

Mathematical Representations of Students with Dyscalculia in Differentiated Learning Environments: A Conceptual Review

Fatqurhohman ^{*1}, Adnan Noor Malini ², Ferdiano Mendyas ³

¹ Universitas Muhammadiyah Jember, Indonesia

² Universiti Pendidikan Sultan Idris, Malaysia

³ University of the Visayas

* Corresponding Author. Email: frohman86@unmuhjember.ac.id

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Abstract

Students with dyscalculia experience persistent difficulties in numerical processing, number sense, relational understanding, and arithmetic procedures, which negatively affect their cognitive, affective, social, and functional development. Conventional mathematics instruction often fails to accommodate these diverse needs, resulting in low engagement, heightened mathematics anxiety, and weak conceptual understanding. This conceptual review synthesizes research on mathematical representation strategies for students with dyscalculia within differentiated learning contexts, with an emphasis on evidence-based approaches that support conceptual understanding and flexible problem solving. A comprehensive review of relevant scholarly literature was conducted, focusing on multimodal representations (concrete, pictorial, and symbolic) integrated within differentiated instruction and Universal Design for Learning (UDL) frameworks. The analysis highlights studies examining cognitive, affective, and functional outcomes in mathematics learning for students with dyscalculia. The findings indicate that the use of multimodal representations combined with differentiated learning reduces cognitive load, supports the progression from concrete to abstract thinking, and enhances problem-solving flexibility. In addition, these approaches help reduce mathematics anxiety, increase student engagement, strengthen self-confidence, and foster a more positive mathematical identity. This review proposes a conceptual framework to guide educators, parents, and practitioners in designing adaptive, inclusive, and evidence-based interventions, contributing to more equitable and sustainable mathematics instruction for students with dyscalculia.

Keywords: *Dyscalculia; Mathematical Representation; Differentiated Learning; Universal Design for Learning (UDL); Conceptual Understanding*

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INTRODUCTION

The advancement of digital technology has permeated nearly all aspects of life, including formal education, necessitating a paradigm shift in mathematics learning. Mathematical competence is no longer measured solely by the ability to perform numerical operations but also by students' capacity to solve real-world problems, understand complex phenomena, and develop critical thinking and data literacy skills (Lambert, 2021; Nurhasanah et al., 2022). This transformation requires integrating mathematical concepts with real-life contexts, so mathematics instruction fosters both conceptual understanding and representational skills. In this regard, mathematical representations (*symbolic, pictorial, and concrete*) play a central role in facilitating conceptual comprehension and knowledge transfer (Fatqurhohman et al., 2017; Fatqurhohman & Susetyo, 2022).

At the primary education level, mathematics instruction often emphasizes mastering operations such as addition, subtraction, multiplication, and division, forming a foundation for more complex concepts, including fractions, decimals, and basic algebra (Permatasari & Fatqurhohman, 2025). However, many students struggle to understand conceptual relationships between operations and numerical relations, making mathematics seem abstract and difficult. These challenges are particularly pronounced in students with dyscalculia, a specific learning disorder affecting number sense, numerical relations, and basic arithmetic procedures (Mahmud et al., 2020).

Dyscalculia affects an estimated 3–6% of the population but is often underrecognized in formal education, resulting in insufficient support (Andersson & Abdelmalek, 2021; Kunwar & Sharma, 2020). Its impact extends beyond academic performance, increasing mathematical anxiety, reducing motivation, and lowering self-confidence (Devine et al., 2018; Espina et al., 2024). Early identification and evidence-based interventions, whether individualized or collaborative with parents and professionals, have proven effective in enhancing numeracy skills and confidence (Mahmud et al., 2020). Tools such as *Calcularis* and school-based programs like *Catch Up Numeracy* significantly improve number representation, arithmetic skills, and conceptual understanding.

Differentiated learning further strengthens instruction by tailoring content, processes, and products to individual characteristics, abilities, and learning styles (Tomlinson & Imbeau, 2023; Sujadi et al., 2024). Integrating differentiated strategies with multimodal mathematical representations facilitates comprehension of abstract concepts, reduces learning barriers, and minimizes anxiety (Fatqurhohman et al., 2025; Lambert, 2024). Therefore, understanding how students with dyscalculia process and represent mathematical concepts within a differentiated learning framework is critical for designing instruction that promotes deep conceptual understanding and 21st-century problem-solving skills.

METHOD

This study employs a conceptual approach aimed at synthesizing the literature on mathematical representations of students with dyscalculia within the context of differentiated learning. The conceptual method was chosen because the focus of this research is on mapping theories, empirical findings, and pedagogical practices, rather than collecting primary data or testing hypotheses. Data sources include journal articles, academic books, and research reports published between 2018 and 2025, in both English and Indonesian, and available through accredited journals and reputable academic repositories. The analyzed literature covers topics such as dyscalculia, learning disabilities, mathematical representations (*symbolic, pictorial, concrete*), and differentiated learning strategies in mathematics.

The search process was conducted systematically using keywords such as dyscalculia, mathematical representation, differentiated learning, and learning difficulties in academic databases, including Google Scholar, Scopus, and national journals. Search results were screened through title, abstract, and keyword review, followed by full-text evaluation to assess relevance and contribution to the conceptual review. Selected literature was thematically analyzed and categorized based on dyscalculia characteristics, types of mathematical representation, and effective differentiated learning strategies.

Synthesis was conducted using thematic and conceptual approaches to identify patterns between dyscalculia, mathematical representations, and differentiation practices, highlighting

pedagogical principles that support the development of students' mathematical skills. The validity of the study was maintained through source triangulation, consistency in thematic analysis, and systematic documentation of the search, selection, and synthesis process. This approach enables the development of a holistic conceptual framework integrating theory, empirical findings, and educational practice, providing a scientific foundation for further research and the implementation of responsive teaching strategies for students with dyscalculia.

RESULT AND DISCUSSION

Dyscalculia is a specific learning disorder that affects numerical processing, number representation, and the understanding of basic mathematical relations and procedures (Kunwar & Sharma, 2020; Mahmud et al., 2020). Key characteristics include weak integration between *concrete, pictorial, and symbolic representations*, which diminishes conceptual understanding and problem-solving flexibility (Fatqurhohman & Susetyo, 2022; Vizha et al., 2025). Affective factors, including anxiety and low motivation, further impair cognitive engagement (Devine et al., 2018; Espina et al., 2024). The implementation of multimodal representations within the frameworks of differentiated learning and UDL supports the distribution of cognitive load, strengthens connections between concepts, and establishes the foundation for inclusive mathematics learning. This discussion covers the challenges of mathematical representation, the role of multimodality in learning, inclusive pedagogical frameworks, and the affective and pedagogical implications for mathematical representation in students with dyscalculia.

1. Dyscalculia and Challenges in Mathematical Processing and Representation

Dyscalculia is a specific learning disorder that directly impacts an individual's ability to process and meaningfully represent numerical information. It differs from general mathematics difficulties because it stems from neurocognitive differences affecting number sense, magnitude processing, and the relationship between symbols and quantitative meaning (Mahmud et al., 2020). This disorder creates obstacles in constructing, integrating, and transforming concrete, visual, and symbolic representations, while also increasing working memory demands during mathematical tasks. Additionally, affective impacts such as anxiety and low self-confidence emerge (Fatqurhohman & Firdaus, 2024). Understanding dyscalculia as a multidimensional condition is crucial for analyzing cognitive deficits, cross-representation integration, and affective implications in mathematics learning.

a. Number Sense Deficit as the Root of Mathematical Representation Difficulties

Deficits in number sense are the root of mathematical representation difficulties in students with dyscalculia, as their intuitive ability to understand magnitude, order, and numerical relationships is impaired. Consequently, numerical symbols are processed mechanically without conceptual understanding, making the transition from concrete to visual and abstract representations unstable (Eidlin-Levy & Rubinsten, 2017; Saga et al., 2022). Disruptions in the *Approximate Number System* (ANS) and magnitude processing further weaken representational flexibility and knowledge transfer (Kroesbergen et al., 2022). Therefore, learning interventions must strengthen number sense through structured representational experiences, linking quantity, visualization, and formal symbols, enabling students to develop robust conceptual understanding and adaptive mathematical application (Damayanti, 2020).

b. Limitations of Integration Across Mathematical Representations

Mathematical representations (*concrete, visual, verbal, symbolic*) serve as primary cognitive tools for understanding mathematics. However, students with dyscalculia struggle to integrate these representations flexibly and meaningfully. This difficulty reduces their understanding of numerical relationships and problem-solving abilities (Gut et al., 2021; Fatqurhohman & Susetyo, 2022). Introducing representations without scaffolding or explanations of their interconnections can increase extrinsic cognitive load (Herold et al., 2020; Ahuja et al., 2022). Therefore, learning should be designed in a tiered, representational manner with explicit clarification of relationships among representations, so that each form serves as a conceptual bridge, facilitating knowledge integration and supporting deep mathematical understanding.

c. The Role of Working Memory and Cognitive Load

Working memory limitations in students with dyscalculia restrict their capacity to process and integrate numerical information simultaneously, particularly in multi-step tasks and complex representations (Mishra & Khan, 2023; Kivirähk-Koor & Kiive, 2025). Excessive cognitive load from dense symbols, lengthy instructions, or simultaneous representations diverts attention from conceptual understanding, increases errors, and lowers self-confidence. Therefore, instructional design should manage cognitive load through simplified representations, segmented information, and gradual scaffolding. This approach optimizes working memory, facilitates the integration of mathematical meaning, enhances accessibility, and strengthens conceptual understanding for students with dyscalculia sustainably.

d. Affective Dimensions in Processing and Representation

Mathematics anxiety in students with dyscalculia exacerbates cognitive difficulties in mathematical processing and representation, disrupting working memory, reducing persistence, and promoting avoidance strategies (Devine et al., 2018; Espina et al., 2024). The interaction between anxiety and cognitive limitations creates a negative cycle that hinders the formation of meaningful representations, reinforces perceptions of incompetence, and decreases engagement. Therefore, mathematics instruction should be explicit, multimodal, and adaptive to students' cognitive-affective profiles. Differentiated learning and UDL frameworks provide the foundation for a flexible, emotionally safe, and inclusive learning environment, minimizing representational barriers while supporting sustainable mathematical understanding and active student participation (Amelia & Supena, 2020; Cheng et al., 2020; Fatqurhohman et al., 2025; Lambert, 2021, 2024; Tomlinson & Imbeau, 2023).

2. Mathematical Representation and Multimodality in Mathematics Learning

Mathematical representations are a fundamental element in mathematics learning, particularly for students with dyscalculia who face difficulties in processing abstract numerical concepts. A multimodal representation approach, which integrates concrete, pictorial, and symbolic forms, is considered an evidence-based pedagogical strategy to bridge gaps in conceptual understanding. Theoretically, employing diverse forms of representation allows students to construct mathematical meaning through multiple cognitive pathways, while reducing working memory load and supporting gradual internalization of concepts (Gut et al., 2021; Fatqurhohman et al., 2025). The integration of representations has been shown to enhance

conceptual understanding, improve accuracy and problem-solving efficiency, and facilitate a smoother transition from concrete to symbolic experiences (Variska et al., 2024; Vizha et al., 2025; Fatqurhohman et al., 2020). Furthermore, the multimodal approach contributes to reduced mathematics anxiety and strengthens students' mathematical identity by providing more meaningful and inclusive learning experiences.

a. Concrete representation as a foundation for conceptual understanding

Concrete representations play a crucial role in developing mathematical understanding for students with dyscalculia, who struggle with processing symbols and numerical abstractions. Manipulatives, such as number blocks, number lines, or counters, enable direct interaction with quantities and mathematical relationships through sensorimotor experiences. This approach reduces intrinsic abstraction, strengthens number sense, and stabilizes mental representations before transitioning to pictorial and symbolic forms. Systematic implementation decreases cognitive load, enhances engagement, and facilitates gradual internalization of concepts. Thus, concrete representations serve as an inclusive conceptual foundation, enabling students to build flexible, meaningful understanding that can be transferred to abstract representations (Fatqurhohman et al., 2025).

b. Pictorial representation for structuring numerical and spatial relations

Pictorial representations serve a strategic role in bridging concrete experiences with abstract understanding, particularly for students with dyscalculia who face symbolic processing challenges. These forms include diagrams, graphs, number lines, and semiotic visuals that explicitly organize numerical and spatial relationships. Visualization facilitates recognition of patterns, structures, and inter-concept relationships while reducing verbal working memory load. Research indicates that systematic use of visual representations enhances understanding of geometric concepts, decreases errors, and strengthens representational coherence (Gut et al., 2021; Vizha et al., 2025; Fatqurhohman et al., 2025). Explicit and progressive integration of pictorial representations fosters stable mental models, improves reasoning accuracy, and prepares meaningful transitions to formal symbolic representations.

c. Symbolic representation as a learning transition goal

Symbolic representation is the primary abstract form in formal mathematics education, yet students with dyscalculia often process it procedurally without quantitative understanding. A multimodal approach positions symbolic representation as the result of a gradual transition from concrete and pictorial forms (Fatqurhohman et al., 2020; Fatqurhohman & Susetyo, 2022). This transition links formal notation to previously understood numerical relationships, allowing symbols to serve as meaningful representations rather than mechanical codes. Research shows that establishing conceptual understanding before introducing symbols improves accuracy, strategy flexibility, and reflective reasoning (Gut et al., 2021). Thus, symbolic representation supports generalization, knowledge transfer, and readiness for complex mathematics in an inclusive and meaningful way.

d. Reducing cognitive load, strengthening problem-solving, strengthening mathematical identity

Multimodal representation significantly reduces cognitive load in students with dyscalculia by integrating concrete, pictorial, and symbolic forms, allowing information

to be distributed across multiple cognitive channels and optimizing working memory utilization (Gut et al., 2021; Ahuja et al., 2022). Gradual presentation emphasizes conceptual relationships, enhancing accuracy, inferential reasoning, and problem-solving flexibility (Herold et al., 2020; Fatqurhohman et al., 2025; Kroesbergen et al., 2022). A strength-based approach, supported by assistive technology, reduces math anxiety, strengthens self-confidence, and fosters a positive mathematical identity (Devine et al., 2018; Espina et al., 2024; Lambert, 2024). This strategy provides inclusive, adaptive, and sustainable learning, connecting concrete experiences with formal abstractions in a meaningful way (Fatqurhohman & Huda, 2025; Sofiana et al., 2025).

3. Differentiated Learning and UDL Framework in Inclusive Learning

Mathematics instruction for students with dyscalculia requires an approach that is not only cognitively adaptive but also pedagogically inclusive. In this context, the integration of multimodal representations becomes increasingly effective when framed within *Differentiated Learning* and *Universal Design for Learning* (UDL). This approach emphasizes the importance of flexible learning, recognition of diverse learning needs, and provision of multiple pathways to access content, processes, and learning outcomes. Multimodal representation serves as a conceptual bridge, enabling the principles of differentiation and UDL to be concretely implemented in mathematics education for students with dyscalculia.

a. The relevance of multimodal representation to UDL principles

The Universal Design for Learning (UDL) framework emphasizes three interrelated core principles: *multiple means of representation*, *multiple means of engagement*, and *multiple means of action and expression*.

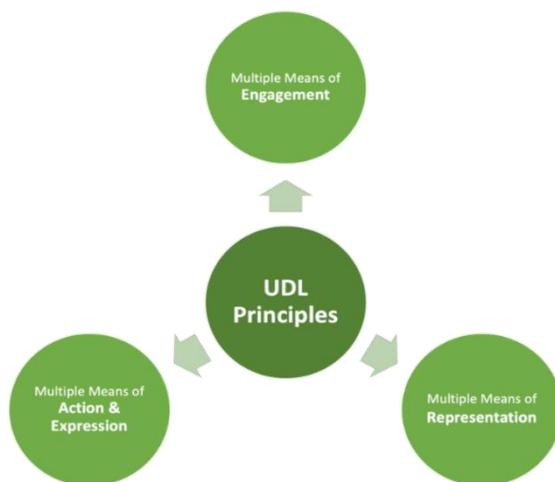


Figure 1. Three Principles of UDL

(1) *Multiple Means of Representation*

Multimodal representation operationalizes the multiple means of representation principle by offering diverse ways to present mathematical information, thereby supporting access for students with varied cognitive profiles, including those with dyscalculia (Fatqurhohman & Susetyo, 2022; Gut et al., 2021). This approach enables students to grasp concepts through concrete, visual, auditory, symbolic, and tactile formats. Flexible presentation considers differences in background, abilities, and learning preferences,

fostering fluency in switching between representations. In classroom practice, this is realized through accessible materials, multimodal resources, varied pedagogical strategies, active student engagement, focus on key concepts, and systematic comprehension checks. These strategies enhance conceptual understanding, accessibility, and active participation, promoting inclusive and sustainable learning outcomes.

(2) *Multiple Means of Engagement*

Flexible representation choices operationalize the multiple means of engagement principle, enhancing motivation, reducing frustration and math anxiety, and fostering active student participation (Devine et al., 2018; Espina et al., 2024). This principle encompasses varied interactive activities, discussions, applied problem-solving, and goal-setting, accounting for differences in student motivation and comfort levels. Providing diverse challenge levels, collaborative opportunities, and support for self-regulation encourages active engagement and autonomous learning. In classroom practice, this is realized through collaborative interactions, technology integration, content choices aligned with student interests, and varied learning activities, enabling students to feel challenged, motivated, and meaningfully engaged in an inclusive learning environment.

(3) *Multiple Means of Action and Expression*

The principle of action and expression enables students to demonstrate understanding through diverse media (*oral, written, visual, and manipulative*) allowing flexible, meaningful application of concepts rather than rote procedural recall (Lambert, 2024; Fatqurhohman & Huda, 2025). Integrating UDL with differentiated learning fosters an inclusive, adaptive, and strength-based instructional design that enhances conceptual understanding, problem-solving, engagement, confidence, and mathematical identity (Fatqurhohman et al., 2025; Gradini et al., 2025). In practice, this involves tasks, assessments, interactive activities, feedback, format choices, and managing assessment anxiety, enabling students to strategically express understanding while supporting executive function development and sustained learning skills.

b. Multimodal representation as an implementation of the principle of differentiation of content, process, and product

Differentiated learning tailors content, process, and product to individual student needs, abilities, and profiles, including those with dyscalculia (Tomlinson & Imbeau, 2023; Sujadi et al., 2024). Multimodal representation operationalizes this principle through concrete, pictorial, and symbolic forms, enabling concept access aligned with cognitive pathways. Students select representation strategies matching their strengths and express understanding visually, orally, or symbolically. This approach enhances problem-solving, higher-order thinking, and deep conceptual understanding (Sofiana et al., 2025; Variska et al., 2024). Collaboration among teachers, parents, and professionals reinforces numeracy, number representation, confidence, motivation, and the development of a positive mathematical identity (Mahmud et al., 2020; Lambert, 2024; Huda et al., 2025).

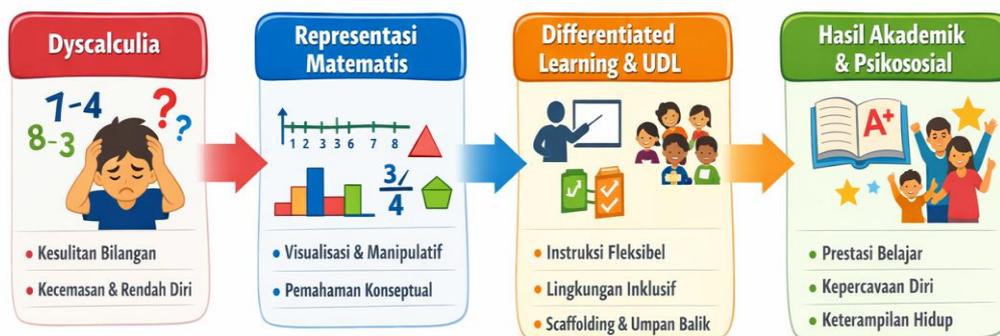


Figure 2. Synergy of Dyscalculia, Mathematical Representation, Differentiated Learning, UDL

The integration of multimodal mathematical representations (*concrete, visual, and symbolic*) facilitates concept internalization, reduces cognitive load, and strengthens problem-solving skills (Fatqurhohman & Susetyo, 2022; Vizha et al., 2025). Differentiated learning adapts content, processes, and products to students' cognitive profiles, interests, and learning styles, offering alternative pathways to conceptual understanding (Tomlinson & Imbeau, 2023; Sofiana et al., 2025). The UDL framework enhances this integration through the principles of representation, engagement, and action & expression, supporting accessibility, motivation, and flexible expression of understanding (Lambert, 2021, 2024; Huda et al., 2025). The synergy of multimodal representations, differentiation, and UDL creates an inclusive, proactive, strength-based learning environment, while collaboration among teachers, parents, and professionals ensures sustained intervention. This approach fosters mathematical understanding, problem-solving, confidence, motivation, and the development of a positive mathematical identity for students with dyscalculia.

c. Reducing learning barriers and strengthening conceptual access

Students with dyscalculia face primary challenges in symbolic abstraction, working memory limitations, and high cognitive load. Integrating multimodal representations within differentiated learning and UDL frameworks offers a pedagogical solution, breaking mathematical concepts into structured concrete, visual, and symbolic experiences (Fatqurhohman & Susetyo, 2022; Vizha et al., 2025). These representations serve as cognitive scaffolds, facilitating the transition to symbolic forms while maintaining conceptual continuity. UDL principles (representation, engagement, and action & expression) ensure accessibility, strategy flexibility, and diverse expression of understanding (Lambert, 2021, 2024; Huda et al., 2025). Scaffolding, multisensory learning, and explicit feedback enhance conceptual access, while differentiation of content, process, and products supports individualized learning pathways. This approach mitigates cognitive and affective barriers, fosters deep conceptual understanding, active engagement, the development of a positive mathematical identity, and sustained learning in an inclusive, equitable environment.

4. Affective Dimensions and Pedagogical Implications of Inclusive Mathematical Representation

Specific learning difficulties in students with dyscalculia affect not only their ability to understand numbers, numerical relationships, and arithmetic procedures but also impact affective, social, and personal dimensions. Understanding these consequences forms the basis for developing inclusive, responsive, and strength-based teaching strategies. Often, correct answers are achieved through mechanical procedures or excessive effort, accompanied by anxiety and limited conceptual understanding. These effects are contextual, depending on the type of mathematical task and learning environment. Therefore, pedagogical interventions should integrate multimodal mathematical representations, gradual scaffolding, and affective support strategies to enhance conceptual understanding, engagement, and students' confidence sustainably.

a. Cognitive Impact

Students with dyscalculia face complex cognitive challenges in understanding numbers, recognizing numerical patterns, recalling mathematical facts, and performing both basic and advanced arithmetic operations (Kunwar & Sharma, 2020; Mishra & Khan, 2023). These difficulties are interrelated, affecting the construction of meaning for mathematical symbols and the connection between procedures and underlying concepts. Consequently, students require more time and additional instructional support for multi-step problem-solving (Fatqurhohman et al., 2025; Gut et al., 2021). Effective teaching strategies include stepwise instruction, systematic scaffolding, and multimodal representations (*concrete, visual, symbolic*), facilitating progressive numerical understanding, strengthening integration across representations, and fostering meaningful and sustainable mathematical competence.

b. Affective Impact

Students with dyscalculia face not only cognitive challenges but also significant affective impacts, including math anxiety, frustration, and low self-confidence (Espina et al., 2024; Lambert, 2024). Repeated experiences of failure and non-responsive learning environments reinforce negative perceptions of mathematical ability, fostering a maladaptive mathematical identity. This cycle reduces motivation, engagement, and increases task avoidance. Strength-based interventions combined with multimodal representations position individual strengths as starting points, facilitating self-reflection, adaptive learning strategies, and positive scaffolding. Such approaches reduce anxiety, enhance competence, and cultivate a more adaptive mathematical identity, supporting simultaneous academic and affective development.

c. Social and Behavioral Impacts

Dyscalculia significantly affects students' social and behavioral dimensions, particularly in classroom interactions and collaborative participation. Repeated mathematical difficulties often trigger avoidance strategies, such as withdrawing from group discussions or reducing engagement, accompanied by feelings of shame and fear of negative evaluation (Baykal & Durmuş, 2025; Espina et al., 2024). These impacts increase the risk of academic isolation and hinder the development of social skills and self-confidence (Salisa & Meiliasari, 2023). Implementing multimodal representations, differentiated learning, and UDL principles creates a safe, inclusive, and supportive

environment, enabling active participation through structured collaboration, peer tutoring, or role-based activities (Lambert, 2021, 2024; Sofiana et al., 2025). This approach not only enhances social engagement but also strengthens positive mathematical identity and adaptive learning behaviors in students with dyscalculia.

d. Impact on Daily Life

Dyscalculia impacts students' functional abilities in daily life, including money management, quantity estimation, time planning, and contextual numerical problem-solving (Mahmud et al., 2020; Baykal & Durmuş, 2025). These challenges reduce independence and increase reliance on others, affecting social and professional readiness. Learning interventions should emphasize transferring mathematical concepts to real-life situations through transaction simulations, time management exercises, practical measurements, and authentic scenarios. This contextual approach strengthens conceptual understanding, boosts motivation, and builds self-confidence, while simultaneously developing students' cognition, autonomy, and life skills in a sustainable and meaningful way.

CONCLUSION

Dyscalculia is a multidimensional specific learning difficulty affecting students' cognitive, affective, social, and functional domains in mathematics learning. Effective pedagogical approaches should be holistic, systematic, and evidence-based, integrating multimodal representations (concrete, pictorial, and symbolic) within *differentiated learning* and *Universal Design for Learning* (UDL) frameworks. These strategies reduce cognitive load, strengthen conceptual understanding, and enhance problem-solving flexibility, while mitigating math anxiety and building self-confidence. Differentiated content, processes, and products, combined with gradual scaffolding and explicit feedback, allow students to express understanding through formats aligned with their strengths. Strength-based implementation, supported by collaboration among teachers, parents, and professionals, creates an inclusive, responsive, and emotionally safe learning environment. Consequently, such integrated interventions enhance academic competence, reinforce affective, social, and autonomous skills, foster positive mathematical identity, and prepare students with dyscalculia to optimize their potential sustainably in education and daily life.

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