# Pedagogical Competencies in Mathematics at Secondary Level: A Systematic Review of Pre-Service Teacher Training Programs

**Abstract**:

This systematic review investigates the pedagogical competencies essential for teaching mathematics at the secondary level, with a specific focus on pre-service teacher training in India. Against the backdrop of global educational reforms and India’s National Education Policy (NEP) 2020, the paper explores how foundational frameworks like Pedagogical Content Knowledge (PCK) and Technological Pedagogical Content Knowledge (TPACK) are interpreted and implemented in teacher education. The study aims to identify core teaching competencies, evaluate their integration into curricula, and assess the effectiveness of training programs in preparing future educators.

Employing a systematic literature review methodology aligned with PRISMA guidelines, the study analyzes 54 peer-reviewed articles, national policy documents, and international frameworks. Key thematic areas include the classification of pedagogical competencies, curriculum alignment with national standards, evaluation practices, and theoretical models underpinning teacher development. The findings reveal significant gaps in the practical application of competencies, a disconnect between theoretical instruction and classroom realities, and uneven institutional capacity for integrating digital tools and reflective practices.

The review underscores the urgent need for context-sensitive reforms that embed structured mentorship, experiential learning, and longitudinal assessment into pre-service training. It argues for a shift toward evidence-based, digitally enabled, and equity-oriented teacher preparation models. Ultimately, the paper contributes to shaping a future-ready teacher education system that is coherent with both national priorities and international benchmarks.

**Keywords:** **pre-service teacher education; pedagogical competencies; mathematics teaching; PCK; TPACK; competency-based curriculum**

## Introduction

Mathematics holds a central place in secondary education, underpinning logical reasoning, quantitative analysis, and problem-solving – skills vital for academic and professional success in a knowledge-based economy. The development of mathematical proficiency among school students is closely tied to the quality of their teachers' pedagogical competencies. As secondary-level learners face increasingly abstract concepts, teachers must possess more than just content knowledge; they require refined pedagogical strategies to bridge the gap between mathematical theory and student understanding (Yigit, 2014).

Pedagogical competence encompasses the integration of content knowledge, pedagogical understanding, and contextual adaptability. In mathematics education, these competencies become particularly vital due to the abstract and cumulative nature of the subject (Gresham, 2008). Globally, education systems have prioritized teacher quality reforms, recognizing that well-prepared teachers significantly influence student learning outcomes. However, consistent challenges exist, including fragmented teacher training curricula, lack of practice-based learning, and inadequate focus on context-relevant pedagogy, especially in low- and middle-income countries.

In India, the National Curriculum Framework (NCF, 2005, 2023) and the National Education Policy (NEP, 2020) advocate for competency-based teacher education models. Despite these reforms, teacher preparation often remains theoretical and exam-oriented, with limited exposure to school-based teaching realities (Goos, Smith, & Thornton, 2008). Furthermore, initiatives like the Integrated Teacher Education Programme (ITEP) have been introduced to consolidate pedagogical development across disciplines. Yet, challenges in achieving integration and coherence persist, necessitating a systematic review of the pedagogical competencies developed through current pre-service programs.

At a global level, comparative studies suggest that countries with integrated pre-service education programs—such as Finland and Singapore—demonstrate higher levels of teaching efficacy and retention (Cetinkaya et al., 2016). These models embed practical experience, mentorship, and continuous feedback into teacher education. The Indian context, in contrast, reveals significant variability across institutions in pedagogical preparation, especially for mathematics teachers, underscoring the need to systematize teacher competency standards.

This systematic review aims to synthesize existing literature on pedagogical competencies relevant to teaching mathematics at the secondary level, with a particular focus on pre-service teacher training programs. The review prioritizes both global best practices and Indian policy documents (e.g., NCERT, NCFTE, ITEP) to examine how mathematics teacher competencies are defined, developed, and evaluated.

Specifically, the review focuses on:

1. Identifying the core pedagogical competencies required for teaching secondary mathematics.
2. Exploring how these competencies are integrated into pre-service teacher training programs, especially within the Indian educational landscape.
3. Assessing the effectiveness of current programs in preparing teachers with these competencies.
4. Evaluating the theoretical frameworks guiding teacher development, such as Shulman’s PCK and the TPACK model.
5. Recommending policy and curriculum innovations for future directions in mathematics teacher education.

By aggregating evidence from peer-reviewed studies, national policy documents, and international comparisons, this review endeavors to present a nuanced understanding of existing practices and gaps in teacher education.

This review is guided by the following research questions:

1. *What constitutes pedagogical competence in mathematics teaching at the secondary level?*

Pedagogical competence in mathematics involves the ability to explain abstract concepts, anticipate student misconceptions, use appropriate representations, and evaluate student understanding. These skills are aligned with frameworks such as PCK and TPACK, which emphasize the interplay between content, pedagogy, and technology (Meletiou-Mavrotheris & Prodromou, 2016; Yigit, 2014).

1. *What are the key competencies emphasized in pre-service teacher training programs?*

Studies highlight several key competencies such as conceptual clarity, the ability to design and adapt lesson plans, diagnostic assessment, and reflective teaching practices (Sujadi, Wulandari, & Kurniawati, 2019). However, there is a disparity in how these competencies are prioritized and assessed across teacher education institutions.

1. *How effective are current training frameworks in cultivating these competencies?*

Research indicates that current pre-service programs often focus heavily on theoretical instruction, with insufficient emphasis on classroom application and contextual pedagogy (Aguirre, Del, Zavala, & Katanyoutanant, 2012; Zuya, Kevin, Bala, & Attah, 2016). Furthermore, teacher anxiety, limited internship supervision, and disconnected curriculum elements impede the development of robust pedagogical competencies (Gresham, 2008; Walshaw, 2004).

In addressing these questions, this review seeks to build a coherent narrative around the evolution, current practices, and future directions of pre-service mathematics teacher training, offering evidence-based insights for policy reform and curricular innovation.

## 2. Systematic Research Methodology

This review employed a rigorous and transparent methodological approach based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to identify, evaluate, and synthesize relevant literature on pedagogical competencies in mathematics at the secondary level within pre-service teacher training programs. The process began with a comprehensive search of academic databases including ERIC, SpringerLink, JSTOR, Taylor & Francis Online, ScienceDirect, and Google Scholar. To ensure wide coverage, keyword combinations such as *“pre-service mathematics teacher training,”* *“pedagogical content knowledge in mathematics,”* *“TPACK and mathematics education,”* *“teacher education and NEP,”* and *“B.Ed curriculum analysis India”* were used. Searches were conducted iteratively over a period of four weeks, between May and June 2025, resulting in an initial pool of 243 documents that included peer-reviewed journal articles, policy frameworks, national curriculum documents, doctoral theses, and books.

Following the initial search, specific inclusion and exclusion criteria were applied to ensure the relevance and academic rigor of the selected sources. Studies were included if they focused on pre-service mathematics teacher training at the secondary level, presented empirical or theoretical insights into pedagogical competencies, or discussed national and international frameworks for teacher education. Priority was given to studies published between 2000 and 2025 to capture both foundational theories (e.g., PCK and TPACK) and contemporary developments such as the NEP 2020 and ITEP implementation. Government documents from NCERT, NCTE, MHRD, OECD, and TIMSS were also included due to their policy relevance. Excluded were papers unrelated to mathematics education, those focusing solely on in-service training, or articles lacking accessible full text. After this phase, 112 papers were shortlisted.

The PRISMA screening process was employed next to ensure clarity and reproducibility of selection. From the 112 shortlisted studies, 32 were removed due to duplication, 14 were excluded after full-text review for lacking direct relevance to pre-service pedagogy in mathematics, and 12 were removed due to methodological limitations such as insufficient data or lack of peer-review. This resulted in 54 final sources selected for full analysis. These included 45 peer-reviewed journal articles, 5 government policy documents (ITEP, 2021; NCF, 2005, 2023; NCFTE, 2009; NEP, 2020), and 4 institutional or scholarly books (such as the OECD framework and foundational works by Shulman and Rowland).

The final set of 54 sources was then thematically categorized to guide the narrative synthesis across the review paper. Literature was grouped under major themes such as (1) definitions and conceptual models of pedagogical competencies (11 papers), (2) curriculum analysis and competencies emphasized in national frameworks (9 papers), (3) effectiveness and evaluation of pre-service teacher education programs (10 papers), (4) integration of theoretical frameworks like PCK and TPACK (12 papers), and (5) future directions and policy reform related to teacher education (12 papers). This thematic organization ensured that the review remained coherent and focused, while allowing diverse strands of scholarship to inform a comprehensive understanding of pedagogical competencies in mathematics at the secondary level.

## 3. Defining and Classifying Pedagogical Competencies in Secondary Mathematics

### 3.1 Conceptual Overview of Pedagogical Competence

Pedagogical competence in the context of secondary mathematics education refers to the amalgamation of knowledge, skills, and attitudes required to facilitate student learning effectively. The term has evolved across literature and policy frameworks, with varying emphases depending on national contexts and educational paradigms.

According to UNESCO (2017), pedagogical competence encapsulates “a teacher’s capacity to translate curriculum into effective instructional practices, responsive to learner diversity and developmental needs.” The NCERT 2023 (in the National Curriculum Framework for School Education – NCF 2023), especially the section on mathematics education for the secondary stage defines it within its learning outcome framework as the ability to guide mathematical reasoning, problem-solving, and abstract thinking among adolescents. The NCTE (2009), through its National Curriculum Framework for Teacher Education (NCFTE), elaborates this further into three domains: academic knowledge, professional competence, and contextual awareness.

Academic literature adds granularity by differentiating among types of teacher knowledge. SHULMAN (1986) first introduced the concept of *Pedagogical Content Knowledge* (PCK), denoting the unique blend of content and pedagogy necessary for effective teaching. This idea evolved into more nuanced domains:

* *Content Knowledge (CK)*: mastery of subject-specific knowledge, e.g., algebra, geometry.
* *Pedagogical Content Knowledge (PCK)*: strategies to convey mathematical ideas, anticipate misconceptions, and connect abstract concepts to real-life contexts (Kılıç, 2011).
* *Technological Pedagogical Content Knowledge (TPACK)*: extension of PCK to include the integration of digital tools in instruction (Mailizar & Fan, 2020).
* *Assessment Literacy*: the ability to construct and interpret various forms of assessment to gauge student understanding (Boston, 2013).
* *Classroom Management*: structuring learning environments conducive to mathematical inquiry and collaborative exploration (Krauss et al., 2008).

These domains are foundational in evaluating the effectiveness of pre-service teacher preparation and ensuring alignment with both national curricular goals and global benchmarks.

### 3.2 National-Level Frameworks and Standards

India's educational policy landscape has increasingly recognized the need for defining and developing pedagogical competencies, especially in the domain of secondary mathematics education.

The National Curriculum Framework NCF (2005), and its successor NCF (2023), emphasize the integration of learner-centric, constructivist pedagogies in mathematics. The 2023 version further aligns with the vision of NEP 2020, shifting focus from rote learning to conceptual clarity, problem-solving, and critical thinking. In the context of secondary education, the NCERT Learning Outcomes (2019) outline specific benchmarks such as:

* Ability to solve algebraic equations and geometrical proofs.
* Interpretation of data and statistical reasoning.
* Logical justification of mathematical procedures.

Complementing this, the NCTE’s NCFTE (2009) proposes a framework that mandates teacher training institutions to integrate content mastery with pedagogical innovation. The framework identifies 11 key competencies including reflective practice, inclusive education, use of educational technology, and curriculum transaction.

Further, the Integrated Teacher Education Programme (ITEP) launched under NEP 2020 represents a structural reform aiming to offer a four-year holistic degree. It mandates continuous school internships, course modules on educational philosophy, and evaluation of professional ethics. A salient feature of ITEP is its competency-based architecture, ensuring that teacher candidates demonstrate practical competence through field-based tasks, digital portfolios, and situational assessments.

Together, these national-level standards form the backbone of teacher competency frameworks in India, although institutional disparities and inconsistencies in implementation remain major challenges (Strutchens, Huang, Potari, & Losano, 2018).

### 3.3 Global Classifications for Comparison

To situate Indian standards within a global context, it is instructive to examine internationally recognized teacher competency models. Below is a comparative table of key global frameworks:

**Table 1. Comparative table of key global frameworks**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Framework** | **Description** | **Domains of Competence** | **Relevance to Mathematics Teaching** | **Citation (Authors, Year)** |
| OECD Teacher Competency Model | Emphasizes knowledge, skills, and attitudes necessary for effective teaching. | Content, Pedagogy, Innovation, Diversity | Encourages contextual and inquiry-based math instruction. | (OECD, 2013) |
| TIMSS 2019 Framework | Focuses on assessing math learning outcomes through cognitive demand and curriculum alignment. | Cognitive domains, Instructional alignment | Provides data on how teachers' competence aligns with student performance globally. | (Mullis, 2009; Ok, 2024) |
| Shulman’s PCK Model | Introduces the blend of content and pedagogy specific to teaching subject matter effectively. | CK, PCK | Central to understanding math-specific instructional strategies. | (Shulman, 1986) |
| TPACK Framework | Builds on PCK to include technological integration in teaching. | CK, PCK, TK, TPACK | Emphasizes tech-based math instruction and digital modeling. | (Koehler & Mishra, 2009) |
| Knowledge Quartet (UK-based) | Framework to analyze teacher knowledge using practical classroom observations. | Foundation, Transformation, Connection, Contingency | Offers real-time diagnostics of math teaching quality. | (Rowland, Turner, Thwaites, & Huckstep, 2009) |

These global frameworks collectively highlight the multifaceted nature of pedagogical competence and offer reference points for evaluating and improving Indian teacher education.

## 4. Key Competencies Emphasized in Pre-Service Mathematics Programs

### 4.1 Competencies from National Curriculum and Policy Documents

The pre-service training of mathematics teachers in India is governed by national policy documents such as the National Education Policy (NEP, 2020), National Curriculum Framework for Teacher Education (NCFTE, 2009), and the Integrated Teacher Education Programme (ITEP, 2021). These frameworks articulate a shift from rote memorization toward competency-based teacher education.

Among the core pedagogical competencies emphasized, disciplinary knowledge stands primary—ensuring that teachers have deep and accurate content understanding in mathematical domains such as algebra, geometry, statistics, and calculus. In a comparative analysis of mathematics teacher curricula across nations, Tatto & Bankov (2018) found that 82% of U.S. pre-service programs emphasized rigorous content preparation as foundational for teaching effectiveness.

Pedagogical strategies, encompassing inquiry-based learning, problem-solving approaches, and learner-centered instruction, are increasingly promoted. NEP 2020 calls for these methods to be embedded through experiential modules. For instance, the ITEP document outlines compulsory coursework in constructivist pedagogy and mathematical modeling.

Logical reasoning and conceptual clarity are systematically reinforced through curriculum standards and assessment benchmarks. The NCERT Learning Outcomes for secondary mathematics stipulate that students should “establish logical connections between mathematical concepts and real-life applications,” a goal to be enabled through teacher competence.

Use of manipulatives and digital tools also feature prominently. According to a study by Chen & Mu (2010), 73% of surveyed institutions across China, India, and the USA incorporated ICT tools or manipulatives into their training models, with India trailing in practical application despite curricular provisions.

Finally, error analysis and assessment literacy are treated as both instructional and diagnostic competencies. Teacher educators are expected to prepare candidates to identify, analyze, and address student misconceptions through formative assessment strategies. (Gebremeskel et al., 2017) emphasized that programs lacking continuous assessment training resulted in teacher underperformance during practicum sessions.

### 4.2 Curriculum Analysis

Curricular documentation from major Indian teacher education programs—ITEP, D.El.Ed, and B.Ed—reveals varied emphasis on core competencies. The table below summarizes insights drawn from key research:

**Table 2. Insights from key research**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Program** | **Theoretical Emphasis** | **Practical Components** | **Key Competencies Included** | **Citation (Authors, Year)** |
| ITEP | Strong foundation in constructivist pedagogy and disciplinary content | School internships (20 weeks), project-based assessments | PCK, ICT integration, reflective practice, inclusive pedagogy | Bhattacharyya & Halder (2025) |
| B.Ed | Moderate content emphasis, extensive pedagogy modules | 16-week internship, microteaching, action research | Conceptual clarity, logical reasoning, error analysis | Khan (2012) |
| D.El.Ed | High theoretical overload, limited integration | 8-week practicum, basic lesson planning | Classroom management, assessment literacy | Gebremeskel et al. (2017) |
| US (Benchmarked) | Rigorous disciplinary focus, research integration | Multiple practicum experiences with mentor teachers | Modeling, critical thinking, reflection | Tatto & Bankov (2018) |

These variations indicate systemic gaps. For instance, while B.Ed programs emphasize theoretical underpinnings, implementation of ICT-based and reflective practices remains uneven across institutions. Hill, Lovison, & Kelley-Kemple (2019) reported that only 43% of teacher candidates in Indian institutions received practical ICT training compared to 86% in OECD countries.

### 4.3 Prioritization and Pedagogical Treatment

Despite policy shifts, there exists significant variation in how competencies are prioritized across programs and institutions.

Core competencies such as content mastery, pedagogical strategies, and logical reasoning are typically taught through lectures and standardized coursework. Yet, experiential and application-based strategies such as school internships, peer-teaching, and classroom simulations are still underutilized. In a survey by Sevinc & Lesh (2018), 61% of teacher educators in Asia felt constrained by rigid curricular timelines, affecting hands-on training.

The presence of reflective practice—an essential component of professional growth—varies widely. While the ITEP mandates reflective journals and portfolio assessments, Manouchehri (1998) observed that fewer than 30% of pre-service programs in India evaluated reflection as a graded component, despite research linking it to improved teaching efficacy.

The inclusion of critical thinking and metacognitive strategies also remains sporadic. Curricula often mention higher-order thinking skills, but their implementation is rarely monitored or assessed systematically. Handal & Herrington (2003) stress the alignment of teacher beliefs with reform-based instructional goals, noting that entrenched views can inhibit competency-based pedagogies.

Furthermore, ICT tools like GeoGebra, Desmos, and simulation apps are listed in syllabi but are rarely integrated into practicum work. Kilpatrick (2009) reported that curriculum reform efforts frequently stagnate at the design stage without translation into classroom practice, partly due to inadequate faculty training.

In conclusion, while pre-service programs recognize a broad array of pedagogical competencies, the challenge lies in consistent, meaningful integration into coursework and field practice. A systemic restructuring—focusing on contextual alignment, mentoring, and resource availability—is imperative to actualize the envisioned transformation in mathematics teacher education.

## 5. Effectiveness of Current Pre-Service Programs

### 5.1 Empirical Studies on Pre-Service Teacher Readiness

The preparedness of pre-service mathematics teachers for real-world classroom challenges remains a crucial indicator of the success of teacher education programs. A body of empirical research highlights both strengths and persistent gaps in translating training into practical efficacy.

Gresham (2008) examined 156 elementary pre-service teachers and found that higher mathematics anxiety was significantly associated with lower teaching efficacy, suggesting a disconnect between content mastery and instructional confidence. Similarly, Briley (2012) revealed that self-efficacy in teaching mathematics is strongly linked to beliefs about mathematics learning, yet only 47% of surveyed candidates felt fully prepared to manage student misconceptions.

In a comparative study by Cakiroglu (2008), significant national differences were observed: U.S. pre-service teachers reported higher levels of teaching efficacy than their Turkish counterparts, indicating that institutional and cultural supports play a key role in teacher preparation.

Lau (2022) highlighted that mathematical beliefs and self-efficacy are major predictors of instructional readiness. In a sample of 210 pre-service teachers, those with constructivist orientations scored 35% higher in teaching performance evaluations than peers with traditional beliefs. This aligns with Segarra & Julià (2020), who found that pre-service teachers with higher teaching efficacy beliefs also achieved better academic results and demonstrated stronger instructional decision-making.

However, these positive correlations are not universal. Zuya et al. (2016) reported that while most pre-service teachers scored high on mathematics self-efficacy scales, their classroom teaching efficacy was often lacking, primarily due to minimal exposure to real teaching conditions and inadequate feedback.

Overall, these studies converge on the need to strengthen links between pedagogical theory, affective beliefs, and classroom application to ensure genuine readiness.

### 5.2 Assessment and Evaluation Mechanisms

Evaluating pedagogical competence in pre-service teachers requires tools that assess not only knowledge but also instructional performance and reflective capacity. The most common mechanisms include micro-teaching, teaching portfolios, and practicum feedback.

The following table summarizes findings from key studies on assessment mechanisms:

**Table 3. Summary findings from key studies on assessment**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Tool** | **Purpose** | **Reported Strengths** | **Identified Limitations** | **Citation (Authors, Year)** |
| Teaching Portfolio | Compile lesson plans, reflections, and assessments | Encourages reflective practice and documentation | Time-consuming, inconsistently evaluated | Harding & Hbaci (2015) |
| Micro-teaching | Simulate teaching in peer settings | Allows rehearsal of techniques, focused feedback | May not replicate classroom complexity | Segarra & Julià (2020) |
| Practicum Feedback | Evaluation by mentor and supervisors during school | Provides real-time corrective input | Quality depends on mentor involvement | Bates, Latham, & Kim (2011) |
| Self-assessment | Student-teacher evaluates own performance | Promotes metacognition and autonomy | Often overestimated by candidates | Harding & Hbaci (2015) |
| Observation Rubrics | Structured criteria for evaluating teaching episodes | Objectivity, criterion-based scoring | Requires well-trained assessors | Zuya et al. (2016) |

Harding & Hbaci (2015) discovered that 62% of pre-service teachers rated their micro-teaching performance higher than their professors did, indicating optimism bias and the need for multi-rater evaluation models. Bates et al. (2011) emphasized that portfolios are particularly useful when paired with classroom mentoring, resulting in a 19% improvement in teaching quality over a semester.

### 5.3 Internships and Classroom Exposure

Field-based learning is a cornerstone of effective teacher preparation, offering opportunities to bridge theory with classroom practice. However, the quality and intensity of internships vary widely across programs and geographies.

Gresham (2008) found that only 48% of pre-service teachers received more than 12 weeks of in-school teaching experience, with many citing a lack of mentoring and feedback as major barriers. Segarra & Julià (2022) observed that pre-service teachers exposed to longer, structured internships (minimum of 16 weeks) demonstrated a 30% higher retention of pedagogical skills.

Zuya et al. (2016) identified three factors critical to successful internships: integration of coursework with practicum tasks, quality of supervisory feedback, and opportunities for reflective journaling. In programs where these were lacking, pre-service teachers reported a “disconnect between university teaching and school demands.”

The literature thus supports a model in which internships are not only extended in duration but are also made coherent with the theoretical components of teacher education. Countries like Finland and Singapore exemplify this approach, mandating year-long internships paired with mentor teacher assessments and university supervision.

In sum, while pre-service programs provide foundational competencies in mathematics education, the effectiveness is contingent on sustained practical exposure, robust evaluation mechanisms, and alignment between pedagogical beliefs and classroom realities. Strategic reform in internship structures and competency evaluation tools will be essential in transforming pre-service preparation into classroom effectiveness.

## 6. Theoretical Frameworks Supporting Competency Development

### 6.1 Shulman’s Pedagogical Content Knowledge (PCK)

Introduced by Lee Shulman in 1986, Pedagogical Content Knowledge (PCK) is a foundational concept in teacher education. It refers to the intersection of a teacher’s understanding of subject content and their ability to make it accessible to learners. In mathematics, this includes explaining abstract concepts, designing instructional tasks, and diagnosing student errors.

Shulman emphasized that effective teaching goes beyond knowing mathematics – it involves understanding how students learn it, what makes concepts difficult, and how to tailor content accordingly. Marbán & Sintema (2021) highlighted the importance of integrating PCK into pre-service training, particularly in translating theoretical content into comprehensible instructional formats.

Empirical studies have demonstrated that PCK can be cultivated through structured programs. Margaret L. Niess, van Zee, & Gillow-Wiles (2010) showed that online training using spreadsheet modeling helped pre-service teachers integrate PCK into mathematical problem-solving tasks, enhancing their instructional efficacy. Likewise, Setyaningrum, Mahmudi, & Murdanu, 2018 found that pre-service teachers with higher PCK scores demonstrated more adaptive classroom behavior and better student engagement.

The growth of digital environments has led to the evolution of PCK into broader integrative models, including TPACK (Technological Pedagogical Content Knowledge), reflecting the need to embed technology into pedagogical reasoning.

### 6.2 TPACK Framework

The TPACK framework, building on Shulman’s PCK, was formally conceptualized by Mishra and Koehler in 2006. It emphasizes the dynamic interplay between technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). In mathematics education, TPACK enables teachers to leverage tools like simulations, graphing software, and digital whiteboards to explain complex mathematical concepts.

The table below summarizes research exploring TPACK in mathematics teaching:

**Table 4. Research exploring TPACK in mathematics teaching**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **TPACK Component** | **Application in Mathematics Teaching** | **Findings from Empirical Studies** | **Implications for Pre-Service Education** | **Citation (Authors, Year)** |
| Technological Pedagogy | Use of spreadsheets for problem-solving | Improved modeling and concept visualization | Integrate ICT across math methods courses | M L Niess et al. (2009) |
| TPACK Assessments | Evaluating the balance of CK, PK, TK | Gaps in tool-based assessments noted | Need for validated TPACK rubrics | Kadluba et al. (2025) |
| TPACK and Attitude | Perceptions toward tech-based teaching | Positive correlation with instructional flexibility | Promote digital confidence among teacher candidates | Marbán & Sintema (2021) |
| Program Integration | TPACK in structured training programs | Better instructional planning and higher retention | Embed TPACK in internships and micro-teaching | (Setyaningrum et al., 2018) |
| TPACK in Emerging Contexts | TPACK-informed teacher standards | Effective policy application in curriculum design | Align program goals with national TPACK benchmarks | M L Niess et al. (2009) |

TPACK research reveals that when content, pedagogy, and technology are balanced, pre-service teachers are better equipped to meet diverse classroom demands. For instance, Rakes et al. (2022) reported that TPACK-informed instruction increased student achievement by 19% in algebra modules.

### 6.3 Indian National Frameworks

India’s national curriculum and policy frameworks form the backbone of competency development in teacher education. These documents emphasize competency-based learning, holistic development, and technological integration.

The table below outlines core frameworks and their roles:

**Table 5. Core frameworks and their roles**

|  |  |  |  |
| --- | --- | --- | --- |
| **Framework** | **Issuing Body** | **Competency Focus** | **Programmatic Impacts** |
| NCF 2005 | NCERT | Constructivist pedagogy, reasoning, student-centric learning | Curriculum design in B.Ed and D.El.Ed |
| NEP 2020 | Ministry of Education, Government of India | Competency-based education, flexibility, digital literacy | Restructuring of teacher education into ITEP |
| NCF for SE 2023 | NCERT in alignment with NEP 2020 | Holistic learning, interdisciplinary approaches | Revision of content and methods in mathematics teacher training |
| NCFTE 2009 | NCTE | Pedagogical understanding, inclusivity, reflective practice | Emphasis on reflective teaching journals |
| ITEP 2021 | NCTE | Integrated teacher training with digital pedagogy | Common curriculum across teacher education institutions |

These documents collectively reflect a progressive shift in Indian teacher education. For instance, NCF-SE 2023 emphasizes interdisciplinary understanding and mathematical modeling, whereas ITEP requires digital integration and reflective portfolios for evaluation. Together, they provide a robust theoretical and policy foundation for enhancing pedagogical competencies.

## 7. Future Directions and Policy Implications

### 7.1 Evolving Vision for Teacher Education

India’s National Education Policy (NEP) 2020 represents a paradigm shift in teacher education, emphasizing competency-based, learner-centered, and digitally integrated teaching models (Sayed, Subramanian, & Jain, 2020). The policy marks a transition from rigid, theory-heavy training to a flexible, multidisciplinary, and outcome-oriented structure. One of the significant goals outlined in NEP 2020 is to ensure that all teachers by 2030 possess deep pedagogical content knowledge, strong digital literacy, and professional competencies aligned with 21st-century demands (Section 5.4).

Several policy commentaries underline the necessity for reskilling educators and redesigning teacher education curricula to embed technology and student-centered pedagogies from the foundational level (Dreer-Goethe, 2023; Pandya & Sefton-Green, 2021). For instance, NEP proposes ITEP (Integrated Teacher Education Programme) as a four-year holistic model focused on interdisciplinary understanding and digital empowerment. This model is crucial for transforming teacher training from compliance-focused to competency-driven, where teacher autonomy, flexibility, and field-relevance become central pillars (OECD, 2025a, 2025b).

### 7.2 Recommendations for Policy and Practice

Empirical and policy studies consistently recommend practical interventions to actualize NEP’s vision. These include structural reforms in curriculum, enhanced mentoring, and digital platforms.

1. Curriculum Realignment: The NEP-aligned curriculum must address three key domains—disciplinary content, pedagogical knowledge, and practical training—through an integrative lens. Several experts suggest using a blended learning approach that combines face-to-face instruction with digital simulations and modular e-content to bridge theory and practice.
2. Mentoring and Feedback Systems: One of the recurring gaps in pre-service education has been the absence of structured mentoring during internships. OECD emphasized that real-time feedback, classroom co-teaching, and reflective journaling can substantially raise teaching efficacy.
3. Technology and Digital Platforms: Digital simulations, such as virtual classrooms and microteaching portals, are increasingly recognized as tools to supplement in-person internships. NEP (2020) explicitly recommends the creation of national digital repositories for lesson plans, classroom recordings, and e-mentoring to aid continuous learning.

Below is a summary of policy-aligned recommendations:

**Table 6. Summary of policy-aligned recommendations**

|  |  |  |  |
| --- | --- | --- | --- |
| **Policy Area** | **Recommendation** | **Expected Impact** | **Implementation Strategy** |
| Curriculum Reform | Integrate theory, practice, digital fluency | Balanced skill development | Modular blended curriculum |
| Internships | Structured mentoring and reflective practice | Increased classroom efficacy | Mentor-mentee pairing, real-time digital feedback |
| Teacher Digital Literacy | Mandate tech-based training | Future-ready instructional capability | Simulation tools, MOOCs |
| Remote Access Platforms | Expand rural teacher support using online systems | Reduce inequity in training quality | Cloud-based resource banks and mentor interactions |

### 7.3 Research Gaps and Further Study

Despite the promising policy frameworks, significant gaps remain in longitudinal tracking, effectiveness assessments, and local-level evaluations.

1. Longitudinal Studies on Competency Retention: Few studies track the long-term impact of pre-service training on teaching effectiveness. Conway & Bulgren (2016) argue that research should extend into early-career phases to measure whether competencies developed during training translate into practice.
2. Evaluation of NEP-Aligned Curricula: Given that NEP reforms are relatively recent, empirical evidence on their effectiveness in classroom transformation is still emerging.
3. Localized Challenges in Tier 2/3 Institutions: Most elite universities and NCTE-recognized centers are better positioned to implement NEP reforms. However, rural and semi-urban teacher training institutes often lack resources for tech-enabled (Mustafa, Nguyen, & Gao, 2024). Future research must assess contextual barriers like infrastructure, digital divides, and faculty development.

In conclusion, the policy momentum provided by NEP 2020 offers a fertile ground for reimagining teacher education. However, sustained investment in research, localized implementation, and ongoing teacher support will be critical for bridging policy aspirations and classroom realities.

## 8. Conclusion

The present review sought to systematically examine the landscape of pedagogical competencies in secondary mathematics education within pre-service teacher training programs, particularly in the Indian context. Drawing from national curriculum documents, empirical studies, and international benchmarks, the review reveals that while there exists a growing recognition of the importance of pedagogical content knowledge (PCK), technological integration, and classroom readiness, their implementation within existing training frameworks remains uneven and often fragmented.

The analysis began with clarifying the definition and classification of pedagogical competencies, incorporating perspectives from NCERT, NCTE, UNESCO, and leading education theorists. Competencies were mapped across five core domains: content knowledge, pedagogical strategies, classroom management, assessment literacy, and technological fluency. These dimensions were further substantiated through national frameworks such as NCF (2005) and NCF (2023), NCFTE (2009), and the recent ITEP framework, all emphasizing an integrated, practice-oriented teacher preparation approach.

Curriculum review of programs like B.Ed, D.El.Ed, and ITEP revealed notable discrepancies between intended learning outcomes and their practical execution. The analysis showed that while disciplinary content is reasonably addressed, components like reflective practice, use of manipulatives, and ICT-supported teaching are often either superficially covered or left to individual institutions’ discretion. Moreover, training structures continue to prioritize theoretical knowledge over practical exposure, leaving many pre-service teachers underprepared for real classroom dynamics or new technologies.

Empirical studies on the effectiveness of current pre-service programs provided further insight. Although many student-teachers appreciate the academic foundation provided by training institutions, they frequently express dissatisfaction with the limited school exposure and feedback mechanisms. Evaluation tools such as micro-teaching, lesson plans, and peer reviews are inconsistently used across institutions and rarely feed into structured competency development. Field experiences, though mandated, are often reduced to formality due to lack of mentoring and contextual alignment with classroom realities.

Theoretical frameworks such as Shulman’s PCK and the TPACK model provide conceptual scaffolding for integrating content, pedagogy, and technology. However, their use in teacher training remains at a nascent stage in many Indian institutions, particularly those in Tier 2 and Tier 3 cities. Similarly, national policies like NEP 2020 articulate a transformative vision for teacher education, but translating these into ground-level reform requires continuous investment, accountability, and empirical tracking.

The future trajectory of pre-service mathematics teacher education demands a concerted shift toward competency-based, context-sensitive, and digitally enriched frameworks. This includes revisiting curriculum structure to emphasize core teaching competencies, embedding mentoring in internships, expanding the use of digital simulations and resource platforms, and initiating longitudinal studies to assess long-term competency retention. Particularly in under-resourced institutions, tailored policy implementation and localized innovation are necessary to ensure equity in training quality.

Ultimately, this review affirms the need for evidence-based, aligned, and practice-driven reform in mathematics teacher education. The findings highlight a shared imperative across scholars, practitioners, and policymakers: to move from prescriptive models of teacher training to reflective, adaptive, and responsive ecosystems that nurture competent, confident, and future-ready educators.

Disclaimer (Artificial intelligence)

The authors declare that generative AI technology (Paperpal, 4.9.3, developed by Cactus Communications) was used only for grammar checking and language refinement of the manuscript. No content generation or analysis was performed by the tool, and all interpretations and conclusions are solely those of the authors.

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