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Theory Informed Colour Supported Instructional Design for Early Numeracy Learning in a Child with ADHD

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Abstract

Children with Attention-Deficit/Hyperactivity Disorder (ADHD) often experience difficulties in early numeracy because of deficits in attention, working memory, and executive functioning. Although flashcards are widely used to support mathematics learning, limited evidence is available regarding the effectiveness of flashcards designed according to evidence-based cognitive learning principles. This study aimed to examine the effectiveness of theory-informed colour-supported flashcards in improving early numeracy performance in a child with ADHD. A single-subject experimental design (A–B) was employed involving one eight-year-old second-grade student with ADHD attending a special school in Indonesia. The intervention consisted of colour-supported flashcards developed by integrating Executive Function Theory, Cognitive Load Theory, Dual Coding Theory, the Cognitive Theory of Multimedia Learning, and the Signaling Principle. Early numeracy performance was assessed across four baseline sessions and five intervention sessions using repeated measurements. Data were analyzed through visual analysis and Percentage of Non-overlapping Data (PND). The participant's mean score increased from 63.75 during baseline to 79.00 during intervention, representing an improvement of approximately 23.9%. Complete non-overlap between baseline and intervention data (PND = 100%) indicated a strong intervention effect. These findings suggest that the observed improvement was associated not merely with repeated flashcard practice but with instructional materials intentionally designed to support attention, reduce unnecessary cognitive processing, and strengthen visual-verbal integration. The study provides preliminary evidence that theory-informed instructional design may enhance early numeracy learning for children with ADHD and offers practical implications for developing cognitively responsive mathematics instruction in inclusive and special education.

Keywords: Attention-Deficit/Hyperactivity Disorder (ADHD), early numeracy, instructional design, cognitive learning theories, mathematics education, single-subject research

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INTRODUCTION

Early numeracy is widely recognized as one of the most fundamental competencies acquired during childhood because it establishes the foundation for subsequent mathematical learning, academic achievement, and effective participation in everyday life. Beyond basic counting and arithmetic, early numeracy encompasses children's understanding of number sense, quantity relationships, numerical magnitude, pattern recognition, and mathematical reasoning, all of which are essential for solving real-world problems. A growing body of evidence has demonstrated that numeracy skills developed during the early years strongly predict later

mathematics achievement, educational attainment, and broader life outcomes. A recent meta-analysis involving more than 13,000 children identified early numeracy as one of the strongest predictors of subsequent mathematics performance, highlighting the long-term educational significance of foundational mathematical competencies (Ruiz et al., 2024). Similarly, Ünal et al. (2024) reported that children's understanding of numerical magnitude and symbolic number representation consistently predicts later mathematical success across different educational contexts. Reflecting this evidence, the Organization for Economic Co-operation and Development (OECD, 2024) identifies numeracy as a core lifelong competency that supports informed decision-making, financial literacy, employment opportunities, health management, and active participation in modern society. Despite its recognized importance, many children with neurodevelopmental conditions continue to experience persistent difficulties in acquiring foundational numeracy skills, suggesting that conventional instructional approaches may not adequately address their learning needs. Among children with neurodevelopmental disorders, Attention-Deficit/Hyperactivity Disorder (ADHD) is consistently associated with substantial challenges in mathematics learning. ADHD is characterized by persistent patterns of inattention, hyperactivity, and impulsivity that interfere with academic functioning and adaptive behavior (American Psychiatric Association, 2022). Although these behavioral characteristics are the most visible manifestations of the disorder, an increasing body of research indicates that underlying deficits in executive functioning constitute one of the principal mechanisms contributing to poor mathematical performance. Executive functions—including working memory, inhibitory control, cognitive flexibility, sustained attention, and planning—enable learners to maintain relevant information, suppress distracting stimuli, shift efficiently between problem-solving strategies, and coordinate multiple cognitive processes during mathematical reasoning. Deficits in these executive processes frequently prevent children with ADHD from following multistep procedures, retaining numerical information while solving problems, maintaining attention to task-relevant information, and monitoring their own responses, ultimately resulting in lower mathematics achievement than their typically developing peers (Kofler et al., 2024; Gaye et al., 2024).

Emerging evidence further suggests that mathematical difficulties in children with ADHD cannot be explained solely by insufficient practice or limited mathematical knowledge. Rather, these difficulties often arise because conventional instructional materials frequently impose cognitive demands that exceed learners' executive processing capacities. Mathematical learning requires students to simultaneously attend to relevant visual information, retain intermediate calculations in working memory, inhibit competing responses, integrate verbal and visual representations, and continuously monitor problem-solving progress. For children with ADHD, whose executive resources are often compromised, these concurrent cognitive demands can overload information processing and reduce learning efficiency (Kofler et al., 2024; Gaye et al., 2024). Within the Indonesian educational context, similar challenges have been reported, indicating that mathematics instruction for students with ADHD should accommodate learners' attentional characteristics and cognitive needs rather than relying solely on conventional instructional practices (Surmilasari et al., 2022). Likewise, research on mathematics instructional design in Indonesia emphasizes that reducing unnecessary cognitive load through well-structured learning materials can improve students' capacity to process mathematical information effectively (Richardo & Cahdriyana, 2021). Consequently, improving numeracy outcomes for children with ADHD requires instructional approaches that are deliberately designed to support cognitive processing rather than simply increasing opportunities for repetitive practice. This perspective has shifted contemporary educational research from asking whether instructional media are effective to examining how instructional materials should be designed to align with learners' cognitive characteristics and facilitate meaningful learning.

The recognition that executive-function deficits underlie many mathematical learning difficulties has important implications for instructional design. If children's performance is constrained by limitations in working memory, attention regulation, and inhibitory control, instructional interventions should be intentionally designed to minimize unnecessary cognitive demands while facilitating efficient information processing (Kofler et al., 2024; Areizaga Barbieri & Rodrigues, 2025). This perspective is consistent with contemporary cognitive learning research, which emphasizes that effective instruction depends not only on what is taught but also on how information is organized, presented, and processed by learners (Fiorella & Mayer, 2022). Rather than viewing instructional materials as passive teaching aids, current cognitive perspectives conceptualize learning materials as cognitive tools that can either reduce or increase learners' processing demands depending on their design (van Merriënboer & Sweller, 2025). Several complementary theoretical frameworks therefore provide a strong foundation for designing instructional materials that support mathematical learning among children with ADHD. Executive Function Theory suggests that instructional environments should compensate for limitations in working memory and attentional control by presenting

information in manageable, well-structured formats that reduce cognitive overload (Kofler et al., 2024). Likewise, Cognitive Load Theory proposes that learning is enhanced when unnecessary mental effort is minimized, allowing learners to allocate limited cognitive resources to meaningful schema construction (Areizaga Barbieri & Rodrigues, 2025). Complementing this perspective, recent evidence indicates that integrating verbal and visual representations promotes deeper conceptual understanding by supporting complementary cognitive processing pathways (Fiorella & Mayer, 2022). Collectively, these perspectives suggest that instructional effectiveness depends not merely on the selection of educational media but on the extent to which instructional materials are deliberately designed to align with learners' cognitive architecture (van Merriënboer & Sweller, 2025).

One instructional feature that has received increasing attention within cognitively informed instructional design is the strategic use of color. In educational settings, color serves a function far beyond aesthetic enhancement. When systematically applied, color acts as an instructional signal that guides learners' attention toward relevant information, facilitates perceptual organization, and reduces visual search demands during problem solving (Skulmowski & Xu, 2022). According to the Signaling Principle, visual cues such as color highlighting enable learners to identify essential information more efficiently by directing selective attention and reducing unnecessary cognitive processing (van Gog, 2021). Rather than increasing the amount of information presented, color improves the organization of existing information, making relationships among concepts more readily identifiable. Recent evidence indicates that color-coded instructional materials enhance learners' ability to distinguish relevant from irrelevant information, thereby improving cognitive efficiency and reducing extraneous processing demands during learning (Fiorella & Mayer, 2022; Skulmowski, 2022). For learners with ADHD, who frequently experience difficulties sustaining attention and filtering competing stimuli, strategically applied color cues may provide external cognitive support that facilitates information processing while reducing executive processing demands (Kofler et al., 2024). The educational value of color is likely to be particularly important during early numeracy instruction, where children must coordinate multiple sources of information simultaneously, including numerical symbols, quantities, mathematical operations, and spatial relationships. Color-supported instructional materials can simplify these complex visual environments by emphasizing critical mathematical features, strengthening associations between symbolic and non-symbolic representations, and reducing interference from irrelevant stimuli. Similar findings have also been reported in Indonesian mathematics education, where instructional media incorporating color and visual emphasis improved students' engagement, conceptual understanding, and mathematics learning outcomes compared with conventional instructional materials (Maghfiroh et al., 2024; Yuliani et al., 2024). Consequently, colour should not be regarded merely as a decorative characteristic of instructional materials but as an evidence-informed design element that supports cognitive processing during mathematical learning. Within this perspective, instructional materials become effective not because they incorporate color itself, but because color is intentionally integrated according to established principles of cognitive learning and instructional design.

Recent empirical studies have consistently demonstrated the educational potential of visual instructional supports, including flashcards, pictorial representations, and other visually structured learning materials, across a variety of learning contexts. Previous research has reported positive effects of flashcard-based interventions on vocabulary acquisition, literacy development, concept learning, and early mathematics achievement, particularly among children requiring additional educational support (Almuwaiziri et al., 2023; Krisdiana & Jamaludin, 2023). These findings suggest that visual instructional materials can enhance learner engagement, facilitate information retention, and improve academic performance by providing concrete and accessible representations of abstract concepts. Similar evidence has also been reported in Indonesian educational settings, where flashcard-based instructional media have been shown to improve students' learning outcomes and engagement across elementary education contexts, including mathematics learning. However, despite this growing body of evidence, much of the existing literature has primarily evaluated the effectiveness of instructional media in terms of learning outcomes, while giving comparatively limited attention to the cognitive mechanisms through which instructional design facilitates learning, especially for children with neurodevelopmental disorders. This limitation is particularly evident in mathematics education for children with ADHD. Although several intervention studies have explored the effectiveness of visual media for improving mathematical performance, relatively few have explicitly grounded instructional design within established cognitive learning theories. For example, visualization-based interventions have demonstrated significant improvements in mathematical word-problem solving among children with ADHD, yet the emphasis remains largely on intervention effectiveness rather than on explaining how specific design features

support executive functioning and cognitive processing (Almuwaiziri et al., 2023). Consequently, it remains unclear whether observed improvements result merely from increased learner motivation and repeated exposure to instructional materials or from instructional features that systematically support executive functioning, reduce unnecessary cognitive load, and facilitate meaningful cognitive processing. Understanding these underlying mechanisms is essential because interventions informed by cognitive theory are more likely to produce instructional designs that can be replicated, refined, and adapted across diverse educational settings than interventions evaluated solely on the basis of learning outcomes.

A second limitation concerns the theoretical integration underpinning instructional interventions. Existing studies typically draw upon a single theoretical perspective or provide only limited theoretical justification for instructional design decisions. Few studies have simultaneously incorporated Executive Function Theory, Cognitive Load Theory, Dual Coding Theory, the Cognitive Theory of Multimedia Learning, and the Signaling Principle within a unified instructional framework specifically developed to support early numeracy learning among children with ADHD (Mayer, 2023; Chen et al., 2023). As a result, there remains limited empirical evidence explaining how these complementary cognitive principles may interact to facilitate mathematical learning through carefully designed visual instructional materials. Addressing this gap is important not only for strengthening the theoretical foundation of instructional interventions but also for advancing evidence-based educational practices in special education. Recent intervention studies have shown that visual supports can improve mathematical performance among children with ADHD; however, these interventions rarely explain their instructional features through an integrated cognitive framework, making it difficult to determine which design principles are responsible for the observed learning gains (Almuwaiziri et al., 2023). In addition, evidence from low- and middle-income countries remains comparatively scarce. Much of the existing literature has been conducted in Western educational contexts, where instructional resources, classroom environments, and educational support systems differ substantially from those available in many developing countries. Consequently, the transferability of previous findings to other educational settings cannot be assumed. Generating contextually relevant evidence is therefore essential for informing instructional practices that are both theoretically grounded and practically applicable within diverse educational systems, including special schools that often operate under limited instructional resources.

Moreover, prior flashcard-based interventions for learners with additional needs have generally relied on generic colour or picture cues intended primarily to increase engagement and repetition, without deriving their visual and structural features from an explicit cognitive framework (Krisdiana & Jamaludin, 2023; Almuwaiziri et al., 2023). Consequently, these studies cannot clarify which specific instructional features, such as colour placement, symbol pairing, cueing, or repetition itself, are responsible for the observed learning gains, nor whether the same materials would remain effective for learners whose executive-function profile differs from the sample studied. The present study departs from this pattern by treating each visual feature of the flashcard as a deliberate translation of a specific theoretical principle: colour is applied as a signaling cue rather than a decorative element (Signaling Principle), numerical symbols are consistently paired with visual quantity representations (Dual Coding Theory), and the amount and sequencing of information presented on each card is constrained to remain within the participant's working-memory capacity (Cognitive Load Theory; Executive Function Theory). This theory-driven design process, rather than the use of colour or flashcards as such, constitutes the principal novelty of the present study relative to earlier card-based interventions.

Accordingly, the present study does not simply examine whether color-supported flashcards improve early numeracy performance. Rather, it investigates how instructional materials intentionally designed according to complementary cognitive learning principles may facilitate early numeracy learning in a child with ADHD. Specifically, the intervention integrates principles derived from Executive Function Theory, Cognitive Load Theory, Dual Coding Theory, the Cognitive Theory of Multimedia Learning, and the Signaling Principle to develop color-supported instructional materials that reduce executive processing demands while promoting meaningful mathematical information processing. This integrative approach reflects recent developments in instructional design research, which emphasize that effective educational interventions should be grounded in complementary cognitive theories rather than relying on isolated instructional principles (Mayer, 2024; Trypke et al., 2023). To evaluate the effectiveness of this theory-informed instructional intervention, the present study employed a Single-Subject Research (SSR) design, a methodological approach widely recognised as appropriate for evaluating educational interventions in low-incidence populations and generating evidence-based practices in special education (Horner et al., 2005; Kratochwill et al., 2013). The study also follows current recommendations for rigorous reporting of single-case intervention research (Tate et al., 2016). By integrating complementary cognitive learning theories within a rigorous single-case

methodology, this study aims not only to examine improvements in early numeracy performance but also to contribute empirical evidence regarding the role of theory-informed instructional design in mathematics education for children with ADHD.

METHOD

This study employed a Single Subject Research (SSR) using an A–B design rather than a reversal (A-B-A) design, because withdrawing an instructional intervention that had already produced measurable gains from a child with a diagnosed neurodevelopmental disorder was judged to raise ethical and practical concerns within the participant's ongoing classroom routine; the A–B design was therefore considered the most appropriate option for generating preliminary evidence of intervention effectiveness in this applied special-education setting to investigate the effectiveness of colored flashcards in improving the early numeracy skills of a child with Attention-Deficit/Hyperactivity Disorder (ADHD). In the classroom, the participant generally presented with a combined pattern of inattentive and hyperactive-impulsive behaviors, including difficulty sustaining attention during instructional tasks, frequent off-task motor activity, and impulsive responding during numeracy exercises. Single Subject Research is an experimental methodology that evaluates intervention effects through repeated measurement of an individual's performance across baseline and intervention conditions, enabling researchers to determine whether observed changes are attributable to the intervention (Gast et al., 2018). The study was designed and reported in accordance with the Single-Case Reporting Guideline in Behavioral Interventions (SCRIBE), which provides methodological recommendations for conducting and reporting single-case experimental research (Tate et al., 2016). The participant was an eight-year-old male student enrolled in the second grade at SLB Fajar Harapan, Indonesia. The participant had a documented diagnosis of ADHD (combined presentation, characterised by both inattentive and hyperactive-impulsive symptoms) and was selected using purposive sampling based on three inclusion criteria: (1) a formal diagnosis of ADHD documented by qualified professionals and recognised by the school, (2) identified difficulties in early numeracy skills based on teacher assessment, and (3) the ability to participate in structured individual learning sessions. Prior to data collection, written informed consent was obtained from the participant's parent or legal guardian, and permission to conduct the study was granted by the school administration.

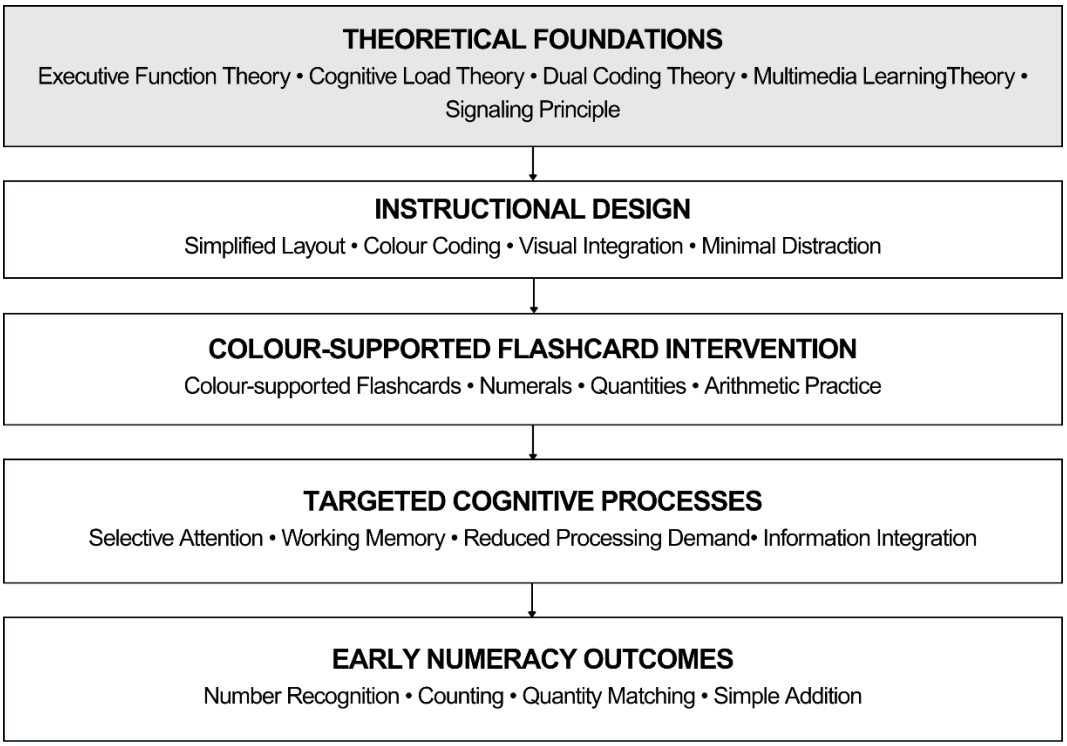

Figure 1. Theory-informed design framework of the color-supported flashcard intervention.

The intervention utilized a set of colored numeracy flashcards specifically developed to facilitate early mathematics learning. The flashcards contained numerical symbols, corresponding quantities, and simple

arithmetic representations designed with meaningful color cues to enhance visual attention, number discrimination, and information processing. The instructional design was informed by Dual Coding Theory (Paivio, 1986), which proposes that learning is strengthened through the integration of verbal and visual information, Multimedia Learning Theory (Mayer, 2020), which emphasizes meaningful learning through coordinated verbal and visual representations, and Cognitive Load Theory, which recommends reducing unnecessary cognitive demands to improve learning efficiency, particularly for learners experiencing mathematics difficulties (Areizaga Barbieri & Rodrigues, 2025). Before implementation, the flashcards and assessment instrument were reviewed by experts in special education and instructional media to establish content validity. The study was conducted individually in a classroom with minimal environmental distractions. The research consisted of two sequential phases: a baseline phase (A) comprising four sessions, followed by an intervention phase (B) comprising five sessions. Each instructional session lasted approximately 30 minutes. During the baseline phase, the participant completed repeated numeracy assessments without receiving instruction using the colored flashcards to establish the initial level and stability of performance. During the intervention phase, mathematics instruction was delivered using the colored flashcards through structured learning activities involving number recognition, counting objects, matching numerals with corresponding quantities, and solving simple addition problems. Immediate corrective feedback and positive reinforcement were provided throughout each session to maintain engagement and encourage active participation. The instructional procedures, learning environment, and assessment methods were maintained consistently across all sessions to minimize potential confounding variables.

Data were collected using a structured numeracy performance assessment administered at the end of each session. The assessment consisted of four indicators of early numeracy skills: (1) number recognition, (2) counting objects, (3) number–quantity matching, and (4) simple addition. Each indicator contributed a maximum score of 25 points, resulting in a total maximum score of 100 points. Participant performance was recorded using a structured observation sheet to monitor changes across the baseline and intervention phases. The data were analyzed using visual analysis, the standard analytical procedure in Single Subject Research. The analysis examined changes in level, trend, stability, immediacy of effect, overlap, and consistency of performance within and between phases (Gast et al., 2018). To strengthen the interpretation of intervention effectiveness, the Percentage of Non-overlapping Data (PND) was calculated by comparing intervention scores with the highest score obtained during the baseline phase. Intervention effectiveness was interpreted based on the combined results of graphical analysis and PND values.

RESULTS AND DISCUSSION

Results

The present study examined the effectiveness of colored flashcards in improving the early numeracy performance of a child with Attention-Deficit/Hyperactivity Disorder (ADHD) using a Single Subject Research (SSR) A–B design. Overall, the intervention produced a clear and consistent improvement in the participant's numeracy performance, as demonstrated by changes in performance level, trend, stability, and data overlap. Prior to the intervention, the participant demonstrated a relatively stable baseline, with a mean numeracy score of 63.75. The limited variation across the four baseline sessions suggests that the participant's mathematical performance remained consistent in the absence of specialized instructional support. Such stability is an important prerequisite in single-case experimental research because it provides evidence that subsequent behavioural changes are less likely to reflect spontaneous maturation or uncontrolled environmental influences. Following the introduction of the coloured flashcards, the participant's mean numeracy score increased to 79.00, representing an improvement of 15.25 points (23.9%) relative to the baseline phase. A noticeable level change occurred immediately after the intervention began, indicating that the participant responded positively to the instructional strategy. Although a slight decrease was observed during the second intervention session, performance recovered rapidly and remained stable throughout the remaining sessions. This pattern indicates that the participant not only demonstrated initial learning gains but also maintained these gains across repeated instructional opportunities.

Table 1. Visual Analysis Summary of Early Numeracy Performance

Indicator	Baseline	Intervention
Number of sessions	4	5
Mean score	63.75	79.00
Highest score	65	80

Lowest score	60	75
Score range	60–65	75–80
Performance level	Lower	Higher
Trend direction	Stable	Increasing then stable
Variability	Low	Low
Immediacy of effect	–	Immediate
Data overlap	–	None
Percentage of Non-overlapping Data (PND)	–	100% (Highly Effective)

Visual analysis further revealed qualitative improvements across several dimensions commonly examined in single-case experimental research. Compared with the baseline phase, the intervention phase demonstrated a higher performance level, an upward trend, lower variability, and greater response stability. Importantly, no intervention data point overlapped with the highest score obtained during baseline. The absence of overlap suggests a clear separation between pre-intervention and intervention performance, providing additional support for the effectiveness of the coloured flashcards. To quantify intervention effectiveness, the Percentage of Non-overlapping Data (PND) was calculated. The analysis yielded a PND value of 100%, indicating that every intervention score exceeded the highest score recorded during the baseline phase. According to the classification proposed by Scruggs and Mastropieri (1998), a PND above 90% represents a highly effective intervention. Taken together, the visual analysis and PND results provide converging evidence that the coloured flashcards were associated with substantial improvements in the participant's early numeracy performance. The results of the visual analysis are summarised in Table 1, whereas the changes in numeracy performance across the baseline and intervention phases are illustrated in Figure 2.

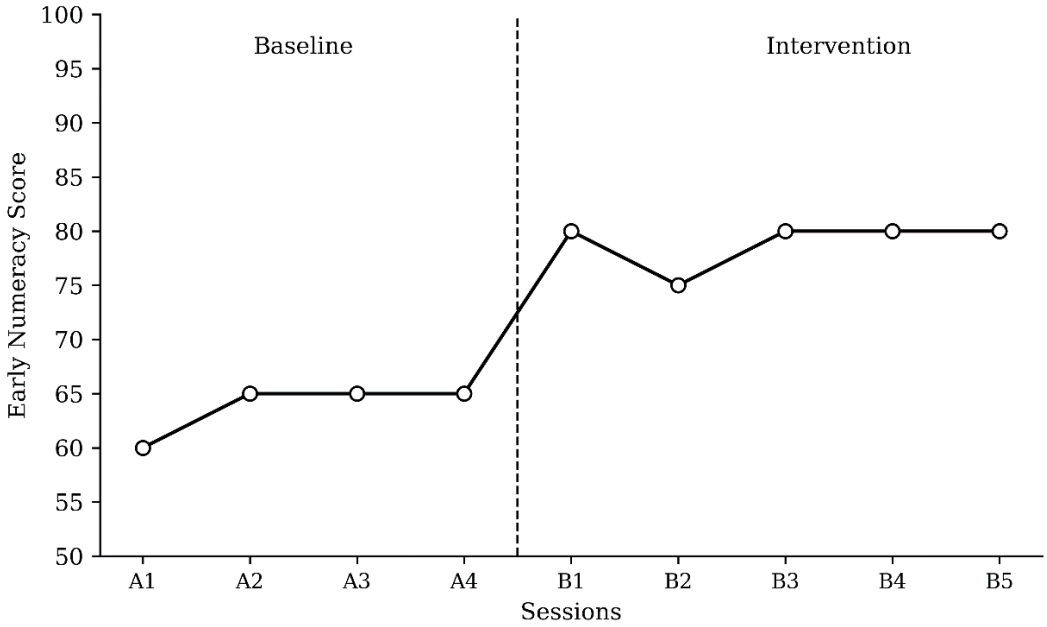

Figure 2. Changes in Early Numeracy Performance Across the Baseline and Intervention Phases

Overall, the visual analysis demonstrated improvements across several indicators commonly examined in single-case experimental research, including performance level, trend, stability, immediacy of effect, and data overlap. The consistent increase in numeracy performance following the introduction of the coloured flashcards suggests a functional relationship between the intervention and the participant's learning outcomes.

Discussion

The present study provides evidence that a theory-informed color-supported flashcard intervention can effectively improve early numeracy performance in a child with Attention-Deficit/Hyperactivity Disorder (ADHD). The improvement observed during the intervention phase was reflected not only in higher numeracy scores but also in an immediate increase in performance level, sustained response stability, and complete non-overlap between baseline and intervention data. Within the framework of single-case experimental research, these converging indicators strengthen the interpretation that the observed behavioral changes were

functionally associated with the intervention rather than with spontaneous maturation or incidental learning (Gast et al., 2018; Scruggs & Mastropieri, 1998). More importantly, the findings suggest that instructional materials intentionally designed according to cognitive learning principles may provide greater learning benefits than visual media developed primarily for repetitive practice, highlighting the importance of theory-informed instructional design in special education. The immediate improvement following the introduction of the intervention suggests that the instructional materials effectively addressed several cognitive challenges commonly experienced by children with ADHD. Rather than functioning solely as visual learning aids, the colour-supported flashcards appear to have provided external cognitive supports that reduced executive processing demands during mathematical tasks. Early numeracy learning requires children to sustain attention, maintain numerical information in working memory, inhibit irrelevant responses, and coordinate sequential problem-solving processes. These executive functions are recognised as fundamental cognitive predictors of mathematical achievement and are frequently impaired among children with ADHD (Cole et al., 2024; Sadozai et al., 2024). Consequently, instructional approaches that reduce reliance on internally regulated executive processes while providing explicit external guidance are expected to facilitate more efficient mathematical learning. This interpretation is consistent with accumulating evidence demonstrating that executive functioning plays a central role in children's mathematical performance. Gaye et al. (2024) reported that central executive functioning, visuospatial working memory, and phonological working memory collectively explain substantial variance in mathematical achievement, whereas Cole et al. (2024) found that deficits in working memory and organizational skills significantly predict poorer academic outcomes among children with ADHD. Together, these findings suggest that mathematical difficulties in ADHD are closely associated with executive processing limitations rather than with mathematical knowledge alone. Within this context, the effectiveness of the present intervention may be explained by its capacity to externalize numerical information into stable visual representations, thereby reducing executive processing demands and unnecessary cognitive load during mathematical tasks. By shifting part of the cognitive burden from internal regulation to externally organised visual supports, the intervention likely enabled the participant to allocate greater working-memory resources to understanding numerical relationships rather than maintaining information during problem solving. Taken together, these findings suggest that the observed improvement was attributable not merely to repeated exposure to flashcards but to the provision of cognitively designed external supports that facilitated more efficient early numeracy learning.

Beyond the cognitive characteristics of the learner, the effectiveness of the present intervention is also likely attributable to the way the instructional materials were deliberately designed to support cognitive processing during mathematical learning. Rather than functioning merely as colored learning aids, the flashcards were intentionally structured to organize numerical information into simple, visually meaningful representations that reduced unnecessary processing demands while directing attention toward essential mathematical concepts. This design is consistent with the view that instructional effectiveness depends not only on the learning medium itself but also on how information is cognitively organized and presented to learners. From the perspective of Dual Coding Theory, learning is enhanced when verbal and visual information are encoded through complementary representational systems, thereby strengthening mental representations and facilitating subsequent retrieval (Paivio, 1986). In the present intervention, numerical symbols were consistently paired with colour-supported visual representations, enabling abstract mathematical concepts to become more concrete and cognitively accessible. This process may have reduced the need for learners to mentally construct numerical representations while simultaneously supporting working-memory efficiency during early numeracy tasks. The findings are further supported by the Cognitive Theory of Multimedia Learning, which proposes that meaningful learning occurs when learners actively select, organize, and integrate verbal and visual information into coherent mental models (Mayer, 2020). Rather than simply increasing the visual attractiveness of the instructional materials, the colour-supported flashcards were designed to facilitate these cognitive processes by presenting information in a structured and integrated manner. Such organization likely enabled the participant to focus cognitive resources on understanding numerical relationships instead of managing fragmented or competing sources of information. The role of colour can be further interpreted through the Signaling Principle, which suggests that visual cues facilitate learning by directing attention toward relevant information while reducing unnecessary cognitive processing (van Gog, 2021). Within the present intervention, colour functioned not as a decorative feature but as an instructional signal that highlighted essential numerical information and supported selective attention during mathematical tasks. Meta-analytic evidence indicates that signaling strategies improve learning by reducing extraneous cognitive load while enhancing retention and transfer, particularly among learners with greater cognitive processing demands. For

children with ADHD, whose attentional resources are frequently compromised, these visual signals may therefore play a particularly important role in supporting efficient information processing. Taken together, these findings suggest that the effectiveness of the intervention cannot be attributed to the use of flashcards or colour alone. Rather, the observed improvement appears to reflect the combined influence of multiple evidence-based cognitive learning principles that were intentionally translated into the instructional design of the flashcards. This interpretation reinforces the view that instructional materials become effective not because of their physical characteristics but because of the cognitive processes they are designed to support.

The present findings are broadly consistent with previous research demonstrating that visual instructional supports can enhance mathematical learning among children with diverse learning needs. Previous studies have shown that flashcards, structured visual representations, and explicit visual cues improve mathematics performance by increasing response accuracy, facilitating concept acquisition, and strengthening learners' engagement with numerical information (Cihak & Foust, 2008; Hayter et al., 2007). More recent research has further suggested that the effectiveness of visual instructional materials depends less on repeated exposure than on the way information is cognitively organized. For example, Riconscente (2013) reported that mathematics materials designed to promote meaningful cognitive engagement produced greater conceptual understanding than materials emphasizing rote practice, whereas Fyfe et al. (2014) demonstrated that carefully structured visual representations support children's progression from concrete experiences to abstract mathematical reasoning. While these studies collectively establish the educational value of visual instructional media, they generally evaluate flashcards and other visual supports as instructional tools rather than examining the cognitive mechanisms underlying their effectiveness. The present study builds upon this literature by demonstrating that the effectiveness of flashcards is closely associated with how they are designed rather than simply whether they are used. Instead of functioning solely as materials for repeated rehearsal, the colour-supported flashcards were intentionally developed by integrating executive-function support, colour signaling, dual coding, and multimedia learning principles into a single instructional intervention. This theoretically informed design was intended to minimize unnecessary cognitive demands while directing learners' attention toward essential numerical relationships. Accordingly, the observed improvement in early numeracy performance is more appropriately interpreted as the product of cognitively informed instructional design rather than the physical characteristics of the flashcards themselves.

Taken together, the present findings contribute to the growing body of research demonstrating that the effectiveness of instructional media depends not merely on the selection of a particular learning medium but on the cognitive principles that inform its design. Although previous studies have consistently shown that flashcards, visual representations, and other visual instructional supports can improve mathematical learning among children with learning difficulties, these interventions have largely been evaluated in terms of their instructional outcomes rather than the cognitive mechanisms through which they facilitate learning. Consequently, relatively little attention has been given to how evidence-based cognitive theories can be systematically translated into the design of instructional materials for children with ADHD. The present study addresses this gap by conceptualizing flashcards not simply as instructional tools but as vehicles through which multiple complementary cognitive learning principles can be operationalized within classroom practice. Rather than treating colour as a decorative feature or flashcards as materials for repeated rehearsal, the intervention intentionally integrated executive-function support, colour signaling, dual coding, multimedia learning, and cognitive load principles into a coherent instructional design. From this perspective, the observed improvement in early numeracy performance is more appropriately understood as the outcome of cognitively informed instructional design rather than the inherent effectiveness of flashcards themselves. More broadly, these findings shift the focus of mathematics instruction for children with ADHD from asking whether visual instructional media are effective to understanding why particular instructional designs facilitate learning. This perspective provides a theoretical foundation for developing evidence-informed instructional materials that are responsive to learners' cognitive characteristics and offers a framework that may guide future research and instructional innovation in inclusive and special education.

The findings of the present study have important theoretical and practical implications for mathematics instruction for children with ADHD. From a theoretical perspective, the findings provide preliminary evidence that instructional effectiveness is influenced not only by the selection of learning media but also by the cognitive principles underpinning their design. Rather than viewing flashcards simply as visual teaching aids, the present study suggests that instructional materials may become more effective when they are intentionally designed to accommodate learners' cognitive characteristics. Integrating executive-function support, cognitive load reduction, colour signaling, dual coding, and multimedia learning principles within a single instructional

intervention may therefore offer a useful framework for developing cognitively responsive mathematics instruction for children with attentional and executive-function difficulties. From a practical perspective, the findings offer several implications for teachers, special educators, and instructional designers. The colour-supported flashcards used in this study represent a low-cost and easily implementable instructional resource that does not require specialized technology or extensive teacher training. However, the present findings suggest that their educational value lies not in the use of flashcards themselves but in the deliberate application of evidence-based cognitive design principles. Consequently, educators should consider not only whether visual instructional media are incorporated into mathematics lessons but also how visual information is organized, signaled, and integrated to support learners' attention, working memory, and conceptual understanding. Applying these principles may contribute to more accessible, cognitively responsive, and inclusive mathematics instruction across both special and inclusive educational settings.

Several limitations should be considered when interpreting the present findings. First, the study involved a single participant and employed an A–B single-case experimental design, which limits the generalizability of the findings to broader populations of children with ADHD. As noted in the Method section, a reversal (A-B-A) design was deliberately not used because withdrawing an already-effective intervention from the participant was judged to raise ethical and practical concerns; however, this choice means that a functional relationship between the intervention and the observed improvement cannot be established with the same certainty as a withdrawal or multiple-baseline design would allow, and this trade-off should be taken into account when interpreting the strength of the present evidence. Although the observed improvements were supported by visual analysis and complete non-overlapping data, replication across additional participants, educational settings, and age groups is required to establish the robustness and external validity of the intervention. Second, the intervention focused exclusively on early numeracy skills over a relatively short instructional period. Consequently, it remains unclear whether the observed improvements would be maintained over time or generalized to more advanced mathematical concepts and authentic classroom learning activities. Future research should examine the effectiveness of theory-informed instructional materials using more rigorous experimental designs, such as multiple-baseline studies or randomized controlled trials involving larger and more diverse samples of children with ADHD. In addition, further investigations should explore the relative contributions of individual instructional design components—including colour signaling, visual organization, information sequencing, and other cognitive support strategies—to determine which features most effectively facilitate mathematical learning. Longitudinal studies are also needed to examine whether cognitively designed instructional interventions produce sustained improvements in mathematical achievement and broader academic functioning. Such research would further strengthen the evidence base for translating cognitive learning theories into effective instructional design for mathematics education in both inclusive and special education settings.

CONCLUSION

This study demonstrated that theory-informed colour-supported flashcards improved early numeracy performance in a child with ADHD within a single-subject experimental design. The observed improvement, reflected in increased numeracy scores and complete non-overlapping data between baseline and intervention phases, suggests that the intervention supported early mathematical learning. Rather than attributing these gains solely to repeated flashcard practice, the findings indicate that instructional materials intentionally designed according to complementary cognitive learning principles may better accommodate the attentional and executive-function characteristics of children with ADHD.

The present study contributes to the growing literature by demonstrating that the effectiveness of instructional media depends not only on the choice of learning materials but also on the cognitive principles underlying their design. By integrating Executive Function Theory, Cognitive Load Theory, Dual Coding Theory, the Cognitive Theory of Multimedia Learning, and the Signaling Principle within a single instructional intervention, this study provides preliminary evidence supporting cognitively responsive mathematics instruction for children with ADHD. Although further research involving larger samples, longer intervention periods, and more rigorous experimental designs is required, the findings offer a promising framework for developing evidence-informed instructional materials in both inclusive and special education settings.

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AUTHOR CONTRIBUTIONS

Lovany Marchelia Shafirarossa: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing Original Draft, Project Administration.
Khofidotur Rofiah: Conceptualization, Methodology, Validation, Supervision, Writing Review & Editing.
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DECLARATION OF COMPETING INTEREST

The authors declare no known financial conflicts of interest or personal relationships that could have influenced the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that the research and writing of this manuscript adhere to ethical standards of research and publication, in accordance with scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCCESS

The authors declare that Generative Artificial Intelligence and other assistive technologies were not excessively utilized in the research and writing processes of this manuscript.

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