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Examining the Effectiveness of Cognitive Learning in Enhancing Intrinsic Motivation for Learning Mathematics in Adolescents

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ABSTRACT

Objective: The objective of this study was to assess the effectiveness of brain-based learning methods in enhancing seventh-grade students' intrinsic motivation and performance in mathematics.

Methods and Materials: An applied, intervention-based study design was employed with 39 seventh-grade male students from a public middle school in Tehran during the 2023-2024 academic year. The study used simple random sampling and included three phases: baseline, intervention, and post-intervention. Quantitative data were collected using the Mathematics Motivation Scale (MMS), while qualitative data were gathered through field notes. The intervention phase incorporated brain-based learning activities such as visual storytelling, role-playing, kinesthetic learning, brainstorming, critical thinking, and creative thinking exercises. Data analysis involved one-way repeated measures analysis of variance (ANOVA) and thematic analysis using SPSS and NVivo software.

Findings: The results indicated that the students' average scores for intrinsic motivation and performance in mathematics were significantly higher during the intervention phase compared to the baseline phase. Although scores decreased in the post-intervention phase, they remained higher than the baseline scores. The ANOVA results, adjusted using the Huynh-Feldt correction, showed a significant effect of brain-based learning activities on intrinsic motivation ($F(2.95) = 111$, $p < 0.01$, $\eta p2 = 0.75$). Qualitative analysis supported these findings, highlighting increased student engagement and participation during the intervention phase.

Conclusion: Brain-based learning activities significantly enhance students' intrinsic motivation and performance in mathematics. The study underscores the importance of incorporating such strategies into regular teaching practices to sustain high levels of student motivation and achievement.

Keywords: *Cognitive assessment, Brain-based learning, Students, Learning motivation, Mathematics.*

1. Introduction

Academic performance is one of the criteria for evaluating the efficiency of educational systems, playing a significant role in the development of the future workforce of the country. Psychologists and education specialists have always been concerned with academic performance and its influencing factors, and in recent years, they have sought to identify variables that can help improve academic performance. Brain-based learning is an educational approach founded on neuroscience findings regarding how the brain learns and functions. This approach was first implemented in the 1990s in U.S. schools (Ferreira & Rodríguez, 2022). Neuroscience studies the brain and the nervous system, investigating how the human brain receives, processes, and stores information. It also examines the factors affecting learning, memory, and motivation (Glaser et al., 2019). By using brain-based learning, teachers can align their teaching methods with brain functioning, thereby enhancing students' learning and motivation. For this purpose, teachers must be familiar with scientific findings about the brain and use them in their educational planning (Ferreira & Rodríguez, 2022). Over time, our understanding of brain functioning and its influencing factors has increased, leading to the evolution of the brain-based learning approach (Tan & Amiel, 2022).

As our understanding of the brain and its cognitive processes expands, educators and school psychologists have come to recognize the profound impact of neuroscience on improving learning, health, and overall academic outcomes for students (Tortella et al., 2021). The primary goal of educational psychology is to maximize students' cognitive, social, and emotional growth (Engelbrecht et al., 2020). Brain-based learning, by providing valuable insights into the underlying neural mechanisms of these processes, helps school psychologists promote this goal (Heyder et al., 2020). Understanding the structure, function, and plasticity of the brain allows school psychologists to design interventions and educational strategies that align with the biological foundations of learning and growth (Wilcox et al., 2021). The brain-based learning approach can significantly contribute to designing interventions to support students' learning and well-being (Drigas & Karyotaki, 2019; Mekarina & Ningsih, 2017).

Recent studies in our country have shown a decline in students' academic performance in mathematics at various educational levels (Rezaei, 2015; Vasheghani Farahani & Rostaminejād, 2021). Factors such as the poor performance of Iranian students in the TIMSS studies from 1999 to 2011 and also the advanced TIMSS 2008 indicated that most students do not perform well in mathematics, and this poor performance is not only related to their knowledge level. Given that mathematics has always been a focal point for parents and students throughout the educational period and is an integral part of the curriculum, many teachers and students consider it a challenging subject. Additionally, the high sensitivity of parents regarding their children's understanding of mathematics, coupled with failure in this subject, can lead to academic failure and a negative mindset in students. Exam anxiety is another consequence of this failure (Rezaei, 2015). Long-term failure to improve learning in students can create fear and anxiety. Negative reactions that students experience when thinking about mathematics include fear, worry, and anxiety, with anxiety being the most common psychological and emotional problem during adolescence. Anxiety refers to an unpleasant state and worry, usually with an unknown source, and is one of the major causes of illness and psychological disorders affecting students' academic, social, and family performance (Vasheghani Farahani & Rostaminejād, 2021).

The positive aspects of academic motivation include self-efficacy, focus on learning, and valuing school, while the positive aspects of academic engagement include perseverance, task planning, and management. The negative aspects of academic motivation include anxiety, fear of failure, and insecure control, while the negative aspects of academic engagement include self-destruction and lack of academic engagement. According to this theory, in educational environments, increasing positive aspects and simultaneously reducing negative aspects can improve students' academic motivation and engagement (Royaee et al., 2023). Experiencing joy during a particular class can be considered an activating and positive activity-related emotion, while anxiety when facing an unpleasant situation can be seen as an activating and negative emotion (Rezaei, 2015).

Neuroscience has proven its importance and functions as a powerful research field with immense potential to transform various disciplines (Palser et al., 2022). At that time, neuroscientists began studying the structure and function of the brain. School psychology is one of the fields that significantly benefits from integration with neuroscience (Benson et al., 2019). Keene and Keene (1995) articulated the theoretical foundations of brain-based learning in twelve principles known as brain-compatible learning principles, summarizing existing knowledge on

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learning and emphasizing its educational implications and applications. They believe that effective learning requires considering three fundamental elements: relaxed alertness, orchestrated immersion in complex experiences, and active processing (Tortella et al., 2021).

By identifying the neural processes associated with specific learning problems or behavioral challenges, school psychologists can offer interventions targeting these underlying neural mechanisms. Brain-based learning provides valuable insights into how children's brains acquire, process, and retain information (Li & Lan, 2022). Understanding brain functions related to attention, memory, motivation, and emotional regulation can guide educators in designing instructional strategies that leverage these processes (Drigas & Karyotaki, 2019). Mathematics plays a vital role in our personal and professional lives and is essential for individual and national economic development (Marzeh HajiAghayi et al., 2023). The multidisciplinary nature of this science contributes to a country's scientific and technological advancement. Mathematics, as a foundational science, supports various fields such as engineering, physics, sociology, chemistry, and art (Weidinger et al., 2017). This science plays a fundamental role in scientific and technological advancements and has extensive applications in research, product development, and business methods.

Motivation, as a key factor in learning, plays a crucial role in the mathematics education process. Various factors can influence students' motivation to learn this subject. Hong et al. (2019) divide the motivation for learning mathematics into two categories: intrinsic and extrinsic. Intrinsic motivation, as a critical factor in learning, plays a fundamental role in the education process (Amjad et al., 2023; Amjad et al., 2022).

The brain-based teaching approach, relying on scientific findings about the brain and learning, seeks to enhance the effectiveness of education. This approach has been used in various educational fields, including studying students' motivation, academic performance, and problem-solving skills (Pohan et al., 2020). Brain-based learning is an effective educational approach for mathematics and can significantly enhance students' motivation and performance in this subject. By activating specific parts of the brain involved in learning mathematics, brain-based learning helps students understand concepts more deeply and use their full mental potential to solve mathematical problems.

The aim of this research article is to examine the impact of neuroscience, specifically the brain-based learning approach, in the field of school psychology. Therefore, this research aims to answer the following questions:

Can we help students better understand concepts using cognitive learning principles (brain-based learning)?

Can we increase students' motivation for learning using cognitive learning principles (brain-based learning)?

Can we help students develop critical thinking skills using cognitive learning principles (brain-based learning)?

2. Methods and Materials

2.1. Study Design and Participants

The present study employs an applied, intervention-based design aimed at assessing the effectiveness of brain-based learning methods in enhancing students' motivation and performance in mathematics. The statistical population consists of seventh-grade students from a public middle school in Tehran during the 2023-2024 academic year. A simple random sampling method was used to select 39 students (all male and aged 13) from a single class. Inclusion criteria were being in the seventh grade, male, and 13 years old. Exclusion criteria included students with learning disorders, psychological illnesses requiring medication, or those not meeting the inclusion criteria. Ethical considerations included obtaining consent from students and their parents, maintaining confidentiality, and conducting classes at mutually agreed times.

2.2. Data Collection

Data collection involved both quantitative and qualitative methods over an 18-week study period. Quantitative data were gathered using the Mathematics Motivation Scale (MMS), which includes 35 items across five scales: self-confidence in mathematics, value of mathematics, enjoyment of mathematics, motivation towards mathematics, and anxiety towards mathematics. Each item was rated on a Likert scale from "strongly disagree" to "strongly agree." The MMS, originally developed by Zakaria and Massimiliano (2021) and validated in Iran (Faroughi et al., 2020), had a Cronbach's alpha of 0.78. Qualitative data were collected through field notes documenting students' intrinsic motivation and engagement in class activities. A field observation guide was used to ensure consistency in note-taking.

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2.3. Intervention

Weeks 1-4: Baseline Phase

During the first four weeks, the study focused on establishing a baseline for students' intrinsic motivation and performance in mathematics. Students received traditional lecture-based instruction on fundamental mathematical concepts. Data on their intrinsic motivation and performance were collected using the Mathematics Motivation Scale (MMS) and field notes documenting classroom behavior and engagement. This phase aimed to capture the students' initial motivation levels and learning outcomes without any intervention, providing a benchmark for later comparison.

Weeks 5-10: Intervention Phase

In weeks 5 through 10, the intervention phase was implemented with a series of brain-based learning activities designed to enhance intrinsic motivation and mathematical performance. These activities included visual storytelling, where students created and shared stories about mathematical concepts, and role-playing, which involved acting out real-life scenarios to solve mathematical problems. Additionally, kinesthetic learning activities and brainstorming sessions encouraged active physical and cognitive engagement. These methods aimed to align teaching strategies with brain functioning, engaging students' emotions and cognitive processes to foster a deeper understanding and retention of mathematical concepts.

Weeks 11-14: Continued Intervention and Skill Reinforcement

During weeks 11 to 14, the intervention continued with a focus on reinforcing the skills and concepts introduced earlier. Creative thinking and critical thinking exercises were incorporated, encouraging students to apply mathematical principles in novel ways and solve complex problems collaboratively. Activities such as group discussions, problem-solving competitions, and creative projects helped maintain high levels of engagement and motivation. This period was crucial for consolidating the gains made in the earlier intervention phase and ensuring that students could transfer their learning to different contexts and challenges.

Weeks 15-18: Post-Intervention Phase

In the final four weeks, the study reverted to traditional teaching methods to observe the lasting effects of the intervention. Data collection continued using the MMS and field notes to assess any changes in students' intrinsic motivation and performance compared to the baseline and intervention phases. Although a slight decrease in motivation and performance was observed compared to the peak levels during the intervention, the scores remained significantly higher than the baseline. This phase demonstrated the lasting impact of brain-based learning activities and highlighted the importance of incorporating such strategies into regular teaching practices to sustain high levels of student motivation and performance.

2.4. Data analysis

Quantitative data from the MMS were analyzed using SPSS version 26. A one-way repeated measures analysis of variance (ANOVA) was employed to examine the effect of the brain-based learning intervention on students' intrinsic motivation and performance in mathematics. Qualitative data were analyzed using NVivo version 12 Pro, following Braun and Clarke's (2006) six-step thematic analysis guidelines. This approach allowed for a comprehensive understanding of the qualitative responses and helped identify patterns and themes related to the intervention's impact on students' learning experiences.

3. Findings and Results

During this study, data were collected nine times. The results showed that the average scores for students' intrinsic motivation for learning and performance in mathematics during the intervention phase, where they were taught using brain-based activities, were significantly higher than their scores at the baseline phase. Additionally, the students' scores in the post-intervention phase decreased compared to the intervention phase but remained higher than their scores at the baseline phase.

Table 1

Descriptive Statistics and The Results of Analysis of Variance

Variable	N	df	Sphericity Assumed	Effect	F ratio	Sig.	Partial Eta Squared	M	SD
Week 1 & 2	39	132.71	.75	IM	111	.000	.75	3.26	.607
Week 3 & 4	39	132.71	.75	IM	111	.000	.75	3.24	.669
Week 5 & 6	39	132.71	.75	IM	111	.000	.75	3.29	.648
Week 7 & 8	39	132.71	.75	IM	111	.000	.75	4.56	.348
Week 9 & 10	39	132.71	.75	IM	111	.000	.75	4.74	.275

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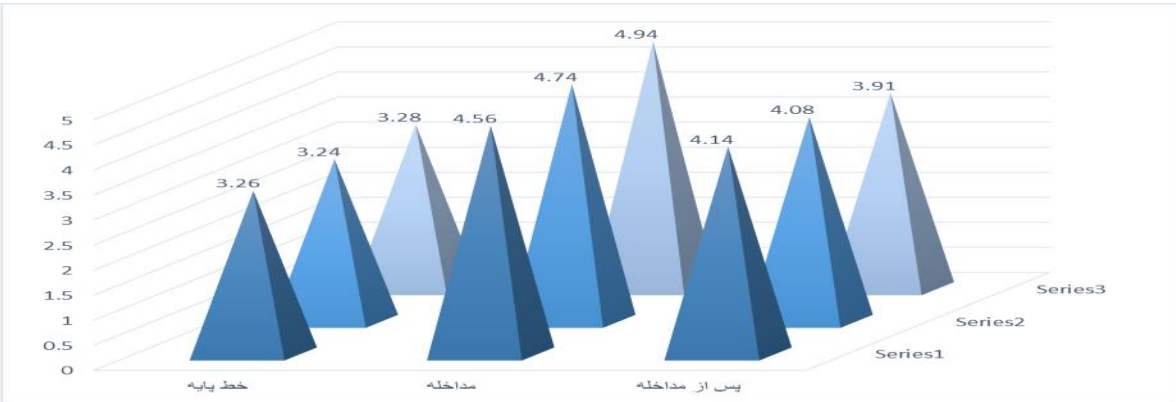
Week 11 & 12	39	132.71	.75	IM	111	.000	.75	4.94	.125
Week 13 & 14	39	132.71	.75	IM	111	.000	.75	4.15	.420
Week 15 & 16	39	132.71	.75	IM	111	.000	.75	4.08	.427
Week 17 & 18	39	132.71	.75	IM	111	.000	.75	3.91	.624

To test the null hypothesis, a one-way repeated measures analysis of variance (ANOVA) was used. In this analysis, the mean scores of the different study phases were examined at a significance level of 0.001. This analysis is based on the assumption of homogeneity of variance (dispersion) between scores at different study phases. The results of the sphericity test are presented in Table 1. This table shows the results of Mauchly's test, which examines the sphericity assumption, stating that the variance of differences between each pair of measurement times should be equal. The results indicate that the sphericity assumption was significantly violated (Mauchly's W = 0.000, $p < 0.01$). In such cases, using sphericity adjustment methods for data analysis, such as the Huynh-Feldt correction, is justified. Since the sphericity adjustment value is greater than 0.75, the Huynh-Feldt correction was used to interpret the results of the nested multilevel analysis (BLS) on students' intrinsic motivation (IM) for learning and performance in mathematics.

Figure 1

Descriptive Representation of The Scores



4. Discussion and Conclusion

The concern about increasing students' motivation in mathematics has long been an issue for educators and educational stakeholders (Faroughi et al., 2020; Talpur et al., 2021). Results from international TIMSS tests and conducted studies indicate that although Iranian children are generally hardworking in school and at home, they do not perform satisfactorily in tests (Khalilpour, 2024). In brain-based education, students' minds are initially activated with new, challenging, and relevant content, then their curiosity, competition, and goal-oriented desires are heightened, and finally, through opportunities for practice, discussion, and real-world application, students are helped to learn and apply the material more deeply. This research yielded notable findings, some of which are highlighted below:

a) The study showed that when students were taught using traditional methods (lecturing), they exhibited poor classroom management during the pre-test phase. They interacted less and were mostly passive in class. It was also observed that few students ever asked questions of their teacher or classmates. In contrast, during the intervention phase, they participated more actively, likely due to the impact of activities designed based on brain-based learning principles. In this phase, students showed enthusiasm and interest, and quantitative results indicated that they had the highest intrinsic motivation for learning and performing in mathematics. In the post-intervention phase, researchers observed that student participation and interaction in class decreased compared to the intervention phase. Although it was still better than the baseline phase, it significantly dropped compared to the intervention phase. When comparing the data, it was concluded that both types of data support each other, confirming the impact of brain-based learning on students' intrinsic motivation for learning and performance in mathematics. This indicated that activities like visual storytelling, role-playing, creative thinking, reinforcing learning through review, and critical thinking

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effectively increased students' intrinsic motivation during the intervention phase.

b) This study used a mixed-methods approach to examine the effect of brain-based learning on students' intrinsic motivation (IM) for learning and performance in mathematics. Throughout the study, participants received traditional lecture-based instruction during the baseline and post-intervention phases, while the intervention phase included activities and principles based on brain-based learning. The results showed that when students were exposed to the brain-based learning approach, their intrinsic motivation significantly increased. This improvement was attributed to the intervention during the treatment phase. These results align with Wilkie and Sullivan's (2018) research, which states that intrinsic motivation plays a central role in overall motivation and encourages efforts to achieve academic goals, especially in mathematics (Wilkie & Sullivan, 2018).

c) Research decisively shows that insufficient motivation leads to high failure rates in mathematics (Haider et al., 2020). In this context, the present study provides a promising explanation by suggesting brain-based learning activities to enhance students' intrinsic motivation (IM), thereby increasing their likelihood of academic success. Froiland and Worrell (2016) support this claim, emphasizing that intrinsically motivated students perform better in various educational events, showing greater enthusiasm, a desire for challenges, more participation, and higher academic performance. Thematic analysis also supports this argument, indicating that when mathematics was taught to students through brain-based learning activities, they felt more excitement and energy for solving mathematical problems (Froiland & Worrell, 2016).

d) A key consideration in education is the extent of student engagement in the classroom, in which motivation plays a critical role. Motivated students actively participate in classroom activities, engage enthusiastically in tasks, and meet deadlines (Amjad et al., 2023; Amjad et al., 2022). Implementing brain-based activities in teaching mathematics can meet students' needs for skills, teaching, and educational experiences, thus boosting their motivation, leading to academic progress and achieving desirable grades. Qualitative analysis showed that when brain-based learning interventions were applied in the classroom, student interaction and participation increased. This finding also confirmed the quantitative results, significantly enhancing students' intrinsic motivation during the treatment period.

e) The findings of this study, obtained using one-way repeated measures ANOVA, unequivocally indicate that brain-based learning activities significantly impact students' intrinsic motivation (IM) for learning and performance in mathematics. These results support the findings of Makenina and Ningsih (2017), who affirm the efficacy of brain-based learning as an educational strategy that increases students' motivation and mathematical skills (Mekarina & Ningsih, 2017). Additionally, the estimated marginal means show a positive relationship between the brain-based learning approach and students' intrinsic motivation for learning and performance in mathematics.

5. Limitations & Suggestions

This study has several limitations that should be acknowledged. Firstly, the sample size was relatively small, comprising only 39 seventh-grade students from a single public school in Tehran, which limits the generalizability of the findings to other populations and educational contexts. Secondly, the study's duration was relatively short, spanning only 18 weeks, which may not be sufficient to capture long-term effects of brain-based learning interventions on students' intrinsic motivation and performance. Additionally, the reliance on self-reported measures and observational data might introduce bias, as students may respond differently based on perceived expectations. Furthermore, the study did not account for potential confounding variables such as prior mathematical ability, socioeconomic status, or parental involvement, which could influence the outcomes. Finally, the transition back to traditional teaching methods in the post-intervention phase might have influenced students' motivation and performance differently than maintaining a consistent brain-based learning approach throughout the entire study period.

Therefore, this research ventures into the realm of educational discoveries, revealing the significant potential of brain-based learning to stimulate students' intrinsic motivation (IM) in learning and performing mathematics. The findings highlight the importance of incorporating the brain-based learning approach in mathematics education to unlock students' full potential and pave the way for academic excellence. As educators and educational stakeholders move forward, it is hoped that these findings will serve as a guiding light to inspire and empower future students to succeed in their mathematical endeavors. Hence, it can be argued that the applications of neuroscience in schools can effectively influence students' psychology.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

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