Strengthening Numeracy Through Working Memory: A Conceptual Framework for Special Education Needs

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Abstract

Numeracy is a foundational skill essential for lifelong learning, independence, and active participation in modern society. However, students with special educational needs (SEN), particularly those with learning disabilities, frequently struggle with numeracy due to underlying cognitive deficits most notably in working memory (WM). Despite global advancements in inclusive education, instructional approaches often overlook the cognitive demands imposed on SEN learners, resulting in persistent achievement gaps. While previous studies have emphasized WM's role in academic performance, there is a lack of structured frameworks that directly integrate WM support into numeracy instruction for SEN populations. This paper aims to address that gap by proposing a conceptual framework that positions WM as a central mechanism for improving numeracy outcomes. Utilizing a conceptual and integrative design, the framework is developed through a synthesis of empirical research and cognitive theory, drawing on models such as Baddeley's WM model and Sweller's cognitive load theory. The predicted outcomes include improved arithmetic accuracy, task persistence, reduced math anxiety, and enhanced executive function skills. Practical strategies such as scaffolding, chunking, and multisensory instruction are highlighted as essential tools for reducing cognitive overload. This framework offers educators and curriculum designers a cognitively responsive approach to inclusive numeracy education, supporting more effective teaching practices and equitable learning experiences. It also aligns with global educational goals by fostering academic participation and cognitive empowerment among marginalized learners.

Keywords: working memory, numeracy, Special Educational Needs (SEN), inclusive education, Cognitive Load Theory, multisensory

Abstrak

Numerasi merupakan kemahiran asas yang penting untuk pembelajaran sepanjang hayat, kebolehan berdikari, dan penglibatan aktif dalam masyarakat moden. Namun demikian, murid berkeperluan pendidikan khas (MBPK), khususnya mereka yang mempunyai ketidakupayaan pembelajaran, sering menghadapi kesukaran dalam numerasi akibat kekangan kognitif yang mendasari, terutamanya dalam memori kerja (working memory, WM). Walaupun terdapat kemajuan global dalam pendidikan inklusif, pendekatan pengajaran yang diamalkan sering mengabaikan tuntutan kognitif yang dikenakan ke atas murid MBPK, sekali gus menyumbang kepada jurang pencapaian yang berterusan. Walaupun kajian terdahulu telah menekankan peranan WM terhadap prestasi akademik, masih terdapat kekurangan kerangka berstruktur yang secara langsung mengintegrasikan sokongan memori kerja dalam pengajaran numerasi bagi populasi MBPK. Artikel ini bertujuan untuk mengisi jurang tersebut dengan mencadangkan satu kerangka konseptual yang meletakkan memori kerja sebagai mekanisme teras dalam meningkatkan hasil pembelajaran numerasi. Menggunakan reka bentuk konseptual dan integratif, kerangka ini dibangunkan melalui sintesis penyelidikan empirikal dan teori kognitif, dengan merujuk kepada model memori kerja Baddeley serta Teori Beban Kognitif oleh Sweller. Hasil jangkaan termasuk peningkatan ketepatan aritmetik, ketekunan dalam tugasan, pengurangan kebimbangan terhadap matematik, serta *pengukuhan kemahiran fungsi eksekutif. Strategi praktikal seperti perancahan (scaffolding), pengelompokan maklumat (chunking), dan pengajaran multisensori diketengahkan sebagai alat penting untuk mengurangkan beban kognitif. Kerangka ini menawarkan kepada pendidik dan pereka kurikulum satu pendekatan numerasi inklusif yang responsif secara kognitif, bagi menyokong amalan pengajaran yang lebih berkesan serta pengalaman pembelajaran yang adil. Selain itu, kerangka ini selari dengan matlamat pendidikan global melalui usaha memupuk penyertaan akademik dan pemerkasaan kognitif dalam kalangan murid terpinggir.*

Kata kunci: *memori kerja, numerasi, Murid Berkeperluan Pendidikan Khas (MBPK), pendidikan inklusif, Teori Beban Kognitif, multisensori*

INTRODUCTION

Numeracy extends beyond simple counting or performing basic arithmetic; it is a vital skill that supports lifelong learning, personal independence, and active involvement in today's society. For students with special educational needs (SEN), especially those with learning difficulties, developing numeracy abilities remains a significant challenge, often due to cognitive weaknesses, particularly in working memory (WM) (Geary, 2011; Alloway & Alloway, 2010). Even with improvements in inclusive education policies around the world, students with working memory deficits continue to face difficulties in math, such as recognizing numbers, understanding sequences, and solving multi-step problems (Peng & Fuchs, 2016; Holmes & Adams, 2006). These ongoing struggles point to the importance of rethinking numeracy instruction from a cognitive perspective, especially by incorporating strategies that enhance working memory.

Working memory, a key part of executive functioning, enables individuals to hold, manipulate, and retrieve information while completing complex tasks (Baddeley, 2000)]. It is recognized as a strong predictor of math success throughout a person's development [(Swanson, 2011; Raghubar et al., 2010)]. For SEN learners, difficulties in the phonological loop and visuospatial sketchpad, two major components of working memory, have been shown to directly hinder their grasp of number concepts and their ability to perform calculations fluently (Schuchardt et al., 2008; Mammarella et al., 2010)]. Therefore, improving numeracy among these learners must be closely tied to instructional methods that match their cognitive strengths and limitations. Multimodal strategies that reduce cognitive load and support conceptual understanding have proven particularly effective in bridging gaps between knowing and doing [(Sweller, 1994; Gathercole & Alloway, 2008)].

This approach is especially crucial in special education, where learners benefit from personalized, cognitively suitable, and engaging teaching strategies. Conventional math instruction often overlooks the cognitive load on students with working memory challenges, leading to limited progress and frustration. As a result, there is a clear need for a teaching framework that connects numeracy learning with working memory support. Such a model should incorporate elements like multisensory engagement, simplified tasks, and training in executive functions to promote lasting, meaningful progress.

This paper introduces a conceptual model that places working memory at the center of efforts to improve numeracy for students with special needs. Based on established cognitive and educational theories, it draws from existing research to present teaching principles and instructional approaches designed to foster more inclusive and effective math learning. In doing so, it supports global educational goals, such as Sustainable Development Goal 4, by aiming to equip marginalized learners with the tools they need through cognitively responsive and innovative educational practices.

LITERATURE REVIEW

Numeracy

The concept of number is a deeply multifaceted construct that spans cognitive, linguistic, developmental, cultural, and embodied domains. In early childhood, numerical understanding begins with the perception of number as quantity, where children learn to associate numbers with collections of discrete items, treating each item as a unit regardless of size or position (Campbell, 2013). As foundational number sense develops, children gain abilities such as estimating, counting, comparing, and recognizing numerical patterns, often guided by an internal mental number line—a spatial representation of numerical magnitude (Lin, 2023). Beyond cognitive development, language plays a crucial role in shaping numerical concepts. It enables abstract, non-iconic representations that connect numerical relationships with real-world objects and events, distinguishing human numerical understanding from that of other species (Wiese, 2003). This is further supported by the idea that the syntactic structure of human language provides a cognitive scaffold that facilitates the transition from an innate sense of number to more complex mathematical operations (Mendívil-Giró, 2025). On a psychological level, the concept of the integer ONE and the notion of exact equality form the foundation for arithmetic inference and compatibility with rational magnitudes, supporting systematic numerical reasoning (Leslie, Gelman, & Gallistel, 2008). The acquisition of the successor principle, which underpins natural number understanding, reflects the child's grasp of generative rules governing numerical sequences and arithmetic growth (Guerrero & Park, 2023).

Cultural dimensions also shape how numbers are understood and valued. Numbers carry symbolic meanings that are embedded in cultural expressions and language, revealing collective attitudes, norms, and even archetypes through numerologically significant phraseological units (Nussupbekova et al., 2022). A historical lens further reveals that mathematical abstraction is not fixed but evolves over time as a human invention, adapting to societal needs and cognitive progress (Kopp, 2020). Finally, from the perspective of embodied cognition, numerical understanding is not purely abstract but rooted in sensorimotor experiences. Physical interactions and spatial constraints shape how numerical information is processed, leading to systematic heuristics and biases in mental arithmetic (Fischer & Shaki, 2018). Together, these perspectives reveal that the concept of number is not a singular, isolated construct but a dynamic interplay of biological, cognitive, cultural, linguistic, and experiential factors that develop over time and vary across individuals and contexts.

Working Memory

A robust body of research underscores the foundational role of working memory (WM) in children's numerical development and mathematical performance, particularly among those with learning difficulties. Meyer et al. (2010) demonstrated that distinct WM components support mathematical outcomes across developmental stages. Specifically, the central executive and phonological loop were key predictors of mathematical reasoning in early childhood, while the visuospatial sketchpad became more influential for number operations in later years. Holmes and Adams (2006) similarly reported that early math proficiency depends heavily on verbal WM and executive control, which gradually give way to greater reliance on visuospatial WM for more complex tasks.

A pivotal meta-analysis by Peng and Fuchs (2016), encompassing 110 studies, found consistent verbal and numerical WM deficits among children with mathematics difficulties (MD) and learning disabilities (LD). These deficits were particularly pronounced in tasks involving numerical manipulation, highlighting WM's central role in number comprehension. Further, Haberstroh and Schulte-Körne (2023) identified visuospatial WM as having a substantial effect on math learning difficulties ($g \approx 0.84$), with moderate contributions from both the central executive and verbal WM suggesting that tailored interventions based on specific WM profiles may be most effective.

WM also shapes how children engage with both symbolic and non-symbolic numeracy. Studies by Passolunghi et al. (2014) and Chan and Wong (2019) found that WM predicts math performance independently of IQ and processing speed, especially in the early stages of numeracy development. Notably, the "double-deficit" hypothesis posits that children with concurrent deficits in number sense and WM face the most severe challenges in mathematical learning (Kroesbergen & Van Dijk, 2015).

Children with intellectual disabilities (ID) typically exhibit reduced WM capacity across verbal, visuospatial, and executive domains. Research by Brankaer et al. (2011), Henry and MacLean (2002), and Schuchardt et al. (2011) found these limitations strongly correlate with poor performance in number recognition and ordering. However, not all difficulties with number sense can be attributed solely to WM deficits. Shalev et al. (2014) refined this understanding by identifying pronounced impairments in serial order memory—rather than simple item recall—among children with developmental dyscalculia, indicating the critical role of temporal aspects of WM in numerical cognition.

Recent theoretical models further complicate our understanding of WM in early childhood. Carretti et al. (2022) proposed a four-factor model encompassing verbal, visual, spatial-simultaneous, and spatial-sequential WM, all coordinated by a central executive. This framework offers valuable insight into how young learners utilize diverse cognitive resources to construct numerical concepts.

Parallel research on the Approximate Number System (ANS) the intuitive, non-symbolic capacity to estimate quantity demonstrates its relationship with symbolic math performance and its overlap with visuospatial WM. Piazza, Dehaene, and Mazzocco (2004) showed that early ANS acuity predicts later arithmetic achievement, emphasizing the importance of targeting both intuitive and symbolic numerical skills in interventions. Finally, informed by Cognitive Load Theory (Sweller, 1994), there is strong evidence that minimizing extraneous cognitive demands can enhance learning outcomes, especially for children with limited WM capacity. Instructional strategies such as chunking, the use of manipulatives, and multisensory tools like "Pop It" frameworks help sustain WM engagement during mathematical tasks and reinforce conceptual retention.

PROBLEM STATEMENT

Current teaching approaches in special education often fail to consider the cognitive mechanisms that underlie number understanding. Although manipulatives and visual aids are frequently applied, they do not adequately address limitations in working memory (WM), which research has identified as a crucial predictor of mathematical difficulties (Geary, 2011). This highlights the urgent need for instructional strategies that incorporate WM support to enhance numeracy development among MBPK. In Malaysia's special education settings (PPKI), the restricted cognitive capacity of MBPK commonly results in weak numeracy performance. While various mathematical interventions have been introduced, few focus on the underlying cognitive architecture particularly WM that is essential for building number concepts.

Despite extensive evidence on the importance of WM in mathematical learning, special education practices continue to neglect how WM deficits consistently obstruct numeracy growth. Studies show that children with a range of learning challenges—including cerebral palsy, Down syndrome, and general learning disabilities—tend to present significant WM weaknesses that predict poor numeracy achievement, in some cases more strongly than IQ (van Rooijen et al., 2016); (Alloway, 2009)]. Children with low WM not only struggle across most areas of early numeracy but also experience slower developmental progress, putting them at risk for long-term underperformance in mathematics (Toll & Van Luit, 2013). Moreover, WM profiles among children with special educational needs (SEN) vary widely; some exhibit broad WM deficits, while others display specific weaknesses in phonological or visuospatial memory, limiting the effectiveness of uniform teaching approaches (Pickering & Gathercole, 2004).

Beyond mathematics, WM also plays a critical role in literacy, intensifying academic challenges and widening learning disparities among SEN learners (Shvartsman & Shaul, 2024). Although WM-focused training has been shown to improve both memory and early numeracy outcomes in young children, such evidence-based methods are rarely adopted within special education curricula (Kroesbergen et al., 2014); (Passolunghi & Costa, 2016)]. Additionally, students with Down syndrome and other intellectual disabilities frequently experience short-term memory difficulties that further restrict their ability to acquire foundational numeracy skills, with insufficient teacher expertise compounding this issue (Jurnal Pendidikan Bitara UPSI, 2023). Collectively, these insights point to a significant concern: the ongoing neglect of WM-centered pedagogy in special education continues to weaken numeracy development, leading to persistent academic underachievement and narrowing future opportunities for children with SEN.

OBJECTIVES

The primary objective of this paper is to propose a conceptual framework that positions working memory (WM) as a central cognitive mechanism in supporting numeracy development among students with special educational needs (SEN). This objective is addressed through the following specific aims:

i. To explore the cognitive underpinnings of numeracy difficulties in SEN learners, with a particular focus on the role of working memory deficits in impeding mathematical understanding and performance.
ii. To synthesize current empirical and theoretical literature from cognitive psychology, special education, and mathematics education in order to identify evidence-based instructional strategies that support learners with working memory limitations.
iii. To develop a cognitive-responsive instructional framework that integrates working memory support into numeracy pedagogy, emphasizing strategies such as task simplification, multisensory learning, and scaffolding.
iv. To highlight the implications of the proposed framework for inclusive curriculum design, teaching practice, and educational policy, with the broader aim of promoting equitable and sustainable learning outcomes in alignment with global education goals (e.g., SDG 4: Quality Education).

RESEARCH QUESTION

i. How do working memory deficits influence the development of numeracy skills in students with special educational needs (SEN)?
ii. What evidence-based instructional strategies have been shown to effectively support numeracy learning in students with working memory limitations?
iii. How can a cognitive-responsive instructional framework be developed to integrate working memory support into numeracy teaching for SEN learners?
iv. What are the implications of a working memory–supported numeracy framework for inclusive pedagogy, curriculum design, and educational policy in the context of SDG 4 (Quality Education)?

METHODOLOGY

This study adopts a conceptual and integrative research design to develop a framework aimed at improving numeracy outcomes for students with special educational needs (SEN), with a particular focus on the role of working memory (WM). The methodology is organized into three interconnected phases: literature synthesis, theoretical integration, and framework development. First, a comprehensive review of both empirical and theoretical literature was conducted to examine the relationship between WM and numeracy acquisition in SEN learners. Peer-reviewed journal articles were sourced from disciplines such as education, psychology, and cognitive science. Key studies related to WM theory including Baddeley's model along with research on numeracy instruction and cognitive interventions, formed the basis of the review. Databases such as ERIC, Scopus and Google Scholar were used to locate relevant studies using keywords such as "working memory, numeracy, SEN, cognitive load, and math intervention. The inclusion criteria emphasized studies that addressed specific WM components (the phonological loop and visuospatial sketchpad), identified numeracy difficulties in SEN populations, or presented instructional models grounded in cognitive principles.

The second phase involved theoretical integration, using an interdisciplinary approach to synthesize findings from cognitive psychology, special education, and developmental learning theory. Central theoretical models such as Baddeley's working memory model and Sweller's cognitive load theory were integrated with inclusive pedagogical principles to highlight how WM limitations hinder numeracy learning in SEN students. This synthesis helped identify essential instructional elements required to meet the cognitive needs of this population.

In the final phase, insights from the literature and theoretical integration informed the development of a conceptual framework that places working memory at the core of numeracy instruction. The framework outlines the cognitive demands posed by numeracy tasks and the specific WM-related barriers faced by SEN learners. It proposes evidence-based instructional strategies such as multisensory learning, task simplification, and cognitive scaffolding to enhance accessibility and learning outcomes. Additionally, the framework offers practical implications for curriculum design, pedagogical planning and educational policy, promoting a cognitively responsive approach to inclusive mathematics education.

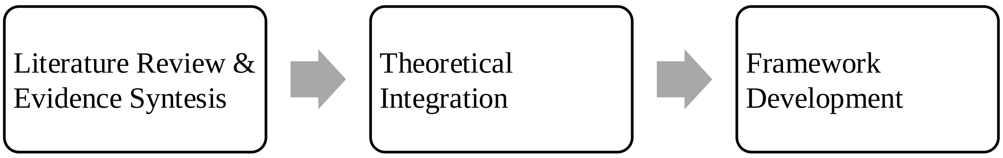

Figure 1: Methodology

CONCEPTUAL FRAMEWORK

In the context of inclusive mathematics instruction for children with special educational needs (MBPK), the Numeracy *Pop It* Approach represents an innovative, multisensory pedagogy designed to enhance number concept acquisition and support cognitive processing, particularly working memory. Grounded in multisensory learning theory (Felder & Silverman, 1988) and the Concrete–Pictorial–Abstract (CPA) model (Bruner, 1966), this approach operationalizes learning through the integration of tactile, visual, and kinesthetic stimuli via the use of "Pop It" tools. Each discrete "pop" represents a quantifiable unit, allowing learners to physically engage with numbers in tasks such as counting, matching, sequencing, and basic arithmetic operations. From a cognitive perspective, this approach aligns with Cognitive Load Theory (Sweller, 1994), as it reduces extraneous processing demands and facilitates efficient encoding of mathematical concepts into working memory. The hands-on nature of Pop It tasks fosters active learning, enhances motivation, and scaffolds number understanding in concrete, observable ways. Furthermore, its adaptability to various numeracy objectives and its affordability make the *Pop It* Approach a sustainable and scalable solution, especially in resource-constrained educational settings, thus aligning with the goals of SDG 4 (quality education) and SDG 12 (responsible consumption and production).

The first dependent variable in this study, number concept, refers to the foundational understanding of numerical relationships, including quantity recognition, one-to-one correspondence, comparison (e.g., more or less), and early operations such as addition or subtraction. For MBPK, who often struggle with abstract reasoning and symbolic representation, conceptual clarity in numeracy is critical not only for academic progress but also for essential life skills such as time management, shopping, and money handling. The *Pop It* tool directly contributes to this development by concretizing abstract numerical ideas through physical interaction. It enables learners to visualize quantities and perform operations in a structured yet engaging manner, which builds the conceptual foundation necessary for higher-order mathematical thinking.

The second dependent variable, working memory, is a core cognitive system responsible for temporarily storing and manipulating information necessary for learning and problem-solving (Baddeley, 2000). It comprises three interrelated components: the phonological loop (for verbal/auditory data), the visuospatial sketchpad (for visual/spatial data), and the central executive (which directs attention and coordinates cognitive processes). In mathematics learning, particularly for students with cognitive impairments, working memory plays a vital role in retaining number sequences, executing multi-step procedures, and managing mental computations. Many MBPK exhibit working memory deficits, which significantly impact their ability to perform even basic mathematical tasks. The *Pop It* Approach mitigates these challenges by breaking down tasks into manageable, memory-friendly chunks and offering immediate sensory reinforcement. It also strengthens visuospatial memory through color and position cues and supports phonological rehearsal in a playful, low-pressure context thereby enhancing overall working memory capacity and improving mathematical fluency.

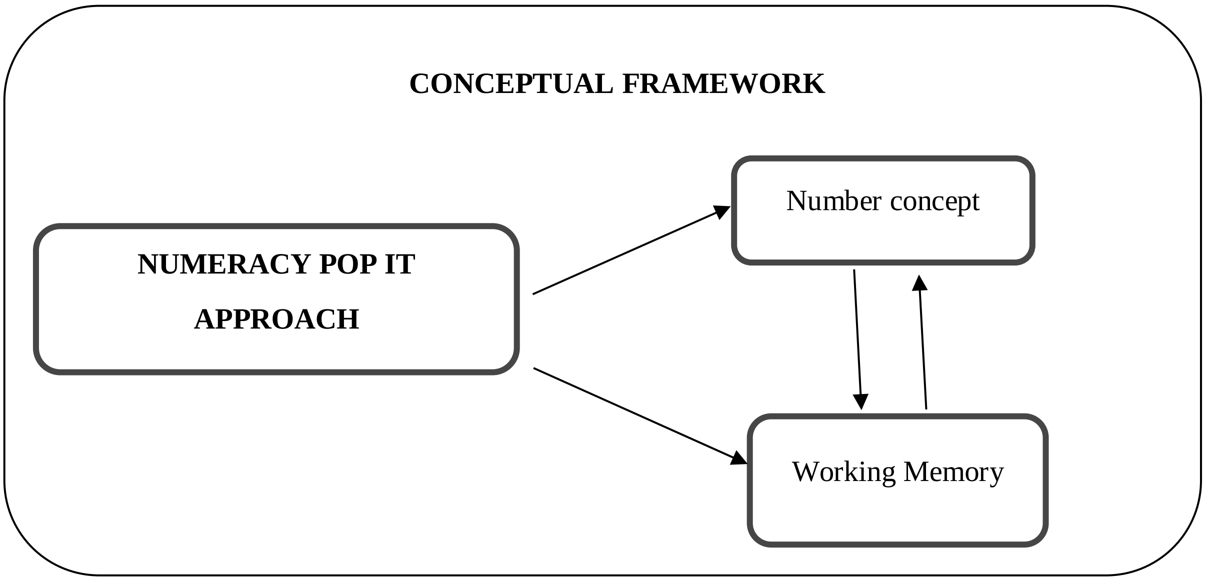

Figure 2: Conceptual Framework

RESULT AND DISCUSSION

Based on the integration of cognitive theory, existing empirical findings and inclusive pedagogy, the proposed framework is to produce several important educational outcomes for SEN students in numeracy learning.

a) Improve Numeracy Performance through Cognitive Alignment

The framework underscores the importance of aligning numeracy instruction with the cognitive profiles of students with special educational needs (SEN), particularly by addressing deficits in working memory (WM). This approach moves beyond a one-size-fits-all model of teaching, instead tailoring instruction to how SEN learners process, store, and retrieve mathematical information. Working memory plays a central role in numeracy, as it allows students to hold numbers in mind while performing calculations, follow multi-step instructions, and apply mathematical rules and procedures. However, many SEN learners, especially those with conditions such as dyscalculia, ADHD, or specific learning disabilities have limited WM capacity, making them vulnerable to cognitive overload during complex tasks. When instruction does not account for this limitation, learners are more likely to forget steps, misplace numbers, or misinterpret sequences, leading to errors and disengagement.

To address these challenges, the framework advocates for cognitively accessible instruction that reduces working memory demands through strategies such as scaffolding, chunking, and the use of visual aids or manipulatives. These methods help structure information in a way that aligns with students' cognitive abilities, enabling them to accurately recognize numbers, complete arithmetic tasks, and solve multi-step problems with greater success. This prediction is grounded in cognitive load theory, which demonstrates that minimizing extraneous mental effort enhances learning by allowing WM to focus on essential problem-solving processes (Sweller, 1994). Likewise, studies by Gathercole and Alloway (2008) show that instructional adjustments tailored to students with WM deficits significantly improve both academic performance and classroom engagement. When these WM-responsive strategies are implemented, learners tend to exhibit higher accuracy, improved task completion, and more efficient problem solving, as they are less burdened by mental fatigue and confusion. Beyond academic performance, these improvements contribute to increased confidence, independence, and willingness to participate in mathematical activities—creating a positive cycle of success and motivation. In essence, by designing numeracy instruction around working memory capacity, educators can unlock the potential of SEN learners, resulting in more equitable, effective, and empowering learning experiences.

b) Reduction in Math Anxiety and Cognitive Frustration

Another outcome of the framework is a significant reduction in mathematics-related anxiety, a common and deeply rooted issue among students with working memory (WM) deficits. These learners often encounter tasks that exceed their cognitive processing capacity, leading to frequent mistakes, incomplete work, and a persistent sense of failure. Over time, these repeated negative experiences can foster a strong aversion to mathematics, reinforcing low self-esteem, helplessness, and academic avoidance. The emotional toll of such frustration is particularly pronounced in students with special educational needs (SEN), who may already struggle with confidence in their academic abilities. By incorporating multisensory, scaffolded, and simplified instructional approaches, the framework seeks to disrupt this negative feedback loop.

Multisensory techniques engage various sensory pathways—such as visual, auditory, and kinesthetic—allowing students to process information in more concrete and accessible ways. Scaffolding and simplification, meanwhile, reduce the cognitive load of each task by breaking it into smaller, manageable steps, making success more achievable and consistent. These supportive methods can create a more inclusive and emotionally safe learning environment where learners feel capable and in control. Research supports this approach, indicating that cognitively accessible instruction not only improves task performance but also reduces academic stress and avoidance behaviors [(Holmes & Adams, 2006); (Peng & Fuchs, 2016)]. As students begin to experience success with less effort and frustration, their confidence in math increases, which in turn boosts motivation and engagement. Thus, the framework not only enhances cognitive access to numeracy content but also addresses the emotional and psychological barriers that often hinder long-term learning and participation in mathematics.

c) Increased Engagement and Task Persistence

An important projected outcome of the proposed framework is an increase in student engagement and task persistence, particularly among learners with working memory (WM) deficits. Students with special educational needs (SEN) often disengage from mathematics tasks not due to a lack of interest, but because the cognitive demands quickly exceed their WM capacity. When too much information must be held and processed simultaneously such as in multi-step problems or abstract arithmetic these learners experience rapid cognitive fatigue, leading to inattention, frustration, and task abandonment. Instructional strategies that are carefully designed to match learners' cognitive capacities, such as the use of visual aids, interactive learning tools, and chunked instructions, help reduce these demands and thus sustain attention over longer periods. Visual supports and manipulatives externalize information that would otherwise overload WM, while chunking allows students to process smaller, manageable segments of content sequentially, avoiding overload [(Sweller, 1994); (Gathercole & Alloway, 2008)].

Interactive and hands-on tools also promote active engagement, encouraging learners to explore math concepts in a low-pressure, supportive context. Furthermore, working memory is closely tied to the executive function system, which governs attention regulation and goal-directed behavior [(Baddeley, 2000); (Swanson, 2011)]. As such, reducing WM strain can free up cognitive resources for sustained focus and better task monitoring. Empirical evidence supports this: studies have shown that cognitively adaptive instruction significantly improves engagement and perseverance in SEN populations, even in subjects typically associated with high dropout rates like mathematics [(Peng & Fuchs, 2016); (Holmes & Adams, 2006)]. By making math tasks cognitively accessible and emotionally manageable, the proposed framework not only helps students begin tasks with confidence but also persist through challenges, fostering a deeper, more resilient form of learning.

d) Transferable Gains in Executive Function and Self-Regulation

Beyond direct improvements in numeracy, the proposed framework is apply to yield significant secondary benefits in executive function and self-regulation, which are crucial for academic success across subject areas. Executive functions refer to a set of high-level cognitive processes including working memory, cognitive flexibility, inhibitory control, planning, and self-monitoring that allow individuals to regulate their thoughts and behaviors to achieve specific goals [(Miyake et al., 2000)]. Regular engagement with numeracy tasks that are explicitly designed to support working memory (WM) may function as implicit cognitive training, helping students strengthen not only their WM capacity but also their ability to plan, sequence, and monitor tasks more effectively. This is particularly relevant for learners with special educational needs (SEN), many of whom exhibit deficits in executive functioning, contributing to difficulties in maintaining attention, managing time, and organizing multi-step tasks [(Diamond, 2013); (Gathercole & Alloway, 2008)].

By incorporating scaffolded, cognitively accessible instruction such as step-by-step problem breakdowns, structured routines, and feedback loops the framework encourages students to internalize strategies for self-monitoring and control. Over time, this process supports the development of metacognitive awareness, as students begin to reflect on their performance, adjust strategies, and persevere through challenges. Such improvements are not restricted to mathematics; they are transferable across academic contexts, promoting better reading comprehension, written expression, and science reasoning [(Best, Miller, & Naglieri, 2011); (Bull & Scerif, 2001)]. Moreover, as executive function skills improve, students are more likely to demonstrate increased autonomy, emotional regulation, and goal-directed behavior in the classroom. Therefore, the framework's emphasis on WM-responsive instruction offers a dual benefit: addressing the immediate demands of numeracy while also fostering the foundational cognitive skills necessary for long-term academic and personal growth.

WORKING MEMORY IMPACT PROBLEM-SOLVING IN EDUCATIONAL

A substantial body of research underscores the pivotal role of working memory (WM) in educational problem-solving, aligning strongly with the framework proposed in this paper. WM enables students to hold and manipulate relevant information during complex cognitive tasks, making it foundational to mathematical reasoning and scientific inquiry. Studies consistently demonstrate that students with higher WM capacity outperform peers in math problem-solving tasks, as they are better equipped to manage multistep procedures and retain intermediate calculations (Utami & Warniasih, 2019; Li et al., 2023). Conversely, students with lower WM capacity often struggle to complete complex problems due to their limited ability to store and process necessary information (Medrano & Miller-Cotto, 2025). This cognitive strain can be mitigated through targeted strategies such as offloading information onto external aids, which helps free up cognitive resources and enhance performance, particularly among students with limited WM (Medrano & Miller-Cotto, 2025). Additionally, WM is closely linked to executive functions especially executive attention which help learners monitor progress, inhibit distractions, and adjust strategies during problem-solving (Kar & Kenderla, 2017; Liu, 2024).

Instructional design also plays a critical role; modular presentation of content, which breaks down complex problems into smaller, manageable parts, has been shown to reduce intrinsic cognitive load and improve comprehension and retention (Gerjets et al., 2004). These findings support the idea that WM-responsive instructional strategies like those emphasized in the proposed framework are essential for increasing both accuracy and task persistence in problem-solving activities. Furthermore, WM is not static; it develops over childhood and can be strengthened through training interventions, such as computerized cognitive training (CCT), which have demonstrated effectiveness in improving academic problem-solving performance (Wiest et al., 2020; Swanson & McMurran, 2018). However, the effectiveness of WM in problem-solving is influenced by external factors like stress, which can impair WM function, and prior knowledge, which can support more efficient use of limited WM resources (Almarzouki, 2024; Medrano & Miller-Cotto, 2025). Collectively, this literature supports the outcomes predicted by the current paper: that enhancing WM through targeted, cognitively aligned strategies not only improves numeracy performance but also strengthens engagement, persistence, and executive functioning in SEN learners.

CRITICAL ANALYSIS AND LIMITATIONS

While the framework offers a promising direction for improving numeracy outcomes through working memory (WM)-responsive instruction, several critical limitations and challenges must be acknowledged. First, there is a tension between generalization and individualization. The framework assumes that WM-based strategies will benefit a broad spectrum of students with special educational needs (SEN), yet the cognitive profiles within this population are highly heterogeneous. For example, while students with dyscalculia may benefit from structured, step-by-step number processing, students with ADHD or autism spectrum disorder (ASD) may require very different supports, such as behavioral regulation or sensory accommodations. Overgeneralizing cognitive strategies across such diverse needs risks reducing effectiveness or even introducing new barriers.

Second, the framework's success is highly dependent on teacher training and implementation fidelity. Teachers must not only understand complex cognitive principles, such as WM limitations and cognitive load, but also be capable of consistently integrating these strategies into daily practice. Without adequate professional development, classroom modeling, and institutional backing, these methods may be inconsistently applied, undermining their intended impact.

Third, it is important to recognize that this framework remains a conceptual model, and thus its effectiveness is still hypothetical. To validate the proposed benefits such as improvements in numeracy, executive functioning, and self-regulation rigorous empirical testing through experimental or quasi-experimental studies is necessary. Without controlled trials and measurable outcomes, its practical relevance and scalability remain uncertain.

Lastly, the complexity of measurement presents a methodological challenge. Accurately assessing changes in working memory capacity, math fluency, engagement, and executive function simultaneously is difficult, particularly in SEN populations where overlapping cognitive, emotional, and behavioral factors are common. Developing valid, reliable, and sensitive tools for this purpose is essential but demanding. Addressing these limitations through individualized approaches, teacher training programs, pilot interventions, and robust evaluation tools will be critical to ensuring the framework's long-term success and real-world applicability.

CONCLUSION

This paper proposes a conceptual framework that positions working memory (WM) as a central cognitive mechanism for enhancing numeracy outcomes in students with special educational needs (SEN). By aligning numeracy instruction with learners' cognitive profiles particularly targeting WM deficits the framework offers a pathway toward more effective, accessible, and inclusive mathematics education. The anticipated outcomes include improved arithmetic accuracy, number recognition, and problem-solving ability, alongside secondary benefits such as reduced math anxiety, increased engagement, and enhanced executive functioning. These gains are expected due to the use of cognitively responsive strategies such as scaffolding, chunking, multisensory input, and task simplification, which collectively reduce cognitive overload and promote deeper learning. Furthermore, regular engagement with WM-supportive tasks may foster broader self-regulatory skills, including planning, attention control, and metacognitive awareness, which are transferable across academic domains. However, the framework's potential impact is contingent on critical factors such as individualized implementation, teacher training, and empirical validation. While promising, it remains a theoretical model that must be tested in diverse classroom contexts using rigorous methodologies. In conclusion, this framework serves as a foundation for rethinking numeracy instruction through a cognitive lens—advocating for instructional practices that not only support academic achievement but also empower SEN learners with the cognitive tools necessary for lifelong learning.

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DECLARATION OF GENERATIVE AI

During the preparation of this work, the author(s) used ChatGPT and Gemini to enhance the clarity and organization of the writing. After using the ChatGPT and Gemini, the author(s) thoroughly reviewed, revised, and edited all generated content as necessary. The author(s) take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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