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Pre-service Teachers' Digital Competence: A Systematic Review of Factors, Frameworks, and Global Patterns

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Abstract. The rapid digital transformation of global education systems has made enhancing the digital competence of pre-service teachers a fundamental objective of teacher education reform in many countries. This study employs the PRISMA protocol systematically review 28 empirical research articles published between 2021 and 2025. The literature was retrieved from three databases (Scopus, Web of Science, and ERIC), encompassing both developed and developing nations. This review aims to identify (1) the factors that affect pre-service teachers' digital competence, (2) similarities and differences in the digital competence of pre-service teachers in different national contexts, and (3) the frameworks and instruments used in the selected articles. The findings reveal five major influencing dimensions: (1) training and curriculum practice support, (2) psychological and environmental support, (3) policy systems and resource environments, (4) legal ethics and digital literacy, and (5) individual characteristics. Although pre-service teachers in many countries often possess fundamental digital competencies, significant disparities are observed in ethical awareness, pedagogical integration, and critical thinking. DigCompEdu, TPACK, and several other frameworks are commonly employed for evaluation, each offering context-specific benefits. This study consolidates essential trends and regional variations in global research, identifies deficiencies in cross-cultural adaptability and the advancement of advanced digital competence, and offers valuable recommendations for enhancing teacher training programs and informing policy decisions.

Keywords: Digital Competence; Digital transformation; Pre-service Teachers; PRISMA; Teacher Education

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1. Introduction

As society and the economy continue to move toward digitalization, digital competence has become an essential issue in reforming the education system (Tzafilkou et al., 2023). Teachers in the 21st century need to be able to use and produce digital content. According to Niyazova et al. (2023), one of the skills required is the capacity to create, modify, and use digital documents to enhance the teaching and learning process. Thus, teachers and students who want to engage in digital education must have digital abilities (Hämäläinen et al., 2021). In response to this trend, international organizations have proposed many frameworks, such as TPACK (Koehler & Mishra, 2009) and DigCompEdu, which are still widely used and validated in current research (Caena & Redecker, 2019), for example, in the studies of Madsen et al. (2023) and Momdjian et al. (2024).

These frameworks indicate teachers' capacity to incorporate digital technology with instructional content and methods to achieve more innovative, personalized, and effective teaching. The digital competence of educators is no longer a technical appendage, but a fundamental element of their professional capacity to teach in this new pattern. Additionally, digital technology has been shown to improve the learning environment in research. According to Marais (2023), digital platforms, tools, and resources are being utilized more frequently as a method of improving the quality of instruction (Kiryakova & Kozhuharova, 2024).

Since they are still in the early phases of their professional growth, pre-service teachers are an important group in the creation of the future digital education system. To successfully and efficiently incorporate technology into the teaching and training process, pre-service teachers must possess digital competency (Nurzhanova et al., 2024). Nevertheless, pre-service educators frequently encounter obstacles, including a dearth of the requisite skills to complete assignments, and classroom and technology implementation opportunities in using digital instruments, evaluating teaching resources, and integrating teaching practices (Napanoy et al., 2021).

In addition, differences in resource allocation and curriculum content among different educational structures have also exacerbated the structural imbalance in the digital capability development process. This study adopts Caena and Redecker's (2019) description of educators' digital competence, considering it an expert competence rather than a simple technical skill, and is dedicated to developing learning experiences that respond to the skill demands and changes in work patterns in the digital age.

Although there have been studies devoted to exploring the factors that influence technology use by educators in the classroom, most of the research focuses on in-service educators, while pre-service educators have long been neglected (Lai Wah & Hashim, 2021). However, in the current education ecosystem, pre-service educators play a core role in leading the teaching transformation driven by cutting-edge technologies (Gamlem et al., 2025). Despite the diverse applications of artificial intelligence (AI) in education, research has shown that teachers may

have limited understanding of digital technologies, including AI, and how they can help them in practice (Chounta et al., 2022). However, the overall research still has obvious limitations of regional concentration, insufficient empirical evidence, and lack of cross-cultural integration. Although there are multiple frameworks for measuring teachers' digital competence, most studies still focus on the inheritance of ICT dimensions and fail to fully systematize the dynamic and diverse needs of teachers in teaching integration (Tzafilkou et al., 2023). Research in various countries is still incomplete and lacks a comparative research foundation under cross-cultural and cross-policy systems, especially concerning the diversity of the global digital education landscape.

1.1 Research Rationale

Existing research still has obvious deficiencies in the following three aspects:
First, although a large number of studies have attempted to investigate the determinants influencing educators' utilization of technology in pedagogy and proposed that these factors interact at multiple levels such as the education system, school and teacher (Antonietti et al., 2022), further in-depth analysis of the factors that affect the development mechanism of teacher capacity is still needed.

Second, our knowledge of how instructors adapt to technological advances is restricted by the unequal geographic distribution of research, particularly in poor nations where there is very little empirical evidence for the topic (Demissie et al., 2022). Third, the present framework for digital competence must be further studied for its cross-cultural efficacy and breadth of application, since it varies in adaptability among nations and cultural backgrounds (Mattar et al., 2022).

In view of the above research gaps, this paper critically examines and systematically explores the factors affecting the advancement of pre-service educators' digital competence, the commonalities and differences between countries, and the application context and applicability of mainstream assessment frameworks through a systematic literature review (SLR) and integration of international empirical studies from 2021 to 2025.

The study aims to clarify the development path and theoretical differences of literature, promote structured understanding in the area of educator education, and provide theoretical support and practical inspiration for different education systems.

1.2 Research questions

1. What factors affect pre-service teachers' digital competence?
2. What are the similarities and differences in the digital competence of pre-service teachers globally in the selected articles?
3. Which frameworks and instruments are used in the selected articles to assess the digital competence of pre-service teachers?

1.3 Conceptual framework of review

In order to systematically organize and analyze the included studies, this study constructed a conceptual framework around three research questions. As shown in Figure 1, this framework provides a structured analytical perspective for the screening, coding, and thematic induction of literature, which helps to improve the logical clarity and focus of the review. In literature review studies, researchers usually construct a conceptual framework to show the hypothesized connections between core concepts and sort out the deficiencies or gaps in existing research. This framework helps to focus on topics related to the research questions and clarify the necessary directions for further research (Luft et al., 2022).

Conceptual framework of review

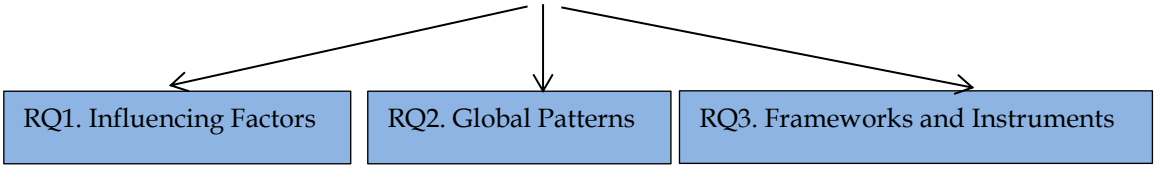

Figure 1: Conceptual framework of review

2. Literature review

Numerous empirical studies on pre-service teachers' digital competence have been conducted in recent years and researchers have explored their development paths from multiple dimensions, including knowledge structure, technology practice, and educational ethics. Cabezas-González et al. (2021) proposed that digital competence should not be viewed as isolated skills but should be integrated and developed across fields and knowledge types. Lim (2023) believed that the pre-service educator education stage is a key window for building the digital literacy of future educators.

Nevertheless, despite the fact that a significant number of pre-service educators maintain a positive attitude, they have not yet acquired adequate competencies to successfully incorporate digital technologies into instruction (Tárraga-Mínguez et al., 2021). McDowall et al. (2021) and Lin et al. (2023) emphasized that data literacy is essential to the incorporation of digital pedagogy and needs to be systematically strengthened in teacher training.

As the trend of digitalization of education accelerates, 21st century competencies are seen as directional indicators of digital competency development. Nguyen et al. (2021) asserted that pre-service educators should be dynamic and versatile in using 21st century strategies to career, learning, and life. Duangngern et al. (2023) further proposed that to be an efficient facilitator of change in the classroom, teachers must have 21st century competencies (Duangngern et al., 2023). Chu et al. (2023) confirmed the factors that influence digital teaching proficiency from the viewpoints of data literacy, technology ethics, and attitudes.

Supportive teaching design is also a key mechanism for improving capacity. Henne et al. (2022) demonstrated that contextual design can enhance pre-service teachers' self-efficacy expectations. Gumbi et al. (2024) demonstrated from a practical perspective that digital gamification learning can enhance teacher engagement and teaching opportunities, while Zimmermann et al. (2022) emphasized the impact of search engine affordance and individual factors on pre-service educators' selection and assessment of information.

Nurzhanova et al. (2024) revealed that background variables such as gender and grade have a major impact on teachers' digital literacy and technology application ability. Dai (2023) suggested that leaders should effectively deal with teachers' negative attitudes towards digital teaching, encourage teachers to actively participate in training, and ensure the rational allocation of relevant school resources. Despite the fact that a substantial number of studies have investigated the path to digital competence, these studies are mainly concentrated in developed countries, while research in developing countries is relatively scarce (Akbar & Biyanto, 2022). This lack of regional representation has seriously affected global understanding and comparative analysis.

On the theoretical level, this study explicitly adopts the two frameworks of TPACK and DigCompEdu as the theoretical basis and analytical perspective of this review. TPACK is inherently situational, which implies that it must be comprehended and implemented within a particular educational context (Petko et al., 2025) and is widely used in teacher professional development research with "teaching context" as the core variable. Although TPACK has been studied for more than 15 years since it was proposed, its cross-domain and cross-context integration still needs to be systematically explored (Schmid et al., 2024). The situational characteristics of TPACK emphasize its applicability and challenges in diverse educational practices.

The DigCompEdu framework includes six areas (Redecker et al., 2017), covering dimensions such as professional engagement, assessment, teaching and learning, empowering learners. Compared with TPACK, which focuses more on the significance of learners' digital competence, DigCompEdu emphasizes the digital learning ecosystem jointly constituted by teachers and learners (Potyrała et al., 2021), clearly defines the application areas of information and communication technology (ICT) in education, and the framework is oriented to the process in a broader educational context (Tomczyk & Fedeli, 2021). It aims to identify the ethical aspects of teachers' activities and outlines a positive professional stance.

In summary, TPACK and DigCompEdu provide complementary theoretical perspectives. TPACK emphasizes that educators integrate technology, content knowledge, and instructional strategies in teaching situations, and is suitable for analyzing practical factors that affect the advancement of digital competence. DigCompEdu, on the other hand, focuses on the structural construction and evaluation standards of teachers' digital competence, and is suitable for cross-national comparison and evaluation tool analysis. Combining the two helps to

systematically answer the three research questions of this study on influencing factors, global patterns, and evaluation frameworks, and to build a clear and comprehensive analytical framework.

3. Methodology

This SLR is a carefully planned analysis of previously published studies that aims to explore the development of digital competence in educators, with a particular focus on the development of digital competence in pre-service educators. According to Pati et al. (2018), SLR is a systematic procedure used to collect, identify, and critically analyze available research findings. Formulating research questions is the most important component of creating an SLR to determine the scope of the investigation (Del Amo et al., 2018).

In order to enhance the logical consistency between the research objectives and the research process, this paper constructed a structured literature screening and analysis path based on three research questions to ensure that the final inclusion and analysis content is closely related to the core research topics. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria for design and structure are adhered to in this systematic literature review (SLR) (Moher et al., 2010). Figure 2 illustrates the four steps of the PRISMA criteria, which are followed in the literature review process: identification, screening, eligibility, and inclusion.

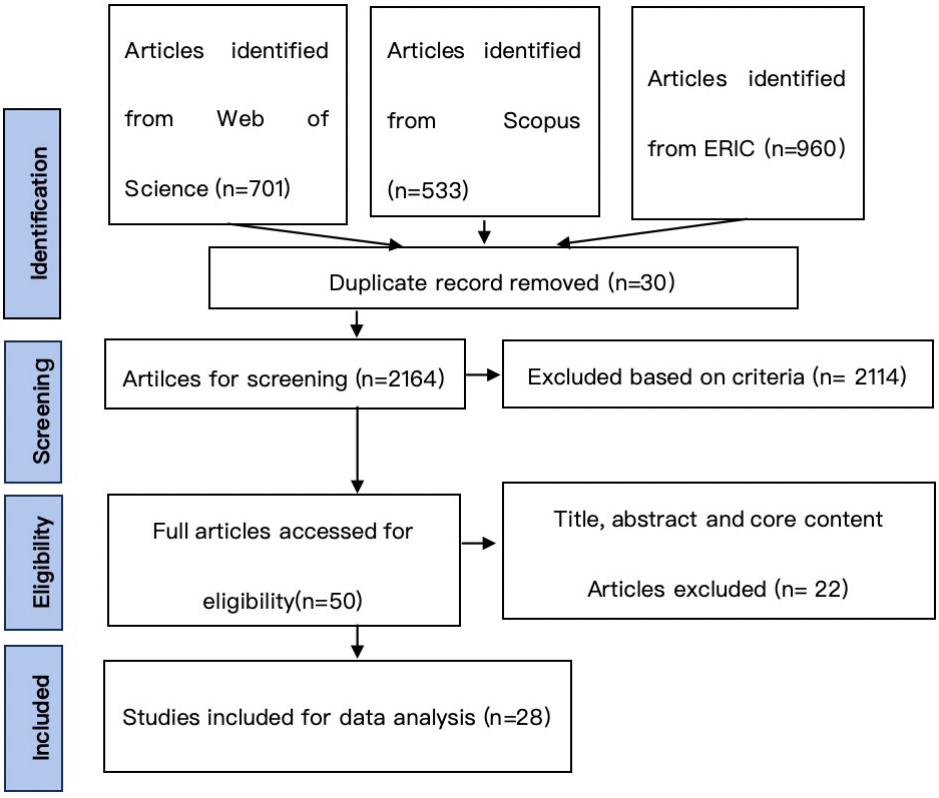

Figure 2: Research flow chart

3.1 Identification of search terms

The identification of search terms began with exploration in three databases: WoS, Scopus, and ERIC. These three databases were chosen because of their extensive coverage and representativeness in the area of educational research. WoS is a multidisciplinary, curated database consisting of various specialized indexes, grouped according to index content type or theme (Pranckutė, 2021). A greater variety of social science and humanities materials are covered by Scopus (Strielkowski et al., 2022), while the ERIC database also covers educational publications from other sources (e.g., conferences) (Lathwesen & Belova, 2021).

The search strings and results are shown in Table 1. Although this study used relatively general terms in the initial search (e.g., teacher digital competence, digital transformation in education), key thematic dimensions such as "influence factors," "Global Patterns," and "evaluation frameworks" were systematically identified and coded during the subsequent thematic analysis. A total of 2194 articles were collected in this step, of which 30 articles were excluded due to duplication. This research sought to provide a thorough review and cover a variety of viewpoints. Therefore, a total of 2164 articles were included.

Table 1: The search strings and keywords utilized in the systematic review process

Database	Search string
WoS	(Teachers' digital competence or digital skills of teachers) AND (digital transformation in education or school context)
Scopus	(Teachers' digital competence or digital skills of teachers) AND (digital transformation in education or school context)
ERIC	(Teachers' digital competence or digital skills of teachers) AND (digital transformation in education or school context)

3.2 Screening

Publications were included and excluded as part of the PRISMA statement's screening phase (Moher et al., 2009). In the screening phase, all potentially relevant studies were evaluated for consistency based on the pre-set research questions. The inclusion standards for the literature also emphasized the relevance to the core concept of "digital competence of pre-service teachers." The research team screened the remaining literature by title and abstract according to the preset exclusion and inclusion criteria in Table 2. The inclusion criteria include empirical articles in English published between 2021 and 2025.

This study only included empirical research to ensure that the analysis of pre-service teachers' digital competence was based on objective data and verifiable results, thus having more practical reference value. The topic focuses on the field of education research. The excluded literature includes non-original research results such as review articles, books, conference papers, conference abstracts, as well as non-English literature and research not directly related to education. A total of 2114 publications not related to the research objectives were excluded. Through strict screening criteria, it is ensured that the final included literature has timeliness, professionalism and application value, which helps to fully grasp the research trends of pre-service teachers' digital competence development.

Table 2: Inclusion and exclusion criteria for systematic review

Criterion	Exclusion	Eligibility
Time frame	<2021	From 2021 to 2025
Type of article	Conference proceedings, reviews article, books, meeting abstract, etc.	Article
Language	Not in English	English
Discipline	Education and educational research are unrelated	Research in education and education
Population	In-service teachers or students	Pre-service teachers
Methodology	Theoretical papers, opinion pieces, or reviews	Qualitative, quantitative, or mixed-method empirical studies

3.3 Eligibility

A total of 50 articles entered the third round of eligibility review. Each article's title, abstract, and main body were carefully examined by the researchers to make sure they satisfied the requirements for inclusion and were extremely pertinent to the study's goals. Twenty-two articles in all were eliminated following screening, primarily because the research subjects were not pre-service teachers, the content did not match the research question, or the full text could not be obtained. Finally, a total of 28 documents were formally included in the data analysis stage, as shown in Figure 2. The literature screening flow chart is shown in detail.

3.4 Appraisal of quality

First, for the quality assessment of the selected literature, the researchers evaluated the quality of the selected articles according to the mixed methods appraisal tool (MMAT) version 2018 (Hong et al., 2018). Two reviewers were assigned to independently score the quality of the article in this SLR. The assessment criteria encompassed the study's objective, the coherence of the statistical methods, the sampling approach, the lucidity of the research inquiries, and the articulation of the research findings. The MMAT criteria assessed the quality, revealing that 25% of the articles were of low quality, 50% were of average quality, 75% were above average quality, and 100% were classified as good quality (Yusop et al., 2022). The reviewers classified 20 articles as being of high average quality, while the other eight were deemed above average.

3.5 Data extraction and analysis

This study used thematic analysis to organize and summarize the 28 empirical studies included. The researchers drew on the thematic synthesis method proposed by Thomas and Harden (2008) to analyze the data of the included literature. This method transforms the thematic analysis tools and processes commonly used in original research into review forms. Its core is to identify common themes in the data and interpret them through multi-level coding (from descriptive to analytical) to reflect the experience and views of the research subjects. The data extraction work was carried out around three research questions. The research team systematically recorded the research background, objectives, methods, key variables and main findings of the literature, focusing

on: (1) the factors that affect pre-service teachers' digital competence; (2) the similarities and differences in the digital competence of pre-service teachers globally; and (3) the frameworks and instruments used.

To ensure the reliability and scientificity of the analysis process, all authors developed a coding scheme based on the research questions in a group discussion. Next, the first author used an iterative process to test the initial coding, identify new coding, and apply the modified coding until saturation was reached. During this process, other authors were asked to independently check whether the coding was applicable to the coded phrases.

In addition, to verify the reliability of the coding, the second and third authors randomly selected three articles (accounting for 11%) and performed blind coding (Dehghanzadeh et al., 2024). Cohen's Kappa (1960) was employed to assess the inter-rater reliability of coding quality. After completing the discussion and unifying the coding scheme, the first author systematically coded all the literature and integrated the research results.

In the final analysis phase, the research team extracted five key influencing factors through multiple rounds of comparison, classification and aggregation, and identified the differences in the performance of digital capabilities from an international perspective and further sorted out the types and applicable scenarios of the current mainstream evaluation framework. The overall analysis process follows the logical path of "identification-classification-integration" to ensure that the obtained themes are theoretically representative and practically explanatory.

4. Results

RQ1: What factors affect pre-service teachers' digital competence?

Table 3: Five categories of factors affecting pre-service teachers' digital competence

Categories	Specific content	authors
Training and curriculum practice support	Direct method, integrated method, teacher modeling	Momdjian et al. (2025b)
	Course quality design and arrangement	Andreasen et al. (2022); Ismaeel et al. (2022); Meling (2022); Temel and Gür (2022); Momdjian et al. (2024, 2025a)
	Teaching practice, reflection, learning opportunities	Andreasen et al. (2022); Belda-Medina et al. (2022); Ismaeel et al. (2022); Kulaksız et al. (2022); Meling (2022); Göltl et al. (2024); Kuru Gönen et al. (2024); Momdjian et al. (2024); Lyubka (2025); Momdjian et al. (2025a)
	Role model	Andreasen et al. (2022); Göltl et al. (2024); Kuru Gönen et al. (2024)
	Teaching and teacher training, computers, technology, and systems training	Kaimara et al. (2021); Belda-Medina et al. (2022); Cebi et al. (2022); Ismaeel et al. (2022); Miço and Cungu (2022); Temel and Gür (2022); Yang et al. (2022); Akkaya (2023); Er (2024); Faraasyatul et al. (2024); Fitrah et al.

		(2025)
Psychological and environmental support	Individual and ability recognition	Kaimara et al. (2021); Kulaksız et al. (2022); Madsen et al. (2023); Er (2024); Göltl et al. (2024); Momdjian et al. (2024)； ; Fitrah et al. (2025); Lyubka (2025); Momdjian et al. (2025a)
	ICT attitudes and self-efficacy, digital awareness and attitudes	Andreasen et al. (2022); Kulaksız et al. (2022); Temel & Gür (2022); Yang et al. (2022); Janeš et al. (2023); Madsen et al. (2023); Er (2024); Hoang (2024); Kuru Gönen et al. (2024); Lyubka (2025)
	Learning motivation	Şahin et al. (2022); Temel and Gür (2022); Kuru Gönen et al. (2024); Fang et al. (2025)
	Emotional support, psychological needs, and self-regulation skills	Şahin et al. (2022); Fang et al. (2025)
	Disciplinary differences and personalization	Göltl et al. (2024)
	Collaboration and support, peer coaching, coaching feedback	Andreasen et al. (2022); Belda-Medina et al. (2022); Cebi et al. (2022); Kulaksız et al. (2022); Kuru Gönen et al. (2024); Göltl et al. (2024); Hoang (2024)
	Infrastructure and technology accessibility	Kaimara et al. (2021); Meling (2022); Miço and Cungu (2022); Hidayat et al. (2023); Madsen et al. (2023); Faraasyatul et al. (2024); Hoang (2024); Fitrah et al. (2025)
Policy system and resource environment	Digital resources, school resources and culture	Lyubka (2025)
	Policy support, financial support, institutional support, technical resources and support	Kaimara et al. (2021); Andreasen et al. (2022); Belda-Medina et al. (2022); Yang et al. (2022); Janeš et al. (2023); Er (2024); Fitrah et al. (2025); Lyubka (2025)
Legal ethics and digital literacy	Legal and copyright awareness, online etiquette	Hidayat et al. (2023)
	Content creation skills, digital communication and collaboration, professional knowledge, technical knowledge	Belda-Medina et al. (2022); Meling (2022); Hidayat et al. (2023)
Individual characteristics	Educational background and education stage	Temel and Gür (2022); Yang et al. (2022); Akkaya (2023); Boyraz et al. (2024)
	Age	Cabezas-González et al. (2021); Yang et al. (2022)

	Gender	Cabezas-González et al. (2021); Akkaya (2023); Boyraz et al. (2024)
	Teaching experience	Yang et al. (2022); Janeš et al. (2023)
	Educational qualifications	Cabezas-González et al. (2021)
	Frequency of Internet use	Akkaya (2023)

The rapid advancement of digital education has made the improvement of pre-service educators' digital competence a key factor in teacher education reform in various countries. This study adopts an SLR method to select representative studies from internationally renowned databases from 2021 to 2025 and summarizes the factors affecting the improvement of pre-service educators' digital competence, as shown in Table 3.

To make the research structure clearer, this study divides the influencing factors into five categories based on content attributes and research focus: 1. Training and curriculum practice support; 2. Psychological and environmental support; 3. Policy system and resource environment; 4. Legal Ethics and Digital Literacy; 5. Individual characteristics.

4.1 Theme 1: Training and curriculum practice support

Systematic training and curriculum design are the key foundations that influence the formation of pre-service teachers' digital competence. A large number of studies have shown that clear teaching strategies (such as direct method, integrated method, teacher modeling) significantly contribute to the advancement of digital competence (Momdjian et al., 2025b). Ismaeel et al. (2022) further emphasized that pre-service educators should be helped to build solid digital skills by optimizing teaching methods and curriculum structure and providing technology-enhanced practice opportunities. Cebi et al. (2022) also proposed that digital competence training can lay the foundation for improving technology integration capabilities.

However, Temel and Gür (2022) noted that if pre-service teachers lack training or experience in using digital technologies during their undergraduate studies, it will be difficult for them to effectively apply these technologies in future teaching. It is worth noting that Andreasen et al. (2022) found that some pre-service educators had a low evaluation of the support role of university lecturers in their digital competence development. Based on this, the study reasonably speculated that teacher educators may act as role models to influence pre-service educators' attitudes toward technology and their perception of the effectiveness of technology application.

In order to improve the effectiveness of training, researchers suggest designing systematic coaching workshops and incorporating the use and reflection process of advanced technologies such as AI to support pre-service educators in autonomously constructing their digital capabilities (Göltl et al., 2024). Kuru Gönen et al. (2024) showed that the introduction of popular technology tools in

foreign language teaching not only improved teachers' ability to integrate mobile technology but also stimulated learners' interest in learning. Participants generally believed that this type of training that integrates practice and reflection has a significant promoting effect on their teaching skills.

In addition, Andreasen et al. (2022) proposed that pre-service teachers need to obtain more real classroom practice opportunities in order to effectively master and apply digital teaching skills. In the global context of digital transformation, Faraasyatul et al. (2024) advocated an electronic training method with self-education as the core, believing that this is one of the necessary ways to achieve fair digital civilization. Therefore, a training path that emphasizes both systematicity, practicality and autonomous reflection is one of the current strategies to enhance the digital capabilities of pre-service educators.

4.2 Theme 2: Psychological and environmental support

Psychological motivation is widely considered to be the core factor affecting the advancement of digital competence of pre-service educators. According to Göltl et al. (2024), pre-service teachers often anticipate greater direction and assistance to improve their motivation, comprehension, and self-assurance in their ability to teach and use technology. According to Hoang (2024), pre-service educators' desire to use technology in teaching may be increased by fostering a collaborative learning environment and raising their information and communication technology (ICT) self-efficacy. Additionally, Madsen et al. (2023) noted that teachers' attitudes, digital abilities, and knowledge are important predictors of future adoption behavior for educational digital technology (EDT). Er (2024) also noted that instructors may only fully utilize digital technology's teaching potential if they have the requisite abilities.

In addition to individual motivation, environmental support is also critical in the advancement of teachers' digital capabilities. Kulaksız et al. (2022) found that collaborative learning had a significant positive impact on pre-service educators' educational technology capabilities. Göltl et al. (2024) further proposed that, although skills can be mastered through self-study, it is difficult to reach a professional level without cooperation and professional guidance. Fang et al. (2025) found that the ES-RSRL method effectively improved educators' digital resource growth capabilities and enhanced external motivation and self-regulation, while the lack of emotional support would weaken their development potential.

Şahin et al. (2022) emphasized that motivation plays a particularly significant role in digital teaching while Cebi et al. (2022) reiterated that teachers should be given special training on digital behavior norms, communication, and collaboration skills. In addition, in order to enhance the practice environment, Lyubka (2025) suggested that schools should cooperate with schools with sound digital infrastructure to provide pre-service educators with real technology application opportunities and promote their positive attitudes and continuous professional growth by integrating teaching beliefs and learning strategies.

4.3 Theme 3: Policy system and resource environment

The development of digital competence of pre-service educators depends largely on policy guidance and institutional support at the macro level. Lyubka (2025) proposed that the cultivation of digital competence of future educators should be combined with curriculum development, teacher continuing education, and infrastructure guarantees to promote more systematic adjustments at the policy level. For example, in Bulgaria, the growth of digital competence of pre-service educators is guided by the European Digital Competence Framework, the Digital Education Action Plan, and the organizational structure of its teacher education (Lyubka, 2025), showing the institutional advantage of high policy coordination.

However, Kaimara et al. (2021) found that the promotion of educational innovation (such as digital gamification learning) in some countries is more dependent on the enthusiasm of policy reform, and this reform intention is often limited by the judgment of actual conditions, such as funding allocation and technical resources. In an environment with insufficient resource support, the progress of institutional reform is often hindered.

The current inefficient allocation of financial resources has become a major problem hindering the development of teachers. Er (2024) also clearly proposed that insufficient budget is a key factor affecting the use of technology in foreign language teaching. In this context, some reform initiatives have attempted to bridge the gap between system and practice. For example, the "ProDiG" project redesigned the educator education program and is committed to improving the professional digital capabilities of teacher educators (Andreasen et al., 2022). Belda-Medina et al. (2022) demonstrated a practical case of training pre-service teachers' collaboration and creation capabilities through AR projects, while, in addition, Fitrah et al. (2025) proposed that technological infrastructure and educational policies have an important impact on the adoption of platforms such as LMS.

Moreover, Yang et al. (2022) criticized the current ICT courses for having little effect on in-service teachers, suggesting that the training system needs to be updated urgently and Janeš et al. (2023) further emphasized that the way of thinking of educational institutions and teachers' attitudes toward digitalization will directly affect the promotion of experiential teaching. Therefore, the institutional and resource environment should not only provide financial and physical support but also promote the synchronous transformation of the concepts of colleges and universities and teachers.

4.4 Theme 4: Legal ethics and digital literacy

In recent years, digital literacy and legal ethics have gradually become a core part of the digital competence of pre-service educators. Studies have shown that Chinese pre-service and in-service educators perform well in digital awareness, especially in information ethics and security awareness (Yang et al., 2022). Hidayat et al. (2023) proposed that network etiquette covers the behavioral norms and moral responsibilities of humans in cyberspace, while, in Indonesia,

pre-service teachers' understanding of copyright issues still needs to be improved. They generally believe that when it comes to uploading, downloading or disseminating content with intellectual property rights, the meaning and consequences of use must be fully understood (Hidayat et al., 2023).

In addition, teachers should not only have basic legal awareness but also master the critical use of digital tools. Belda-Medina et al. (2022) adopted collaborative learning strategies in their experiments to help teacher candidates share knowledge, develop AR projects, and improve their digital content creation capabilities. Meling (2022) further emphasized that pre-service educators need to allocate adequate time mastering how to use a digital tool before incorporating it into teaching. Only when teachers are proficient in using technology can they critically evaluate the actual impact of technology on learning outcomes. Therefore, legal ethics awareness and digital literacy are not an appendage of digital capabilities, but one of its core dimensions, which directly affects the professionalism and legitimacy of teaching.

4.5 Theme 5: Individual characteristics

The digital competence of pre-service educators is affected by a variety of individual background factors, among which education, age and teaching years have been widely addressed by many studies. Yang et al. (2022) proposed that in-service educators with higher education have higher perception levels in the dimensions of "technology-supported teaching" and "technology-supported learning."

In addition, the age and teaching years of in-service teachers are negatively correlated with their digital competence perception, while the age of pre-service teachers is positively correlated, indicating that age may be one of the decisive variables affecting the level of digital competence. Akkaya (2023) further proposed that, in the process of education and training, individuals at all levels should have the ability to quickly acquire and understand digital information in order to effectively adapt to technological changes.

In addition to age and education, variables such as teaching years and Internet experience have been repeatedly mentioned in the articles. Boyraz et al. (2024) believed that teaching years is an important factor affecting the digital competence of pre-service educators, but gender does not have a significant impact, which is also supported by Cabezas-González et al. (2021). Temel and Gür (2022) showed that second-year teacher candidates had a negative attitude toward technology, and, as the grade increased, teachers' acceptance and evaluation of digital technology also increased.

In addition, it has been demonstrated that instructors' prior experience with Internet usage has a substantial impact on their readiness to utilize digital technology (Janeš et al., 2023), and students' overall digital literacy scores also revealed notable variations in the frequency of computer use (Akkaya, 2023). All things considered, even if individual background variables are not dominant

elements, they nonetheless have a reference value that is essential for comprehending variations in digital competency and developing training intervention techniques.

In summary, the advancement of pre-service educators' digital competence is influenced by multiple factors, including curriculum training, psychological motivation, institutional policies, ethical literacy, and personal background. The interaction of these factors reflects the key role of practical opportunities, resource guarantees, and individual characteristics in the process of competence construction, providing an important reference for teacher education reform and subsequent research.

RQ2：What are the similarities and differences in the digital competence of pre-service teachers globally in the selected articles?

Table 4: Summary of reviewed articles by country

Country	Number of articles	Author
Lebanon	3	Momdjian et al. (2024, 2025a, 2025b)
Vietnam	1	Hoang (2024)
Turkey	5	Cebi et al. (2022); Kulaksız et al. (2022); Temel & Gür (2022); Boyraz et al. (2024); Kuru Gönen et al. (2024)
Norway	2	Andreasen et al. (2022); Meling (2022)
Indonesia	3	Hidayat et al. (2023); Faraasyatul et al. (2024); Fitrah et al. (2025)
Bulgaria	1	Lyubka (2025)
Austria	1	Göltl et al. (2024)
CHINA	2	Yang et al. (2022); Fang et al. (2025)
Saudi Arabia	1	Ismaeel et al. (2022)
Greece	1	Kaimara et al. (2021)
Spain	2	Cabezas-González et al. (2021); Belda-Medina et al. (2022)
Albania	1	Miço and Cungu (2022)
Türkiye and other countries	1	Madsen et al. (2023)
Norway and other countries	1	Janeš et al. (2023)
Not specified	3	Şahin et al. (2022; Akkaya (2023); Er (2024)

In recent years, the progression of worldwide educational informatization has resulted in a notable rise in empirical studies about the digital competency of pre-service instructors, and the research results are relatively rich worldwide.

The 28 papers reviewed in this study cover at least 12 specific countries and regions, including Lebanon, Vietnam, Türkiye, Norway, Indonesia, and China, some of them involve multiple countries (such as "Türkiye and other countries", "Norway and other countries"), and another three papers do not specify the

national background (not specified), showing the relatively wide range of research.

As can be seen from Table 4, Türkiye, Lebanon, and Indonesia are the representative countries with the largest number of studies, indicating that these countries attach great importance to the digital competence of pre-service educators. In comparison, some countries such as Austria, Bulgaria, and Saudi Arabia only have a single study, indicating that their research is still in the initial stage. Overall, the distribution of literature shows that it is mainly in European and Asian countries, reflecting the uneven promotion of global education digital transformation in different countries.

Although existing studies vary in number and regional distribution, many reveal some common characteristics of pre-service educators' digital competence. Most studies show that pre-service teachers generally have basic information retrieval skills, digital tool operation skills, and the ability to integrate teaching resources.

ICT self-efficacy is deemed a significant predictor of digital competence (Hoang, 2024), whereas digital skills, attitudes, and knowledge are essential determinants of pre-service educators' propensity to utilize educational technologies in the future (Madsen et al., 2023). Moreover, a growing body of study has utilized standardized frameworks like DigCompEdu (e.g., Madsen et al., 2023; Momdjian et al., 2025b), therefore enabling cross-national comparisons of competency aspects and improving the theoretical coherence of studies. These data indicated that fundamental digital competency has emerged as a significant emphasis in teacher education globally.

Table 5 compares developed countries (such as Norway and Spain) with developing regions (such as Indonesia and Vietnam) to present the typical characteristics and key differences of teachers' digital competence development in different national contexts. In Norway and Spain, the advancement of pre-service educators' digital competence is strongly supported by systematic training mechanisms, practical courses, and technological infrastructure. Collaborative programs between university teachers and supervisors also advocate the advancement of their professional digital competence (Andreasen et al., 2022).

Research has shown that teacher training programs usually include the integration of the TPACK framework, focusing on teaching design, interactive teaching material development, and practical operation skills (Belda-Medina et al., 2022; Meling, 2022). For example, augmented reality is integrated into language teaching courses to enhance teaching interactivity (Belda-Medina et al., 2022). In Indonesia, learning management systems (LMS) are used to promote TPACK competence development, indicating that some developing countries are also actively exploring technology integration paths (Fitrah et al., 2025).

In contrast, teacher education systems in developing regions such as Indonesia and Vietnam face many challenges in terms of training execution, resource supply and curriculum integration. Although Indonesian pre-service teachers have a high demand for digital teaching integration, existing training still lacks systematic and practical support. For example, 85% of trainee teachers hope to improve their digital teaching integration capabilities (Faraasyatul et al., 2024), but many educators have challenges in properly integrating technology into their teaching owing to insufficient practical training and professional development assistance (Fitrah et al., 2025).

Vietnam also faces problems such as inadequate policy implementation and weak teacher ICT training (Hoang, 2024). In addition, these countries generally have infrastructure bottlenecks such as uneven urban and rural resources and outdated digital equipment, which pose a real constraint on the advancement of educators' digital capabilities (Faraasyatul et al., 2024; Fitrah et al., 2025; Hoang, 2024).

Table 5: Comparison of digital competence development of pre-service teachers in developed and developing countries

Dimensions	Country Type	
	Developed country	Developing country
Training mechanism and institutional support	Systematic training mechanism, including classroom practice, online demonstration, etc. (Meling, 2022); Improved teacher collaboration mechanism (Andreasen et al., 2022)	Incomplete training system (Fitrah et al., 2025); Reliance on self-directed e-training (Faraasyatul et al., 2024)
Practical teaching opportunities	Provide lectures and teaching practices (Meling, 2022); AR teaching practices (Belda-Medina & Calvo-Ferrer, 2022)	Lack of opportunities for effective practice (Fitrah et al., 2025)
Technical infrastructure	Have collaborative AR projects to support digital teaching (Belda-Medina & Calvo-Ferrer, 2022)	Large urban-rural disparity (Hoang, 2024); Insufficient infrastructure (Faraasyatul et al., 2024; Fitrah et al., 2025)

The enhancement of digital competence among pre-service educators in Norway and Spain is facilitated by superior institutional coordination and practice, with training material emphasizing teaching design and technology integration (Andreasen et al., 2022; Belda-Medina et al., 2022). However, Indonesia and Vietnam encounter more structural limitations, including inadequate policy execution and disparities in resources between urban and rural areas (Faraasyatul et al., 2024; Hoang, 2024).

Potential factors contributing to these disparities include educational policy goals, budgetary investment capabilities, and varying degrees of focus on the

digital literacy culture of educators. This comparison provides a valuable perspective for understanding the background differences in the growth of digital competence of educators in different countries.

RQ3: Which frameworks and instruments are used in the selected articles to assess the digital competence of pre-service teachers?

Table 6: Framework and instrument for pre-service teachers' digital competence assessment

Framework Category	Framework /Tool	Type	Coverage & Strengths	References
Standardized Framework	DigCompEdu / DigCompEdu (Adapted)	European Framework for Digital Competence of Teachers	Designed for educators, covers all educational stages, highlights the successful incorporation of digital tools into pedagogical methods, empowers students and teachers to grow professionally, has international recognition and can be adapted to different educational contexts (Caena et al., 2019; Lucas et al., 2021)	Miço and Cungu (2022); Hoang (2024); Momdjian et al. (2024, 2025a, 2025b); Lyubka (2025)
Standardized Framework	DigComp(Adapted Version)	Digital Competence Framework for Citizens	Assessing citizens' general digital literacy, covering core competencies such as information literacy, collaboration, problem solving, and creation, security, suitable for citizens' general digital literacy assessment, and often used to measure basic competencies of teachers and students (Carretero et al., 2017; Ferrari et al., 2013)	Hidayat et al. (2023); Boyraz et al. (2024)

Integrated Framework	DigComp+TPACK	Integrative Theoretical Framework	The integration of digital competence and knowledge of teaching content technology is suitable for analyzing the knowledge structure of pre-service educators in the incorporation of technology in instruction, taking into account the teaching context, ethical awareness and digital skills (Kabakci Yurdakul et al., 2012; Mishra et al., 2006)	Cebi et al. (2022)
Theoretical Framework	TPACK	Teaching content integration framework	Integration of technology pedagogy in the educational environment	Belda-Medina et al. (2022); Ismaeel et al. (2022); Madsen et al. (2023); Fitrah et al. (2025)
National/Contextual Framework	Chinese IT Standards / PDC (Norway)	National/local framework	Based on national or regional policy formulation, it focuses on digital competency assessment within the framework of teacher education reform and is applicable to local pre-service teacher training and curriculum design (Andreasen et al., 2022; Yan et al., 2018).	Andreasen et al. (2022); Yang et al. (2022)
Standardized Survey Instruments	Madsen & Thorvaldsen Digital Competence Survey	Standardized assessment instruments	It has been validated in multiple country contexts and has good cross-cultural applicability (Madsen & Thorvaldsen, 2022)	Janeš et al. (2023)
	Digital Teacher Competence Dimensions		Understanding the different dimensions of pre-service educators' digital teaching competence	Meling (2022)

In recent years, investigations into the digital competency of pre-service educators have increasingly been systematic and varied. Different studies have adopted a variety of frameworks and tools to assess their digital literacy levels. The 17 articles selected for this study can be mainly classified into five categories: standardized framework, integrated framework, theoretical

framework, national framework, and standardized survey instruments, as shown in Table 6. Commonly used frameworks in current research include DigCompEdu and TPACK. The former emphasizes cross-cultural adaptation and structural integrity, while the latter is more suitable for technology integration analysis in teaching situations. Frameworks such as ISTE are used less frequently, are mainly limited to general skills assessment, and lack adaptability to teaching scenarios. In addition, different frameworks also show certain gaps in implementation tool support and assessment dimension coverage.

First, the most widely adopted is the DigComEdu, its international structure, cross-cultural adaptability, and high fit to teaching situations resulting in it being widely used in pre-service teacher research in many countries (Hoang, 2024; Lyubka, 2025; Momdjian et al., 2024, 2025a, 2025b). In addition, some studies are based on DigComp to assess citizens' general digital literacy, covering core competencies such as collaboration, information literacy, problem-solving, creation, and security (Carretero et al., 2017; Ferrari et al., 2013).

Secondly, some scholars have attempted to construct an integrative theory, integrating DigComp with the TPACK framework (e.g., Cebi et al., 2022) to capture teachers' progress in technology teaching content knowledge and digital competence. The TPACK framework itself is also widely used by Belda-Medina et al. (2022), Ismaeel et al. (2022), Madsen et al. (2023) and Fitrah et al. (2025). TPACK is a practical conceptual framework, particularly suitable for understanding how teachers integrate digital tools in actual teaching and carry out technology-enhanced teaching activities (Ismaeel et al., 2022).

In addition, to adapt to the regional education reform background and policy orientation, many studies have adopted national or local frameworks. For example, the Norwegian study adopted the Professional Digital Competence framework, emphasizing the awareness of moral consciousness and the multidimensional professional ability of teacher development, reflecting the deep integration of the local culture and institutional environment of teacher education (Andreasen et al., 2022). In the Chinese context, an evaluation system designed based on national information technology standards was also studied to accurately assess pre-service educators' self-assessed digital competence and establish a scientific foundation for their digital competence training (Yan et al., 2018).

Finally, some standardized assessment tools have also emerged in the research, such as the use of digital tools developed by Madsen and Thorvaldsen (2022), which has been verified in multiple national contexts and has become an empirical tool with cross-cultural comparability (Janeš et al., 2023). It is worth noting that Meling (2022) introduced a five-dimensional model called Digital Teacher Competence Dimensions in his research, aiming to understand the diverse performance of pre-service educators in digital teaching.

In short, the current measurement tools for pre-service educators' digital competence are becoming increasingly diverse, ranging from international

standards to theoretical construction to local adaptation. Future research can further explore the integration and adaptability of these frameworks to serve teacher education practices in different cultures and education systems.

In addition, in terms of frequency of use, TPACK and DigCompEdu are currently the most commonly used frameworks, which respectively emphasize determining teachers' ability to effectively use technology in teaching (Almaiah et al., 2022) and fostering the enhancement of educators' digital competencies (Redecker et al., 2017). The TPACK theoretical framework has been embraced by several scholars in education and is seen as effective in incorporating technology into teaching practices (Gür, 2015).

For example, Andreasen et al. (2022) evaluated teachers' teaching ability in integrating augmented reality technology based on the TPACK framework in their study in Norway and found that project-based learning can effectively improve their teaching integration literacy. In addition, Momdjian et al. (2024) conducted research in Lebanon comparing the digital competencies of pre-service and in-service teachers using the DigCompEdu paradigm, revealing that pre-service teachers lagged considerably in several competency characteristics, highlighting the urgency of systematically cultivating digital literacy in teacher education.

TPACK is seen as an emerging form of knowledge that provides a foundation for high-quality technology-integrated teaching. The model requires the organic integration of pedagogical knowledge, subject content knowledge, and technological knowledge, and emphasizes the teacher's ability to design instruction at the intersection of multidimensional knowledge. TPACK offers a contextualized and nuanced viewpoint, providing a theoretical framework for the creation of teacher training methods focused on digital competency (Risquez et al., 2022). However, the primary obstacle to its broad use in empirical research is the absence of standardized instruments for efficient evaluation of each key area (López-Nuñez et al., 2024).

In contrast, DigCompEdu is an empirically based framework that can be used as a basis for educational policy making and for national or regional teacher training programs. By providing a unified terminology and structure, the framework helps countries engage in cross-border dialogue and share best practices in teacher digital competence building (Risquez et al., 2022).

However, a limitation of DigCompEdu is that it pays less attention to the impact of individual differences, external support conditions, or specific teaching contexts on teachers' digital competence performance (Risquez et al., 2022). Overall, TPACK emphasizes knowledge construction in the process of teaching integration, while DigCompEdu is more policy oriented. The two have different focuses in terms of functional positioning and application and can provide complementary support for different research and practice goals.

5. Discussion

This research aims to systematically examine the factors that affect pre-service educators' digital competence, the global patterns between countries, and the currently commonly used assessment frameworks. The results show that: (1) Multidimensional factors such as training design and individual psychology jointly affect the advancement of pre-service teachers' digital competence; (2) Basic skills are common in different countries, but there are significant differences in high-level competence; (3) DigCompEdu and TPACK are currently the most commonly used assessment frameworks.

These findings provide important references for teacher education curriculum design, policy making, and subsequent research. Regarding the first research question, the literature shows that (1) training and curriculum practice support, (2) psychological and environmental support, (3) policy system and resource environment, (4) legal ethics and digital literacy, (5) and individual characteristics are important influencing factors. For example, self-efficacy and a collaborative atmosphere significantly influence the enhancement of digital competencies (Hoang, 2024).

Çebi et al. (2022) highlighted a positive association between digital skills and TPACK competencies. Gender, age, and education can be considered as influencing factors in the acquisition of digital capabilities, but not determining factors (Cabezas-González et al., 2021), this view is also supported by Nurzhanova et al.'s (2024) empirical research on the impact of background variables on teachers' technological literacy. At the same time, these results not only verify the findings of Peiffer et al. (2020) and Jorge-Vázquez et al. (2021), but also further confirm the views of McDowall et al. (2021) and Lin et al. (2023) who emphasized strengthening technology integration capabilities in teacher training.

The second question explored the similarities and differences between different countries. From a comparative analysis, pre-service teachers in most countries have basic digital skills, but there are differences in teaching integration, policy orientation, and infrastructure supply. For example, Nordic countries such as Norway pay more attention to teaching innovation (Kaimara et al., 2021), and pre-service teachers are ready to incorporate digital technology into teaching (Janeš et al., 2023), while countries such as Vietnam and Indonesia emphasize technology functionality and accessibility (Faraasyatul et al., 2024; Hoang, 2024). These differences not only reflect differences in educational policies, resource accessibility, and cultural values, but also suggest that we should consider its adaptability and locality when promoting the global digital teacher competency framework.

The third research question focuses on the use of assessment instruments. Currently, widely used frameworks include DigCompEdu, the TPACK model, and localized standards in various countries, such as China's "Standards for Information Technology Application Competence of Primary and Secondary School Teachers" (Yan et al., 2018). DigCompEdu performs well in terms of

structural integrity and international adaptability, which further supports the view of Tomczyk and Fedeli (2021) that the framework is applicable to a wider range of educational contexts and diverse teaching practices, but their international comparability is relatively weak. This suggests that, in the future, we should promote the local adaptation of global frameworks or develop compatible assessment tools to achieve a balance between standardization and differentiation.

6. Implication

This study theoretically integrates the three perspectives of impact mechanism, global patterns and evaluation system, enriching the international dimension of the research on digital competence of pre-service educators. It is valuable insights for teacher educators, curriculum developers, and policy makers and emphasizes that training programs with local adaptability should be locally adapted to specific teaching contexts, the digital competence assessment framework should be optimized, and attention should be paid to the dual challenges of technological operation and ethical considerations. In addition, research in developing regions is still relatively weak, and factors such as institutional support, technology resource allocation, and teaching practice opportunities should receive more attention. The relevant suggestions are based on the reviewed literature and have certain cross-cultural applicability and practical value.

7. Limitation

Although this study is based on a systematic literature review, it still has some limitations. The literature mainly comes from English databases, which may ignore some high-quality non-English studies and regional results. In addition, the number of studies in some subject areas is limited, which is not enough to support in-depth comparison and trend analysis. In addition, the included studies have differences in method design, sample selection and evaluation tools, which may have a certain impact on the consistency and comprehensive interpretation of the results. Future research can further broaden the search sources, combine longitudinal research designs, and further focus on the development of digital capabilities of teacher educators themselves, especially in resource-poor areas.

8. Conclusion

This study systematically reviewed the empirical research on pre-service teachers' digital competence in recent years, and categorized it into three aspects: influencing factors, international commonalities and differences, and assessment tools and frameworks. The research is based on the teaching hypothesis that digital competence is a cultivatable, context-dependent professional ability the development of which is affected by multiple factors such as curriculum design, institutional support and individual characteristics. This study summarized five major influencing dimensions, including the joint influence of multidimensional factors such as training and curriculum practice support, psychological and environmental support, policy system and resource environment, legal ethics and digital literacy, and individual characteristics. The results show that some

basic skills are universal, but there are obvious regional differences in high-level capabilities and practical applications, reflecting the multi-faceted influence of policy and resource conditions. The innovation of this study lies in the construction of a multidimensional classification framework, integrating the scattered findings of previous studies, and incorporating ethical and policy factors into the analysis perspective, filling the gap of previous studies that focused on skills and neglected context.

The implications for educational practice include curriculum developers should adopt a hierarchical modular training model that incorporates real teaching situations and reflection mechanisms; teacher educators should simultaneously strengthen the training of technology and teaching integration; and policymakers may consider establishing a digital competence certification system to achieve effective connection between training, evaluation and resource allocation. Future research can further focus on the local adaptation of the framework, the development path of high-level competencies and cross-national comparison, so as to promote the sustainable improvement of teachers' digital capabilities in the context of global education digital transformation.

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