

The Construction of a Theoretical Model and Practical Pathways for Cultivating Digital Literacy in Pre-Service Teachers

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Abstract

Educational digitalization has become a major global trend in educational transformation. Cultivating pre-service teachers' digital literacy is not only a core issue in teacher professional development but also an urgent demand for advancing educational digitalization. This study employs a systematic literature review to clarify the practical challenges in developing pre-service teachers' digital literacy. By integrating the TOE (Technology-Organization-Environment) framework and the TAM (Technology Acceptance Model), it proposes a dynamic closed-loop model of pre-service teachers' digital literacy cultivation, structured as "external support – internal transformation – literacy generation". Using the "Future Teacher Digital Literacy Enhancement Project in the Three Northeastern Provinces and One Region of China" as a case, the study demonstrates a systematic path, comprising "standard formulation – intelligent environment construction – curriculum reconstruction – practical empowerment". That provides replicable strategies for addressing the challenges in cultivating pre-service teachers' digital literacy. The findings offer both a novel theoretical perspective for research on teacher digital literacy and a scalable practical paradigm for the digital transformation of teacher education.

Keywords: digital literacy, pre-service teacher, Technology Acceptance Model (TAM), Technology-Organization-Environment (TOE) framework.

Разработка теоретической модели и практических механизмов формирования цифровой грамотности у будущих учителей

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Аннотация

Цифровизация образования стала основной тенденцией в глобальном реформировании образования. Развитие цифровой грамотности будущих учителей является ключевым вопросом профессионального развития педагогов, насущной потребностью для цифровой трансформации образования. В настоящем исследовании использован систематический обзор литературы для выявления практических проблем, возникающих при подготовке будущих учителей.

лей к цифровому образованию. В процессе интеграции двух теоретических моделей – TOE (Technology-Organization-Environment – Технология-Организация-Среда) и TAM (Technology Acceptance Model – Модель принятия технологии) – предлагается динамическая замкнутая модель формирования цифровой грамотности будущих учителей по принципу «внешняя поддержка – внутренняя трансформация – генерация компетенций». На примере проекта «Повышение цифровой грамотности будущих учителей», реализуемого в трёх северо-восточных провинциях Китая и одном муниципалитете, показан системный путь «разработка стандартов – создание интеллектуальной среды – перестройка учебной программы – практическое расширение возможностей», представляющий воспроизводимый опыт решения проблем формирования цифровой грамотности будущих учителей. Результаты исследования открывают новые перспективы для изучения цифровой грамотности педагогов и предлагают масштабируемую практическую модель цифровой трансформации педагогического образования. **Ключевые слова:** цифровая грамотность, будущие учителя, модель принятия технологии (TAM), модель «Технология-Организация-Среда» (TOE).

Introduction

The rapid advancement of digital technologies, such as generative artificial intelligence and virtual reality is propelling a paradigm shift in education from the mere application of technological tools to the establishment of a comprehensive digital education ecosystem. This transformation not only necessitates innovation in teaching content and pedagogy but also presents systematic challenges to teachers' digital literacy. Recognizing the pivotal role of teachers in this transformation, countries around the world have increasingly prioritized the development of teachers' digital literacy by formulating and implementing digital competence standards and frameworks to guide teachers' professional growth. For instance, the European Framework for the Digital Competence of Educators: DigCompEdu, published by the European Union, which defines operational dimensions of digital literacy and advanced development paths for teachers at all educational levels (European Commission's Joint Research Centre, 2017; Redecker, 2017). Adding further impetus, UNESCO's ICT Competency Framework for Teachers (ICT-CFT) aligns teachers' professional capabilities with national digital education objectives, outlining a developmental spectrum advancing from knowledge acquisition to knowledge creation (UNESCO, 2022). Likewise, the ISTE Standards: For Educators from the International Society for Technology in Education emphasize from the perspective of seven roles that teachers in technological environments are not only technology users but also learning innovators and leaders (ISTE, 2017). In 2023, China formally enacted the national standard Teacher Digital Literacy, establishing an authoritative benchmark for the development and assessment of Chinese teachers' digital literacy (Letter of Ministry of Education of the People's Republic of China, 2022).

As the main force of future educators, pre-service teachers represent a critical window for the cultivation of teachers' digital literacy. However, survey results indicate that the overall level of digital literacy among pre-service teachers remains relatively low, and the process of its development faces a series of practical challenges (Nurzhanova et al., 2024; Polat, 2021). A systematic research framework on the cultivation models of pre-service teachers' digital literacy has yet to be established, calling for in-depth exploration to provide theoretical references and practical paradigms for both digital literacy research and the digital transformation of teacher education.

Therefore, this study aims to address the following research questions:

RQ1: What multifaceted practical challenges currently hinder the cultivation of digital literacy among pre-service teachers?

RQ2: How can a theoretical model for pre-service teachers' digital literacy development be constructed to integrate external conditions and internal motivation?

RQ3: How does this theoretical model effectively promote the enhancement of pre-service teachers' digital literacy in practice, and what are its implementation pathways?

Literature Review

Digital Literacy

Digital literacy has emerged as a key twenty-first-century literacy alongside the growing infusion of information and communication technologies (ICT) into education. It represents both an extension and a deepening of earlier concepts such as information literacy and media literacy. As early as the 1990s, digital literacy was defined as “the ability to understand and use a computer to access and process a range of information” (Gilster, 1997). Later, the connotation of digital literacy was further developed and a five-element conceptual framework of “image-image literacy”, “re-creation literacy”, “branch literacy”, “information literacy” and “social-emotional literacy” was proposed (Eshet-Alkalai, 2004). As the digital transformation of education continues to deepen, the conception of digital literacy has shifted from an initial emphasis on the application of digital technology toward a more integrated framework that encompasses technological integration, critical thinking, and ethical awareness (Mishra et al., 2017). For instance, the European Union’s Key Competences for Lifelong Learning: A European Reference Framework defines digital literacy as the “confident, critical and responsible use of digital technologies for learning, at work, and for participation in society”, including information and data literacy, communication and collaboration, digital content creation, safety and security, intellectual property-related issues, problem-solving and critical thinking (European Union, 2007). The New Media Consortium (NMC) (2017) similarly maintains that digital literacy includes not only technical skills such as producing digital content, using digital media, and applying digital tools, but also socio-cultural elements like critical thinking, a sense of responsibility, and social skills.

Pre-service Teacher Digital Literacy

Teacher Digital Literacy represents a domain-specific extension of digital literacy. In 2007, Krumsivik proposed that teachers’ digital literacy refers to their proficiency in using ICT in a professional context, having good teaching judgment, and being aware of its impact on teaching strategies and the implementation of digital education, and also proposed a teacher digital literacy model consisting of four parts: basic ICT skills, ICT teaching ability, learning strategies, and digital education (Krumsivik, 2008). In 2014, the DigiLit Leicester project was carried out by the Library and Learning Services Directorate at De Montfort University, posited that to be digitally literate, educators must leverage technology to enhance and transform classroom practice while simultaneously enriching their own professional growth and professional identity (Hall et al., 2014). Furthermore, digitally literate educators are able to critically evaluate why, how, and when technology can effectively complement learning and teaching (Hall et al., 2014). In 2017, the European Union released the DigCompEdu, which structures teacher digital competence across three dimensions: professional competence, pedagogical competence, and learner competence. The framework comprises six competence areas – Professional Engagement, Digital Resources, Teaching and Learning, Assessment, Empowering Learners, and Facilitating Learners’ Digital Competence – further broken down into 22 specific competencies (European Commission’s Joint Research Centre, 2017; Redecker, 2017). The Norwegian Centre for ICT in Education contends that, to be effective in cultivating learners’ digital literacy, future teachers must embed professional digital literacy as a core component of teacher professional development (Kelentrić et al., 2017). China’s Teacher Digital Literacy framework defines the construct as “the awareness, competence, and responsibility with which teachers appropriately deploy digital technologies to access, process, utilize, manage, and evaluate digital information and resources, to identify, analyze, and solve educational problems, and to optimize, innovate, and transform

teaching and learning activities”. The framework further partitions teacher digital literacy into five dimensions: (1) digital awareness, (2) knowledge and skills of digital technologies, (3) digital application, (4) digital social responsibility, and (5) professional development (Letter of Ministry of Education of the People’s Republic of China, 2022).

Pre-service teacher digital literacy is the expansion and extension of teacher digital literacy in the stage of teacher education. Based on digital literacy, it highlights the teaching context, teaching practice and teacher development of pre-service teacher education. Pre-service teacher digital literacy refers to the awareness, competence and responsibility that should be possessed in response to future educational demands by using digital technology tools to acquire, process, manage and evaluate digital information and resources, discover, analyze and solve personal learning problems, and optimize, innovate and transform educational and teaching activities.

Methodology

This study adopts literature review and case study method to explore the related issues of the cultivation of pre-service teacher digital literacy.

With the keywords “digital literacy”, “digital competence”, “teacher digital literacy”, and “pre-service teacher digital literacy”, a systematic search was conducted across Web of Science, Scopus, ProQuest, Springer, and CNKI. After excluding irrelevant content, the relevant journal articles, academic books and authoritative research reports were ultimately retained.

The literature review was adopted to sort out and analyze the relevant literature, and clarify the practical challenges faced by the cultivation of pre-service teacher digital literacy. Based on practical challenges, a theoretical model for cultivating pre-service teacher digital literacy that integrates external condition support and internal psychological factors was constructed.

The case study method was adopted to analyze typical cases. This study selected the case of the “Future Teacher Digital Literacy Enhancement Project in the Three Northeastern Provinces and One Region of China” implemented by the Faculty of Education of Liaoning Normal University. The goals and contents of this case are highly consistent with this study. Through in-depth exploration of this case, the practical pathways for cultivating pre-service teacher digital literacy guided by the theoretical model were proposed.

Results

The Practical Dilemmas of Pre-service Teacher Digital Literacy Cultivation

Policy implementation erosion: the gap between national plans and local practice

In recent years, the Chinese government has continuously strengthened policy support for the cultivation of teachers’ digital literacy, issuing a series of strategic documents such as the Education Informatization 2.0 Action Plan (Letter of Ministry of Education of the People’s Republic of China, 2018), and The 2024-2035 master plan on building China into a leading country in education (The State Council of the People’s Republic of China, 2025). These policies elevate teachers’ digital literacy to a strategic level and emphasize the construction of a corresponding standards system. However, a significant implementation gap exists between national policies and local teacher training institutions, resulting in digital literacy standards becoming largely “symbolic documents”. In February 2023, the Ministry of China released the Standard for Teachers’ Digital Literacy, yet a “weak coupling” is observed between this national standard and the actual training programs in local institutions. Most universities still rely primarily on traditional courses such as Modern Educational Technology and Computer Basics to develop pre-service teachers’ digital literacy, failing to establish a curriculum that deeply integrates digital teaching with

subject-specific pedagogy. Moreover, key dimensions like digital literacy are not included in the national teacher qualification examination. This structural misalignment between certification requirements and competency expectations undermines the motivation for reform in teacher training institutions, reducing digital literacy to a form of “symbolic compliance” rather than a core component of professional development.

Curriculum architecture lags behind: knowledge iteration stalls and practical transfer fractures

Although several normal universities have begun offering digital literacy courses, the curriculum content remains largely fragmented. Most institutions only provide stand-alone information technology courses, which lack deep integration with core pedagogical and subject-specific teaching methodologies. This results in a significant disconnect between theoretical knowledge and practical application (Tondeur et al., 2012). Empirical evidence consistently indicates that, although pre-service teachers generally possess rudimentary technical proficiency, they struggle to translate digital tools into effective instructional practices, thereby manifesting a widely documented “can use technology, but cannot teach with technology” dilemma (Tondeur et al., 2012). Moreover, the iteration speed of course content lags significantly behind technological advancements. Currently, most courses still focus on low-order skill training such as Office software and basic programming, with a relatively low proportion dedicated to cutting-edge topics like generative AI in teaching, educational big data analysis, and AI ethics in education (Dolezal et al., 2025). The relevant survey also shows that the curriculum system places too much emphasis on skill training, lacks interdisciplinary integration and a practical orientation, and is unable to effectively support pre-service teachers in achieving knowledge transformation in the digital and intelligent teaching environment. Therefore, how to establish a curriculum system that keeps pace with technological development and emphasizes the integration of knowledge and practice has become a key challenge in the cultivation of pre-service teachers’ digital literacy.

Digital and intelligent teaching environment suspended: the “efficiency paradox” of technological investment and teaching transformation

The cultivation of digital literacy cannot be achieved without the support of digitalized teaching environments. In recent years, higher normal universities have invested a large number of resources in the renovation of hardware facilities and the upgrade of software. However, in reality, the phenomenon of “emphasizing construction but neglecting application” still prevails. On one hand, outdated equipment and inadequate network infrastructure in some institutions fail to meet the demands of digital teaching (Zhao et al., 2021). On the other hand, even though some universities have established smart classrooms and virtual simulation laboratories, there is a significant mismatch between the hardware construction and the teaching practice requirements. The integration of teaching design, implementation and reflection throughout the entire process has not been achieved. A survey shows that the utilization rate of smart classrooms is about 50% of teacher training institutions is relatively low, and some equipment remains idle for a long time, mostly used for display-based teaching rather than for regular and exploratory applications. This results in the technology remaining at the “tool level”, making it difficult to promote the reconstruction of the teaching ecosystem.

Digital resource allocation is unbalanced: large supply, insufficient adaptability

Due to factors such as the COVID-19 pandemic, the scale of digital resource in teacher education institutions has continued to expand. However, it presents the characteristic

of “quantitative growth without qualitative advancement”. Further analysis reveals that basic tool-based resources (such as PPT creation and micro-lecture design) account for a relatively high proportion of existing resources, while integrated case resources truly serving subject teaching constitute less than 15%, resulting in a significant misalignment between resources and training objectives. Pre-service teachers generally rely on generic resources but lack discipline-specific digital case studies and instructional design training, leading to “strong technical operational skills but insufficient disciplinary integration capabilities” (Tondeur et al., 2012). Moreover, normal university curricula tend to emphasize theoretical instruction while neglecting the development of digital resource design and development capabilities, resulting in pre-service teachers relying on ready-made resources rather than engaging in independent innovation. This makes it difficult to effectively support pre-service teachers in implementing integrated digital instructional design in real teaching scenarios, which has become a bottleneck constraining the development of digital literacy.

Developing a Theoretical Model for Pre-service Teacher Digital Literacy Cultivation

Logic of theoretical model development

Teacher digital literacy exhibits characteristics such as complexity, contextuality and dynamic generativity. Its formation and development do not occur overnight. It requires not only external conditions but also the stimulation of the intrinsic subjective initiative of pre-service teachers. Based on the above analysis of the current situation and in accordance with the Technology-Organization-Environment (TOE) framework and the Technology Acceptance Model (TAM), this study has constructed a theoretical model for the cultivation of pre-service teachers’ digital literacy (Figure 1). The model takes the three elements of technology (resource assurance), organization (university governance mechanisms), and environment (national policy) in the TOE theory as external support conditions, and combines the TAM theory as the internal driving factors for analyzing the development of digital literacy of pre-service teachers. This process forms a closed-loop pathway of “external support – internal transformation – literacy emergence” ultimately fostering the development of pre-service teacher digital literacy.

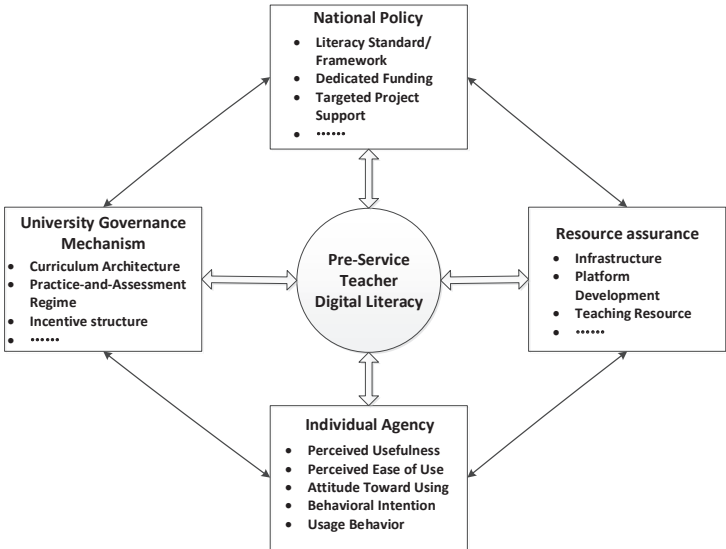


Figure 1. Theoretical model for cultivating pre-service teacher digital literacy

Explanation of the theoretical model

National policy support provides the institutional guarantee for cultivating pre-service teacher digital literacy.

The national policies primarily encompass elements such as external systems, policies and regulations, market norms, and industry standards. These influence organizational decisions and individual behaviors by establishing normative objectives, optimizing resource allocation mechanisms, and providing external incentives. In the context of cultivating pre-service teacher digital literacy, the supportive function of national policy is mainly manifested at two levels:

First, by establishing digital literacy frameworks or competency standards at the national or regional level, clear guidelines are provided to normal universities for curriculum development, training objective formulation, and outcome evaluation. For instance, the European Union released the “Educators’ Digital Competence Framework (DigCompEdu)” in 2017, which divides teachers’ digital literacy into 6 competency domains and 22 competencies, and developed corresponding online self-assessment tools (European Commission’s Joint Research Centre, 2017; Redecker, 2017). The framework has been widely utilized across EU member states and regions for developing localized competency frameworks and designing training programs. The U.S. federal government periodically updates the National Educational Technology Plan (NETP), providing systemic vision and implementation roadmaps for the digital transformation of education across states and schools. This creates synergistic effects with the Educator Standards released by ISTE, jointly guiding teacher professional development and curriculum reform practices. In 2023, China’s Ministry of Education issued the Digital Literacy for Teachers framework, establishing a basis for setting training objectives, optimizing curriculum structures, and evaluating pre-service teachers’ digital literacy.

Second, the state creates strong institutional incentives through special funding and project support, driving higher education institutions to integrate digital literacy cultivation into their talent development objectives and ensuring sustained implementation. For instance, the European Union’s Digital Education Action Plan 2021–2027 advances 14 actions to foster a high-quality digital education ecosystem, obliging member states to devise national strategies and intensify teacher digital literacy training (European Commission, 2020a). Through the Erasmus+ Teacher Academies project, dedicated funds are provided to support the development of teachers’ digital literacy (European Commission, 2020b). Through policies such as the Initial Teacher Training and Early Career Framework (ITTECF) and the EdTech strategy, the UK integrates the requirement for “technology integration in teaching” into pre-service teacher training and school curriculum reform, while also providing supporting platforms and tools (GOV.UK, 2024). Meanwhile, the EdTech Demonstrator Programme provides grants ranging from £75,000 to £150,000 to support innovative technology applications in demonstration schools, including the cultivation of pre-service teacher digital literacy (GOV.UK, 2019).

University governance mechanisms provide a practical environment for cultivating pre-service teacher digital literacy.

The university governance mechanism, as the practical field for cultivating pre-service teachers’ digital literacy, derives its core value from constructing a normative and developmental training space through the collaborative coupling of multidimensional mechanisms. This field is not merely a physical aggregation but an organizational ecosystem formed by the interaction of curriculum systems, practical training, evaluation, and incentive mechanisms, providing systematic support for the formation and development of pre-service teachers’ digital literacy. First, the curriculum system serves

as the foundational cornerstone for cultivating pre-service digital literacy. A three-tier curriculum structure – comprising digital technology literacy courses, subject-specific teaching integration courses, and innovative practical application courses – constructed on the underlying logic of the TPACK theory, breaks through the linear model of traditional knowledge transmission and forms a dynamic learning system rooted in authentic teaching scenarios. Second, practice and assessment serve as the core regulatory mechanisms, forming a dynamic feedback system for developing pre-service teacher digital literacy. On one hand, by establishing smart and immersive practice environments, pre-service teachers are provided with low-risk opportunities for technological experimentation, enabling them to gradually overcome technology-related anxiety and build confidence in using digital tools. On the other hand, digital literacy is broken down into observable behavioral sequences, and scaffolded progressive tasks are designed to align closely with its core dimensions. Through multiple assessment methods – including diagnostic, formative, summative, and value-added evaluation – an iterative cycle of “practice-feedback-refinement” is established. This promotes the progression of pre-service teacher digital literacy from cognition to application, and ultimately to innovation. Finally, incentive mechanisms provide ongoing impetus for the cultivation of pre-service teacher digital literacy. By linking digital literacy performance to tangible benefits such as scholarship awards and internship assessments, an institutionalized incentive structure is created that effectively motivates pre-service teachers to internalize the development of digital capabilities as an intrinsic need for learning and practice.

Resource assurance is the practical foundation for cultivating pre-service teacher digital literacy.

Resource assurance includes resource availability, subject adaptability and technological accessibility. It is the material foundation and implementation prerequisite for cultivating pre-service teacher digital literacy. Resource availability refers to the fact that infrastructure and platform construction should take into account both availability and friendliness, and be deeply integrated with teaching scenarios. For instance, smart classrooms and virtual simulation platforms should lower the threshold for users by optimizing interaction logic and simplifying operation processes, thereby enhancing pre-service teachers’ acceptance of technology and their willingness to continue using it, and providing hardware support for cultivating pre-service teacher digital literacy. Subject adaptability is the key to achieving effective teaching transformation, which means that teaching resources should be matched with the subject content. For instance, dynamic geometry systems can be provided for pre-service mathematics teachers to cultivate their spatial imagination and the ability to combine numbers and shapes in teaching. Resource development and design should break through simple tool operations and apply tools around classroom teaching scenarios to achieve a deep integration of technology and teaching methods. Technological accessibility refers to the establishment of a technical support service system to ensure the continuous availability of resources. By equipping full-time technical mentors and providing precise one-on-one guidance and services, the perceived usefulness and ease of use of digital tools by pre-service teachers can be enhanced, promoting the transformation of their digital literacy from cognitive recognition to teaching practice.

Individual agency is the inherent driving force for the development of pre-service teachers’ digital literacy.

Individual agency serves as the inherent motivator in the development of pre-service teacher digital literacy, determining whether they can translate policy support and external

resources into practical application. Compared to other factors, individual agency directly influences pre-service teachers' attitudes and behaviors toward technology use. The depth and breadth of their digital literacy development depend on their internal identification with and developmental need for digital technologies. When pre-service teachers perceive digital literacy as a core element of professional competence, they actively explore and experiment with new technologies; when encountering technical challenges, they seek solutions independently rather than avoiding or relying on others. This intrinsic motivation forms a self-reinforcing cycle of "need-exploration-acquisition". Moreover, the essence of digital literacy lies in the innovative integration of technology into teaching rather than the mechanical application of technical tools. Pre-service teachers with strong individual agency actively transform acquired technical knowledge into teaching practice, integrating digital tools with subject-specific instruction. For instance, they may use data visualization tools to analyze student learning conditions. This process involves a shift from "knowing how to use tools" to "knowing how to create learning contexts", from "imitating examples" to "restructuring pedagogical patterns", ultimately forming a personalized digital teaching approach.

Practical Approaches to Cultivating Pre-service Teacher Digital Literacy

Based on the theoretical model for cultivating digital literacy among pre-service teachers, this study takes the "Future Teacher Digital Literacy Enhancement Project in the Three Northeastern Provinces and One Region of China" as a case to elucidate the practical pathways employed by the program to foster digital literacy in pre-service teachers. The program, led by the Faculty of Education at Liaoning Normal University and collaboratively implemented by 13 universities from Liaoning, Jilin, Heilongjiang, and the Inner Mongolia Autonomous Region in June 2023, is funded by the Tin Ka Ping Foundation. It primarily focuses on the following aspects to cultivate digital literacy among pre-service teachers.

Developing a pre-service teacher digital literacy framework to articulate clear educational objectives

Guided by China's "Teacher Digital Literacy" industry standard, the program constructed a digital literacy framework for pre-service teachers through content analysis of authoritative domestic and international frameworks and standards, consideration of the differences in career development stages and professional growth needs between pre-service and in-service teachers, as well as expert interviews and questionnaire surveys. The framework comprises six first-level dimensions – digital awareness, digital technology knowledge and skills, digital learning, digital teaching, information social responsibility, and professional development – along with 18 second-level dimensions, thereby clarifying the training objectives for pre-service teachers' digital literacy. Simultaneously, based on the "Pre-service Teacher Digital Literacy Framework", the project team developed the "Pre-service Teacher Digital Literacy Questionnaire". This questionnaire provides robust tool support for assessing pre-service teachers' digital literacy and effectively stimulates their individual proactive engagement.

Constructing an intelligent teaching environment to provide environmental support for cultivating pre-service teacher digital literacy

Building an intelligent teaching environment is a fundamental project to support the development of pre-service teachers' digital literacy. Hardware facilities serve as the fundamental support, digital teaching resources as the core content, and the intelligent teaching management platform as the collaboration center, collectively forming an

integrated teaching environment of technology, resources and evaluation. In terms of hardware, relying on smart classrooms and virtual simulation training rooms, an immersive and interactive virtual-real integrated teaching venue is constructed, achieving a transformation from a traditional lecture venue to a digital practice venue. In terms of resources, integrate multimodal digital resources and form a resource system that supports the advancement of competence through independent development, introduction and sharing. Examples include self-developed virtual simulation experiments like “AI-Enabled Cultivation of Core Competencies for Future Teachers”, acquired resources such as “Future Classroom Primary and Secondary School Teaching Resources”, and shared platforms like the “National Smart Education Platform for Primary and Secondary Schools”. These diverse resources not only provide tailored materials for personalized learning but also bridge the gap between theoretical knowledge and teaching practice through contextualized resources. At the platform level, an AI-powered teaching management platform covers the entire process of “data collection-analysis-feedback-intervention”. It collects behavioral data from pre-service teachers in scenarios such as resource utilization, classroom interaction, and instructional design, accurately identifies deficiencies in their digital literacy, and offers personalized learning path recommendations. These three elements synergistically create an intelligent teaching environment that supports perception, practical operation, collaboration, and innovation. This not only lowers the threshold for technology adoption but also continuously fosters the cultivation, internalization, and transfer of pre-service teachers’ digital literacy in both physical and virtual contexts, laying a solid environmental foundation for their competence in future intelligent education.

Reconstruct the curriculum system to promote the development of pre-service teachers’ digital literacy

The top-level design of organizational management plays a crucial role in advancing pre-service teacher digital literacy. During project implementation, the project unit clear talent development goals based on the top-level design. Objectives for cultivating digital literacy were systematically integrated into teacher education courses such as Digital Teaching Resource Development, Digital Instructional Design and Practice, TPACK Competency Development, Virtual Simulation Experiment on Cultivating Future Teachers’ Core Literacy, and AI Applications in Education. Collectively, these courses form a spirally progressive curriculum that develops from basic cognition through applied skills to integrative innovation. The foundational level offers general digital technology courses aimed at developing pre-service teachers’ ability to retrieve information and operate digital tools. The application level provides pedagogy courses that integrate digital technology with subject teaching, fostering skills in developing digital teaching resources and applying smart teaching environments. The innovation level, primarily employs task-driven, project-based, and human-computer collaborative teaching methods to engage pre-service teachers in digital teaching practices that simulate real-world scenarios. These courses facilitate the transformation of pre-service teachers’ knowledge and skills into comprehensive digital literacy, ensuring a coherent and progressive developmental path that guides them from mere tool usage toward a deep integration of technology and teaching.

Empowering through practice: stimulating proactive engagement in pre-service teachers’ digital literacy development

The development of pre-service teachers’ digital literacy also requires stimulating their intrinsic motivation and subjective awareness to form sustainable self-development

capabilities. Through immersive practical experiences and competition-based empowerment mechanisms, the program has established a multi-layered system of experiential learning and reflection, effectively guiding pre-service teachers' transition from passive acceptance to active exploration of digital technologies. First, in daily teaching, organize pre-service teachers to observe exemplary cases of digital teaching and also observe in the classroom. Through firsthand experience of the innovative application of technology in teaching and its actual effects, establish a cognitive foundation for the "perceived usefulness" of digital technology. Second, the program conducts digital literacy and skills competitions, encouraging pre-service teachers to deeply integrate digital technologies such as artificial intelligence with teaching content. This stimulates their awareness of technology-integrated teaching, and through continuous debugging and optimization of their technology application practices, significantly enhances their perceived ease of use and technological self-efficacy. Meanwhile, by organizing post-competition seminars and expert commentary sessions, the program promotes reflective dialogue among pre-service teachers. This not only improves their technical application skills but also fosters profound understanding of technology ethics, data security, and educational responsibilities.

Discussion

This study integrates the external support factors of the TOE with the individual psychological mechanisms of the TAM, proposing a closed-loop pathway of "external support – internal transformation – literacy generation". The findings reveal that the cultivation of pre-service teachers' digital literacy requires not only external conditions such as national policies, institutional management, and resource support but also the fostering of positive technological cognition and affective identification among pre-service teachers. Only through this dual mechanism can the sustainable development of digital literacy be effectively promoted, thereby addressing challenges such as institutional decoupling, disruptions in practice transformation, and the resource mismatch.

This study advances existing research. Compared with the "pre-service teachers' technology integration ecological model" (Tondeur et al., 2016), it further uncovers that policy and organizational support can only exert internalized effects through individual cognitive transformation. Moreover, unlike TPACK model (Koehler & Mishra, 2009), which emphasizes the integration of knowledge structures, this study highlights the influence pathways through which systemic external support shapes teachers' psychological readiness for technology adoption. In addition, this study deepens the argument that effective policy implementation must be accompanied by teacher agency, by identifying teachers' perceived cognition as a mediating factor in the transmission chain of policy effectiveness (Fullan, 2016).

Therefore, the innovation of this study lies in revealing, from a systemic perspective, the dynamic coupling relationship between macro-level supportive systems and micro-level behavioral transformation in promoting pre-service teachers' digital literacy. It provides an operational theoretical and practical framework for advancing digital literacy cultivation among pre-service teachers.

Conclusion

This study systematically addresses the practical challenges in cultivating pre-service teachers' digital literacy, including institutional decoupling, disruptions in practice transformation, and the resource mismatch. By integrating the TOE framework with the TAM, it proposes a dynamic closed-loop model of "external support – internal transformation – literacy generation", whose feasibility and explanatory power were

validated through case analysis. The findings suggest that the development of pre-service teachers' digital literacy is not the result of a single driving factor, but rather the synergistic outcome of external structural conditions and internal psychological mechanisms. The TOE framework provides institutional guarantees and environmental support, while the TAM facilitates the internal transformation of teacher agency; the interaction between the two serves as a key driver for the generation of digital literacy. This model bridges the macro-level support system and the individual cognitive mechanism, thereby extending the systemic explanatory framework of teachers' digital literacy research. At the practical level, it offers a replicable pathway for addressing the real challenges in cultivating pre-service teachers' digital literacy through a systematic process of "standard formulation – intelligent environment construction – curriculum reconstruction – practical empowerment".

However, the validity of the theoretical model developed in this study has been verified within a specific regional context in China. Whether the model remains robust across more diverse regions requires further investigation. Future research should conduct longitudinal and comparative studies in different educational ecosystems and cultural contexts to further examine its generalizability and sustainable impact.

Conflict of Interest

The author declares no conflict of interest.

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References

- Dolezal, D., Motschnig, R., & Ambros, R. (2025). Pre-service teachers' digital competence: A call for action. *Education Sciences*, 15(2), 160. <https://doi.org/10.3390/educsci15020160>
- Eshet-Alkalai, Y. (2004). Digital literacy: A conceptual framework for survival skills in the digital era. *Journal of Educational Multimedia and Hypermedia*, 13(1), 93–106.
- European Commission. (2020a). Digital education action plan: Policy background. Analytical report. https://education.ec.europa.eu/focus-topics/digital-education/plan?utm_source=chatgpt.com
- European Commission. (2020b). Erasmus+ teacher academies. Analytical report. <https://education.ec.europa.eu/education-levels/school-education/erasmus-teacher-academies>
- European Commission's Joint Research Centre (JRC). (2017). Digital Competence Framework for Educators (DigCompEdu). Analytical report. https://joint-research-centre.ec.europa.eu/digcompedu_en
- European Union. (2007). Key competences for lifelong learning a European reference framework. Printed on white chlorine-free paper. Analytical report. <https://www.britishcouncil.org/sites/default/files/youth-in-action-keycomp-en.pdf>
- Fullan, M. (2016). *The new meaning of educational change* (5th ed.). Teachers College Press.
- Gilster, P. (1997). *Digital literacy*. Wiley.
- GOV.UK. (2019). EdTech: Demonstrator schools and colleges programme. Analytical report. https://www.gov.uk/guidance/edtech-demonstrator-schools-and-colleges-programme?utm_source=chatgpt.com#about-the-programme
- GOV.UK. (2024). Initial teacher training and early career framework. Analytical report. https://www.gov.uk/government/publications/initial-teacher-training-and-early-career-framework?utm_source=chatgpt.com

- Hall, R., Atkins, L., & Fraser, J. (2014). Defining a self-evaluation digital literacy framework for secondary educators: the DigiLit Leicester project. *Research in Learning Technology*, 22(1), 21440. <https://doi.org/10.3402/rlt.v22.21440>
- ISTE. (2017). ISTE standards: For educators. Analytical report. <https://iste.org/standards/educators>
- Kelentrić, M., Helland, K., & Arstorp, A. T. (2017). *Professional digital competence framework for teachers*. The Norwegian Centre for ICT in Education.
- Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary issues in technology and teacher education*, 9(1), 60–70.
- Krumsvik, R. J. (2008). Situated learning and teachers' digital competence. *Education and Information Technologies*, 13, 279–290. <https://doi.org/10.1007/s10639-008-9069-5>
- Letter of the Ministry of Education of the People's Republic of China. (2018). "Notice of the Ministry of Education on the Education Informatization 2.0 Action Plan", Letter No. 2018-6, 18th April. http://www.moe.gov.cn/srcsite/A16/s3342/201804/t20180425_334188.html
- Letter of the Ministry of Education of the People's Republic of China. (2022). "Notice of the Ministry of Education on the Promulgation of the Industry Standard for Teacher Digital Literacy", Letter No. 2022-58, 2nd December. http://www.moe.gov.cn/srcsite/A16/s3342/202302/t20230214_1044634.html
- Mishra, K. E., Wilder, K., & Mishra, A. K. (2017). Digital literacy in the marketing curriculum: Are female college students prepared for digital jobs? *Industry and Higher Education*, 31(3), 204–211. <https://doi.org/10.1177/0950422217697838>
- New Media Consortium (NMC). (2017). Digital Literacy in Higher Education, Part II: An NMC Horizon Project Strategic Brief. New Media Consortium (NMC). Analytical report. <https://library.educause.edu/-/media/files/library/2017/8/2017nmcstrategicbriefdigitalliteracyheii.pdf>
- Nurzhanova, S., Stambekova, A., Zhaxylikova, K., Tatarinova, G., Aitenova, E., & Zhumabayeva, Zh. (2024). Investigation of future teachers' digital literacy and technology use skills. *International Journal of Education in Mathematics, Science and Technology*, 12(2), 387–405. <https://doi.org/10.46328/ijemst.3826>
- Polat, M. (2021). Pre-service teachers' digital literacy levels, views on distance education and pre-university school memories. *International Journal of Progressive Education*, 17(5), 299–314. <https://doi.org/10.29329/ijpe.2021.375.19>
- Redecker, C. (2017). European framework for the digital competence of educators: DigCompEdu. Publications Office of the European Union. <https://publications.jrc.ec.europa.eu/repository/handle/JRC107466>
- The State Council of the People's Republic of China. (2025). "The central committee of the communist party of China and the state council issued the national plan for building a leading education power (2024–2035)", Order No. 2025-4, 19th January. https://www.gov.cn/gongbao/2025/issue_11846/202502/content_7002799.html
- Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, 59(1), 134–144. <https://doi.org/10.1016/j.compedu.2011.10.009>
- Tondeur, J., van Braak J., Siddiq, F., & Scherer, R. (2016). Time for a new approach to prepare future teachers for educational technology use: Its meaning and measurement. *Computers & Education*, 94, 134–150. <https://doi.org/10.1016/j.compedu.2015.11.009>
- UNESCO. (2022). The ICT competency framework for teachers harnessing OER project: Digital skills development for teachers. Analytical report. <https://unesdoc.unesco.org/ark:/48223/pf0000383206>
- Zhao, Y., Sánchez Gómez, M. C., Pinto Llorente, A. M., & Zhao, L. (2021). Digital competence in higher education: Students' perception and personal factors. *Sustainability*, 13(21), 12184. <https://doi.org/10.3390/su132112184>