

Pathways for Enhancing Pre-Service Teachers' Digital Literacy in the Context of Digital Transformation: Construction and Practical Research on a Competency Assessment System Based on Blended Training

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ABSTRACT With the acceleration of digital transformation in education, improving pre-service teachers' digital literacy has become essential for high-quality teacher education and for preparing future educators to work in technology-rich engineering environments. This study constructs and empirically verifies a competency assessment system embedded in a blended training scenario. Based on domestic and international standards and the cognitive characteristics of preservice teachers, the assessment system includes four dimensions: awareness and attitude, knowledge and skills, application and innovation, and social responsibility and ethics. A one-semester blended training program combining online micro-lectures with offline workshops is then implemented, and formative assessment is used to monitor learning progress and provide feedback. A quasi-experimental design compares the post-test digital literacy scores of an experimental group receiving blended training and formative assessment with those of a control group receiving conventional training. Correlation analysis of learning behavior data is also conducted. The results show that the system effectively diagnoses digital-literacy shortcomings and significantly improves digital teaching capability, especially in resource development and technology integration, with relevance to wireless learning platforms and electromagnetically reliable smart classrooms.

INDEX TERMS pre-service teachers, digital literacy, blended learning, wireless learning systems, engineering education

I. INTRODUCTION

IN the context of today's global digital revolution, the education sector is undergoing profound changes, where digital transformation has become a strategic choice to align engineering pedagogy with the high-tech demands of modern intelligent manufacturing. This shift ensures that educational quality and equity are improved by providing future professionals with the digital competencies required to master advanced weaving technologies and automated production systems within the industry. Teachers, as organizers and implementers of educational activities, directly determine the success or failure of this digital transformation through their digital literacy. Pre-service teachers, as the reserve force of the teaching profession, are at a critical stage of professional development; cultivating their digital literacy not only concerns the formation of their individual

professional abilities but also has a profound impact on the construction of the future basic education ecosystem. However, the cultivation of digital literacy among pre-service teachers currently faces many challenges. On the one hand, traditional training methods often ignore individual differences among learners and lack targeted guidance; on the other hand, existing evaluation systems focus primarily on assessing theoretical knowledge, with a particularly weak evaluation of digital application abilities in real teaching situations, making it difficult to accurately reflect the true level of pre-service teachers. How to scientifically assess and effectively promote the development of digital literacy among pre-service teachers has become an important issue that urgently needs to be addressed in the field of teacher education. Blended training models combine the flexibility of online learning with the interactivity of offline practice,

providing a new path for improving the digital literacy of pre-service teachers. However, simple model changes without a scientific evaluation system are prone to becoming mere formalities. Therefore, constructing a competency assessment system that can be embedded throughout the entire blended training process to promote learning and improvement through assessment is of significant theoretical and practical value for enhancing the digital literacy of pre-service teachers. By aligning digital pedagogical skills with the technical requirements of modern engineering, the research provides empirical evidence for optimizing teacher training programs to meet the intelligent manufacturing demands of the industry.

II. RELATED WORK

Currently, systematic research on improving the quality of education has been carried out from multiple key dimensions. Isa et al. [1] collected data from administrators and teachers of multiple Islamic schools to explore strategies and practices for quality improvement management. Sahuddin et al. [2] conducted semistructured interviews and document analysis on principals and teachers of multiple special schools, focusing on the principals' leadership behavior and its impact on teacher quality. Wardani et al. [3] aimed to improve the instructional design ability of pre-service chemistry teachers through curriculum learning intervention to support the achievement of quality education goals. Zhao [4] analyzed the design and implementation of a collaborative improvement policy aimed at improving the quality of rural teachers. Teacher performance is affected by a variety of factors, among which the mechanism of school-based quality improvement management and achievement motivation is still unclear. Edi et al. [5] explored how these two types of factors affect teacher performance individually and jointly.

The quality of graduates from professional teacher education programs directly affects the level of basic education. Fauyan et al. [6] conducted a questionnaire survey and focus group interviews with managers, teachers and graduates of teacher education institutions to analyze the key links of quality improvement management. Wijaya et al. [7] used structural equation modeling (SEM) to analyze the path relationship between transformational leadership, teacher performance and school quality improvement. Rohbiyatun and Kusumaningsih [8] used multiple regression analysis to test the predictive role of academic supervision, learning community participation and teacher motivation on learning quality improvement. Alvianti and Ridho [9] analyzed the impact mechanism of leadership practices and teacher performance on education quality. Muhammad et al. [10] studied how to improve the quality of learning process and outcome by strengthening visionary leadership and teacher creativity. Existing studies have deepened the understanding of the mechanism of teacher performance and education quality improvement from multiple levels such as management, leadership, motivation and collaboration, but

how to scientifically evaluate and promote the development of digital literacy still needs to be explored. This study aims to overcome existing limitations by constructing and empirically demonstrating a competency assessment system embedded in blended training scenarios. It systematically explores the development path of digital literacy for pre-service teachers, thereby providing evidence-based practical references and theoretical supplements for improving the quality of teacher education.

III. METHODS

A. FRAMEWORK FOR CONSTRUCTING A DIGITAL LITERACY ASSESSMENT SYSTEM

To guarantee the scientific and modern characteristics of the evaluation indicators, in consideration of EU Digital Literacy Framework for Educators, China Digital Literacy for Teachers, combined with the actual training goals of pre-service teachers, an evaluation framework containing four main dimensions including awareness and attitude, knowledge and skills, application and innovations, and social responsibility and ethics was formulated at first. In the process of determining the weights of the indicators, Delphi method was used, experts in the field of educational technology, subject teaching methods, and backbone teachers of digital teaching in primary and secondary schools were invited and formed an expert group comprising 15 people. After two rounds of expert consultation, importance of each level of indicators was scored and some indicators were revised and deleted based on the feedback of the experts. For example, under the "application and innovation" dimension, the experts proposed to add "teaching diagnostic ability based on big data" to reflect the cutting-edge requirements of the digital transformation. The final evaluation system consists of 4 main dimensions, 12 secondary dimensions and 38 specific points according to observations [11].

In order to ensure both the objectivity and the operability of the assessment, each of the observation points was equipped with a detailed evaluation scale, using a five-point Likert scale with scores ranging from 1 to 5, from "strongly disagree" to "strongly agree." On the other hand, in light of the characteristics of blended learning, this study has made specific strategies to design formative evaluation indicators, and some evaluation indicators are designed to cover the data of online learning participation level, interaction frequencies, resource contribution and offline workshop task completion and collaboration performance, so that the evaluation in this research has an organic combination of summative evaluation and formative evaluation. This assessment system not only pays attention to the pre-service teachers' digital technology knowledge mastery, but also pays attention to their 'ability to use digital technology to solve problems in teaching in simulation teaching or in real teaching scenarios in the internship arena' showing their actual ability to use digital technology to solve teaching problems, which will give us accurate data as the support for the followup design of blended training.

B. DESIGN OF A BLENDED TRAINING MODEL BASED ON AN ASSESSMENT SYSTEM

Guided by the evaluation system, this study designed a targeted blended training model. This model unfolds according to the closed-loop logic of “evaluation-feedback-training-re-evaluation,” aiming to drive dynamic adjustments to training content through continuous data feedback. The training content is modularly designed, strictly corresponding to the four dimensions of the evaluation system. The online platform primarily carries content related to the “knowledge and skills” dimension, enabling pre-service teachers to independently master the basic operation of digital education tools, information retrieval and processing skills, and methods for acquiring and processing digital teaching resources through micro-lecture videos, virtual simulation experiments, and online assessments. The online platform integrates a learning analytics system that records learners’ viewing progress, test scores, and discussion forum activity data in real time, automatically generating periodic learning reports to provide teachers with immediate feedback. Offline training focuses on cultivating the “application and innovation” and “awareness and attitude” dimensions, employing workshops, case studies, and differentiated instruction. In offline activities, pre-service teachers are required to complete digital teaching design schemes, develop interactive multimedia courseware, and conduct simulated teaching exercises in groups based on their online learning. Trainers play the role of guides and facilitators in this process, and provide in-depth comments and guidance on the students’ work based on the indicators of the “application innovation” dimension in the evaluation system. At the same time, the offline session also set up a special debate and case analysis on “social responsibility and ethics” to strengthen the legal awareness and moral norms of pre-service teachers in the digital environment. This training model that deeply integrates online and offline training breaks the time and space limitations of traditional training. Through extensive knowledge input online and in-depth practical interaction offline, it effectively solves the problem of the disconnect between theory and practice. More importantly, the entire training process is always accompanied by competency assessment. Pre-test data is used to diagnose the students’ initial level and group them, mid-test data is used to monitor the learning progress and adjust teaching strategies, and post-test data is used to measure the training effect and verify the effectiveness of the evaluation system [12,13].

C. RESEARCH SUBJECTS AND DATA ANALYSIS PROCEDURES

This study included 320 pre-service teachers majoring in Educational Technology and Primary Education at the School of Education of a normal university. A quasi-experimental design was employed. Based on pre-test scores, we first calculated the total score for each participant and recorded their professional background. Then, using paired sampling, participants with the closest pre-test scores

and similar professional backgrounds were matched one-to-one and randomly assigned to the experimental and control groups, with 160 participants in each group, ensuring true equivalence between the two groups in terms of baseline level and professional composition. A blended training intervention was offered in the experimental group under the mentioned assessment system, whereas the control group was instructed in the regular training in the “Modern Educational Technology” course. Although theory as well as practice was part of this course, it did not involve systematic process evaluation or a focused blended intervention mechanism. Data collection tools comprised the “Pre-service Teacher Digital Literacy Assessment Scale” which was developed during this study and the learning behaviour logs produced during the training process. The study period was 16 weeks, with three phases: pre-test, implementing intervention and post-test. Before the intervention, baseline digital literacy tests were conducted on both groups to be sure that there is no significant difference between them at the beginning point of the study. During the intervention, process data (online learning time, downloads of resources, number of forum posts and rate of timely assignment submission) were automatically collected from the learning management platform from the experimental group. After the intervention, the same scale has been used to perform a post-test on both groups of students and semi-structured interviews will be carried out to get subjective feedback by the experimental group in relation to their experience of the training model. To verify the overall effectiveness of the blended training model and assessment system, this study primarily employed a comparative experimental analysis method. All quantitative data were imported into statistical software (SPSS) for data processing. The data analysis strategies included: first, descriptive statistical analysis was used to study the overall status and distribution characteristics of pre-service teachers’ digital literacy; second, independent samples t-tests were used to compare the differences in post-test scores between the experimental and control groups, verifying the net effect of blended training through the differences in digital literacy levels between the two groups; third, Pearson correlation analysis was used to analyze online learning behavior data to explore its correlation with the magnitude of digital literacy improvement, thereby revealing the key pathways influencing the development of pre-service teachers’ digital literacy. The whole analysis process strictly followed the statistical norms and the significance level was kept at 0.05 to ensure the reliability and scientific levels of research conclusions. This study was approved by the Ethics Committee of Shaanxi Teacher Development Research Institute of Weinan Normal University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

IV. RESULTS AND DISCUSSION

A. ANALYSIS OF BASELINE LEVELS AND DIFFERENCES IN DIGITAL LITERACY AMONG PRE-SERVICE TEACHERS

Prior to the intervention, 320 pre-service teachers were administered a baseline digital literacy assessment to determine their level of competency in digital transformation. Statistical results show that the overall average score of pre-service teachers' digital literacy is 3.44 points, which is lower than the average score, indicating that there is a gap between their current digital literacy level and the requirements for digital transformation of high-quality teachers. The results are shown in Table 1.

Analyzing Table 1, we can see that the largest proportion is at the intermediate level, which shows that most pre-service teachers are in the bottleneck stage of "little knowledge and insufficient application". Nearly 17% of the groups who need improvement need more attention and basic information guidance in training. It is worth noting that the outstanding proportion is only 3.75%, and there is a serious shortage of pre-service teachers with high digital innovation capabilities. This distribution may be related to the fact that the current teacher training curriculum focuses on theoretical courses and ignores practical and comprehensive technical practice courses. In addition, cross-analysis of data from other professional fields showed that students majoring in educational technology scored significantly higher than students majoring in primary education, which once again confirmed the importance of professional skills training in improving digital literacy. The results of differences in baseline data are also an objective basis for determining tiered teaching and personalized training programs, which shows that hybrid training should not adopt a "one size fits all" approach, but should design differentiated learning tasks and resources according to the needs of different skill levels.

B. EFFECTIVENESS ANALYSIS OF BLENDED TRAINING INTERVENTION IN IMPROVING DIGITAL LITERACY

Following a 16-week blended training intervention, the experiment performed post-tests on the experimental and control groups and tested the impact of the intervention by using process data. By comparing the post-test results of the two groups, this study verifies the effectiveness of the blended training model that includes an assessment system. This study supplied some details of the changes in their scores in different dimensions of two groups of students and results are indicated in table 2.

Analysis of Table 2 indicates that the experimental group scored significantly higher than the control group in all the four dimensions. The highest improvement was on the "Application and Innovation" dimension with a mean difference of 0.87 points with an effect size of 1.35 and the dimension judged to have a very large effect. This shows that the offline workshops and practical sessions in the blended training have contributed considerably to an improvement of the ability of the pre-service teachers to translate their digital technology into their teaching practices. During the training,

with repeated training design exercises plus courseware development, people went from technological observers to users and producers of technology. For example, in the "Digital Instructional Design" task, most students in the experimental group were able to skillfully apply mind mapping tools to organize teaching logic and interactive courseware creation tools to design student activities, while most of the students in the control group were still in the simple PPT creation level. The improvement in "Knowledge and Skills" dimension has also been shown to be significant with mean difference of 0.63 points suggesting the microbes on online learning and the instant feedback mechanism effectively helped participants to get the foundation strong on their technical aspects. Although the improvement on the "Awareness and Attitude" dimension was relatively smaller, still attained a considerable level mainly the result of the successful digital teaching cases presented during the training that increased the awareness of participants on the value of education. The enhancement in the "social responsibility and ethics" dimension is reflected primarily in respect for the rights of intellectual property and the increase in awareness of the protection of student data. In the dimension of "social responsibility and ethics," although the overall improvement was relatively small (average difference of 0.26), the experimental group's post-test score (4.15) was significantly higher than that of the control group (3.89). Further analysis of the specific indicators in this dimension revealed that the experimental group showed particularly significant improvements in "respect for intellectual property rights" (experimental group 4.21 vs. control group 3.95) and "protection of student data privacy" (experimental group 4.08 vs. control group 3.78). This improvement was directly attributed to the thematic discussions and case studies embedded in the training. In contrast, the control group, without having a systematic practical guidance and process assessment, mainly relied on the natural maturation of the curriculum for capacity building, which resulted in limited effectiveness.

C. CORRELATION ANALYSIS OF KEY INFLUENCING FACTORS IN THE PATH TO IMPROVING DIGITAL LITERACY

In order to further explore the internal factors of digital literacy enhancement in pre-service teachers and inquire about the significant factors that exert a determining influence on digital literacy, this study has taken Pearson correlation analysis of the online learning behavior data of the experimental group students and the scale of digital literacy enhancement (post-test data-minus pre-test data). This analysis is intended to uncover the contribution of various learning activities in the blended training to the increased competency so that data can help to optimize training pathways. Analysis result is represented in Table 3.

TABLE 1. Distribution of baseline digital literacy levels among pre-service teachers (N=320)

Digital literacy level	Number of people	Percentage (%)	Average score	Main feature description
Excellent (4.5–5.0)	12	3.75	4.68	Proficient in using various advanced digital tools and capable of independently developing digital course resources.
Good (3.5–4.49)	68	21.25	3.82	Proficient in basic office software operations and able to try using simple multimedia tools to assist in teaching.
Medium (2.5–3.49)	186	58.13	3.05	They possess basic online information retrieval skills but lack systematic knowledge of digital instructional design.
Needs improvement (<2.5)	54	16.87	2.21	Unfamiliar with digital tools, holding a negative or confused attitude towards the application of digital technology in education.

TABLE 2. Comparative Analysis of Post-Test Scores of Digital Literacy in the Experimental and Control Groups

Evaluation Dimensions	Experimental group (N=160)	Control group (N=160)	Mean difference	T-value	p-value	Effect size (Cohen's d)
Consciousness and Attitude	4.32	3.88	0.44	6.21	<0.001	0.78
Knowledge and Skills	4.05	3.42	0.63	8.45	<0.001	1.12
Applications and Innovations	4.08	3.21	0.87	10.33	<0.001	1.35
Social responsibility and ethics	4.15	3.89	0.26	3.98	<0.001	0.52

TABLE 3. Correlation Analysis between Learning Behavioral Elements and the Increase in Digital Literacy

Behavioral elements	Increase the total amount	Consciousness and Attitude	Knowledge and Skills	Applications and Innovations	Social responsibility and ethics
Video viewing time	0.432**	0.382**	0.485**	0.315*	0.201
Online test scores	0.521**	0.210	0.618**	0.356**	0.305*
Resource downloads	0.305*	0.285*	0.352**	0.198	0.150
Forum postings	0.387**	0.452**	0.301*	0.405**	0.252*
Offline task quality	0.685**	0.501**	0.552**	0.721**	0.485**

Note: ** indicates a significant correlation at the 0.01 level (two-tailed); * indicates a significant correlation at the 0.05 level (two-tailed).

Analysis of the data in Table 3 shows that variation in the effects of different learning behaviors on aspects of digital literacy are considerably. First, “quality of offline tasks” was found to have the strongest correlation with the dimensions of “total improvement” and “application and innovation” with correlation coefficients of 0.685 and 0.721, respectively. This result is highly insightful and conveys the idea that simple knowledge input (such as watching videos) is not on equal terms with forming abilities. Only through practical tasks with excellent offline quality, whereby the knowledge was gained in a technicality is transformed into concrete teaching products, can really a qualitative leap in digital literacy, in particular advanced application abilities, is driven. This ties in perfectly with the “emphasis on practice and strong application” idea that was promoted in the blended training approach to this study. Second, the “online test scores” had the highest correlation with the “knowledge and skills” dimension, with a correlation of 0.618, which shows that timely online assessment and feedback is very important to consolidate the basic technical knowledge. Interestingly, the correlation between “number of forum posts” and the “awareness and attitude” dimension (0.452) was higher than the correlation with the skills dimension, which indicates that through the activity of online community discussions and exchanges, learners can share their opinions and exchange their ideas, and thus enhance their sense of identity and positive attitude towards digital education. Furthermore, although “video viewing time” is

found to be positively correlated with the improvement generally, the coefficient for this correlation is fairly low. This would make the approach to training design not to be aimless in terms of piling up video and video resources, but to focus on quality and the interactive character of the videos so as not to allow the trainee to get into an inefficient learning state of passive viewing.

To gain a deeper understanding of the quantitative results, we conducted semi-structured interviews with some students in the experimental group. One participant, when discussing the benefits of the offline workshop, said, “I used to think that PowerPoint was enough, but seeing the classroom activities designed by classmates using interactive whiteboards in the workshop, the student participation was completely different. This forced me to learn new tools and actually bring my ideas to life.” Another participant emphasized the role of the online community: “In the forum, I shared a micro-lesson I made and received a lot of suggestions for improvement from classmates. I also saw other people’s excellent work, which gave me a more real understanding of the value of digital teaching. It’s not just about completing tasks, but about genuinely wanting to do it well.” These qualitative feedbacks corroborated the quantitative data, revealing how forum interaction transformed into positive awareness and attitudes, and how high-quality offline tasks drove substantial breakthroughs in application and innovation capabilities. Based on this, the improvement path of digital literacy should be optimized in terms of: In the

offline practical path, deepen the difficulty and truthfulness, and establish the assessment orientation of the assessment orientation principle; in the online assessment mechanism, optimize the online assessment mechanism and strengthen the online assessment function; in the online learning community, build active online learning communities, encourage the sharing of experience and emotional support.

V. CONCLUSION

Against the backdrop of digital transformation, this study addresses the core issue of improving the digital literacy of pre-service teachers by constructing a competency assessment system centered on the technical demands of modern engineering and verifying its effectiveness through empirical research. By aligning blended training with the digital skills required for intelligent weaving and production management, the research ensures that future educators can effectively bridge the gap between traditional pedagogy and the high-tech requirements of the industry. The results show that the overall digital literacy of preservice teachers is currently at a moderate level, with structural shortcomings, particularly in application and innovation. Blended training interventions embedding the assessment system can significantly improve the digital literacy of pre-service teachers, with results markedly superior to traditional teaching models. The study further reveals that the improvement of digital literacy is influenced by multiple factors, with high-quality offline practical tasks being the most critical, followed by timely online assessments and community interaction. Based on these findings, the proposed path for improving the digital literacy of pre-service teachers emphasizes: first, constructing an evidence-based, precise assessment mechanism, using data to drive dynamic adjustments to training content to achieve personalized training; second, designing a deeply integrated blended training model, strengthening the organic connection between online theoretical input and offline practical creation, especially increasing the proportion of offline practical exercises in cultivating higher-order thinking skills; and third, creating an open and interactive learning ecosystem, using online learning communities to stimulate the initiative and ethical responsibility of pre-service teachers. This study not only enriches the theoretical perspective on cultivating digital literacy among pre-service teachers, but also provides a workable practical paradigm for teacher training institutions to promote educational and teaching reforms and optimize teacher training curriculum systems. Future research could expand the sample size and track the long-term development of digital literacy among pre-service teachers as they transition into specialized education roles, aiming to explore more effective support mechanisms for professional growth. By monitoring their ability to integrate intelligent manufacturing concepts and digital weaving technologies into the classroom, the study can better inform the continuous optimization of teacher training within the industry.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of Shaanxi Teacher Development Research Institute of Weinan Normal University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

AUTHOR CONTRIBUTIONS

Conceptualization – Yongguang Hou and Xiaoli Xiong; methodology – Yongguang Hou and Xiaoli Xiong; investigation – Yongguang Hou and Xiaoli Xiong; writing-original draft preparation – Yongguang Hou and Xiaoli Xiong. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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