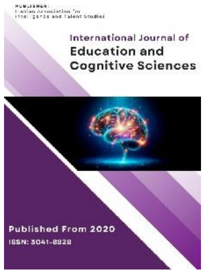
Journal Website

Article history:
Received 07 May 2024
Revised 25 June 2024
Accepted 09 July 2024
Published online 30 Sept. 2024

International Journal of Education and Cognitive Sciences

Volume 5, Issue 5, pp 30-39



E-ISSN: 3041-8828

Comparison of the Effectiveness of Mathematical Thinking Intervention and Dual Balance Training on the Quantitative Reasoning of Students with Mathematical Learning Disabilities

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Article Info

Article type:
Original Research

How to cite this article:
Safarzadeh T, Jajarmi M, Mahdian H. (2024). Comparison of the Effectiveness of Mathematical Thinking Intervention and Dual Balance Training on the Quantitative Reasoning of Students with Mathematical Learning Disabilities. *International Journal of Education and Cognitive Sciences, 5*(5), 30-39.
https://doi.org/10.61838/kman.ijecs.5.5.4

ABSTRACT

Purpose: The objective of this study was to compare the effectiveness of a mathematical thinking intervention and dual balance training on the quantitative reasoning abilities of students with mathematical learning disabilities (MLD).

Methods and Materials: The study was a semi-experimental design with a pre-test, post-test, and follow-up with two experimental groups and one control group. A total of 45 students with MLD were selected through purposive sampling and randomly assigned to the mathematical thinking intervention group (n = 15), the dual balance training group (n = 15), and the control group (n = 15). The tools used for data collection included the KeyMath Test for quantitative reasoning and the Wisconsin Card Sorting Test for cognitive flexibility. Repeated measures analysis of variance (ANOVA) and Bonferroni post hoc tests were used to analyze the data across three test phases (pre-test, post-test, follow-up).

Findings: Significant improvements were observed in the quantitative reasoning scores of both the mathematical thinking intervention group ($F(1.48) = 919.50$, $P < .001$, $\eta^2 = 0.97$) and the dual balance training group ($F(1.48) = 88.25$, $P < .001$, $\eta^2 = 0.76$) compared to the control group. The mathematical thinking group showed greater improvements from pre-test to post-test ($M = -26.60$, $P = .001$) and from pre-test to follow-up ($M = -26.13$, $P = .001$) compared to the dual balance training group (pre-test to post-test: $M = -13.87$, $P = .001$; pre-test to follow-up: $M = -13.93$, $P = .001$).

Conclusion: Both the mathematical thinking intervention and dual balance training were effective in improving the quantitative reasoning of students with MLD. However, the mathematical thinking intervention showed greater efficacy, suggesting that cognitive-based interventions have a stronger impact on mathematical reasoning than physical-based interventions.

Keywords: *Mathematical learning disabilities, quantitative reasoning, mathematical thinking intervention, dual balance training, cognitive flexibility*

1. Introduction

Learning disabilities, particularly mathematical learning disabilities (MLD), pose significant challenges to students' academic success and emotional well-being (Enayati Shabkolai et al., 2023). Research has shown that students with MLD often struggle not only with cognitive aspects of mathematics but also experience heightened levels of anxiety, depression, and low self-esteem as a result of their academic difficulties (Mammarella et al., 2021). In particular, mathematical learning disabilities receive less attention than reading disabilities but often have far-reaching implications for a child's ability to engage with core academic content (Nieminen, 2024). MLD is not only a barrier to academic performance but also limits participation in everyday activities that require mathematical reasoning, such as managing finances or problem-solving in practical scenarios (Devine et al., 2018; Lievore, 2024).

Mathematical learning disabilities are prevalent across a wide range of educational contexts. According to Geary et al. (2012), approximately 5-10% of school-aged children are affected by MLD, a figure that remains relatively consistent across different countries and cultures (Geary et al., 2012). These students often exhibit difficulties in fundamental mathematical concepts, such as counting, arithmetic operations, and understanding mathematical symbols (Geary, 2013). A systematic review conducted by Gunasegar, Devarajah, and Rosli (2021) identified that students with MLD typically face significant delays in developing number sense and struggle with mathematical operations that require working memory and attention to detail (Gunasegar et al., 2021). Baten and Desoete (2019) further highlight that motivation and metacognition are crucial factors that distinguish students with MLD from their typically developing peers, suggesting that interventions should target not only mathematical skills but also the cognitive processes that underlie successful learning (Baten & Desoete, 2019).

Cognitive deficits associated with MLD are well-documented, particularly in areas such as working memory, executive functioning, and cognitive flexibility (Shin & Bryant, 2013). These deficits make it difficult for students to grasp abstract mathematical concepts, perform multi-step problem-solving tasks, or apply learned skills to new situations (Cook et al., 2019). According to studies by Das (2021), inclusive mathematics education needs to address these specific cognitive barriers, ensuring that students with MLD have access to structured and supportive learning environments (Das, 2021).

In addition to cognitive difficulties, students with MLD often experience emotional challenges that exacerbate their learning difficulties. For instance, anxiety and negative self-perception are common among students who consistently struggle with mathematical tasks (Alesi et al., 2014; Lufi et al., 2004; Zuppardo et al., 2023). These emotional factors create a cycle of avoidance, where students disengage from learning opportunities, leading to further delays in academic progress (Devine et al., 2018). Therefore, interventions designed for students with MLD must be sensitive to these emotional and motivational challenges, providing not only instructional support but also fostering a positive learning environment.

Several educational researchers emphasize the importance of targeted interventions to help students with MLD overcome their difficulties. One widely researched approach is the Concrete-Representational-Abstract (CRA) instructional sequence, which has been shown to improve mathematical understanding by gradually transitioning students from concrete manipulatives to abstract representations of mathematical concepts (Bouck et al., 2019; Bouck et al., 2017). AL-salahat (2022) found that the CRA approach was particularly effective in teaching geometric concepts, such as the perimeter of shapes, to students with MLD (Al-salahat, 2022). Similarly, Bouck et al. (2019) demonstrated that the use of virtual-abstract instructional sequences helped students with MLD improve their algebraic reasoning by providing multiple representations of mathematical problems, which enhanced their understanding (Bouck et al., 2019).

Other researchers have explored the use of schema-based instruction (SBI) to support mathematical word problem-solving for students with MLD. Jitendra and Star (2011) argue that SBI helps students develop a framework for understanding word problems by focusing on the underlying mathematical relationships rather than superficial features of the problems (Jitendra & Star, 2011). In a meta-analysis conducted by Jitendra et al. (2017), the authors concluded that SBI is particularly effective in improving the problem-solving abilities of secondary students with MLD. This evidence underscores the importance of structured and systematic instructional methods for students with MLD, particularly those that scaffold learning and support the development of problem-solving strategies (Jitendra et al., 2017).

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In addition to direct mathematical instruction, interventions that target broader cognitive skills such as executive functioning and cognitive flexibility can also benefit students with MLD. The Wisconsin Card Sorting Test (WCST) has been widely used in psychological research to assess cognitive flexibility, which refers to the ability to adapt to changing rules and situations (Bryant et al., 2014). Studies have shown that students with MLD often exhibit impairments in cognitive flexibility, making it difficult for them to switch between different problem-solving strategies or adjust to new types of mathematical tasks (Watson & Gable, 2013). Therefore, interventions that promote cognitive flexibility, such as dual-task training or balance exercises, may help students develop the executive functioning skills necessary for successful mathematical learning. Bouck et al. (2019) emphasize that dual-task interventions, which combine physical balance training with cognitive challenges, can enhance students' overall cognitive flexibility. In their study, students who participated in dual-task exercises showed improvements not only in physical coordination but also in their ability to switch between different types of mathematical problems. This suggests that interventions targeting executive functioning may have a broad impact on students' cognitive abilities, extending beyond specific mathematical skills to support overall academic performance (Bouck et al., 2019).

One of the key challenges for students with MLD is the transition from concrete to abstract thinking in mathematics. According to Chin, Meng, and Suseelan (2022), the process of moving from tangible, hands-on experiences with manipulatives to more abstract mathematical reasoning is particularly difficult for students with cognitive impairments. This is why instructional methods such as the CRA approach and schema-based instruction are so effective for students with MLD—they provide a scaffold that helps students make this critical cognitive leap (Chin et al., 2022).

However, as Baharom, Salleh, and Tahar (2021) note, it is essential to ensure that interventions are tailored to the specific learning styles and needs of students with MLD. In their study, the authors developed a mathematics intervention instrument based on the learning styles of students with MLD, using the Rasch assessment model to ensure validity and reliability. Their findings suggest that personalized interventions that take into account individual differences in learning preferences are more likely to be effective than one-size-fits-all approaches (Baharom et al., 2021).

Building on the existing body of research, the present study aims to compare the effectiveness of two interventions—mathematical thinking and dual balance training—on the quantitative reasoning of students with MLD. While previous studies have demonstrated the effectiveness of instructional strategies such as CRA and schema-based instruction in supporting students with MLD (Bouck et al., 2019; Bouck et al., 2017; Jitendra et al., 2017; Jitendra & Star, 2011), there is less research on the potential benefits of interventions that target cognitive flexibility and executive functioning, such as dual-task training. This study aims to investigate the effectiveness of two interventions, mathematical thinking and dual balance training, on improving the quantitative reasoning of students with MLD.

2. Methods and Materials

2.1. Study Design and Participants

The present study is an applied research in terms of its objective, and it is semi-experimental in design, utilizing a pre-test, post-test, and follow-up with a control group. The statistical population of the research included all female students with mathematical learning disabilities in the city of Mashhad during the 2021-2022 academic year. A total of 60 students were selected through convenience sampling and were divided into three groups of 20 students each (two experimental groups and one control group). The inclusion criteria included physical health, willingness to participate in the study, no use of psychiatric medications, and the absence of stressful events such as divorce or parental death in the past three months. The exclusion criteria included missing two or more sessions and withdrawing from further participation.

Initially, all three groups underwent the pre-test, and the Wisconsin test (for assessing flexibility), along with the subtests of memory and reasoning from the Binet-Simon test, were administered to all three groups. Then, the experimental variables were implemented: the first experimental group received the mathematical thinking program, the second experimental group received the dual balance training program, and the control group received no training. Finally, all three groups were assessed using the post-test.

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2.2. Measures

2.2.1. KeyMath Standardized Test

This test was published by Connolly, Nachman, and Brichtder. The reliability of the KeyMath test, measured using Cronbach's alpha method across five grades, ranged from 0.80 to 0.84. This test, which contains fourteen subtests in three general domains of content, operations, and applications, is administered individually and is suitable for children from kindergarten (pre-school) to eighth grade (up to 11 years old). The scoring method of the test is standardized. Most questions are presented visually and orally to the child, and the child is required to respond verbally. This test is used to assess students' mathematical performance (Narimani et al., 2013; Omale, 2024; Soleymani et al., 2020).

2.2.2. Wisconsin Card Sorting Test

In this study, the Wisconsin Card Sorting Test was used to assess flexibility. This test consists of 64 cards that include four different types of cards with various shapes (cross, circle, triangle, and square) that differ in color and number. Each card is either red, blue, yellow, or green, and the number of shapes on each card varies from one to four. No two cards are identical. For the test, four stimulus cards (one red triangle, two green stars, three yellow crosses, and four blue circles) are placed in front of the participant from left to right. The remaining cards are provided to the participant as response cards, and they are asked to place each card under the stimulus card they think is correct, starting from the leftmost stimulus card (i.e., the red triangle). After each card is placed, the researcher informs the participant whether their choice is correct or incorrect by stating "correct" or "incorrect." The researcher internally follows one of three rules (color, shape, or number) and evaluates the participant's responses according to the selected rule. If the participant correctly matches ten consecutive cards according to the rule, the researcher silently switches to another rule. The test continues until the four rules (in order: color, shape, number, and color) are applied or all 64 cards are used. The participant can make up to 35 attempts to follow a rule; otherwise, the rule is changed, and the next stimulus card is introduced with a new rule. The validity and reliability of this test were calculated as 0.64 and 0.75, respectively (Babaei et al., 2024; Seadatee Shamir, 2024; Yao et al., 2024).

2.2.3. Binet-Simon Test

This version was introduced by Roid in 2003. The most significant contribution of this version is the complete alignment between verbal and non-verbal content in each factor. In this version, a mean score of 10 with a standard deviation of 3 is obtained for each subtest. For composite scores, a mean of 100 and a standard deviation of 15 are considered. This version emphasizes five factors: knowledge, fluid reasoning, quantitative reasoning, visual-spatial processing, and working memory. The age range for this version is from 2 to 90 years (Seadatee Shamir, 2024).

2.3. Interventions

2.3.1. Mathematical Thinking Training

The Mathematical Thinking Program consisted of 10 sessions, each lasting 60 minutes. The goal of the intervention was to improve the students' ability to think mathematically through engaging activities and problem-solving tasks. In the first session, the facilitator introduced basic mathematical concepts and logical reasoning, encouraging students to explore numerical patterns and relationships. The second and third sessions focused on strengthening number sense through exercises in estimation, comparison, and mental calculations. In sessions four and five, students were introduced to algebraic thinking, learning to solve simple equations and understand the concept of variables. Sessions six and seven emphasized spatial reasoning through geometry tasks, including shape recognition, area, and volume calculations. In the final three sessions, students engaged in more complex problem-solving activities, applying mathematical reasoning to real-world scenarios. These sessions also included group discussions to foster collaborative thinking, and students were encouraged to explain their reasoning, fostering metacognitive awareness of their mathematical thinking process.

2.3.2. Dual Balance Training

The Dual Balance Training Program was designed to enhance both physical and cognitive balance through 10 sessions, each lasting 45 minutes. The first session focused on familiarizing students with basic balance exercises, such as standing on one leg and maintaining posture while performing simple tasks. The second session incorporated dual-task exercises, requiring students to maintain physical balance while simultaneously engaging in cognitive tasks,

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such as counting backwards or solving simple math problems. In sessions three and four, the complexity of the physical tasks was increased, with students balancing on unstable surfaces or engaging in dynamic movements while performing cognitive challenges. Sessions five and six introduced group activities, where students worked in pairs to complete balance tasks while communicating and problem-solving together. The final four sessions focused on refining both physical and cognitive balance skills, with students performing more difficult dual-task activities, such as walking on a balance beam while answering logical questions. The goal of these sessions was to improve both motor coordination and cognitive flexibility, providing a comprehensive approach to enhancing balance in everyday tasks.

2.4. Data Analysis

The data were analyzed using SPSS version 21 software and repeated measures analysis of variance (ANOVA).

3. Findings and Results

The sample of the present study consisted of 45 students with mathematical learning disabilities who were divided into two experimental groups and one control group. In the mathematical thinking intervention group, dual balance training group, and control group, the percentage of female students was 46.7%, 53.3%, and 26.7%, respectively. The mean age in the mathematical thinking intervention, dual balance training, and control groups was 9.34, 9.57, and 8.93 years, respectively.

Table 1

Descriptive statistics of variables based on test phases and groups

Variables	Group	Pre-test	Post-test	Follow-up
		M (SD)	M (SD)	M (SD)
Quantitative Reasoning	Mathematical Thinking Intervention	87.60 (10.52)	114.20 (10.31)	113.73 (9.27)
	Dual Balance Training	87.47 (10.82)	101.33 (11.62)	101.40 (11.34)
	Control	87.93 (9.48)	85.87 (10.79)	86.47 (9.96)

In this study, repeated measures analysis of variance (ANOVA) was used to examine between-group differences. The analysis showed that the homogeneity of variances in quantitative reasoning across the test phases was confirmed ($P > .05$). However, Mauchly's test indicated that the sphericity assumption was violated ($P \leq .05$, $\chi2 = 17.58$, $w = 0.52$). Therefore, the Greenhouse-Geisser correction was applied in analyzing the results. The results of the repeated measures ANOVA are presented in Table 2.

Table 2

Between-group differences in quantitative reasoning in the experimental groups

Variable	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	p	Eta Squared
Quantitative Reasoning	Test	8107.62	1.48	5476.76	919.50	.001	0.97
	Group Membership	1604.44	1	1604.44	4.82	.04	0.15
	Test × Group Membership	778.16	1.48	525.65	88.25	.001	0.76

Table 2 shows that there are significant differences between the mathematical thinking intervention group and the dual balance training group, based on test phases, group membership, and the interaction effect of test phase and group membership ($P < .05$). The results of the Bonferroni post hoc test for comparing mean differences based on test phases across the groups are presented in Table 3.

Table 3

Bonferroni post hoc test for comparing mean differences in the study variables based on test phases in the experimental groups

Variable	Group	Pre-test - Post-test	Pre-test - Follow-up	Post-test - Follow-up
		Mean Difference (p)	Mean Difference (p)	Mean Difference (p)
Quantitative Reasoning	Mathematical Thinking Intervention	-26.60 (.001)	-26.13 (.001)	0.47 (.99)
	Dual Balance Training	-13.87 (.001)	-13.93 (.001)	-0.07 (.99)

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The results in Table 3 indicate that in both experimental groups, the mean scores significantly increased from pre-test to post-test and from pre-test to follow-up ($P < .001$). However, no significant changes were observed between post-test and follow-up in either group ($P > .05$). Comparing the means shows that the mathematical thinking intervention led to a greater improvement in quantitative reasoning.

4. Discussion and Conclusion

The primary aim of this study was to compare the effectiveness of two interventions—mathematical thinking and dual balance training—on the quantitative reasoning abilities of students with mathematical learning disabilities (MLD). The findings revealed significant improvements in the mathematical performance of both experimental groups, with the mathematical thinking intervention demonstrating a higher impact on enhancing quantitative reasoning compared to dual balance training. These results provide critical insights into the efficacy of targeted interventions designed to support students with MLD in overcoming cognitive and emotional barriers to learning mathematics.

The results from the mathematical thinking group align with existing literature on cognitive-based interventions for students with learning disabilities. Specifically, the findings support the growing body of evidence that suggests that structured, cognitive-based approaches such as the Concrete-Representational-Abstract (CRA) sequence and schema-based instruction (SBI) are effective in improving mathematical reasoning in students with MLD (Bouck et al., 2017; Jitendra et al., 2017; Jitendra & Star, 2011; Spooner et al., 2018; Tan et al., 2022). These interventions provide students with a scaffolded learning experience that transitions from hands-on manipulatives to more abstract forms of problem-solving, enabling students to better grasp complex mathematical concepts (Bouck et al., 2019). The significant improvement in the quantitative reasoning abilities of students in the mathematical thinking group can be attributed to this structured approach, which helps students internalize and apply mathematical concepts in diverse contexts. AL-salahat (2022) also highlighted the importance of a sequential instructional model, such as the CRA sequence, in improving the mathematical performance of students with learning disabilities, further supporting the findings of this study (Chin et al., 2022).

Moreover, the results of this study also emphasize the importance of cognitive flexibility in mathematical learning, as evidenced by the improvements in the dual balance training group. The Wisconsin Card Sorting Test (WCST) used in the intervention is a well-known measure of cognitive flexibility, which has been shown to be deficient in students with MLD (Shin & Bryant, 2013). The dual balance training intervention was designed to simultaneously enhance both cognitive flexibility and physical coordination, which previous research has demonstrated can lead to improvements in executive functioning skills such as working memory, attentional control, and problem-solving (Bryant et al., 2014). These executive functioning skills are crucial for mathematical learning, as they enable students to organize information, switch between tasks, and apply learned concepts to new problems. The significant improvements in the dual balance training group provide further evidence for the efficacy of cognitive flexibility training in enhancing mathematical performance.

However, while the dual balance training intervention was effective in improving cognitive flexibility, the mathematical thinking intervention had a more profound impact on quantitative reasoning. This result is consistent with previous studies that suggest cognitive-based mathematical interventions have a stronger direct effect on mathematical performance than physical or cognitive flexibility interventions (Geary, 2011, 2013; Geary et al., 2012; Jitendra et al., 2017; Jitendra & Star, 2011). For instance, the meta-analysis by Jitendra et al. (2017) found that cognitive-based interventions, such as schema-based instruction, had a significant effect on improving problem-solving skills in students with MLD (Jitendra et al., 2017). These findings suggest that while cognitive flexibility is important for supporting executive functions that are essential for learning, interventions that directly target mathematical reasoning skills may have a more immediate impact on students' academic performance.

The improvements observed in both experimental groups also highlight the potential for integrated interventions that address both cognitive and physical aspects of learning. The combination of mathematical thinking and cognitive flexibility training could provide a more holistic approach to supporting students with MLD, as it addresses both the direct cognitive challenges associated with mathematical learning and the broader executive functioning deficits that often accompany these challenges. Studies such as those conducted by Baten and Desoete (2019) have underscored the importance of addressing both cognitive and motivational factors in interventions for students with MLD (Baten & Desoete, 2019). The findings of the current study

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suggest that integrating these approaches could further enhance the effectiveness of interventions for students with MLD, particularly in contexts where students struggle with both mathematical reasoning and cognitive flexibility.

Furthermore, the significant improvements in the experimental groups contrast sharply with the control group, which did not receive any intervention and showed no significant changes in performance. This finding reinforces the importance of providing targeted interventions for students with MLD, as simply allowing students to continue with regular instruction without specialized support is unlikely to lead to meaningful improvements in mathematical performance (Geary, 2011, 2013; Geary et al., 2012). The absence of improvement in the control group mirrors the results of other studies that have found that students with MLD often require explicit, structured interventions to make progress in their mathematical learning (Bouck et al., 2019; Bouck et al., 2017; Cook et al., 2019).

Despite the promising results, there are several limitations to this study that should be acknowledged. First, the sample size was relatively small, with only 60 students participating in the study. While the results provide valuable insights into the effectiveness of the interventions, a larger sample size would increase the generalizability of the findings. Additionally, the study focused exclusively on female students in Mashhad, which limits the applicability of the results to other populations. Future studies should consider including a more diverse sample, including male students and students from different regions, to determine whether the interventions are equally effective across different demographic groups.

Another limitation of the study is the relatively short duration of the intervention. The study only included 10 sessions for each intervention, which may not be sufficient to fully capture the long-term effects of the interventions on students' mathematical performance. It is possible that the improvements observed in the experimental groups may diminish over time without continued practice and reinforcement. Future studies should include follow-up assessments several months after the intervention to determine whether the gains in mathematical reasoning and cognitive flexibility are sustained over the long term.

Additionally, while the study demonstrated significant improvements in quantitative reasoning and cognitive flexibility, it did not assess other important outcomes related to mathematical learning, such as students' attitudes toward mathematics, self-efficacy, or math anxiety. Previous research has shown that emotional factors, such as anxiety and self-perception, play a significant role in students' mathematical performance. Future studies should consider incorporating measures of these emotional outcomes to provide a more comprehensive understanding of the impact of the interventions on students with MLD.

Building on the limitations identified, future research should aim to expand the sample size and demographic diversity of participants to better understand the generalizability of the interventions. In particular, including male students and students from various geographic locations could provide valuable insights into whether gender or cultural differences influence the effectiveness of mathematical thinking and dual balance training interventions.

Future studies should also explore the long-term effects of these interventions by conducting follow-up assessments several months after the initial intervention period. Longitudinal studies would help determine whether the improvements in mathematical reasoning and cognitive flexibility are sustained over time and whether additional reinforcement is necessary to maintain these gains.

Moreover, future research should investigate the potential benefits of integrating cognitive and physical interventions into a single, comprehensive program. Given that both cognitive flexibility and mathematical reasoning are critical for academic success in mathematics, combining these approaches could provide a more effective intervention for students with MLD. Exploring the impact of an integrated intervention that addresses both cognitive and physical components could lead to more holistic and sustained improvements in mathematical performance.

Additionally, future research should examine the impact of these interventions on students' emotional and motivational outcomes, such as math anxiety, self-efficacy, and attitudes toward learning mathematics. Including these factors in future studies would provide a more complete picture of how interventions influence both the cognitive and emotional dimensions of mathematical learning.

In practice, educators should consider implementing structured, cognitive-based interventions, such as the CRA sequence or schema-based instruction, to support students with MLD. These approaches have been shown to be effective in improving mathematical reasoning by providing a scaffolded learning experience that transitions from concrete to abstract representations.

Additionally, incorporating cognitive flexibility training, such as dual-task exercises, into the classroom could help

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students with MLD develop the executive functioning skills necessary for mathematical learning. These exercises can be integrated into physical education or as part of regular classroom activities to promote both cognitive and physical development.

Finally, it is important for educators to create a supportive learning environment that addresses both the cognitive and emotional needs of students with MLD. By providing targeted interventions that focus on mathematical reasoning, cognitive flexibility, and emotional support, educators can help students overcome the challenges associated with MLD and achieve academic success in mathematics. Schools should also offer professional development opportunities for teachers to learn how to implement these evidence-based interventions effectively.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We hereby thank all individuals for participating and cooperating us in this study.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the interview and participated in the research with informed consent.

E-ISSN: 3041-8828

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