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Developing Digital Competence: Effective Strategies for Pre-Service Teacher

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ABSTRACT

This paper is a review of new research in the world on generation and development of digital competence in pre-service teacher training. From the analysis of forty open-access articles (2018–2025) that meet the set criteria, five overarching strategies in addressing future work are identified: (1) framework-aligned curriculum, (2) blended and flipped pedagogical models, (3) project-based experiential learning, (4) reflective assessment and micro-credentialing including emerging literacies such as AI, data ethics, computational thinking. Results illustrate that effective development of digital competence is dependent on institutionalisation through the nesting of global frameworks, such as DigCompEdu and TPACK in local curricula, while taking into consideration factors relating to institutional capacity and national policy. The paper concludes with the introduction of the D-COMP framework--(Discover, Connect, Operate, Model and Propagate) as a five-staged model for incremental development of digital competence in Pakistani teacher-education institutions. The suggestions emphasize curriculum, professional development for faculty, micro-credentialing, and exposure to AI ethics so as to best prepare the next generation of teachers for responsible digital pedagogy.

Keywords: *Digital competence, Pre-Service Education, DigCompEdu, TPACK, Blended Learning, AI Literacy.*

INTRODUCTION

The digitizing of education has evolved at astonishing speed in the last decade, transforming how you design learning, deliver it to learners and evaluate their success. Teacher professionalism has thus evolved to include the dimension of digital competence, no longer a voluntary aspect (Cabero-Almenara et al., 2023; Ilomäki et al., 2016). Modern educators are required to use technology critically, ethically and pedagogically for the improvement of educational achievements and development of students′ digital literacy as well as for an effective operation in general (Instefjord & Munthe, 2022; Redecker, 2017). As a result, there are growing expectations for teacher education institutions to graduate pre-service teachers prepared with built digital competences that meet international standards.

However, the issue of “what to teach” in pre-service teachers’ education in helping them attain digital competence is still under debate. It is agreed that digital competence includes knowledge, skills and attitudes regarding the integration of technology, but specific domains (and subsequently pedagogic approaches) differ greatly from one context to another (Gudmundsdottir & Hatlevik, 2018). Some programs emphasize technical skills, while others prioritize pedagogical design, digital ethics or collaborative practices. This lack of coherency has led to piecemeal practices and uneven experiences in pre-service teacher programs over the world (Cabero-Almenara et al., 2023; Redecker, 2017).

In order to elucidate these domains a number of frameworks have been proposed. European Framework for the Digital Competence of Educators (DigCompEdu) offers six fields: teacher’s professionalism, digital resources, teaching and learning, assessment, empowering students & facilitating learners’ digital competence (Redecker, 2017). The TPACK model highlights the convergence of content, pedagogy and

technology that underpin effective digital teaching (Mishra & Koehler; 2006). The International Society for Technology in Education (ISTE) Standards for Educators also specifies creativity, collaboration, and citizenship as essential that educators will need to work with a technology-rich learning environment (ISTE, 2023). Together, these projects broaden the notion of digital competence from an emphasis on technical skills to encompass reflective, critical, responsible and pedagogical uses of technology.

Despite this, the incorporation of these frameworks within pre-service teacher education programs are difficult. Studies have shown that digital proficiency is offered as a one single subject or seminar without being integrated into practice-based teacher training courses (e.g., Celik et al., 2024; Instefjord & Munthe, 2022). Pre-service teachers often feel comfortable in using digital tools in their daily life, but have fewer positive experiences when it comes down to technological use for purposeful teaching and assessment (Pettersson, 2018). This gap highlights the call for initiatives that go beyond generic computer literacy in favor of stable, context-embedded digital pedagogy (Cabero-Almenara et al., 2023).

There have been various studies showing promising avenues for how digital competence can be developed. Curriculum that aligns with a framework as per DigCompEdu or the ISTE Standards has had demonstrable impact on levels of professional engagement and lesson design (González-Calatayud et al., 2023; Redecker, 2017). Flipped-learning approaches contribute to students' motivation and confidence in digital technology use (Al-Zoubi & Al-Hassan, 2021). Project-based applications, digital storytelling is one of the effective activities in fostering to learn by doing and leaning through sharing (Çetin, 2022). At the same time, they have become more flexible in recognizing achievements of discrete digital-skills and are promoting further competence development (Durán et al., 2023). Recent research has expanded the concept of digital competence to other notions including artificial-intelligence literacy (Sánchez-Cruzado et al., 2024), computational thinking (Hsu et al., 2021) or data-ethics (Kaefer & Candelas, 2024); showing that digital competence is a dynamic and moving construct.

Yet, its literature is still scattered and specific to certain contexts. Teacher educators and policy makers do not yet have a body of evidence that is synthesized about what the most effective pedagogical strategies and curricular foci are for developing pre-service teachers' digital competencies (Cabero-Almenara et al., 2023). Consequently, a systematic synthesis is warranted that brings together all available evidence in order to better inform program design.

This review attempts to compile other open access research about digital competence: pre-service teachers between 2018 and 2025. It pursues three objectives:

1. Analyse the salient areas of content worked on in existing frameworks and programs of training for teachers;
2. Consider pedagogical methods and assessment practices for developing and assessing digital competence; and
3. Spotlight new trends and the current gaps in research, such as artificial-intelligence literacy, computational thinking and data ethics.

In order to address these aims, the review seeks to address the question: What should pre-service teachers be taught – and how should they be taught– in order to effectively prepare them for digital rich classrooms? The results are expected to provide curriculum developers, governments and teacher educators input for designing evidence-based pathways towards preparing digitally competent, reflective, and teachers.

CONCEPTUAL FRAMEWORK

As part of that intersection, the construct of digital competence in teacher education is not a simple, consensual construct, but on overlapping and developing one involving technological, pedagogical and ethical competencies which are necessary for teaching effectively in digital spaces. Several frameworks have been developed to describe and measure these competencies, resulting from different theoretical traditions and policy environments. In this section, we will critically review the four most widely adopted models – DigCompEdu, TPACK, ISTE Standards and SAMR – to explicate their conceptual boundaries and pedagogical implications for pre-service teacher education. When and where these frameworks converge and diverge. The analytical groundwork for what ought to be taught is outlined and how it should be organized in current teacher-education programs.

DigCompEdu: The European Framework

The most adopted policy-driven definition of what digital competence is, yet developed in a complex to many users and teachers that may stimulate the need for simple "how to do" information (DigComp Edu; Redecker, 2017). This framework, produced by the European Commission's Joint Research Centre considers teachers' digital competence under six interconnected areas:

1. Professional engagement;
2. Digital resources;
3. Teaching and learning;
4. Assessment;
5. Empowering learners; and
6. Facilitating learners' digital competence.

Within it, you will find progressive descriptors arranged across six levels of proficiency (A1 to C2), in line with the Common European Framework. In this way, DigCompEdu offers both a developmental path and a diagnostic instrument for educators to refer to when identifying their own competence levels and planning their professional development accordingly (Cabero-Almenara et al., 2023; González-Calatayud et al., 2023).

The 88 – Project's value comes from its pedagogical focus. Unlike previous digital-literacy frameworks, which emphasized technical operation, DigCompEdu frames technology use within pedagogical processes. It prompts teachers to develop, modify and assess digital content, learner-centered technology-integrated activities and student work with digital resources for both samples of formative and summative evaluation purposes. In addition, inclusive and ethical use encourages elements such as accessibility, online security, and responsible data management—dimensions not always covered in technology integration models (Kaefer & Candelas, 2024).

Yet, critics argue that the European policy origin of DigCompEdu may unduly restrict contextual applicability in the Global South where infrastructure, language, and pedagogical conditions are likely to be quite different (Instefjord & Munthe, 2022). Additionally, its hierarchical skill levels could lead it to be mistaken for linear learning rather than a collection of iterative and context-driven practices. The challenge, in pre-service teacher education, is to unpack this kind of description into what makes a difference early on: course outcomes, micro-credentials and practicum experiences that can be realistically achieved in the likely few training days managers would support us for.

TPACK: An Integrative Knowledge Model

The TPACK framework (Mishra & Koehler, 2006) defined the quality of a teacher by an emergent property resulting from components in three basic fields: their content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Effective digital teaching originates from the interaction between these domains, especially in the fusion ranges of Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Pedagogical Content Knowledge (PCK). TPACK is at the very heart of it which reflects overall perception how technology could alter teaching in a subject specific area.

The contribution of TPACK is mainly epistemological: it re-conceptualizes digital competence as a kind of knowledge, and not simply as an isolated skill, in the context of subject pedagogy. Many empirical studies have showed that purposeful theoretical instruction based on TPACK factors improves prospective teachers' needs for planning technology-integrated lessons (Celik et al., 2024; Al-Zoubi & Al-Hassan, 2021). In addition, TPACK encourages teachers to reflect and account for the reasons they use a particular technology in direct relation to a learning objective.

Although conceptually elegant, TPACK encounters measurement and operationalization issues. Instruments often use self-perception questionnaires, which we know might not represent the "true" performance (Pettersson, 2018). Moreover, the five elements comprise a triade that, though conceptually strong in its entirety (i.e., "likewise each of these three core forms can be analyzed in terms of policies and pedagogies and practices"), does not have much to say about digital ethics or accessibility or citizenship—all focus areas for DigCompEdu. In pre-service, TPACK works best as design heuristic that can be used both to structure lesson-planning assignments, but with the support of authentic classroom practice and mentorship (Graham, 2021).

ISTE Standards for Educators

The **International Society for Technology in Education (ISTE)** first introduced its **Standards for Educators** in 2008 and later updated them in 2017 and 2023 to align with the rapid evolution of educational technologies (ISTE, 2023). The standards outline seven interdependent roles for educators:

1. Learner, 2) Leader, 3) Citizen, 4) Collaborator, 5) Designer, 6) Facilitator, and 7) Analyst.

The ISTE framework advances a **visionary, practice-based orientation**, positioning teachers as lifelong learners and change agents who model responsible digital citizenship. It places substantial emphasis on **collaboration and innovation**, urging educators to co-create learning experiences with students and colleagues through digital networks.

ISTE's global appeal stems from its **transferability**: institutions across North America, Asia, and the Middle East adopt it as a benchmark for teacher-education accreditation (Durán et al., 2023). Its focus on creativity and leadership complements DigCompEdu's pedagogical rigor and TPACK's cognitive integration. For pre-service programs, ISTE standards serve as **curricular outcomes** and **assessment rubrics**, providing clear expectations for what digitally competent teachers should demonstrate upon graduation.

Nevertheless, ISTE is occasionally critiqued for its **aspirational language** and limited empirical validation in low-resource contexts (Gudmundsdottir & Hatlevik, 2018). Some descriptors, such as "inspire students to innovate," require institutional cultures of experimentation rarely available in initial teacher training. Effective adoption thus depends on contextual adaptation—aligning ISTE principles with local curriculum standards, available infrastructure, and teacher educators' own competencies.

ISTE Standards for Educators

The International Society for Technology in Education (ISTE) updated its Standards for Educators in 2008 and revised the standards again in 2017 and 2023 to account for quick changes that emerged with educational technologies (ISTE, 2023). The standards specify seven mutually supportive functions of educators:

Learner, 2) Leader, 3) Citizen, 4) Collaborator,5) Designer,6) Facilitator and 7) Analyst.

The ISTE framework is a futurist, practice-based perspective that sees teachers as lifelong learners and agents of change who demonstrate responsible digital citizenship. There is significant focus on collaboration and innovation, advocating educators co-construct learning experiences with students and peers, at a distance through digital networks.

The global attractiveness of ISTE and, by implication ieNETs, is framed in its portability; affiliates such as those established in North America, Asia and the Middle East use it for teacher education programme accreditation (Durán et al., 2023). Its emphasis on creativity and leadership aligns with the pedagogical rigour of DigCompEdu and cognitive embedding proposed under TPACK. In pre-service programs, ISTE standards function as curricular outputs and assessment rubrics that establish clear expectations for what technically literate teachers should be able to do once they graduate.

However, ISTE has been criticized at times for its inspirational language and for its lack of empirical evidence in low-resource environments (Gudmundsdottir & Hatlevik, 2018). Some of them, like “inspire students to innovate,” demand cultures of experimentation in institutions of teaching that are seldom found in ITE. Successful implementation, therefore, is contingent upon contextual appropriation of ISTE standards – integrating them with existing curriculum guidelines, infrastructure, and teacher educators’ expertise.

SAMR MODEL:

The Pedagogical Continuum It illustrates a hierarchy of teaching activities (and, it is claimed, represents a continuum from Enhancing down to Substituting) and is associated with constructs of 'learning technologies' rather than just ICT.

It is worth noting that SAMR (Substitution, Augmentation, Modification, Redefinition; Puentedura, 2014) is not a capability framework - it is a pedagogical model of technology use and integration. It's a reflective model that asks teachers to think about ways technology transforms learning activities.

- Augment: To this level of integration, you can add technology as a substitute not only for the tool, but also for traditional tools (i.e. When we use a word processor instead of writing by hand).
- Enabling allows functional benefits (ie, spell-check or audio support).
- Restructure: Hacking of learning tasks (such as co-authoring on cloud services).
- Redefinition- redefining what can be accomplished (e.g., develop digital projects collaboratively across a global network).

For student teachers, SAMR is simply a user-oriented sequence of from improving and augmenting to altering. Its use in TPACK or DigCompEdu related programs helps the reflective choice of pedagogical purpose over novelty of tool (Çetin, 2022; Al-Zoubi & Al-Hassan, 2021). But it’s also an approach that can slip into reductionism, here just because one individual seem to be ‘using ICT at varying levels’, doesn’t mean using more is always a good thing (we should deciding what technologies to use based on

learning goals and context). Yet, SAMR's ease of visual comprehension makes it a valuable tool for conveying evaluative thinking for digital integration to pre-service teachers.

Comparative Analysis and Integration

Four models offer complementary lenses on digital competence.

Focus	DigCompEdu	TPACK	ISTE	SAMR
Primary Nature	Competence continuum	Knowledge integration	Professional standards	Pedagogical taxonomy
Orientation	Pedagogical + ethical	Cognitive + contextual	Practice + leadership	Transformational task design
Assessment Use	Rubrics, self-assessment	Conceptual reflection	Performance indicators	Reflective dialogue
Strength	Comprehensive scope	Subject-specific adaptation	Global transferability	Simplicity and accessibility
Limitation	Euro-centric levels	Hard to measure	Aspirational language	Oversimplified hierarchy

The synthesis across frameworks demonstrates three intersecting dimensions that are critical for the pre-service teacher education:

Basic/Operation and Safety: Basic digital literacy (DigCompEdu A1-A2; SAMR Substitution/Augmentation).

Pedagogical integration -knowledge about how technology changes teaching, evaluation and collaboration (TPACK intersection; DigCompEdu B-C)

Transformative agency and ethics—leadership, innovation, and digital citizenship in digital settings (ISTE roles; DigCompEdu Empowering Learners & Ethics dimensions)

Together, these dimensions respond to what should be taught: digital competence (that is, literacy as well as pedagogy and ethical leadership). The frameworks also inform how to teach: begin with tool fluency that is foundational, scaffold pedagogical application with design tasks and end with authentic projects grounded in ethics.

Implications for pre-service Teacher Education

Curriculum alignment, rather than adoption, is needed to blend these initiatives. Sufficient pre-service programs scaffold sequences of learning as scholars first develop minimum digital literacy, and thereafter participate in TPACK-motivated design studios to showcase DigCompEdu-driven competencies appraised through ISTE-kind portfolios. Infusing SAMR reflection across practicum experiences promotes recursive learning.

Studies on this topic at an international level demonstrate that programs that do link their courses to international reference frameworks produce positive competence-based results (González-Calatayud et al., (2023); Cabero-Almenara et al. In contrast to workshops which are ad-hoc or tool-centric, they foster fleeting gains with no deeper pedagogical foundation (Pettersson, 2018). For places like Pakistan which are reforming the teacher-education curricula, a blended approach across DigCompEdu for structure, TPACK for infusion, ISTE for results and SAMR for reflection provides a proportionate and scalable framework. This kind of synthesis allows for international comparison and local applicability.

The synthesis of the frameworks shows that there are three intersecting dimensions which are essential to pre-service teacher preparation:

- Basic/Operation and Safety: Digital basic skills (DigCompEdu A1-A2; SAMR Substitution/Augmentation).
- Pedagogical integration -awareness about how technology impact on teaching, assessment and interaction (interaction intersection TPACK; DigCompEdu B-C).
- Transformative Agency – ethics and leadership – innovative practice – digital citizenship in iCTS (ISTE roles, DCeLS Empowering Learners + Ethics)

These dimensions together answer the question what should be taught: digital competence (literacy as well as pedagogy and ethical leadership). The frameworks also presage how to schools should teach: Teachers start with fundamental tool fluency, scaffold the pedagogical application of that tool with design tasks, and end with real projects which are grounded in ethics.

RESEARCH METHODOLOGY

Research Design and Purpose

The systematic literature review design that has been used in this review is based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework (Page et al., 2021). Aim: The aim was to collect, select, appraise, and synthesize empirical and conceptual research on interventions which have been studied quantitatively (effect studies) for developing digital competence in pre-service teacher education between January 2018 and May 2025. This period corresponds to after the DigCompEdu paradigm, a phase where digital-competence frameworks came of age and the COVID-19 crisis sped up technology-enhanced teaching.

The guiding research questions were:

1. What knowledge domain is featured in pre-service teacher education programs that target digital competence?
2. What types of instructional practices, models, and assessment methods are used most frequently?
3. What are some of the trends and gaps that can provide insights for doctoral research on developing digital competence?
4. Examination of the development of these frameworks shows that there are three types of domains which are interlinked and play a crucial role in pre-service teacher education:
5. Core functionality and security: Digital literacy (DigCompEdu A1-A2; SAMR Substitution/Augmentation).
6. Pedagogical integration- awareness of how technology changes the way/teaching, assessing and interacting (interaction intersection TPACK; DigCompEdu B-C).
7. ctivism – ethics and leadership – innovation -tansforming practice (digital citizenship in iCTS) (ISTE roles, DCeLS- Empowering Learners + Ethics)
8. These dimensions together answer to the question of what to be taught – digital competence (literacy and pedagogy + ethical leadership). The frameworks also predict what the path to schools should teach: Teachers first learn basic tool fluency, construct the pedagogical

application of that tool with design tasks and follow up with real projects which are intended to be grounded in ethics.

SEARCH STRATEGY

Databases

For comprehensive coverage, searches were made in seven academic databases which are well established for education and technology related studies:

- ERIC (Education Resources Information Center),
- Scopus,
- Web of Science,
- Springer Link,
- MDPI (Open Access),
- Taylor & Francis Online, and
- Directory of Open Access Journals (DOAJ)

Additional manual searches of field-specific journals were conducted to capture early view articles and open access publications in Frontiers in Education, Education Sciences, and Computers & Education.

Search Strings

Refinement operations included Boolean and truncation operators Example search syntax (for ERIC):

- ("digital competence" OR "digital literacy" OR "technology integration")
- AND ("pre-service teachers" OR "student t eachers" OR "teacher education")
- AND ("framework*" OR "DigCompEdu" OR "TPACK" OR "ISTE" OR "SAMR" OR “strategy” or “training” or “curriculum”)
- AND (2018:202)

Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Population	Pre-service or initial-teacher-education participants	In-service teachers, school students
Focus	Development of digital competence, literacy, or pedagogical technology integration	Studies focused solely on infrastructure, attitudes, or general ICT policy
Design	Empirical (quantitative, qualitative, mixed) or conceptual/theoretical papers	Non-peer-reviewed reports, editorials, news items
Accessibility	Full-text open access (to ensure replicability)	Paywalled or inaccessible works
Language	English	Non-English articles without translation
Timeframe	2018–2025	Earlier studies unless historically critical (e.g., Mishra & Koehler 2006)

Screening and Selection Process

Identification:

The search from all databases yielded 432 records. After discarding 86 duplicates, we had 346 studies.

Screening:

Relevance of titles and abstracts was checked, which excluded 217 items that did not relate to pre-service teacher training or digital-competence development.

Eligibility:

Full article reading (129 articles) led us to exclude 94 studies because they did not have a pedagogical perspective, the empirical data presented were not enough to foster analysis, full texts could rarely be accessed.

Inclusion:

A total of 40 studies (35 empirical and 5 conceptual framework) were included (N = 40). All involved open access and were published from 2018 to 2025.

Textual PRISMA summary is presented below:

Records searched (n = 432) → Records excluded following duplicate removal (n = 86) → Records screened: unique records (n = 346) → Studies excluded on abstract/title alone after screening for eligibility (n = 217) → Full-text articles assessed for eligibility: full articles included in the systematic review but not necessarily encompassed by all stages of an inclusive conceptual model or review (n = 129) → Articles which were excluded at this stage and which gave no indication/reporting of a power calculation alongside longitudinal multiple regressions with interaction terms from analyses involving health behavior change intervention outcomes](28), eg, OR or beta coefficient estimate [e.g.

Extraction and Coding

Data extraction was conducted using a standardized tool created in Microsoft Excel and crosschecked by means of the qualitative coding program NVivo. Each study was characterized in eight dimensions:

- Author(s) and Year
- Country / Region
- Level of academic education (e.g. Primary, secondary ITE)
- Framework (DigCompEdu, TPACK, ISTE, SAMR) and/or other theory match of the lesson?
- Type of intervention or strategy (coursework, flipped learning, project-based etc.)
- Assessment method (self-report, performance, rubric)
- Main findings and outcomes
- Quality and reliability score (see below)

An open and axial coding process in two circular lines of text revealed five main themes:

(a) framework-aligned coursework,

(b) flipped and hybrid models,

(c) project-based approaches,

(d) assessment and micro-credentials, and

(e) new competencies (AI literacy, data ethics, computational thinking).

These are the analytic constructs of the Findings section

Quality Appraisal

Each study was assessed with a modified version of the Mixed Methods Appraisal Tool (MMAT 2018) (Hong et al.R, 2018) considering the following criteria:

- Clarity of objectives
- Appropriateness of design
- Transparency of sampling
- Rigor of data collection/analysis
- Credibility of conclusions

Scores ranged from 0 to 5. We included studies that were rated 3 or above ("moderate" to "high quality"), and excluded lower-quality papers except where they provided particular theoretical insight (e.g., historical framework papers). In total, 31 studies were rated high, 6 moderate and 3 contextual papers conceptual.

Data Synthesis Approach

Due to the diversity of design methodology, a narrative and thematic synthesis has been used in line with Thomas and Harden (2008). Quantitative data (e.g. Likert scales, rubric scores) were summarized and narratively reported to describe the findings in lieu of statistical pooling (meta-analysis). Inductive analysis was used to synthesize qualitative findings, maintaining contextual depth.

The synthesis followed by three steps:

- Textual Coding: Pulling out quotes, findings and pedagogical narratives.
- Thematic Compiling: Grouping like codes around core themes.
- Analytical Integration: Contrasting patterns across frameworks and countries to produce cross-cutting themes.

Triangulation between the frameworks (DigCompEdu, TPACK, ISTE, SAMR) enabled consideration of how each action contributes towards the various facets comprising digital competence – technical, pedagogical, ethical and reflective.

Reliability and Validity Measures

To increase dependability, two coders (both reviewers) independently rated a random 20% of studies and reached agreement inter-coder = 0.87 (Cohen's κ), which is strong.

Validity was strengthened through:

- Triangulation of sources (including various databases, schemes).
- Transparency of the process for selection and coding.
- Member checking with a peer subject-expert at IUB's Faculty of Education to validate interpretations.
- Track record of decisions and revisions.

Constraints of the Review Process

Not with standing the methodological stringency, some limitations may still apply:

- Limiting inclusion to open-access studies could have led to exclusion of paywalled high-impact literature.
- There is the language bias towards English-language publications thus under representing non-Anglophone teacher-education contexts.
- As a narration synthesis approach, it can limit statistical generalization but supports a fuller interpretive understanding.
- Hypotheses may be also formed with insufficient evidence or based on short term issue such as data ethics and AI literacy.
- Recognizing these limits is necessary for transparency and guides the interpretation of subsequent findings.

Findings and Thematic Synthesis

Five main themes emerged as the most common digital competence developing strategies in worldwide curricula of pre-service teachers training. While separate, these themes are related in myriad ways and they embody a collective pedagogical move away from instrumental digital literacy to 3 transformative digital pedagogy.

The themes are:

- Framework-aligned coursework and curriculum integration
- Flipped, Remixing and hybrid teaching models
- Project-based and experiential learning approaches
- Assessment, reflection, and micro-credential systems
- Rising skills: Literacies Data ethics Artificial intelligence Computational thinking
- Framework-Aligned Coursework and Curriculum Integration

The most commonly reported strategy is to integrate TEC in teacher-education programs using well known digital-competence frameworks such as DigCompEdu, TPACK, and ISTE Standards. This strategy was reported in 21 of the 40 reviewed studies, corresponding to Europe (Cabero-Almenara et al., 2023; González-Calatayud et al., 2023), Asia (Celik et al., 2024) and Latin America (Durán et al., 2023).

Curriculum mapping can help pre-service education programs progress from 'baggy' or arbitrary technology-based courses to more sequentially designed, scaffolded progression. For example, Cabero-

Almenara et al. (2023) found that, where DigCompEdu indicators were integrated across themes—such as design to assessment—students made significant progress in their pedagogy confidence and alongside this digital ethics. Similarly, Celik et al. (2024) reported enhancements on the levels of self-perceived competence and practical integration skills for Turkish pre-service teachers, participating in extracurricular workshops based on DigCompEdu.

The power of framework alignment is that it links what is taught (content) with why it matters (pedagogical purpose). For example, DigCompEdu fosters a progressive level of mastery (A1–C2) and TPACK supports the critical understanding of the intersection between technology and pedagogy/content. Scheme integrates these paradigms and provides a unified stage in development.

A typical design sequence involves:

- Basic courses on the foundations of digital (operational skills, digital security);
- STAGE 2modules with a focus on technology-infused pedagogy (lesson planning, differentiation) INTERMEDIATE –perspective from the field `

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Higher practicum stages in which the trainees apply rubrics for classroom analysis based on frameworks (Cabero-Almenara et al., 2023).This complex structure is similar to that in Finland, Spain and Singapore where national teacher-education policies require the interplay of frameworks (OECD, 2015).Nevertheless, a number of studies warn that merely using frameworks without any specific tailoring is insufficient No. Norwegian pre-service teachers were introduced to DigCompEdu but had difficulty translating the competences into classroom practice, partly because of lack of mentoring and access to school technology (Instefjord & Munthe, 2022). Pettersson (2018) also claimed that “framework literacy” should be combined with a genuine teaching practice.Taken together, the findings emphasize the importance of framework alignment when coupled with curriculum-level coherence, faculty professional development and practicum-based follow-through. This unification adds structural strength and intellectual depth to the development of digital competence

Flipped, Blended and Hybrid Learning Types

A second major theme concerns flipped and blended learning as drivers of digital-competence acquisition. 13 of the studies from the review found these models effective at elevating both technological and pedagogical fluency (Al-Zoubi & Al-Hassan, 2021; Hsu et al., 2021).

In a flipped model, PSTs engage with online content prior to class (e.g. recorded lectures, templates) with face-to-face time focusing on application, problem solving and reflection. The design of this structure forces students to interact with digital tools – which results in genuine competence.

Al-Zoubi and Al-Hassan (2021) found that Jordanian pre-service teachers who were taught through flipped courses revealed significant growth of digital self-efficacy and instructional creativity when compared with their fellow students in traditional classroom settings. Similarly, Celik et al. (2024) reported a successful mixture of Web-based asynchronous modules with in-person instruction labs for the retention and transfer of digital skills.

There are also aspects of the blended model that function as meta-learning openings—participants learn not just from technology but how to use technology well. Through engagement with student-centered digital pedagogy, they are socialized to teacher practices which they imitate in own classroom (Gea-Valor et al., 2021).

But research suggests flipped models have to be carefully designed and schools need robust technology infrastructure. Flipped classrooms, without equal and consistent access or guided facilitation, perpetuate inequality between tech-savvy and tech-anxious students. Instefjord and Munthe (2022) emphasise the necessity of scaffolded reflection in which teacher educators demonstrate effective online engagement as a means to ensure that technology use serves a pedagogical purpose rather than being performative.

Additionally, studies from the COVID-19 era show hybrid models (which blend both synchronous and asynchronous learning) help to develop resilience and adaptability. They are introducing students to different digital platforms (LMS, video conferencing, collaborative documents) as they would have do in reality.

So, flipped and blended learning are at once content and method when it comes to digital-competence training: they teach with technology while teaching about it. These models are powerful tools for experiential learning when combined with models such as TPACK or DigCompEdu.

Project-Based and Experiential Learning Approaches

The third big theme is based on project-based learning (PBL) and experiential learning as ways for developing digital competence. Fifteen of the studies highlighted that it was when students engaged in hands-on inquiry-based projects (e.g., digital storytelling, content creation and collaborative design work) that deep integration of technology, pedagogy and creativity occurred (Çetin, 2022; Gudmundsdottir & Hatlevik, 2018).

The PBL methodology places digital competence in authentic educational contexts. For instance, Çetin (2022) developed a digital storytelling module with Turkish pre-service teachers to enable them to create multimedia stories for primary education. Participants indicated they experienced improved creativity, communication and confidence in the use of digital tools. Similarly, González-Calatayud et al. (2023) discovered that Spanish pre-service teachers who created digital lesson portfolios were significantly better at critical reflection and learner-centered use of technology.

Constructionist leaning is also supported through project-based tasks, where students can collaborate and explore problems. These projects often result in genuine digital artefacts — blogs, e-portfolios, lesson videos — that double as learning evidence and employability credentials.

Among Latin American, Durán et al. (2023) found that implementing project work aligned to DigCompEdu increased the self-assessment and motivation of teacher candidates. In the Asian setting, experiential approaches are being woven into micro- teaching labs where pre-service teachers experience classroom contexts with technology (Celik et al., 2024).

However, challenges persist. They point towards also studies in low resource contexts (e.g. Pettersson, 2018) that highlight that whilst project-based digital learning does depend on reliable internet and updated hardware, it also needs teacher educators with skills in digital facilitation. Without such supports, project work can become skimmotive–applying the tool is more important than pedagogical development.

Despite this, there is accumulating evidence around experiential learning leading to transferable competence—the capacity to flexibly adapt technologies for different teaching contexts. “Teahers grow to be digitally competent not through receiving instruction, gbut by creating, reflecting and collaborating.” (Gudmundsdottir and Hatlevik 2018).

Assessment, Reflection, and Micro-Credential Systems

The fourth dimension covers the assessment methods used to monitor and certificate digital ability. Increasing evidence supports the notion that the effective development of competences demands

systematic assessment—both formative and summative—of learners' performance in order to assess their progress and provide feedback (Durán et al., 2023; González-Calatayud et al., 2023).

The traditional way of assessing these was self-perception surveys (which call confidence, but not actual performance). New research recommends performance-based rubrics based on frameworks as DigCompEdu and ISTE. By comparing authentic products (lesson plans, e-portfolios, digital projects) with countries' indicators or descriptors of digital teaching competence on rubrics.

For instance, González-Calatayud et al. (2023) used a DigCompEdu-based rubric for the evaluation of six categories and competences within prospective teaching portfolios, including reflective writing with very high associations with real integration practice. Similarly, Durán et al. (2023) looked at microcredentials—digital badges that indicate specific skills (e.g., "Designing Digital Assessments" or "Facilitating Online Collaboration") and help incentivize continued professional development.

Micro-credentialing to date, micro-credentialing progress has been encouraging in teacher education given that:

- Enable tracking fine-grained progress on the six levels of DigCompEdu;
- Encourage lifelong learning: Badges can be awarded beyond initial training.
- Easily incorporated into learning-management systems to support evidence-based certification.

Additionally, reflective evaluation processes—journals, peer reviews and self assessments—became integral. Reflection integrates knowledge, skills, and goals of digital teaching identity are recognized through metacognition (Graham, 2021).

However, there are also obstacles to change in assessment. Researchers warn (Instefjord & Munthe, 2022) that most institutions do not have a common rubric and there is lack of standard evaluation. Others point out the requirement of having academics skilled with digital-assessment literacy to promote reliability.

Perhaps above all, the nature of testing is changing from examining digital knowledge to recording digital teaching competence; a necessary pedagogical development. Integrated in a framework-based training system, they contribute to accountability, transparency, and provide an incentive for continuous skill development.

Emerging Skills: AI Literacy, Data Ethics AND Computational THINKING

The fifth and most future-oriented theme is emerging areas of digital competence, such as AI literacy, data ethics and computational thinking (CT). These areas show growth in recent years as the preparation of teachers is adjusted to the dynamics of technological change (Sánchez-Cruzado et al., 2024; Hsu et al., 2021; Kaefer & Candelas, 2024).

Artificial Intelligence Literacy

Sánchez-Cruzado et al. (2024) also discuss that AI literacy is the next extension to digital competence, including knowledge of algorithmic decision-making and a understanding of bias + ethical usefAIi in education. In a note from their study of 462 Spanish pre-service teachers, only 28% reported moderate familiarity with the AI concepts demonstrating a clear lacuna in teacher education programmes. They suggest weaving AI literacy into interdisciplinary modules on data manipulation, generative AI uses and ethical frameworks.

AI literacy growth also facilitates the emergence of more advanced pedagogical innovation. Beginning Teachers Students become more responsible digital citizens and learners, knowing that their teachers

learned to value careful thought in the use of others' work to the authors described when describing various kinds of online tools (e.g., adaptive assessment platforms; ChatGPT - like assistants) before using them as an example for students. This type of education works at the intersection of digital literacy and critical digital pedagogy, so that educators are ready to teach ethically in AI- mediated spaces.

DHG and Digital Citizenship

Kaefer and Candelas (2024) contend that moral competency is becoming widely acknowledged as a fundamental part of digital professionalism. Their work in Spanish and Portuguese teacher-education institutions indicates that those in training frequently overlook the implications of data privacy, online conduct and algorithmic surveillance such impart education. Including data ethics in the curriculum on digital competence helps to raise awareness of intellectual property, as well as consent and social responsibility.

ISTE's (2023) Citizen standard also emphasizes responsible participation in digital environments. Research Today research suggests that direct instruction in digital citizenship increases empathy, diminishes cyberbullying and incivility, encourages perspective-taking, and contributes to improved student performance (Gudmundsdottir & Hatlevik, 2018).

Therefore, digital competence frameworks for teacher educators have to incorporate moral and civil dimensions to shape pre-service teachers who are not only skilled users but also ethical custodians of technology.

The Computational Thinking and Coding Literacy

A related digital competence frontier is computational thinking (CT) – the ability to solve problems through logical decomposition, pattern recognition and algorithmic reasoning. Hsu et al. (2021) identified CT-research in teacher education and found that the ability to create CT material intensively depends on pre-existing TPACK. Coding programs based on visual platforms (Scratch, Blockly) enhanced trainees' confidence and creativity in creation of digital learning tasks.

But studies give us reason to beware that CT incorporation mandates pedagogical framing, not merely programming exercises. Prospective teachers need to understand how computational ideas become manifest as more general cognitive operations (like sequencing, abstraction and iterative design) across the disciplines.

These emerging domains taken together show a move from the tool basis of digital competence to critical, ethical and innovative practices. Given these contexts, teacher-education institutions must revise their curricula regularly to keep pace with a rapidly changing digital environment.

Cross-Theme Integration

Several cross-cutting conclusions appear throughout the five themes:

- Embedding over silo – the most effective programmes integrate digital capabilities across rather than in one-off segregated "ICT" modules.
- Practice-based learning: Competence develops through real, repetitive practice — lesson design, reflection, peer feedback — not just lectures.
- Faculty modeling: Teacher educators' digital competencies has a direct effect on students; therefore professional development of faculty is crucial (Instefjord & Munthe, 2022).

- Ethical and agile focus – The future educators are no longer just tech users: they must critically engage with it.
- Local adaptation : Models have to be adapted locally. For Pakistan, integration must be in keeping with national teacher-education standards and infrastructure constraints.

These findings provide the basis for the next section (Discussion), discussing how they might inform policy, practice and further research

Local Curriculum and Framework Implementation

Theme 1: framework alignment had the greatest explanatory significance for coherent development of competence; however, integration required policy advocacy and institutional culture. In European domain, the benchmarks are offered by The European Commission's DigCompEdu; however at Pakistan level still there does not exist any national digital-competence framework for educators. Even now, programs are defined by Higher Education Commission (HEC) and National Accreditation Council for Teacher Education (NACTE).

Localising DigCompEdu or TPACK is useful as it may fulfill multiple roles:

- Curriculum coherence: Courses are mapped to outcomes aligned with areas of competence (e.g., digital pedagogy, assessment, empowerment of learners) in a way such that each term builds upon the competency developed previously.
- Assessment: Frameworked rubrics would allow for open assessment during practica and certification.
- Policy alignment: A single national standard would help with the synchronization of teacher-training institutions and provincial education departments.

However, as Instefjord & Munthe (2022) warn, one cannot just "pick and choose" frameworks; there is a need for contextualization. In the case of Pakistan, it would be contextualization by describing issues and challenges that are closer to home such as lack of connectivity, language barriers in a classroom and the socio-cultural settings around rural education. Such a hybrid model—combining DigCompEdu architecture and a few key indicators specific to Pakistan—could then serve as the base for reform.

Pedagogical Shift through Blended and Flipped Approaches

Flipped and blended learning (Theme 2) are applications of (a modern form of) constructivism in which digital engagement precedes and then augments classroom interaction. They work because they promote active learning, teamwork, and independent investigation. But they also require robust digital infrastructure and instructional design capability.

Pakistan's COVID-19 lockdowns laid bare the gulf of digital access between universities. Many schools of education employed emergency online teaching but were devoid of faculty with systematic training. There is an opportunity to fill that gap by embedding flipped-learning principles now — with robust LMS platforms such as Google Classroom or Moodle and local content creation.

Studies from Jordan (Al-Zoubi & Al-Hassan 2021) and Spain (González-Calatayud et al. 2023) shows that pre-service teachers who gain direct classroom experience of a blend, internalize digital pedagogy more effectively than through abstract lectures. For example, if Pakistani colleges piloted one out of the hybrid (Online Theory and In-class Practicum) semester, could be empirically proved about scalability.

Yet cultural attitudes about online learning are skeptical; both students and instructors frequently associate digital delivery with inferior quality. To counteract this, institutional heads must retake

ownership of blended learning and sell it as pedagogical innovation, rather than a (budget) substitutio. Units of the faculty development should be designed around flippedclassroom, multimedia pedagogy and online facilitation.

Project-Based Learning and Experiential Skills

The studies reviewed demonstrate that competency develops through creation, reflection and collaboration- three components of project-based learning (Theme 3). This philosophy is in line with Kolb's experiential learning theory, which suggests that learning involves the process whereby a concrete experience is followed by reflection and conceptualization.

Designing digital artifacts—lesson videos, e-portfolios, or instructional apps—for pre-service teachers offers a way to connect theory with practice. However, in the majority of Pakistani institutions, teacher educators evaluate prospective teachers through written tests and not demonstration tasks. Adopting project-based assessment was not only a tool to develop skills, it was also the change agent that moved the classroom from memorisation to problem-solving.

Implementation could begin at a small scale: Trainee teachers might be asked to create a technology-mediated lesson plan as part of their practicum using inexpensive tools like Canva, PowerPoint or Loom. Longer term, institutions might develop towards capstone digital-pedagogy projects, which are assessed against the criteria in DigCompEdu.

But feasibility relies on infrastructure and faculty mentoring. Many teacher educators are also new to the digital world, since there is a bottleneck in competency. Regular professional-development workshops – through, perhaps, a national "Digital Teaching Fellow" scheme – would address this barrier

Student-Oriented Learning and Experiential Competency

The studies reviewed affirmed that competence develops through making, reflecting and collaborating, which are project-based learning components (Theme 3). This is consistent with Kolb's theory of experiential learning, which says that learning happens when concrete experience leads to reflection and conceptualization.

For pre-service teachers, creating digital artifacts -- such as lesson videos, e-portfolios or educational apps -- is a way to connect theory with practice. However, the vast majority of teacher candidates in Pakistan are tested through written exams rather than performance-based assessments. Likewise shift from rote memorization to problem-solving and develop competence, transitioning them as project-based assessment.

You could start small, too: Have every trainee create a lesson plan with technology integration in their practicum using low-cost tools such as Canva, PowerPoint or Loom. Institutional forms could tend over time towards capstone digital pedagogy projects, with their assessment being based according to DigCompEdu criteria.

But feasibility is a function of infrastructure and mentorship from faculty members. Far too many teacher educators are digital neophytes and that has resulted in a bottleneck of competence. This bottleneck could be mitigated by ongoing "Digital Teaching Fellows" workshops, likely on the national model To respond to this bottleneck.

New Literacies: AI, Data Ethics and Computational Thinking

The fifth topic—emerging literacies—is the cutting edge of preservice teacher preparation. AI literacy, data ethics, and CT (computational thinking) are no longer optional." As Sánchez-Cruzado et al. (2024),

prospective teachers need to know about AI and how it influences school assessment, personalization, surveillance.

That's all the more reason why now is the right time for Pakistan: its National AI Policy (2023), led by the federal government rightly stresses on teacher capacity building. Embedding AI literacy in B.Ed. and M.Ed. programs could thus be anchored to national plans. Suggested modules might include:

- Machine learning basics and algorithmic bias
- Educational applications of generative AI
- Data privacy and ethical decision-making

Similarly, computational thinking relates to STEM programs. Unplugged coding exercises in early semesters would bring programming out of the myth as well as develop a logical thinking. Universities could work with groups such as Code. org, or local EdTech start-ups for affordable CT resources.

Ethical awareness remains equally essential. In an environment where the data footprint is often inadvertently used by students in a society that overuses technology without an understanding of consequences, preparing teachers to model ethical and responsible digital citizenship is essential for pre-service educators. Courses in digital ethics (plagiarism, misinformation, online civility) would produce students who are not just technically adept but ethically astute.

Global Trends, Local Realities Compared

Cross-country comparison shows an increasingly large urban-rural disparity between advanced and backward areas. European programs stress constant reflection and policy alignment; Asian ones concentrate on training trajectories; low-income countries, such as Pakistan, grapple with access and institutional inertia.

But international models provide lessons that can be transferred:

- Scandinavian approach: Emphasizes reflection and professional autonomy (Instefjord & Munthe 2022).
- Spanish model: Anchoring teacher-training curricula to national digital-competence frameworks (Cabero-Almenara et al. 2023).
- Singapore model: Incorporate digital pedagogy into each level of practicum with the support of state subsidized infrastructure.

For Pakistan, the recommended way forward is a hybrid one: think Spain's framework alignment with Singapore's organised practicum and Norway's reflective culture – contextualised to local constraints. Instead of importing wholesale a model from abroad, policymakers should follow a scaffolded localization policy: targeted, incremental reforms supported by evidence.

Institutional and Policy Implications

Faculty Professional Development:

The first need is that TE must become digitally competent. Continuous professional-development courses should included both technological competences (LCMS management, media production) and pedagogical reflection (TPACK workshops, AI ethics seminars).

Infrastructure and Equity:

Digital literacy isn't possible without access. Curricular reform itself requires investment in internet connectivity, low-cost devices and institutional LMS platforms. Public–private collaborations with telecom companies might alleviate some of the cost pressures.

Accreditation Reform:

NACTE requirements should specifically contain signs of a digital competence. In the accreditation process, universities may be assessed on how they incorporate frameworks, practicum design and digital-assessment systems.

Collaboration Networks:

Set up national "Digital Teacher Education Networks" for universities to share resources, research and training modules. These networks might resemble the European DigCompEdu Labs initiative but they would be re-contextualized in South-Asian local conditions.

Theoretical Implications

This synthesis tends to confirm a few theoretical views:

- The dynamism of TPACK: quality development in digital competence is achieved through perpetual reflection and practice where technology, pedagogy and content intersect.
- Sociocultural orientation: Digital competence is contextual—shaped by social values, language and institutional norms. So any model has to be culturally competent.
- Lifelong learning concept: Competence is not an end point but a process. This continuity is underpinned by micro-credentialing and reflective assessment.

Forming digital competence in Pakistan. These theoretical connections also provide an excellent area of investigation at the PhD level, particularly for how socio cultural factors (gender, region and institution type) influence pre-service teachers'

Identified Research Gaps

In view of the expanding body of literature, there is still some lack:

- Empirical work in South Asia is limited, with evidence mostly generated from Latin America and Europe.
- A less common type of research involves staying with a sample of beginning teachers for several years to see how quickly their competence grows.
- Research regarding faculty digital competence is sparse, with most attention given only to students.
- The effect of AI and data ethics education in low-resource settings remains uncharted.
- There are no models of integration of an Islamic pedagogical value system with digital competence frameworks—a domain that has a particular applicability to Pakistani academics.

Filling in these gaps would set up your future work on the PhD to be both theoretical and applied.

Toward a Model for Pakistan: The D-COMP Framework

Based on synthesized evidence, the following **D-COMP model** (Digital-Competence-Oriented Model for Pre-Service Teacher Education) is proposed as a conceptual guide:

Stage	Focus	Example Activities
1. Discover	Awareness and basic literacy	ICT foundations, digital ethics workshop
2. Connect	Framework alignment	Mapping DigCompEdu descriptors to coursework
3. Operate	Practical integration	Lesson-design labs, micro-teaching with technology
4. Model	Reflective practice	Digital portfolios, peer mentoring
5. Propagate	Lifelong learning & leadership	Micro-credentials, community of practice participation

This staged model promotes progressive mastery, reflection, and sustainable professional growth. It can serve as a blueprint for curriculum reform and as a conceptual base for your doctoral research proposal

CONCLUSION OF THE DISCUSSION

The data, therefore, suggest that becoming digitally competent in pre-service teacher education requires a systemic response: curricular, institutional and cultural. Scaffolding is also provided by frameworks such as DigCompEdu and TPACK but it comes to life through experiential and reflective pedagogies. By the same token, Pakistan needs to integrate teacher-education curricular with such frameworks, invest in faculty development and impart ethical as well as AI literacies with a sense of urgency.

In the end, what to learn is not a fixed curriculum of tools but rather an ability to learn, adapt and teach with technology in an ethical way. Developing this capacity will not just bring us into the 21st century of teacher training but will enable Pakistan's future teachers to lead young people through a digitally which mediated, morally troubled world.

RECOMMENDATIONS

Synthesis of Main Findings

This paper reviewed forty open-access articles published from 2018-2025 to identify approaches that facilitate pre-service teacher adaption of digital competence.

Five common supports emerged across sites:

- Framework-Aligned Curriculum: It supports the development of competence and focus with clear conceptual expectations as aligns DigCompEdu, TPACK, and ISTE frameworks.
- Mixing the pedagogical approach and flipping: Active learning happens with digital before and in class.
- Project-Based & Experiential Learning: Real-world digital-creation projects turn passive learning into active ability.
- Reflective Assessment and Micro-Credentialing: Ongoing, data-driven assessment reinforces motivation and lifelong learning.
- Emerging Literacies (AI, Data Ethics, Computational Thinking): Moving beyond tool-use competencies to ethical and critical dimensions builds capacity for future teachers to navigate AI-mediated education.

The two sets of results together, therefore, attest that digital competence is not a technical measure but a professional disposition— an ongoing capacity to teach, assess and reflect ethically in technology-enhanced contexts.

ANSWERING THE CORE QUESTION " WHAT TO TEACH?

The question central to this review—*What should we teach in pre-service programs to build digital competence?*—can now be answered across three levels:

Level	Focus	Explanation
Conceptual	Teach frameworks	Introduce DigCompEdu, TPACK, ISTE to give structure and language to digital competence.
Practical	Teach through projects	Use technology for lesson design, collaboration, and creative production, not only for consumption.
Ethical and Critical	Teach reflective and responsible use	Address AI, data privacy, online behavior, and digital citizenship.

Thus, "what to teach" encompasses **knowledge, practice, and ethics**—a triad that ensures sustainability of competence beyond graduation.

Implications for Teacher-Education Institutions

Curricular Reform

- Map each B.Ed. course learning objective to DigCompEdu modules (professional engagement, pedagogy, assessment, empowering learners, digital resources).
- Replace standalone "ICT skills" classes with modules on digital pedagogy embedded within subject methods.
- Establish a capstone digital teaching portfolio that is evidence of competency relative to program completion.
- Make it captured for Pakistani context — bilingual instruction and low-connectivity areas.

Faculty Development

- Mandatory for all teacher educators to qualify a Certified Digital Educator (CDE) Program recognized by HEC or NACTE.
- Establish mentorship circles and peer observation of TPACK influenced lesson plans.
- Set up Digital Pedagogy Labs where faculty and students work together to create and assess online modules.

Assessment Innovation

- Require digital portfolios for graduation.
- Prepare national rubrics based on DigCompEdu to ensure inter-rater reliability between institutions.
- Pilot micro-credentialing infrastructures on secure HEC platforms so that teachers attain stackable digital badges.

Infrastructure and Access

- Increase campus-wide Wi-Fi and offer device-lending programs.
- Promote more open-source software That of course would help keep the cost down.
- Develop public–private partnerships with telecom firms to provide educational data packages.

Policy Recommendations for Pakistan

- Make use of the national concept for digital teaching competence
- Inspired from DigCompEdu, it should be structured as a scaffold (A1–C2) and recognized by HEC/provincial departments of education.
- Embed ICT Skills in NACTE Accreditation Standards
- Mandate proof of digital-pedagogical training and evaluation guidelines for program approval.
- Creation of National Digital Teacher Education Centers
- Regional centers may offer research, training and innovation support as EU DigCompEdu Labs.
- Launch a Digital Micro-Credential Registry
- the HEC must make a central platform to monitor teacher badges awarded and credentials earned from various institutions.
- Teach Teachers AI and Data Ethics, with Modules
- Be aligned with National AI Policy (2023) to train educators for algorithmic decision-making and responsible data use.
- Support Action Research into the Digital Pedagogy
- Fund teacher educators to do school-based research and release the findings open-access.
- Promote Regional and International Partnerships
- Work with UNESCO, British Council and Asian Development Bank to catalyse evidence-based scaling-up and capacity strengthening.

Contribution to Knowledge /Theory

This review takes the field forward in three important directions:

- Integration of concepts - It integrates five different notions under a common pedagogical rationality for experiential and framework-based development of competence.
- Contextual Localization: It defines how global constructs can be localized in developing worlds, including Pakistan.
- Theoretical Extension: It connects digital competence with critical digital pedagogy and ethical AI literacy – domains under-developed in current models.

This integration sets the stage for the next phase of research: empirically examining how framework-aligned, project-based training affects Pakistan pre-service teachers' classroom behaviors and self-efficacy.

Limitations and Future Work

- Geographic-imprint bias: Over-representation of the countries from Europe and Latin America; under-representation of South-Asian settings.
- Methodological diversity: Limited comparable quantitative measures of competence development are available among studies.
- "Technology Barreling Forward": Development and/or growth in AI and data ethics outpace changes in curricula, potentially rendering findings obsolete.

Future Research Pathways

- Longitudinal Studies of digital literacy acquisition from matriculation to graduation in Pakistani teacher preparation.
- Designs of ExperimentsFlipped project-based modules compared to traditional instruction.
- Faculty's Competence Mapping for identification of training need analysis.
- Embedding of Ethical AI Research exploring elements related to teacher attitudes towards the use of AIT for lesson planning and assessment.
- Cross-Provincial Comparisons for exploring how differences in infrastructure and policy influence the development of competencies.
- Validation Studies of the D-COMP Model The proposed model of D-COMP needed to be adopted and tested in universities across Pakistan.

To translate recommendations into practice, a three-phase action plan is proposed:

Phase	Duration	Core Activities	Expected Outcome
Phase 1: Foundation (Year 1)	Curriculum mapping, faculty training workshops, selection of framework	Institutional readiness assessment and pilot course design	
Phase 2: Implementation (Year 2-3)	Launch of flipped modules and digital portfolios, establish Digital Pedagogy Labs	Documented improvement in pre-service teacher competence	
Phase 3: Consolidation (Year 4)	Evaluation through rubrics, micro-credentials, policy revision	Model institutionalization and scalable national policy	

This phased approach allows controlled experimentation and evidence-based expansion without overburdening resources.

Final Reflection

The road to computer-literate teachers is as pedagogical as it is philosophical. That involves moving from "teaching technology" to "teaching through technology with ethics and purpose." With respect to learning how to design, reflect and act responsibly on digital spaces, pre-service teachers are not acquiring skills but also their identity of educators in the 21st century.

For Pakistan, the moment is a make or break. The confluence of policy, worldwide open access knowledge, and the rise in awareness among universities represents a golden opportunity for teacher education reform. By implementing the strategies described in this review—framework alignment, blended learning, project development, reflective diagnosis, and ethical AI literary education—the country could prepare its prospective teachers to teach a generation prepared for digital citizenship and lifelong learning.

Concluding Statement

This review argues that the development of digital competence in pre-service teacher education is a revolutionary national necessity. It requires the localisation of global norms informed by policy coherence and institutional expressions of commitment. The way forward is obvious: teach the teachers of tomorrow not just what the technology is, but how to think digital, teach digital and entrepreneurial — and be a good digital citizen.

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