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Global trends in mathematics teacher education: Pedagogical practices and approaches for pre-service secondary teachers (2015-2025)

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Abstract

There are various ways around the world in which pre-service mathematics teachers are trained. This systematic review explores global approaches to training pre-service secondary mathematics teachers between 2015 and 2025. Guided by complexity theory and following PRISMA protocols, the study analysed 21 peer-reviewed articles from five continents. Thematic analysis identified five recurring areas: gaps in foundational mathematics knowledge, limited digital competencies, insufficient development of 21st-century teaching skills, the influence of teacher beliefs and attitudes, and the need for enhanced programme design. Findings reveal persistent challenges in content mastery, technological integration, and pedagogical preparedness. This research is significant in revealing systemic weaknesses in mathematics teacher education and emphasises the necessity for policy reforms that embed digital literacy, reflective practice, and emotional resilience within pre-service training. Overall, the study highlights the importance of holistic and adaptive teacher education models to equip future mathematics educators for complex, technology-driven classroom environments.

Keywords: complexity theory, mathematics teacher training, pedagogical practices, pre-service teachers

INTRODUCTION

One of the main issues is the shortage of qualified mathematics teachers, which has been identified as a key contributor to poor learner performance (UNESCO, 2024). Mathematics is a critical subject for learners who wish to pursue further studies in science, technology, engineering, and mathematics (STEM) fields, making its effective teaching essential for national development. However, concerns persist about the overall quality of mathematics education (Mabena et al., 2021; Spaull, 2019). Several systemic problems have been identified, including a lack of well-trained teachers, inadequate teaching facilities, and limited access to essential learning resources (Bridgman, 2020).

Many countries around the world are also struggling to improve mathematics education and teacher preparation. For example, in the UK, Skipp and Dommett (2021) reported similar shortcomings in teacher training and instructional quality. On a global scale, the annual results report for education by UNICEF (2024) revealed that millions of learners still lack basic numeracy and literacy skills, highlighting the widespread nature of the problem. These findings suggest that improving mathematics education requires a strong focus on how teachers are trained before they enter the classroom.

As Masterson et al. (2024) point out, many teachers lack the pedagogical content knowledge and instructional skills needed to support learners effectively. This gap in teacher preparation has a direct impact on learner outcomes, especially in grade 10 to grade 12, where the curriculum becomes more complex and demanding. Strengthening pre-service teacher education is, therefore, a crucial step toward improving mathematics performance and ensuring that learners are equipped with the skills they need for success in higher education and the workforce.

To address these issues, it is important to learn from successful international models of pre-service mathematics teacher training. By examining global approaches and pedagogical practices, pre-service mathematics training programs can identify strategies

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Contribution to the literature

- This study provides a complexity-theory–driven global synthesis of pre-service mathematics teacher education (2015–2025), revealing how small enhancements in teacher preparation can generate far-reaching systemic improvements.
- This study identifies and integrates five recurring international challenges—content knowledge gaps, digital competency limitations, underdeveloped 21st-century skills, influential teacher beliefs, and insufficient programme design—offering a coherent, cross-continental picture of factors shaping teacher readiness.
- This study delivers actionable, context-sensitive insights for policy and programme reform, highlighting persistent global weaknesses and offering evidence-based guidance to strengthen national pre-service mathematics teacher training frameworks, including those in South Africa.

that may be adapted to their own context. This systematic review aims to explore how mathematics teacher education has evolved globally between 2015 and 2025, with a focus on pedagogical approaches and training practices that have shown positive outcomes.

The following research questions guide this review:

1. What are the approaches and pedagogical practices used globally in mathematics training for pre-service teachers between 2015 and 2025?
2. How do these global approaches and pedagogical practices enhance pre-service mathematics training programs?

The goal is to contribute to the development of a national framework that supports the effective training of mathematics teachers, ensuring they are well-prepared to meet the demands of secondary school education in South Africa and other countries.

THEORETICAL FRAMEWORK

This study draws on complexity theory, with a particular emphasis on the butterfly effect, to explore the multifaceted nature of mathematics teacher education. Complexity theory conceptualizes education as a dynamic, adaptive system characterized by nonlinearity, feedback loops, and self-organization (Jacobson et al., 2019; Kernick, 2018). Within this framework, small changes in one part of the system—such as adjustments in teacher preparation—can lead to significant and often unpredictable outcomes across the broader educational landscape.

The butterfly effect, introduced by Lorenz in 1961, illustrates how minor initial inputs can result in large, unforeseen consequences over time (Dooley, 2009; Katamei & Omwono, 2015). In the context of education, this metaphor underscores the importance of foundational teacher training, particularly in mathematics, where early interventions in pre-service programs can profoundly influence classroom practices and learner achievement. Teachers act as transformative agents within this complex system, shaping learning environments through their decisions, beliefs, and instructional strategies (Zaminpira & Niknamian, 2017).

Educational reform, when viewed through the lens of complexity theory, is not a straightforward or linear process. Instead, it involves navigating unpredictable patterns, emergent behaviors, and interconnected variables. This perspective is especially relevant in South Africa, where historical inequalities, resource disparities, and evolving curriculum demands contribute to a highly complex educational context. Recognizing the interrelated nature of pedagogical practices, curriculum design, teacher beliefs, and systemic structures reinforces the relevance of complexity theory to this study.

By adopting this theoretical lens, the review acknowledges that improving mathematics teacher education requires more than isolated interventions. It calls for a holistic understanding of how various components of teacher preparation interact and influence long-term educational outcomes. The butterfly effect serves as a reminder that even small, well-considered changes in pre-service training can catalyze broader systemic transformation. Therefore, this study positions complexity theory as a guiding framework to analyze global pedagogical practices and to identify strategies that can be adapted to strengthen mathematics teacher education.

METHODOLOGY

This study aims to uncover international trends that impact the training of mathematics pre-service teachers at the secondary school level. To ensure methodological rigor, the review follows the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Page et al., 2021). PRISMA guides academic authors in developing exhaustive systematic reviews, which resonate with the research community's interests, help readers thoroughly understand the research subject, and suggest new research pathways (Aifang et al., 2024). According to Pazin et al. (2022), PRISMA provides three main benefits:

(1) crafting focused research questions necessary for conducting systematic investigations;

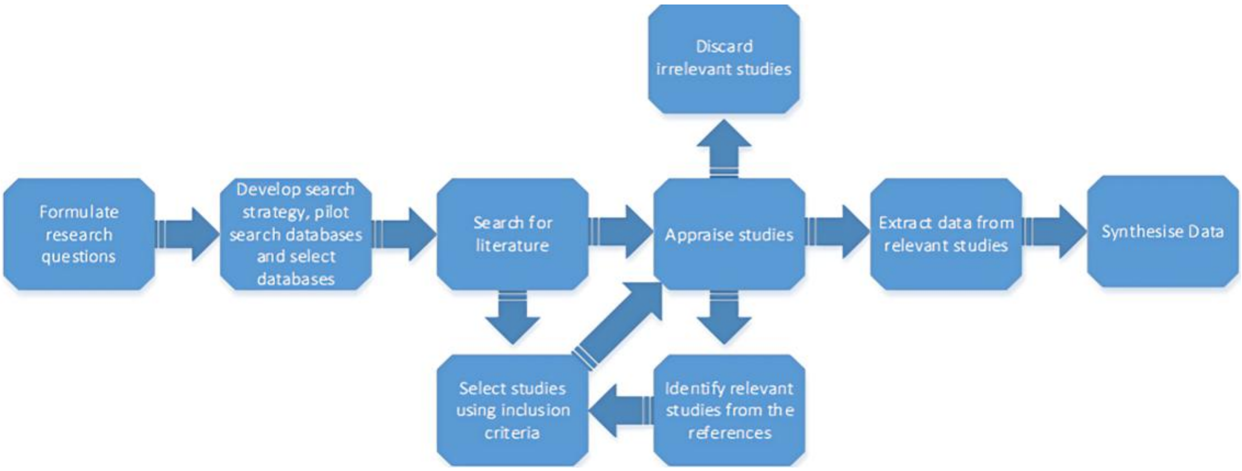

Figure 1. Diagrammatic representation of the research methodology (Adeniji et al., 2022)

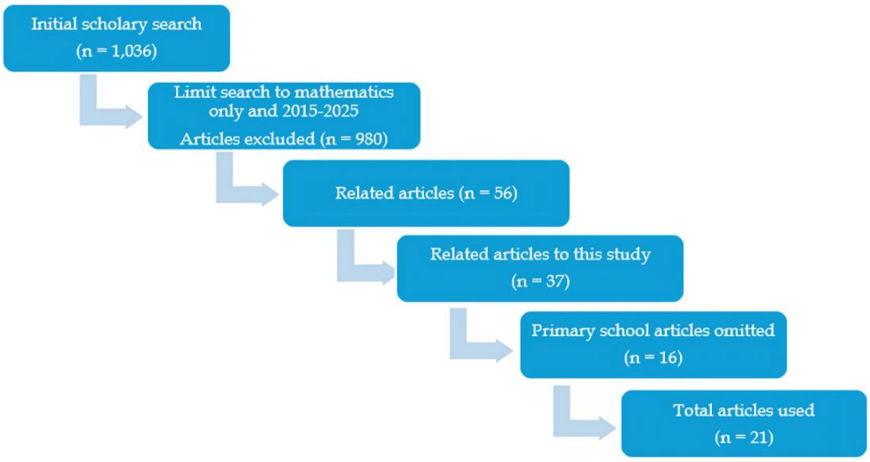

Figure 2. Schematic diagram of the data collection process (Source: Authors' own elaboration)

(2) establishing explicit inclusion and exclusion criteria; and

(3) evaluating broad literature databases over a designated timeframe.

The methodology for this review was designed around these three key principles.

Research Design

Figure 1 presents the research framework utilized in this study. The process began with formulating the research questions, which laid the foundation for the initial search. Subsequent steps involved a literature search for pertinent studies. Articles that aligned best with the inclusion and exclusion criteria were sourced from the database for subsequent data analysis (Adeniji et al., 2022).

Data Collection

Figure 2 shows the schematic diagram of the data collection process.

In preparation for the initial search, the following search was conducted within the Scopus database. The search was done within the *article title*, *abstract*, and *keyword* fields of the search engine. Pre-service teacher OR Mathematics didactics OR teacher training) AND PUBYEAR > 2014 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "MATH") AND (LIMIT-TO (DOCTYPE, "article") AND (LIMIT-TO (EXACTKEYWORD, "Pre-service Teachers") OR LIMIT-TO (EXACTKEYWORD, "Teacher Training") OR LIMIT-TO (EXACTKEYWORD, "Pre-service Teacher").

From this search, 1,036 articles were found. After the initial search, a further search was conducted, limited to mathematics only and within a time frame of 2015-2025. A total of 56 articles were published from that specific search. Of the 56 articles, 19 were not related and consequently omitted (not relevant) from the search, which a search ended up on 37. In the last search of 37 journal articles, 16 articles were omitted as the research was done in primary schools. The remaining 21 articles were used to conduct this review.

Inclusion and Exclusion Criteria

To ensure methodological transparency and alignment with PRISMA guidelines (Page et al., 2021), following inclusion and exclusion criteria were applied:

Inclusion criteria

- Peer-reviewed journal articles published between 2015 and 2025.
- Studies focusing on pre-service mathematics teacher education at the secondary school level.
- Research published in English.
- Articles indexed in the Scopus database.
- Studies addressing pedagogical practices, teacher preparation, or training approaches.

Exclusion criteria

- Articles outside **2015-2025** publication window.
- Studies focused on **primary or early childhood education**.
- Publications not available in English.
- Sources such as conference papers, book chapters, editorials, or theses.
- Articles unrelated to mathematics teacher education or lacking sufficient methodological detail.

Data Sources

The search period was confined to works published between 2015 and 2025, thus covering research conducted before, during, and after the COVID-19 pandemic. A preliminary exploration of the topic was conducted to identify relevant literature that would aid in selecting a database matching the data. Scopus was utilized as the principal database for this study.

Data Analysis

The data-analysis approach used for this review was thematic analysis, which was found to be very useful as it is flexible and aligns with multiple paradigms (Nowell et al. 2017). Themes were identified inductively through repeated reading and coding of the selected articles, focusing on patterns related to teacher preparation models and their outcomes. **Table 1** indicates the contribution of each article to mathematics performance in the selected countries.

Table 1. List of articles indicating research on approaches and pedagogical practices on pre-service teachers' training

No	Authors	Country	Title	Journal	Findings
1	Hwang and Han (2025)	Korea	Pre-service mathematics teachers' competencies in designing mathematical modelling tasks	Journal of Mathematics Teacher Education	Theoretical and practical components of competencies
2	Cheng et al. (2025)	Japan	Adopting maker education: A comparative analysis of intentions between in-service and pre-service STEM teachers	International Journal of Science and Mathematics Education	The importance of tailored PD for teachers
3	Haşlaman et al. (2024)	Türkiye	Development and in-depth investigation of pre-service teachers' digital competencies based on DigCompEdu: A case study	Quality and Quantity	Teachers' digital competencies
4	López-Serentill (2024)	Spain	Mathematical knowledge of pre-service teachers when performing measurement estimation tasks	Eurasia Journal of Mathematics, Science and Technology Education	Improving measurement proficiency
5	Rajasekaran et al. (2024)	India	DECODE-based STEM workshop in improving academic resilience and teaching competency of pre-service teachers	Eurasia Journal of Mathematics, Science and Technology Education	Enhancing teaching effectiveness and resilience
6	Kukul (2023)	Türkiye	Modelling the spectrum of technology integration from teacher training to usage intention: Findings from a two-phase study	Technology, Knowledge and Learning	Training on technology integration
7	Calderón-Garrido and Gil-Fernández (2023)	Spain	Pre-service teachers' use of general social networking sites linked to current scenarios: Nature and characteristics	Technology, Knowledge and Learning	Consumption of information on social media
8	Yurt (2023)	Türkiye	21st-century skills as predictors of pre-service teachers' professional qualifications: A cross-sectional study	International Journal of Education in Mathematics, Science and Technology	21st-century skills needed
9	He et al. (2025)	UK & China	A comparative study of pre-service teachers' perceptions of STEAM education in the UK and China	STEM Education	Preservice teachers lacked an understanding of STEAM education in general
10	Makamure and Jojo (2022)	Saudi Arabia	An analysis of errors for pre-service teachers in first-order ordinary differential equations	Eurasia Journal of Mathematics, Science and Technology Education	Knowledge gaps in the integration of algebraic rules

Table 1 (Continued). List of articles indicating research on approaches and pedagogical practices on pre-service teachers' training

No	Authors	Country	Title	Journal	Findings
11	Turan (2021)	USA	Pre-service teacher experiences of the 5E instructional model: A systematic review of qualitative studies	Eurasia Journal of Mathematics, Science and Technology Education	School resources are identified as influences on the practice of pre-service teachers
12	Sevinc (2024)	Türkiye	Pre-service mathematics teachers' personal meanings proclaiming the characteristics of realistic mathematics problems	Mathematics Education Research Journal	Pre-service teachers' interpretations of realistic mathematics problems
13	Vargas González et al. (2023)	Costa Rica	Pre-service teachers' understanding of the derivative of a function at a point	International journal of mathematical education in science and technology	Participants' failure to mention elements and requisites essential to the definition of derivatives
14	Vesga-Bravo et al. (2022)	Colombia	Beliefs about mathematics, its teaching, and learning: Contrast between pre-service and in-service teachers	International Journal of Science and Mathematics Education	Improve beliefs
15	Çam and Erdamar Koç (2021)	Türkiye	Technological pedagogical content knowledge practices in higher education: First impressions of preservice teachers	Technology, Knowledge and Learning	Digital teaching methods needed
16	Hine and Thai (2019)	Australia	Pre-service mathematics teachers' self-perceptions of readiness to teach secondary school mathematics	Mathematics Teacher Education and Development	However, further training is required to develop both their content and pedagogical knowledge
17	Alex (2019)	Saudi Arabia	The preparation of secondary school mathematics teachers in South Africa: Prospective teachers' student-level disciplinary content knowledge	Eurasia Journal of Mathematics, Science and Technology Education	Limited student-level disciplinary content knowledge on the topics that they were meant to teach in the schools
18	Meletiou-Mavrotheris and Prodromou (2016)	Cyprus	Pre-service teacher training on game-enhanced mathematics teaching and learning	Technology, Knowledge and Learning	Positive impact on pre-service teachers' perceptions regarding game-based learning
19	Mello and Gravett (2025)	Saudi Arabia	Pre-service teachers' views of an ideal teacher for a fast-changing world	Perspectives in Education	Be adaptable; be digitally literate
20	Zareen Gul (2023)	USA	Pre-service mathematics teachers' experience with productive struggle	The Educational Forum	PSTs criticized high cognitive demand tasks, planned and implemented them.
21	Ng'eno and Chesimet (2015)	Kenya	Teachers' perception of their preparedness to apply facilitation teaching in secondary school mathematics instruction by teacher characteristics	Journal of Education and Practice	Advise policymakers on the improvement of teacher training programs

FINDINGS

Following sections provide an in-depth analysis of the various aspects investigated in this review, offering insights into the global perspectives on mathematics training for secondary school pre-service teachers.

Country and Respondents

The studies in this review originate from diverse countries and continents worldwide.

Table 2 indicates that this review was globally presented in countries from all continents.

Table 2. Global representation of related articles

Continent	Country	Studies
Asia	Türkiye	4
	Korea	1
	Japan	1
	India	1
	China/UK (comparative)	1
Europe	Spain	2
	Cyprus	1
	Costa Rica	1
	China/UK (comparative)	1
Africa	South Africa	3
	Kenya	1

Table 2 (Continued). Global representation of related articles

Continent	Country	Studies
America	USA	2
	Colombia	1
Oceania	Australia	1
Total		21

Data Collection and Approach Methods

Table 3 is a summary of the methodology approaches and data-collection methods used. From the 21 articles, it can be summarized that 8 used quantitative, 7 qualitative, 2 mixed-methods, and 3 used other approaches. Furthermore, the data collection methods are also diverse, with a variety of methods like questionnaires, observations and interviews.

Findings From Collected Data

The findings from the analysis of the 21 papers reveal that there are common global factors that contribute to global perspectives on mathematics training for pre-service teachers.

The findings listed in Table 4 will be used in discussing and responding to the research questions posed in this paper.

DISCUSSION

An examination of the literature through thematic analysis revealed specific themes and sub-themes that globally influence the approaches and pedagogical practices in mathematics training for pre-service teachers in secondary schools. Referring to the lens of complexity theory, the influence of approaches and pedagogical practices is non-linear and more than one., The findings presented are confined to those identified in Table 1 and Table 4, namely knowledge gaps and content competency issues, technology integration and digital competencies, 21st century skills and professional competencies, beliefs, attitudes, and perceptions, and training program enhancement needs.

Knowledge Gaps and Content Competency Issues

A pervasive deficiency in the comprehension of STEAM education principles and integration concepts

Table 3. The data collection and research approaches of all the selected journals

No	Authors & source	Approach	Data collection methods
1	Hwang and Han (2025)	Mixed method	Surveys, task development reports
2	Cheng et al. (2025)	Quantitative	Extended TPB survey, PLS-SEM analysis
3	Haşlaman et al. (2024)	Case study	E-portfolios, reflection reports
4	López-Serentill (2024)	Descriptive pre-post	Pre-/post-tests, training activities
5	Rajasekaran et al. (2024)	Quasi-experimental	Pre-/post-workshop assessments
6	Kukul (2023)	Two-phase quantitative	Surveys
7	Calderón-Garrido and Gil-Fernández (2023)	Descriptive quantitative	Questionnaire
8	Yurt (2023)	Quantitative cross-sectional	Online surveys
9	He et al. (2025)	Comparative quantitative	Questionnaires
10	Makamure and Jojo (2022)	Qualitative test-analysis	Written tests, error analysis
11	Turan (2021)	Systematic review	Meta-ethnography of qualitative studies
12	Sevinc (2024)	Design-based qualitative	Group discussions, written artefacts
13	Vargas González et al. (2023)	Qualitative descriptive	Written responses
14	Vesga-Bravo et al. (2022)	Mixed method	Questionnaires, interviews, and lesson plans
15	Çam and Erdamar Koç (2021)	Qualitative case study	Observations, feedback survey
16	Hine and Thai (2019)	Quantitative	Surveys, interviews
17	Alex (2019)	Quantitative pre-experimental	Diagnostic tests
18	Meletiou-Mavrotheris and Prodromou (2016)	Qualitative	Training observations, reflections
19	Mello and Gravett (2025)	Qualitative	Open-ended survey responses, thematic analysis
20	Zareen Gul(2023)	Qualitative	Reflective journals, interviews
21	Ng'eno and Chesimet (2015)	Quantitative	Structured questionnaires

Table 4. Summary of approaches and pedagogical practices in mathematics pre-service teacher training

Approaches and pedagogical practices in mathematics training	Number of the article in Table 1
Knowledge gaps and content competency issues	1, 4, 9, 10, 13, 16, 17
Technology integration and digital competencies	3, 6, 7, 15, 18,19
21st century skills and professional competencies	2, 5, 8, 11
Beliefs, attitudes, and perceptions	12, 14, 18, 20
Training program enhancement needs	1, 2, 5, 9, 10, 16,21

was observed, indicating a necessity for enhanced training focused on interdisciplinary methodologies (He et al., 2025). Numerous pre-service educators perceived themselves as adequately prepared to instruct lower secondary mathematics yet lacked confidence and pedagogical content knowledge for grade 10-grade 12 teaching (Hine & Thai, 2019). Deficiencies were evident in integration rules, algebraic computations, differentiation, and fundamental algebra concepts (Makamure & Jojo, 2022; Vargas González et al., 2023), alongside inadequate measurement skills (López-Serentill, 2024). From a complexity theory perspective, these gaps represent sensitive points in the system where small improvements can trigger significant downstream effects. The butterfly effect suggests that strengthening foundational content knowledge during pre-service training could catalyze systemic change, as teachers act as transformative agents within this nonlinear educational landscape (Dooley, 2009; Zaminpira & Niknamian, 2017).

Technology Integration and Digital Competencies

Enhancing digital skills systematically among future mathematics teachers is crucial. Programs on models such as DigCompEdu help in effectively acquiring these skills (Haşlaman et al., 2024), with training linked to the perceived ease and utility of incorporating technology (Kukul, 2023). Although social media is widely used, pre-service teachers often do not fully exploit these platforms for professional development (Calderón-Garrido & Gil-Fernández, 2023), and many prefer technology-aided methods over traditional ones, which they find less satisfactory (Çam & Erdamar Koç, 2021). Game-based learning shows promise in promoting pedagogical innovation (Meletiou-Mavrotheris & Prodromou, 2016). Complexity theory views technology integration as a dynamic tool for systemic change, where gradual advances in digital literacy can influence the system, creating adaptive and innovative teaching settings (Dooley, 2009; Lorenz, 1961).

Professional Competencies and 21st Century Skills

Pre-service mathematics educators require competencies such as critical thinking, problem-solving, technological literacy, and leadership (Yurt, 2023). Teaching effectiveness and resilience are closely linked, necessitating programs that develop technical and emotional strength (Rajasekaran et al., 2024). Contextual factors—resources, training quality, and classroom dynamics—further shape pedagogical practices (Turan, 2021), while personalized professional development enhances STEM teaching effectiveness (Cheng et al., 2025). Complexity theory underscores that these competencies are interdependent variables within an adaptive system; targeted interventions like embedding resilience and leadership can initiate feedback loops that strengthen classroom adaptability. The butterfly effect illustrates how small, strategic changes in training can yield transformative outcomes across the educational ecosystem (Jacobson et al., 2019; Kernick, 2018).

Beliefs, Attitudes, and Perceptions

Beliefs and attitudes significantly influence pedagogical approaches, shaping interpretations of mathematical problems and instructional strategies (Sevinc, 2024). Disparities between pre-service and in-service educators reveal divergent philosophies on teaching and learning (Vesga-Bravo et al., 2022). Integrating innovative strategies such as game-based learning and digital tools enhances attitudes and fosters openness to change (Meletiou-Mavrotheris & Prodromou, 2016). Complexity theory positions these cognitive frameworks as sensitive variables within nonlinear systems; even subtle shifts during training can cascade into significant pedagogical transformations. The butterfly effect reinforces that cultivating reflective and adaptive mindsets early can create emergent patterns of innovation and responsiveness in classrooms (Katamei & Omwono, 2015; Zaminpira & Niknamian, 2017).

Training Program Enhancement Needs

The results obtained from the review suggest that existing teacher preparation programs necessitate significant enhancement to address the changing requisites of mathematics education. Existing teacher preparation programs require substantial enhancement to balance theoretical foundations with practical applications (Hwang & Han, 2025). Specialized programs tailored to diverse teacher demographics and immersive workshops like DECODE have shown promise in improving resilience and effectiveness (Rajasekaran et al., 2024). Reinforcing foundational concepts such as integration and algebra remains critical (He et al., 2025; Makamure & Jojo, 2022), and differentiated support is essential for addressing the distinct needs of lower versus upper secondary instruction (Hine & Thai, 2019). Complexity theory frames program enhancement as a systemic intervention with nonlinear effects; small, strategic adjustments—such as embedding practical experiences—can initiate self-organising improvements across teacher education systems. The butterfly effect suggests that incremental refinements in training design can lead to disproportionate gains in teacher readiness and learner achievement (Dooley, 2009; Lorenz, 1961).

Lessons Drawn From International Approaches and Practices for the Enhancement of Pre-Service Mathematics Training Programs

The global review of mathematics teacher preparation between 2015 and 2025 offers several critical lessons for pre-service training programs for secondary school educators. The knowledge gaps in foundational mathematics content, including integration, algebraic computations, and measurement estimation, highlight the urgent need to reinforce core disciplinary knowledge before advancing to complex topics.

The integration of digital competencies into teacher education is no longer optional. International models demonstrate the value of structured digital training frameworks such as DigCompEdu, which enhance self-efficacy and promote the meaningful use of educational technologies. Institutions should integrate digital literacy and pedagogical innovation into their curricula to prepare teachers for a rapidly changing, technology-driven classroom environment. Furthermore, the emphasis on 21st century skills—including critical thinking, problem-solving, leadership, and career consciousness—suggests that teacher education must go beyond content delivery. Institution programs should adopt holistic approaches for both technical and emotional resilience, enabling teachers to adapt to the diverse challenges of the classroom.

Furthermore, the review underscores the importance of beliefs, attitudes, and perceptions in shaping teaching practice. Pre-service teachers must be encouraged to reflect on their educational philosophies and embrace innovative methodologies such as game-based learning and interdisciplinary teaching. Finally, the need for training program enhancement is a recurring theme across all contexts. Tertiary institutions can benefit from adopting differentiated and context-sensitive training models that balance theory with practice, tailor professional development to individual needs, and address the distinct demands of lower and upper secondary mathematics instruction.

Limitations and Recommendations

This review was limited to publications indexed in the Scopus database between 2015 and 2025, with only English-language articles included. Consequently, studies published in other languages or indexed in alternative databases may not have been captured. The analysis focused exclusively on secondary schools, excluding research conducted in pre-primary and primary education settings. Additionally, the limited number of studies from various regions of Africa may restrict the generalizability of the findings. The potential for publication bias must also be acknowledged, as studies reporting significant or positive outcomes are more likely to be published and indexed. Despite these limitations, the review offers meaningful insights into factors influencing mathematics performance within South African secondary schools.

It is suggested that future research should expand the range of databases consulted, extend the temporal scope, and explore contributing factors to mathematics achievement in early childhood development.

CONCLUSION

This paper highlights important approaches and pedagogical practices in preparing future mathematics teachers for secondary school education, directly affecting the pre-service teacher education framework. The thematic analysis identified ongoing issues in foundational content knowledge, digital skills, and pedagogical preparedness, along with the necessity of developing 21st century skills and reflective professional attitudes. These challenges are not unique but are prevalent across various international settings, emphasizing the common challenges in mathematics teacher education.

The implications of the findings of the study indicate that successful reform needs a comprehensive approach. Teacher preparation programs should balance theoretical understanding with practical classroom experiences. Digital literacy and technology use should be integrated into training programs like DigCompEdu, while professional development must be customized to individual teachers' contexts and career stages. Additionally, nurturing flexible mindsets and attitudes toward innovation and interdisciplinary teaching—especially in STEAM education—is crucial for equipping educators for the future. For tertiary institutions, these insights provide valuable guidance. By aligning local teacher education policies with global best practices and addressing the gaps identified in this review, stakeholders can improve the quality and effectiveness of mathematics instruction in secondary schools. Ultimately, investing in thorough, context-sensitive, and competency-based training programs will be key in transforming mathematics education and enhancing student outcomes nationwide.

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AI statement: The authors stated that during the preparation of this work, the authors used Co-Pilot, Manus, and Scholarly GPT in order to (1) synthesize and formulate paragraphs and concepts, (2) assist in the analysis of the data collected into themes, and (3) referencing accuracy in-text and in the reference list.

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