2.908	3.569	0.661
Digital academic assessment competence	2.688	2.868	0.18
Digital collaborative education competence	2.952	2.958	0.006

5.2.2. Pre- and post-course differences in practical AI application competence

An independent-samples *t*-test was also conducted to compare pre-course and post-course differences in

practical AI application competence. The results show that the P -value was below 0.05, indicating a statistically significant difference between the two conditions. Overall, students' post-course practical application competence was higher than their pre-course competence. See **Table 4**.

At the dimensional level, intelligent resource development competence showed the largest difference, with $t = 13.792$ and $P < 0.001$. The post-course mean score for intelligent resource development competence was 3.662 (SD = 0.519), compared with a pre-course mean of 2.756 (SD = 0.615). This indicates substantial improvement following course participation.

Based on the relative size of the t -values ($13.792 > 12.637 > 9.121 > 2.394 > 0.824$), the rank order of improvement across the five dimensions was as follows: intelligent resource development competence > intelligent instructional implementation competence > intelligent instructional design competence > intelligent instructional evaluation competence > intelligent collaborative education competence. These results indicate that the course had a strong effect on improving pre-service teachers' practical AI application competence, especially in areas closely related to resource development and instructional implementation.

However, the P -value for intelligent collaborative education competence was 0.411, which exceeded 0.05. This suggests that no statistically significant difference emerged between the pre-course and post-course conditions for this dimension. In other words, the course had a limited impact on improving students' competence in intelligent collaborative education and should therefore strengthen related content in future iterations.

Table 4. t -test analysis of pre- and post-course differences in practical application competence

Dimension	Status	n	Mean (SD)	t	P	Difference
Intelligent instructional design	Post-course (A)	144	3.634 (0.552)	9.121	<0.001***	Post > Pre
	Pre-course (B)	155	2.961 (0.719)			
Intelligent resource development	Post-course (A)	144	3.662 (0.519)	13.792	<0.001***	Post > Pre
	Pre-course (B)	155	2.756 (0.615)			
Intelligent instructional implementation	Post-course (A)	144	3.655 (0.525)	12.637	<0.001***	Post > Pre
	Pre-course (B)	155	2.835 (0.593)			
Intelligent instructional evaluation	Post-course (A)	144	2.991 (0.747)	2.394	0.017*	Post > Pre
	Pre-course (B)	155	2.794 (0.676)			
Intelligent collaborative education	Post-course (A)	144	3.051 (0.795)	0.824	0.411	Post = Pre
	Pre-course (B)	155	2.978 (0.720)			

The visual comparison in **Figure 4** further shows that students' overall practical application competence improved markedly after the course, with the largest gain found in intelligent resource development competence. Although intelligent instructional evaluation competence also increased, its post-course score remained relatively low, indicating that evaluation-related learning was still difficult for students. Similar to

the findings for digital application competence, intelligent collaborative education competence showed little change, suggesting that this component was underemphasized in the course design.

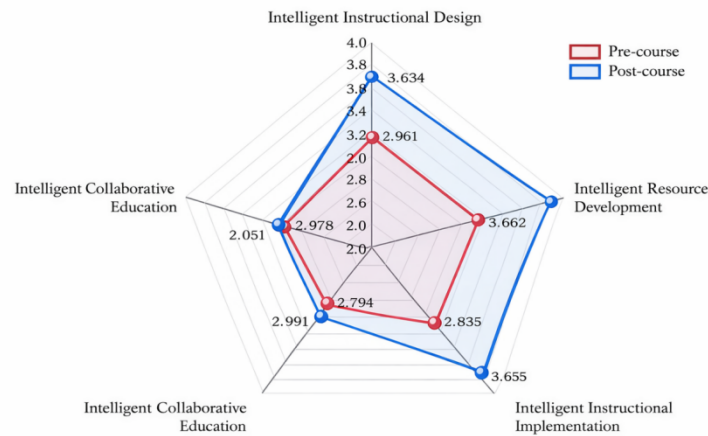


Figure 4. Comparison of improvements in intelligent literacy competence

6. Conclusion

Based on the analyses above, significant differences were found between the pre-course and post-course conditions in both digital application competence and practical AI application competence among humanities-oriented sophomore pre-service teachers. Overall, both domains showed a clear upward trend after course participation.

More specifically, the results indicate that:

- (1) digital instructional design competence and digital instructional implementation competence showed the most substantial improvement;
- (2) intelligent resource development competence, intelligent instructional implementation competence, and intelligent instructional design competence also improved significantly;
- (3) although digital academic assessment competence and intelligent instructional evaluation competence improved to some extent, both remained at relatively low levels overall; and
- (4) digital collaborative education competence and intelligent collaborative education competence did not show statistically significant differences between the pre-course and post-course conditions, suggesting that the course had limited instructional impact in these areas.

Taken together, these findings suggest that the AI general education course AI-Enhanced Instructional Design Innovation and Application was effective in enhancing pre-service teachers' instructional application competence in digital-intelligent literacy, particularly in instructional design, resource development, and instructional implementation.

Disclosure statement

The author declares no conflict of interest.

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