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Functional Thinking Development in Pre-Service Mathematics Teachers: A Systematic Review of Characteristics, Pedagogical Supports, and Effective Methodologies (2010–2022)

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ABSTRACT

This systematic literature review (SLR) examines current knowledge on pre-service teachers' functional thinking, particularly within early algebra learning. The review covers studies published between 2010 and 2022, analysing 16 carefully selected articles from international peer-reviewed journals. The purpose is to understand how future teachers conceptualise patterns, functions, and relationships—essential components of mathematical thinking. Following the PRISMA framework, this review identifies trends, gaps, and promising practices in this specialised field. Findings indicate that while many pre-service teachers struggle with functional concepts, well-designed instructional tasks and targeted interventions effectively develop algebraic thinking. The analysis reveals common challenges include procedural approaches and generalisation difficulties, while successful strategies emphasise multiple representations and pattern-based reasoning. This review not only illuminates effective practices but also highlights areas requiring further investigation—particularly in creating meaningful learning experiences for future educators and examining the long-term impact of these interventions on both teacher development and student learning outcomes.

Keywords: Algebraic Thinking, Functional Thinking, Mathematics Education, Pre-Service Teachers, Systematic Review.

INTRODUCTION

In recent years, mathematics education researchers have increasingly emphasised the need to foster algebraic thinking from the early stages of schooling (Cabral et al., 2021; Zapatera & Quevedo, 2021). A critical component of algebraic thinking is functional thinking, which involves recognising and expressing relationships between quantities that change (Oliveira et al., 2021). As pre-service teachers are the future facilitators of mathematical thinking in classrooms, their understanding and ability to promote functional thinking are a matter of significant concern (Cabral et al., 2021).

Despite the importance of functional thinking, existing literature shows that many pre-service teachers face challenges in grasping functional relationships, often relying on procedural strategies without deeper conceptual understanding (Pincheira & Alsina, 2022; Zapatera & Quevedo, 2021). Pre-service teachers frequently rely on procedural strategies, such as memorising formulas, without a deeper conceptual understanding of how variables co-vary (Oliveira et al., 2021). This limited understanding has profound implications. Firstly, a lack of understanding of these concepts can negatively affect teachers' future instructional effectiveness, which could lead to lessons that emphasise rote procedures rather than meaningful reasoning. This can create a cycle in which students practice without comprehension, undermining the goals of early algebra education. Secondly, this issue is particularly critical because it reflects a foundational gap in teacher preparation; educators who lack confidence in their own functional thinking are less likely to foster classroom environments that nurture algebraic habits of mind, ultimately affecting students' long-term mathematical achievement.

While the existence of this problem is established, the literature remains fragmented. Individual studies diagnose challenges or test isolated interventions, but a consolidated synthesis is lacking. Therefore, this review systematically analyses studies published from 2010 to 2022 on pre-service teachers' functional thinking to address a threefold gap by providing a comprehensive, systematic analysis of the evidence. By doing so, this review aims to provide evidence-based guidance to support the development of more effective teacher education practices and to identify promising directions for future research. The study is guided by the following research questions:

(1) What are the characteristics of functional thinking in pre-service teachers?
(2) How do teacher education programs support or hinder the development of functional thinking?
(3) What methodologies and tasks have proven effective in enhancing this aspect of algebraic reasoning?

METHOD

The systematic literature review employed a qualitative thematic synthesis approach to examine the development of functional thinking among pre-service teachers. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines. The procedure consisted of several stages, beginning with the identification of relevant studies through database searches, followed by screening based on predefined eligibility criteria, full-text review for inclusion, and finally, a qualitative synthesis of the selected studies.

The review focused on empirical research published between 2010 and 2022 that explored how functional thinking is understood and developed among pre-service teachers. The data were analysed through a thematic synthesis conducted in three stages. The process consisted of coding the findings from each study line by line, grouping these codes into descriptive themes, and culminating in the development of analytical themes that address the research questions.

Search Strategy

A systematic search of the literature was conducted to identify relevant empirical studies published in English. Four databases were used: ERIC, Scopus, Web of Science, and Google Scholar. The search process utilised keywords and phrases aligned with the core concepts of the review, including functional thinking, algebraic thinking, pre-service teachers, prospective teachers, early algebra, and mathematics education. Boolean operators were applied to refine the search, where "OR" combined synonymous terms and "AND" linked the main conceptual areas. Truncation techniques were also used to capture variations in word endings. All retrieved records were first screened by title to remove irrelevant publications. Abstracts of the remaining studies were then reviewed based on the eligibility criteria, followed by a full-text assessment for those meeting the inclusion requirements. Data from the final set of studies were extracted systematically using a standardised data extraction table. Key information recorded included the authors, year of publication, study location, participant characteristics, research methods, and major findings relevant to the research questions. This structured extraction process ensured a coherent thematic synthesis of the evidence.

Inclusion and Exclusion Criteria

The study selection process followed specific inclusion and exclusion criteria, outlined in Table 1. The population was limited to pre-service or prospective teachers to align with the review's focus on initial teacher preparation. Only empirical studies were included to ensure the synthesis was grounded in analysed data. The 2010–2022 publication period ensured the review addressed recent developments, given the increased global focus on early algebra. The requirement for peer-reviewed, full-text articles maintained methodological rigour. Theoretical papers were excluded as they do not provide empirical results. Studies involving in-service teachers or

students were excluded to maintain focus on pre-service teacher preparation. The review was limited to English-language publications to ensure consistency in interpretation and analysis.

Table 1. Inclusion and exclusion criteria.

Criteria Type	Criteria Description
Inclusion Criteria	• Focus on functional or algebraic thinking among pre-service or prospective teachers. • Empirical in nature • Published between 2010 and 2022 • Available in full-text and peer-reviewed
Exclusion Criteria	• Theoretical or conceptual papers without data • Studies focusing only on in-service teachers or students • Non-English publications

PRISMA Flow

The study selection process for this review adhered to the PRISMA 2020 protocol, illustrated in Figure 1. An initial search of four databases identified 164 records. After the removal of 30 duplicates, 134 publications were screened by title and abstract, which excluded 93 irrelevant records, leaving 41 articles for full-text eligibility assessment. Upon applying the inclusion and exclusion criteria, 25 studies were excluded for being non-empirical, targeting an incorrect population, or being published in a non-English language, resulting in a final set of 16 empirical studies for synthesis. The reviewed studies reflect an international scope, with research conducted across Europe, the Americas, Asia, and the Middle East. The publications span from 2010 to 2022, allowing this review to cover both early work and more recent advancements in the field.

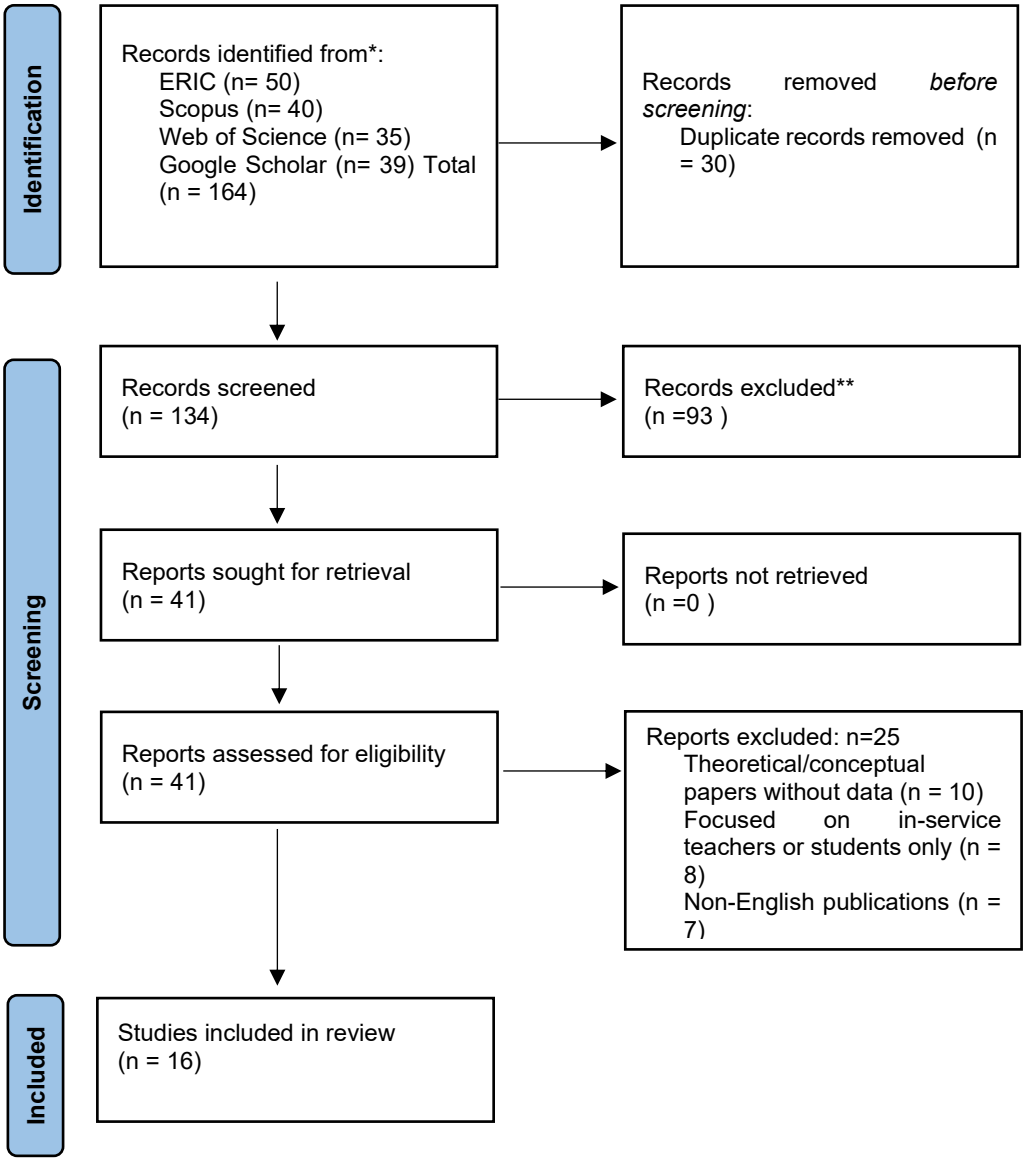

Fig. 1 Prisma flowchart (adapted from Page et al., 2021).

Data Extraction and Synthesis

Each of the 16 articles was systematically analysed using a coding matrix focusing on year, country, research design, sample characteristics, algebraic focus, and main findings. The characteristics of the included studies are summarised in Table 2. A thematic analysis was conducted to group the studies into emerging categories reflecting the nature of functional thinking, instructional strategies, and challenges faced by pre-service teachers.

Table 2. Summary of the included studies.

Author & Year	Country	Research Design	Sample Characteristics	Aim / Purpose	Main Findings
Ahmat et al., 2022	Malaysia	Cross-sectional survey	110 pre-service mathematics teachers.	To determine pre-service teachers' knowledge, skills, and attitudes towards higher-order mathematics thinking and the relationship between exposure and competency.	Moderate knowledge and skills were observed, along with high levels of attitude and exposure, showing a positive correlation between exposure and competency.
Cabral et al., 2021	Portugal	Qualitative study	4 pre-service teachers	To understand how pre-service teachers' algebraic thinking aligns with their ability to recognise and respond to preschoolers' algebraic thinking within a teacher education setting.	Participants could identify pattern structures but showed limited comprehension and only partial recognition of children's algebraic thinking.
Coşkun, 2021	Turkey	Case study	32 pre-service elementary teachers	To examine figural pattern generalisation and justification strategies among pre-service teachers.	Figural reasoning was the primary strategy for generalising non-linear patterns, and its use correlated with greater success in forming deductive justifications.
Dede et al., 2022	Turkey	Design-based research	17 pre-service mathematics teachers	To improve pre-service mathematics teachers' understanding and conceptualisation of function ideas through a learning module.	Improved function definitions and examples were demonstrated, with mapping emerging as the dominant conceptual understanding.
Kehler-Poljak et al., 2022	Germany & Croatia	Mixed method	61 pre-service teachers	To investigate pre-service mathematics teachers' understanding of the function concept, focusing on their concept definitions and concept images in relation to curriculum experiences.	Curriculum influenced how pre-service mathematics teachers understand functions, improving their formal definitions, but their overall concept images varied.
Lau, 2019	Hong Kong (China)	Mixed-methods	24 pre-service mathematics teachers	To examine changes in pre-service teachers' beliefs and confidence in teaching algebra after participating in a professional learning course	Confidence gains outpaced belief changes. The course shifted beliefs from performance to understanding and enhanced pedagogical content knowledge.
Magiera et al., 2017	USA	Qualitative study	18 K-8 pre-service teachers	To investigate pre-service teachers' use of seven features of the algebraic habit of mind Building Rules to Represent Functions (organise information, predict patterns, chunk	Rule justification was the weakest skill, correlating with pattern prediction and information chunking. Analysis revealed feature interrelationships,

Author & Year	Country	Research Design	Sample Characteristics	Aim / Purpose	Main Findings
				information, use multiple representations, describe a rule, describe change, justify a rule)	offering instructional insights.
Obara, 2019	USA	Qualitative case study	Pre-service elementary school teachers	To explore how pre-service teachers analyse and symbolise their generalisations from patterns in algebraic problem-solving	Difficulty translating input-output relationships to symbolic functions underscores the need for early pattern-based activities and stronger algebraic pedagogical preparation.
Oliveira et al., 2021	Spain & Portugal	Cross-sectional diagnostic	164 prospective elementary teachers	To examine the aspects of functional thinking demonstrated by prospective elementary teachers at the start of their teacher education programs.	Limited success in generalising functions was observed, characterised by local reasoning and difficulty connecting representations.
Pincheira & Alsina, 2022	Spain	Qualitative descriptive	40 pre-service teachers	To analyse pre-service teachers' task design skills and justification strategies for algebraic patterns.	Pre-service teachers showed limited task design skills, weak justification, and teaching strategies.
Rahayu et al. 2019	Indonesia	Quantitative, comparative research	498 pre-service elementary school teachers	To determine the level of mathematics anxiety among pre-service elementary teachers and compare mathematics anxiety by gender and semester level	High mathematics anxiety was prevalent, showing no demographic variation but potential negative effects on teaching competence.
Subekti et al., 2022	Indonesia	Descriptive qualitative method	33 pre-service Mathematics teachers	To identify numerical thinking profiles of pre-service teachers based on self-efficacy levels.	Problem-solving performance correlated directly with self-efficacy levels, ranging from systematic approaches among high self-efficacy teachers to significant struggles among those with low self-efficacy.
Suppa & Hohensee, 2021	USA	Qualitative	10 pre-service teachers	To investigate the challenges elementary pre-service teachers face when learning pre-symbolic algebra.	Pre-service teachers struggled with changes in algebraic artefacts, understanding algebraic objects, and their own role in doing algebra.
Tashtoush et al., 2022	Oman	Quasi-experimental	24 pre-service math teachers	To examine the effect of a TIMSS-based training program on developing habits of mind and mathematical reasoning skills among pre-service mathematics teachers.	The experimental group showed significant improvements in both mathematical reasoning and habits of mind compared to the control group.
Wilkie, 2015	Australia	Design-based research	10 upper primary school teachers	To investigate how professional learning can support teachers in developing their students' functional thinking through pattern generalisation, using a framework of	Teachers showed growth in some aspects of mathematical knowledge for teaching algebra and functional thinking, though certain difficulties remained.

Author & Year	Country	Research Design	Sample Characteristics	Aim / Purpose	Main Findings
				mathematical knowledge for teaching	
Zapatera & Quevedo, 2021	Spain	Descriptive quantitative	106 pre-service teachers	To examine the algebraic knowledge of pre-service teachers at the beginning of their training and how they design tasks to develop algebraic reasoning in primary school students.	Pre-service teachers turned open problems into closed tasks and lacked sufficient algebraic knowledge for effective teaching.

FINDINGS

Thematic analysis of the 16 selected studies revealed several key insights related to pre-service teachers' functional thinking development. These findings are organised into four main themes:

Challenges in Functional Thinking

A synthesis of qualitative, diagnostic, and intervention-based studies reveals that many pre-service teachers rely on procedural approaches when engaging with functional relationships (Coşkun, 2021; Magiera et al., 2017; Oliveira et al., 2021). This procedural approach is marked by the reliance on step-by-step algorithms, including recursive patterning and table-filling, which bypass the need for the deeper relational reasoning needed to develop generalizable rules (Coşkun, 2021; Oliveira et al., 2021). The persistence of this procedural approach appears linked to pre-service teachers' own early mathematical experiences. Findings from studies indicate that pre-service teachers' prior educational experiences, often guided by curricula focused on computational fluency and high-stakes assessment, shaped their tendency to prioritise efficiency and correct answers over deeper conceptual understanding. This leads them to perceive algebra as a set of procedures to be performed rather than a language for representing covarying relationships (Oliveira et al., 2021; Zapatera & Quevedo, 2021). The impact of this procedural approach is reflected in pre-service teachers' struggles with essential algebraic tasks. Evidence from qualitative research indicates that when asked to represent quantities symbolically or translate between forms, pre-service teachers often lack a coherent conceptual understanding, leading them to rely on ineffective procedural strategies (Obara, 2019; Suppa & Hohensee, 2021). Their difficulties in depicting input-output relationships symbolically highlight a limited understanding of variables as dynamic quantities rather than fixed unknowns.

Effective Instructional Tasks and Interventions

Research from intervention-based and design studies indicates that strategically designed instructional tasks can counter the procedural approaches often adopted by pre-service teachers (Pincheira & Alsina, 2022; Tashtoush et al., 2022; Wilkie, 2015). Pattern generalisation and contextualised problem-solving are two primary and mutually reinforcing types of tasks that promote conceptual development. (Coşkun, 2021; Wilkie, 2015; Zapatera & Quevedo, 2021). Tasks focused on pattern generalisation, particularly figural patterns, encourage pre-service teachers to engage in visual analysis and consider covarying quantities. Research shows that these tasks require a shift from step-by-step counting to perceiving the overall structure of the pattern (Coşkun, 2021). In contrast, problem-solving tasks situated in real-world contexts create cognitive challenges that cannot be resolved through procedural methods alone. Wilkie (2015) demonstrates that when pre-service teachers are required to represent a single scenario in multiple forms, including graphs, tables, and equations, they are prompted to examine the functions of variables and their interrelationships. Gaining fluency in moving between these representations helps make abstract concepts concrete and evaluate the coherence of a pre-service teacher's conceptual understanding. Design-based research indicates that the most effective results occur when both task types are intentionally combined (Dede et al., 2022; Tashtoush et al., 2022). A structured instructional sequence, beginning with visual pattern tasks to establish covariation and followed by contextual problems for application and justification, provides a systematic framework. This integrated approach goes beyond simple content delivery by actively cultivating algebraic habits of mind, such as recognising structure and constructing reasoned arguments, thereby creating an adaptable foundation for teaching practice.

Cognitive and Affective Factors

Studies have also shown that attitudes, beliefs, and prior experiences significantly shape pre-service teachers' development of functional thinking (Ahmat et al., 2022; Rahayu et al., 2019; Subekti et al., 2022). These factors serve as a critical filter that can either facilitate or hinder conceptual growth. Research shows that pre-service teachers with high mathematical anxiety or low confidence often fall back on procedural strategies when confronted with tasks requiring functional reasoning (Subekti et al., 2022; Rahayu et al., 2019). Evidence from task design studies further indicates that such anxiety can lead teachers to simplify complex mathematical problems, reinforcing reliance on algorithms (Pincheira & Alsina, 2022). Similarly, pre-service teachers with negative attitudes toward algebra or limited mathematical self-efficacy are more likely to depend on rote procedures and face challenges in interpreting and communicating mathematical relationships, showing that low confidence constrains reasoning flexibility and deeper engagement (Ahmat et al., 2022; Subekti et al., 2022).

Nevertheless, this dynamic can be positively modified through carefully designed instructional approaches. Reflective, collaborative, and inquiry-based learning environments have been found to reduce anxiety, foster a growth mindset, and encourage engagement with complex, non-routine tasks (Lau, 2019; Ahmat et al., 2022). By mitigating the social and psychological fear of making errors, such environments allow pre-service teachers to coordinate multiple representations, justify their reasoning, and transition from procedural to conceptual thinking, as shown in professional learning course studies (Lau, 2019; Wilkie, 2015). As confidence and positive attitudes grow, teachers develop a stronger ability to interpret mathematical relationships conceptually rather than relying solely on step-by-step methods, reflecting the mutually reinforcing development of cognitive and affective skills. The observed link between repeated exposure to challenging tasks and increased competency highlights the value of supportive practice (Ahmat et al., 2022). Therefore, promoting functional thinking in algebra requires attention not only to conceptual knowledge but also to fostering mathematical confidence and resilience (Ahmat et al., 2022; Lau, 2019; Subekti et al., 2022).

Conceptual Growth and Progression

Longitudinal and intervention-based studies have reported improvements in pre-service teachers' functional reasoning over time (Dede et al., 2022; Ashutosh et al., 2022; Wilkie, 2015). Analysis of these studies indicates a three-stage developmental progression. The first stage, pattern recognition, involves learners identifying regularities within numerical, figural, or contextual sequences. The second stage, rule formulation, requires pre-service teachers to express the relationships they observe across various representations, including tables, graphs, algebraic expressions, and verbal explanations (Coşkun, 2021; Dede et al., 2022). The final stage, function generalisation, involves applying these rules to new contexts, synthesising multiple representations, and abstracting consistent covariational relationships (Dede et al., 2022; Oliveira et al., 2021).

Working with multiple representations allows learners to move beyond procedural approaches such as table-filling or recursive counting, enabling them to detect invariant patterns across different formats (Coşkun, 2021; Oliveira et al., 2021). Integrating symbolic, numerical, and graphical forms enhances understanding of covariation and clarifies how function rules represent these relationships (Dede et al., 2022). Focusing on constructing and interpreting function rules promotes conceptual reasoning by helping learners organise mathematical ideas around relationships rather than mere calculations (Wilkie, 2015). This integration minimises fragmented understanding and strengthens teachers' ability to express and interpret generalisations symbolically (Dede et al., 2022; Zapatera & Quevedo, 2021). As a result, pre-service teachers develop a more coherent and flexible comprehension of functions, transitioning from routine computation to relational reasoning about mathematical structures (Coşkun, 2021; Wilkie, 2015).

DISCUSSION

The findings of this systematic literature review underscore the complexity of fostering functional thinking among pre-service teachers. In response to RQ1 regarding how functional thinking is conceptualised, the review reveals consistent challenges in pre-service teachers' understanding of functional relationships. While the literature presents varying perspectives on how functional thinking is defined, a shared understanding centres on learners' capacity to identify, represent, and generalise relationships between variables. For instance, Dede et al. (2022) reported significant gains in functional understanding as a result of targeted instructional modules, whereas Zapatera and Quevedo (2021) reported that pre-service teachers often transformed open-ended problems into closed tasks, reflecting limitations in their algebraic knowledge for teaching and difficulties in flexibly engaging with functional relationships.

Addressing RQ2 concerning instructional approaches, the reviewed studies highlight the importance of deliberate and structured instructional design. The transition from arithmetic to algebraic thinking requires

intentional scaffolding through purposeful learning experiences. Effective approaches include incorporating diagnostic tasks to identify misconceptions, lesson-study models to connect theory with practice, and reflective journals to deepen awareness of student thinking (Lau, 2019; Wilkie, 2015). These strategies collectively support the development of relational reasoning, representational fluency, and reflective pedagogical awareness.

Regarding RQ3 on challenges and gaps, the findings show that pre-service teachers' beliefs, attitudes, and previous mathematical experiences significantly influence their ability to engage in functional reasoning. Therefore, teacher preparation programs need to address both cognitive and affective dimensions by incorporating inquiry-based instruction, collaborative learning, and reflective discussions. Creating such supportive environments promotes deeper conceptual engagement and reduces anxiety related to algebraic reasoning (Ahmat et al., 2022; Subekti et al., 2022).

From a policy and curriculum perspective, functional thinking should be emphasised more deliberately in mathematics methods courses. National and international curriculum frameworks, including the Malaysian curriculum and early-algebra recommendations internationally, can operationalise functional thinking through progressive standards that emphasise pattern generalisation and functional reasoning across grade levels. Teacher education courses should not only introduce the concept of function but also model its developmental trajectory and real-world applications.

CONCLUSION

This systematic literature review has synthesised findings from 16 peer-reviewed studies examining functional thinking among pre-service teachers. Taken together, the evidence reveals a consistent narrative that pre-service teachers often enter teacher education with significant conceptual gaps, defaulting to procedural strategies that hinder their ability to foster algebraic reasoning in their future students. Collectively, the studies underscore that overcoming this procedural mindset requires more than content review; it demands instructional experiences that deliberately scaffold the transition from pattern recognition to symbolic generalisation through multi-representational tasks and attention to affective domains.

In essence, this synthesis reveals that functional thinking is not a single skill but a developmental progression. Effective teacher education must therefore operationalise this progression within its curriculum. This can be achieved by aligning with international curriculum standards that emphasise functional thinking, such as the Malaysian curriculum's focus on pattern recognition and relationship mapping across grade levels, which provides a clear model for embedding these concepts in learning progressions. Ultimately, this review consolidates a dispersed body of research into a clear call for action. Prioritising the development of robust functional thinking in pre-service teachers is not merely an academic exercise but a fundamental investment in the quality of future mathematics instruction.

Implications of the Review

Future research should employ longitudinal and mixed-methods designs to examine the progression of functional reasoning from teacher preparation into the early years of teaching. Cross-cultural comparisons may further provide insights into how curriculum structures and educational contexts shape functional thinking development. This review contributes to the existing literature by synthesising evidence on conceptual understanding, pedagogical practices, and affective influences, offering a comprehensive foundation for strengthening the development of functional thinking in teacher education programs

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