Advancing Inclusive Mathematics Teacher Education: A Systematic Review of Universal Design for Learning Integration

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Abstract

Global curriculum reforms increasingly prioritise inclusive teacher preparation, positioning Universal Design for Learning (UDL) as a key framework for advancing equitable mathematics education. This systematic review explores how UDL is integrated into mathematics teacher education globally, assesses the effectiveness of UDL strategies in preparing teachers for inclusive practice, and identifies the key enablers and barriers to implementation. Guided by the PRISMA 2020 framework, a comprehensive literature search was conducted across five major databases and Google Scholar, covering peer-reviewed empirical studies published between 2015 and 2024. Fifteen studies met the inclusion criteria, encompassing diverse geographical regions and methodological designs. Data were extracted systematically and analysed using a narrative thematic synthesis approach. The findings reveal that while UDL is increasingly recognised for its potential to foster inclusive mathematics instruction, its integration into teacher education remains uneven. Key benefits include improved student engagement, conceptual understanding, and accessibility, yet challenges such as resistance to pedagogical change, limited teacher training, and inadequate institutional support persist. Quality appraisal using the Mixed Methods Appraisal Tool (MMAT) confirmed the methodological robustness of most studies. This review underscores the transformative potential of UDL in mathematics education and calls for comprehensive curriculum reforms, sustained professional development, and policy alignment to support its effective adoption in teacher preparation programmes.

Keywords: universal design for learning, mathematics teacher education, inclusive pedagogy, systematic review, 21st-century skills, teacher training, educational equity

1. Introduction

Mathematics education plays a central role in equipping learners with problem-solving, critical thinking, and analytical skills that are essential for innovation and participation in modern societies (Okeke et al., 2025). In the context of the 21st century, characterised by globalisation, rapid digitalisation, a growing emphasis on STEM disciplines, and increasing demands for equity in education, mathematics serves as a foundation for both individual success and national development (Egara & Mogege, 2024; Egara et al., 2025). In the evolving landscape of 21st-century education, mathematics teachers face increasing pressure to meet the needs of a diverse learner population. Traditional pedagogical approaches, which often emphasise uniform instruction and standardised assessments, fail to accommodate students' varying abilities, learning preferences, and sociocultural contexts (Rao et al., 2014, 2021). This is especially critical in mathematics education, where abstract concepts and procedural thinking may pose barriers for students with disabilities, multilingual learners, and those from historically marginalised communities (Courey et al., 2013). International commitments such as the United Nations' Sustainable Development Goal 4 (Quality Education) stress inclusive education principles that prioritise equity, access, and participation for all learners. These principles call for instructional approaches that dismantle barriers and foster meaningful engagement across diverse student populations. To address these challenges, the Universal Design for Learning (UDL) framework has emerged as a promising model for guiding inclusive instruction that fosters engagement, accessibility, and mastery of learning outcomes across all learner profiles.

UDL, developed by the Centre for Applied Special Technology (CAST), is grounded in the neuroscience of learning and encourages educators to provide multiple means of representation, expression, and engagement (CAST, 2018). Its integration into mathematics education has the potential to transform rigid instructional practices into adaptable, student-centred learning experiences (Almeqdad et al., 2023). However, the successful application of UDL in mathematics classrooms largely depends on how well teachers are prepared to understand and use it (Thamae, 2022). As a result, mathematics teacher education, both pre-service and in-service, plays a pivotal role in equipping educators with the competencies to design inclusive and equitable learning environments.

Over the past decade, an emerging body of literature has documented efforts to embed UDL principles in teacher preparation programmes. Studies have examined course redesigns (Katz & Sugden, 2013), professional development models (Matthews et al., 2014), and digital tools that support UDL implementation in math contexts (Rao et al., 2021). While these studies offer valuable insights, findings remain dispersed across diverse contexts, and no comprehensive synthesis examines how UDL is operationalised within mathematics teacher education globally.

1.1 Problem Statement and Research Gap

Despite the increasing emphasis on inclusive education in policy and practice, limited empirical work systematically examines how UDL empowers mathematics teachers. Much of the existing research focuses on general education or special education contexts, often leaving out the content-specific needs and strategies relevant to mathematics teaching. Few studies have investigated how UDL informs math-specific instructional practices that address the unique conceptual and procedural demands of the subject. Mathematics is characterised by abstract reasoning, symbolic representation, and the integration of conceptual understanding with procedural fluency. Learners are often required to simultaneously interpret symbols, apply algorithms, and make sense of underlying concepts, which can pose significant challenges, particularly for students with diverse learning needs. These complexities underscore the importance of instructional approaches, such as UDL, that provide multiple pathways for representation, engagement, and expression in mathematics learning. Moreover, there is limited evidence on teacher outcomes, including their knowledge, beliefs, and classroom practices in relation to UDL. Comparative insights across diverse global contexts also remain sparse, leaving little understanding of how UDL is adapted in different educational systems. A systematic review is thus warranted to consolidate what is known, identify effective strategies, highlight existing gaps, and offer a roadmap for advancing inclusive mathematics teacher education.

1.2 Purpose of the Study

This systematic review aims to analyse and synthesise existing empirical studies on implementing UDL in mathematics teacher education. It focuses on the strategies used, challenges encountered, and outcomes observed to provide evidence-based insights that inform curriculum design, teacher training programmes, and education policy.

1.3 Research Questions

To address the identified gaps, this review is guided by the following research questions:

1. How is UDL integrated into mathematics teacher education programmes globally?

2. What UDL-informed instructional strategies are used in mathematics teaching within teacher education programmes?

3. What are the observed outcomes of UDL implementation on teacher knowledge, attitudes, and instructional practices?

4. What challenges and enabling factors influence the implementation of UDL in mathematics teacher education?

1.4 Theoretical Framework

This review is grounded in the Universal Design for Learning framework developed by CAST (2018), which provides the theoretical underpinning for understanding inclusive instructional design. UDL is based on three core principles that align with cognitive neuroscience findings about how humans learn: (i) Multiple Means of Representation – Addressing the "what" of learning by providing diverse ways of presenting information. (ii) Multiple Means of Action and Expression – Addressing the "how" of learning by allowing learners to demonstrate understanding differently. (iii) Multiple Means of Engagement – Addressing the "why" of learning by offering varied ways to motivate and engage students (CAST, 2018). This tripartite model is rooted in the understanding that learner variability is the norm, not the exception (Meyer et al., 2014). In mathematics teacher education, this framework supports teacher candidates in moving beyond one-size-fits-all approaches by equipping them to anticipate learner diversity and design responsive lessons (Khelifi & Hamzaoui-El, 2024).

In addition to UDL, this review draws on Constructivist Learning Theory, which posits that learners construct knowledge through interaction with their environment, peers, and instructional materials (Vygotsky, 1978). UDL aligns with this epistemology by advocating for learning environments that are socially, emotionally, and cognitively responsive. In teacher education, constructivism supports the notion that pre-service and in-service teachers must actively engage in reflective, situated, and scaffolded learning experiences to develop inclusive pedagogical competencies. By integrating UDL with constructivist theory, this review conceptualises mathematics teacher empowerment as a dynamic process involving reflection, adaptation, and continuous professional learning. The framework serves as a lens for analysing how UDL is used in empirical studies and as a benchmark for evaluating its transformative potential in mathematics education.

2. Method

This study employed a systematic review methodology to synthesise and critically evaluate existing research on applying UDL in mathematics teacher education. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework guided the approach, which ensured transparency, replicability, and methodological rigour. Systematic review methods were deemed appropriate as they allow for a comprehensive mapping of the evidence base, identifying patterns and gaps in the literature, and generating insights that extend beyond individual studies. The process involved a structured search of multiple databases, application of predefined inclusion and exclusion criteria, and thematic synthesis of findings to address the research questions.

2.1 Search Strategy

A systematic and structured search was conducted across multiple academic databases, including ERIC (Education Resources Information Centre), Scopus, Web of Science, and Education Source (via EBSCOhost), to ensure comprehensive coverage of relevant literature. The search was carried out between June and July 2025 and employed a combination of targeted keywords and Boolean operators to retrieve studies aligned with the research focus. To enhance transparency and replicability, the search strategy was tailored slightly for each database to align with its indexing system and search functionalities, while maintaining consistent core search concepts. The Boolean search strings applied were as follows:

In Scopus, the search was conducted using: (TITLE-ABS-KEY (“Universal Design for Learning” OR “UDL”) AND TITLE-ABS-KEY (“mathematics teacher education” OR “mathematics teacher preparation” OR “pre-service mathematics teachers” OR “in-service mathematics teachers” OR “math teacher training”)).

In Web of Science, the following topic search (TS) was used: (TS = (“Universal Design for Learning” OR “UDL”) AND TS = (“mathematics teacher education” OR “mathematics teacher preparation” OR “pre-service mathematics teachers” OR “in-service mathematics teachers” OR “math teacher training”)).

In ERIC, the search was conducted using: (“Universal Design for Learning” OR “UDL”) AND (“mathematics teacher education” OR “mathematics teacher preparation” OR “pre-service mathematics teachers” OR “in-service mathematics teachers” OR “math teacher training”), with filters applied to title and abstract fields.

In Education Source (EBSCOhost), the search string used was: (TI OR AB (“Universal Design for Learning” OR “UDL”) AND TI OR AB (“mathematics teacher education” OR “mathematics teacher preparation” OR “pre-service mathematics teachers” OR “in-service mathematics teachers” OR “math teacher training”)).

All retrieved records were exported into a reference management system, where duplicate entries—particularly those arising from overlap between Scopus and Web of Science—were identified and removed prior to screening. This ensured that each study was uniquely represented in the review process. To refine the search and enhance relevance, specific filters included only peer-reviewed journal articles published between 2015 and 2024 and written in English. In addition to database searches, manual screening of reference lists from selected articles was conducted to uncover any additional studies that met the inclusion criteria, particularly those not indexed in the primary databases.

2.2 Inclusion and Exclusion Criteria

To ensure the rigour and relevance of this systematic review, a set of well-defined inclusion and exclusion criteria was applied during the screening process. The review specifically targeted empirical studies that explored integrating UDL principles within mathematics teacher education, focusing on pre-service and in-service teacher training contexts. Studies were included if they: (a) focused on mathematics teacher education, either in pre-service or in-service settings;

(b) explicitly incorporated or discussed UDL principles; (c) reported empirical findings using qualitative, quantitative, or mixed-methods approaches; (d) were published in peer-reviewed journals between 2015 and 2024; and (e) were written in English and available in full text. Conversely, studies were excluded if they: (a) centred solely on K–12 students without any linkage to teacher education; (b) addressed UDL without relevance to mathematics education; (c) were purely conceptual or theoretical without presenting empirical data; or (d) were not peer-reviewed, including conference papers, dissertations, and other grey literature.

However, some studies that examined the implementation of UDL in mathematics classroom contexts were retained where they provided explicit insights into instructional strategies, pedagogical practices, or teacher-related outcomes relevant to mathematics teaching. These studies were considered valuable because they offer empirical evidence on how UDL principles are enacted in practice, thereby informing teacher preparation, professional development, and instructional design in mathematics teacher education. Including such studies enabled the review to capture both direct and practice-informed perspectives on UDL integration, strengthening the overall analytical depth and applicability of the findings. This also explains the inclusion of a small number of conceptual and review-based studies, which were retained to provide theoretical and design-oriented insights that complement the empirical evidence base.

2.3 Screening Process

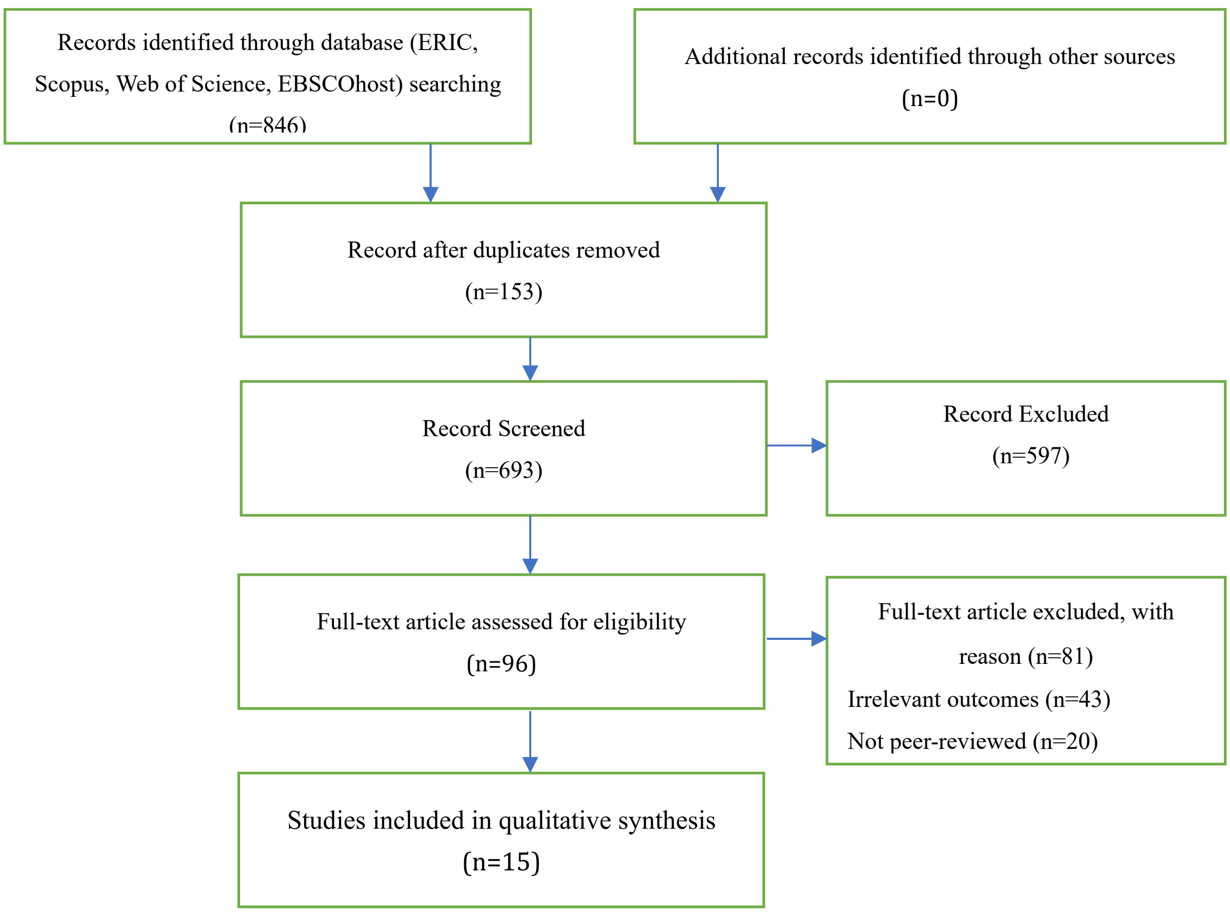

Figure 1. Meta-Analysis Approach Diagram Illustrating the Step-by-Step Process

The screening and selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, and the stages are illustrated in the PRISMA flow diagram (see Figure 1). The process was conducted in four phases: identification, screening, eligibility, and inclusion. In the identification phase, a total of 846 records were retrieved from the selected academic databases. Following this, 153 duplicate records were identified and removed using a reference management system, resulting in 693 unique records. In the screening phase, the titles and abstracts of the 693 records were independently reviewed to assess their relevance to the study. Based on the predefined inclusion and exclusion criteria, 597 records were excluded at this stage. In the eligibility phase, the full texts of the remaining 96 articles were assessed in detail. Of these, 81 articles were excluded for reasons such as irrelevant outcomes (n = 43), not being peer-reviewed (n = 20), language limitations (n = 10), and other factors (n = 8). Finally, 15 studies met all inclusion criteria and were retained for qualitative synthesis. The numerical progression of studies across all stages was cross-checked to ensure consistency between the textual description and the PRISMA flow diagram.

2.4 Data Extraction

A structured data extraction protocol was developed to ensure consistent and comprehensive data collection from each eligible study. Key variables extracted included the author(s) and year of publication, country of study, research design (qualitative, quantitative, or mixed-methods), the target population and sample size, the context and manner of UDL implementation, and core findings and recommendations. Particular attention was paid to how UDL principles were operationalised in mathematics teacher education programmes, whether for pre-service or in-service teachers. Additionally, challenges to implementation and any limitations noted by the original authors were recorded to inform both the interpretation and contextualisation of the review findings. Two independent reviewers conducted the data extraction process to enhance reliability and mitigate bias. In addition, the screening process (including title/abstract screening and full-text eligibility assessment) was conducted independently by the same two reviewers using the predefined inclusion and exclusion criteria. Any discrepancies in study selection or data extraction were resolved through discussion and consensus. This iterative process ensured consistency in decision-making and strengthened the reliability of the review, in line with established standards for inter-rater reliability in qualitative research (Noble & Smith, 2015).

2.5 Quality Assessment

Table 1. Methodological Quality Assessment of Included Studies Using MMAT Criteria

Author(s) & Year	Study Design	Clarity of Research Questions	Appropriateness of Methodology	Data Collection & Analysis	Overall Appraisal
Almeqdad et al. (2023)	Systematic Review	Clear	Appropriate	Rigorous	High
Dlamini (2017)	Qualitative	Clear	Appropriate	Adequate	Moderate
Kusumaha & Ani (2021)	Qualitative	Clear	Appropriate	Adequate	Moderate
Kwon & Capraro (2021)	Mixed Methods	Clear	Appropriate	Rigorous	High
Lambert (2021)	Literature Review	Clear	Appropriate	Adequate	Moderate
Moleko (2018)	Action Research	Clear	Appropriate	Rigorous	High
Moleko (2021)	Qualitative	Clear	Appropriate	Rigorous	High
Moleko (2022)	Mixed Methods	Clear	Appropriate	Rigorous	High
Thamae (2022)	Qualitative	Clear	Appropriate	Adequate	Moderate
Root et al. (2020)	Experimental	Clear	Appropriate	Rigorous	High
Triana & Supena (2023)	Quantitative	Clear	Appropriate	Rigorous	High
Yavuzarslan & Arslan (2020)	Mixed Methods	Clear	Appropriate	Adequate	Moderate
Lee & Shin (2023)	Content Analysis	Clear	Appropriate	Adequate	Moderate
Meyers & Nillas (2024)	Self-study	Clear	Appropriate	Adequate	Moderate
Nieminen (2022)	Conceptual Study	Clear	Appropriate	Limited empirical basis	Moderate

To assess the methodological quality of the included studies, the Mixed Methods Appraisal Tool (MMAT) Version 2018 was employed (Hong et al., 2018). This tool is particularly suited for systematic reviews that include diverse methodological approaches, allowing for consistent evaluation of qualitative, quantitative, and mixed-methods studies using a unified set of criteria. Each study was evaluated based on the clarity of its research questions and objectives, the appropriateness of its methodological design, the rigour of its data collection and analysis techniques, the strength of its interpretations and conclusions, and the extent to which it acknowledged its limitations and sources of bias. While studies were not excluded solely based on quality scores, the results of the quality appraisal informed the interpretation of findings during synthesis. A summary of the methodological quality assessment based on MMAT criteria is presented in Table 1. The appraisal focused on key dimensions, including the clarity of research questions, appropriateness of methodology, and rigor of data collection and analysis. Most studies demonstrated moderate to high methodological quality, although some exhibited limitations related to sample size, generalisability, or depth of analysis.

2.6 Data Synthesis Approach

Given the methodological heterogeneity of the included studies, a narrative thematic synthesis approach was adopted, as outlined by Thomas and Harden (2008). The synthesis process followed three iterative stages. First, an initial coding phase was conducted in which relevant data from each study (e.g., findings, reported strategies, outcomes, and challenges) were extracted and assigned descriptive codes. These codes were developed inductively from the data while being guided by the review's research questions. Second, related codes were grouped into broader categories to identify patterns and relationships across studies. Through this process, preliminary themes were generated, reflecting key dimensions such as UDL integration, instructional strategies, teacher-related outcomes, and implementation factors. Third, the themes were reviewed, refined, and validated through comparison across studies to ensure internal consistency and alignment with the research questions. This iterative analytical process was conducted collaboratively by the reviewers, enhancing the credibility and reliability of the thematic synthesis. This method is particularly effective for integrating findings from diverse research designs, allowing for both convergence and divergence in themes to be identified and explored: the review's overarching research questions and emergent patterns from the extracted data guided thematic synthesis. Studies were grouped under thematic categories such as: (1) UDL integration within mathematics teacher education curricula; (2) UDL-informed instructional strategies for mathematics teaching; (3) outcomes related to teacher knowledge, attitudes, and instructional practices; and (4) enablers and barriers to UDL implementation in teacher education contexts. Throughout the synthesis, attention was given to contextual factors (e.g., country, institutional support) and methodological limitations, to ensure a critical interpretation of the evidence base. A summary of the characteristics of the included studies is provided in Table 2.

3. Results

This systematic review synthesised findings from 15 peer-reviewed studies that explored the application of UDL in mathematics teacher education. The studies spanned diverse geographic contexts, including South Africa, the United States, South Korea, Indonesia, and Finland, and employed varied methodological approaches. The findings are presented under four interrelated themes, each corresponding to a specific research question. Table 2 provides a detailed overview of the included studies, including their design, context, UDL focus, and key findings.

As shown in Table 2, the included studies span diverse geographical contexts and methodological approaches, reflecting the growing global interest in integrating UDL within mathematics teacher education. The table highlights variations in study design, implementation focus, and reported outcomes, enabling comparison across contexts without duplicating detailed findings presented in the subsequent thematic analysis.

Table 2. Empirical Summary Studies on UDL in Mathematics Teacher Education

Author(s) & Year	Country	Study Design	Participants	UDL Focus	Key Findings	Challenges	Recommendations
Almeqdad et al. (2023)	International	Systematic review and meta-analysis	22 peer-reviewed studies on UDL	Overall effectiveness of UDL	UDL significantly improves student outcomes across contexts	Inconsistent application of UDL principles	Develop standardised frameworks and evaluation metrics for UDL implementation
Dlamini, (2017)	Eswatini	Qualitative (thematic analysis)	Primary math teachers and students	Multiple means of representation	Multiple representations enhanced fraction understanding	Limited teacher training	Provide targeted professional development on multiple representations
Kusumaha & Ani (2021)	Indonesia	Qualitative case study	Secondary school math students	Representation strategies	UDL strategies improved student comprehension in math	Insufficient resources	Invest in tech-supported UDL tools and resources
Kwon & Capraro (2021)	USA	Mixed-methods	Young learners in elementary classrooms	Multiple means of representation	Boosted creativity and real-world problem-posing abilities	Lack of clear guidance for teachers	Create structured guidelines for UDL implementation in early math education
Lambert (2021)	USA	Literature review	Math educators and instructional designers	General UDL in mathematics	UDL supports inclusive, flexible engagement and expression in math	Limited empirical data	Conduct more empirical research on UDL in specific math topics
Moleko (2018)	South Africa	Participatory Action Research	Mathematics teachers, learners, HOD, principal	UDL strategies for teaching word problems in multilingual classrooms	UDL approach improved learners' ability to solve word problems	Teachers' negative attitudes towards using learners' home languages	Encourage use of learners' home languages as resources in teaching
Moleko (2021)	South Africa	Qualitative	Teachers and students in pandemic-regulated classrooms	Multiple means of engagement	UDL helped maintain engagement during COVID disruptions	Online engagement was difficult	Offer training in digital UDL tools and platforms
Moleko (2022)	South Africa	Mixed-methods case study	Geometry teachers and students	Flexible instructional design	UDL supported accessibility and differentiated instruction in geometry	Implementation challenges due to limited support	Expand teacher training and peer support systems
Thamae (2022)	South Africa	Qualitative (Participatory Action Research)	5 mathematics teachers, HOD, subject advisor, curriculum specialist	Implementing UDL in teaching Euclidean geometry	UDL principles enhanced accessibility and understanding of geometry content	Resistance to change from traditional teaching methods	Conduct workshops demonstrating UDL benefits in math instruction
Root et al. (2020)	USA	Multiple Probe Across Participants Design	3 middle school students with extensive support needs	UDL framework in mathematics instruction	UDL-based intervention improved problem-solving skills in percent of change word problems	Limited generalisation of skills to new contexts	Incorporate varied practice opportunities to enhance generalisation

Table 2. Empirical Summary Studies on UDL in Mathematics Teacher Education(continued)

Author(s) & Year	Country	Study Design	Participants	UDL Focus	Key Findings	Challenges	Recommendations
Triana & Supena (2023)	Indonesia	Quantitative (pre/post-test)	Elementary students	Process and outcomes of UDL	UDL increased learning effectiveness, comprehension, and engagement	Teachers unprepared for UDL implementation	Incorporate UDL into pre-service and in-service training programmes
Yavuzarslan & Arslan (2020)	Turkey	Mixed-methods	Secondary school students	UDL implementation in math courses	UDL improved performance and motivation	Lack of tech in classrooms	Invest in ICT tools and teacher support for UDL
Lee & Shin (2023)	South Korea	Content Analysis	10 digital mathematics textbooks	UDL in digital math textbooks for students with disabilities	Digital textbooks partially align with UDL principles; multiple means of action and expression most frequently observed	Inconsistent application of UDL guidelines across textbooks	Develop standardised UDL criteria for digital content
Meyers & Nillas (2024)	USA	Self-study	High school students in Algebra II, Finite Math, and AP Statistics classes	Implementing UDL in high school mathematics classrooms	UDL strategies increased student engagement and conceptual understanding	Time constraints in planning and implementing UDL strategies	Provide teachers with planning time and resources for UDL integration
Nieminen (2022)	Finland	Conceptual Study	N/A	Universal Design for Assessment (UDA) in mathematics	Proposed UDA framework to make mathematics assessments more accessible	Traditional assessments may not accommodate diverse learners	Adopt UDA principles to design inclusive assessments

3.1 Integration of UDL into Mathematics Teacher Education Curricula

Several studies reported deliberate incorporation of UDL principles into mathematics teacher education programmes, though the extent of integration varied. Lambert (2021) found that UDL was introduced in teacher preparation curricula to encourage inclusive mathematics pedagogy, focusing on multiple means of representation and engagement. In South Africa, Moleko (2021) showed how UDL-based strategies sustained learning continuity during COVID-19 disruptions by promoting flexible and student-centred teaching. Nieminen (2022) described Finland's national teacher education policy that embedded UDL into curriculum-wide frameworks, positioning it as a pillar of equity. However, Lee and Shin (2023) found digital mathematics textbooks only partially aligned with UDL, showing inconsistencies in accessibility and representation. These studies indicate that while UDL integration is gaining traction globally, its depth and consistency remain uneven.

3.2 UDL-Informed Instructional Strategies

The studies also highlighted specific strategies that mathematics educators employed that aligned with UDL principles. Root et al. (2020) demonstrated that using manipulatives, visual aids, and differentiated problem-solving approaches improved performance for students with extensive support needs. Kusumaha and Ani (2021) found that culturally responsive and linguistically flexible approaches in Indonesia improved comprehension and engagement, particularly for multilingual learners. Triana and Supena (2023) reported that scaffolded instruction, multimodal content delivery, and interactive activities enhanced teacher adaptability and learner achievement. Similarly, Meyers and Nillas (2024) documented the use of learner profiling, choice boards, and tiered tasks, which promoted conceptual understanding, learner autonomy, and active participation in U.S. high school classrooms. Together, these strategies show that UDL fosters creative, flexible, and inclusive teaching approaches in mathematics.

3.3 Outcomes on Teacher Knowledge, Attitudes, and Practices

Several studies reported that engaging with UDL shaped teachers' professional knowledge, beliefs, and instructional practices. Meyers and Nillas (2024) observed that teachers became more confident in designing accessible lessons and more reflective in practice. Moleko (2018) found that pre-service teachers in South Africa, after exposure to UDL, began incorporating home languages, real-world contexts, and differentiated assessment strategies into their lessons. Dlamini (2017) showed that primary teachers in Eswatini used multiple representations in fractions, enhancing learner understanding while fostering more participatory and culturally responsive practices. Nieminen (2022) reported that Finnish teachers developed a stronger sense of professional agency, seeing differentiation not as an additional burden but as an integral part of professional responsibility. These findings demonstrate that UDL influences instructional strategies and cultivates inclusive mindsets and reflective practices among teachers.

3.4 Enablers and Barriers to Implementation

Implementing UDL in mathematics teacher education was shaped by enabling factors and barriers. Key enablers included professional development workshops, reflective communities of practice, and institutional or policy support (Moleko, 2022). These provided teachers with technical skills and collegial support to sustain UDL practices. However, barriers were widespread. Thamae (2022) and Lambert (2021) reported teacher resistance to moving away from traditional methods. Yavuzarslan and Arslan (2020) highlighted inadequate training and insufficient access to technology as constraints in Turkish schools. Time limitations, rigid curricula, and limited institutional commitment hindered implementation across contexts. Almeqdad et al. (2023), in their meta-analysis, emphasised the fragmented nature of UDL adoption globally and recommended the creation of standardised frameworks and stronger policy support to ensure consistent uptake.

4. Discussion

This review examined how UDL has been integrated into mathematics teacher education, the strategies employed, the outcomes observed, and the systemic factors that shape its adoption. The findings provided compelling evidence that UDL holds a transformative promise for mathematics teacher education. However, the effectiveness and sustainability of its implementation vary significantly across contexts. The themes identified in the results can be better understood when interpreted through the theoretical lenses of UDL and constructivist learning theory.

The evidence reveals that UDL is gradually being integrated into teacher education curricula across multiple regions, yet this integration is uneven. Countries like Finland, where UDL is embedded into national education policy, demonstrate a stronger, system-wide adoption (Nieminen, 2022). In contrast, contexts like South Korea show only partial alignment of resources with UDL principles (Lee & Shin, 2023). This unevenness may stem from inconsistent policy mandates, leaving implementation dependent on individual institutions or educators. From a constructivist perspective, the varying depth of integration reflects differing levels of institutional willingness to embrace learner-centred and socially responsive approaches to teaching. Where policy frameworks provide scaffolding, as in Finland, UDL becomes normalised as part of teacher preparation. Conversely, integration remains fragmented in settings without policy backing, leaving teachers less prepared to anticipate and respond to learner variability.

The review also shows that UDL-informed strategies consistently enhance mathematics learning across diverse settings. Using manipulatives, multimodal representations, and culturally relevant examples improved engagement and comprehension (Root et al., 2020; Kusumaha & Ani, 2021). Constructivist learning theory helps explain why: by allowing students to engage with mathematics through multiple representations and culturally meaningful contexts, learners can construct knowledge actively, connecting abstract concepts to their lived experiences. However, the diversity of strategies also highlights an important point: UDL is not a one-size-fits-all formula but a flexible framework that allows teachers to adapt their pedagogy. This flexibility empowers teachers to make mathematics instruction more inclusive, but it also underscores the need for strong training to ensure teachers can apply UDL effectively across different mathematical domains.

Exposure to UDL also impacted teachers' professional identities and classroom practices profoundly. Teachers became more reflective, more confident, and more willing to adapt lessons to accommodate diverse learners (Meyers & Nillas, 2024; Moleko, 2018; Dlamini, 2017). This outcome is deeply connected to UDL's philosophical assumption that learner variability is the norm rather than the exception (Meyer et al., 2014). Constructivist learning theory explains these shifts: teachers, much like their students, learn through active engagement and reflection. When teacher education programmes scaffold UDL engagement through coursework and practice, teachers internalise inclusive pedagogical approaches as part of their professional growth. The result is improved instructional competence and the cultivation of inclusive mindsets, demonstrating that UDL functions simultaneously as a pedagogical and professional development tool.

At the same time, the evidence underscores the importance of systemic factors in enabling or hindering UDL adoption. Professional development workshops, learning communities, and supportive policies emerged as strong enablers (Moleko, 2022). These structures align with constructivist theory, providing opportunities for collaborative learning, reflection, and peer scaffolding among teachers. However, systemic barriers such as entrenched traditional teaching practices, rigid curricula, and lacking resources limited UDL's wider adoption (Thamae, 2022; Yavuzarslan & Arslan, 2020). Resistance to change can be understood as a product of teachers' prior knowledge structures and professional cultures, which often privilege uniform, teacher-centred practices over student-centred ones. Teachers may find it difficult to shift away from these entrenched norms without institutional support and clear policy frameworks. Thus, while individual teachers may be motivated to implement UDL, systemic inertia often constrains its impact. In sum, the findings confirm that UDL's transformative potential is contingent not only on teachers' willingness to adopt inclusive strategies but also on institutional structures and policies that sustain and normalise its use. The theoretical frameworks of UDL and constructivism highlight that inclusive pedagogy is most effective when teachers and institutions view learner diversity as a resource rather than a challenge.

5. Conclusion

The evidence from this review confirms that UDL has considerable potential to transform mathematics teacher education. Across diverse contexts, UDL has been shown to increase student engagement, enhance conceptual understanding, and build teachers' confidence in delivering inclusive lessons. Teachers exposed to UDL also demonstrated greater reflectiveness and a stronger commitment to addressing learner diversity. At the same time, the review underscores persistent inconsistencies in implementation. In systems with supportive policy frameworks and curriculum integration, adoption is deeper and more sustainable, whereas in other contexts, uptake remains partial and fragmented. While UDL-informed instructional strategies such as multimodal teaching, differentiated assessment, and culturally responsive practices are effective, their wider use is constrained by entrenched pedagogical traditions, rigid curricula, limited training, and inadequate resources. Conclusively, UDL represents a paradigm shift that requires teachers, institutions, and policymakers to view learner diversity as a strength rather than a challenge. By bringing together global evidence on strategies, outcomes, and systemic conditions, this review highlights the promise and the obstacles of UDL in mathematics teacher education. Its transformative potential will only be realised when professional development, institutional structures, and education policies align to sustain inclusive practice. With such alignment, UDL can move beyond aspiration to become the standard for preparing mathematics teachers in the 21st century.

6. Educational Implications

The findings from this systematic review suggest that UDL holds considerable promise for improving inclusivity, flexibility, and instructional effectiveness in mathematics teacher education. However, for UDL to achieve its transformative potential, a range of systemic, curricular, and pedagogical shifts may need to occur across multiple levels of teacher education systems.

One key implication is the potential for teacher educators and curriculum developers to embed UDL principles more systematically into mathematics teacher education programmes. The review found that when UDL was explicitly integrated, through coursework, practicum activities, and case-based learning, pre-service teachers developed stronger attitudes toward inclusion, greater awareness of learner variability, and more adaptive teaching practices.

From a policy and institutional standpoint, the findings indicate that ad hoc or individual efforts may not be sufficient for sustained UDL implementation. In contexts where UDL was embedded into national teacher education standards or institutional frameworks, its uptake and impact appeared notably stronger. This suggests that policy support could play a significant role in embedding UDL at a systems level. National teacher education policies and accreditation standards could explicitly support the integration of UDL. In addition, institutions might promote inclusive education policies that facilitate digital accessibility and curriculum flexibility. Establishing cross-institutional learning networks could also encourage sharing best practices and help institutions collectively address barriers to UDL adoption.

The review further highlights important implications for pre-service and in-service teacher development. While pre-service exposure to UDL principles showed promise in shaping inclusive mindsets, many of these gains might fade over time without follow-up support. For in-service teachers, especially those working in diverse classrooms, professional development may be more effective if it is context-specific and addresses how UDL can be adapted to local needs, including in rural or multilingual settings.

Finally, the review identifies critical gaps in the current research literature. While interest in UDL is growing, more empirical studies are needed to assess its long-term effectiveness, particularly in mathematics education. Future research could explore how UDL-informed teacher preparation affects actual classroom practices and student outcomes over time. There is also a need to examine how UDL can be applied across different mathematics content areas and how it might be adapted to be culturally relevant in under-researched regions such as sub-Saharan Africa, Southeast Asia, and Latin America.

7. Limitations

Several limitations should be acknowledged when interpreting the findings of this review. Firstly, the study was limited to English-language publications, which may have excluded relevant evidence published in other languages. Secondly, only 15 studies met the inclusion criteria, constraining the evidence base's breadth. Thirdly, the geographic distribution of studies was uneven, with limited representation from Latin America, Sub-Saharan Africa (beyond South Africa), and Southeast Asia, which restricts the generalisability of findings across diverse contexts. Lastly, most of the included studies were short-term investigations, offering limited longitudinal evidence regarding the sustained impact of UDL on teacher practice and student outcomes.

8. Recommendations

Several recommendations emerge for strengthening the role of UDL in mathematics teacher education. First, mathematics teacher education programmes should intentionally integrate UDL principles into their curriculum. This integration should move beyond theoretical exposure and provide structured opportunities for pre-service teachers to engage with UDL concepts, reflect on learner diversity, and apply these principles through practicum experiences and case-based learning. Professional development for teacher educators is also essential to ensure they are well prepared to model UDL-informed pedagogy and support pre-service teachers in adopting inclusive practices.

Developing mathematics-specific instructional resources that exemplify UDL principles, particularly in abstract areas such as algebra and geometry, is strongly recommended. Such resources would make UDL more practical and accessible for teachers in diverse classroom contexts. At a policy and institutional level, national teacher education standards and accreditation requirements should explicitly mandate the inclusion of UDL. Institutions should also implement inclusive education policies that promote curriculum flexibility and digital accessibility, while fostering cross-institutional networks that facilitate sharing best practices and collaborative solutions to implementation challenges.

Sustained teacher development is equally important. UDL should not be confined to initial teacher preparation but extended into induction programmes, mentoring structures, and continuous professional development opportunities. Encouraging reflective practices, such as using teaching portfolios to document UDL-based lesson adaptations, would help teachers consolidate their skills and maintain inclusive teaching approaches over time. For in-service teachers, professional development should be tailored to context, particularly in rural, multilingual, or under-resourced environments where inclusive practices face unique challenges.

Finally, research on UDL in mathematics education should be expanded to provide stronger empirical evidence of its long-term effectiveness. Future studies should examine how UDL-informed teacher preparation influences classroom practice and learner outcomes across different mathematical content areas. There is also a pressing need for research that adapts and tests UDL in culturally diverse and understudied contexts, including sub-Saharan Africa, Southeast Asia, and Latin America, to ensure the framework's global relevance and applicability.

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