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The Impact of Brain-Based Learning on Students' Intrinsic Motivation to Learn and Perform in Mathematics: A Neuroscientific Study in School Psychology

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Abstract

The current study aimed to explore the effect of Brain-Based Learning on students' intrinsic motivation (IM) to learn and perform in mathematics. Owing to the educational implications of Neuroscience, the researchers planned the mixed-methods experimental study with a convergent parallel research design. The participants were eighth-graders enrolled in a boy's public secondary school in the district Kasur of Pakistan in the academic year 2021-2022. Students were taught mathematics using the traditional lecture method in the baseline phase (A) and withdrawal phase (A). In contrast, in the treatment phase (B), they were taught mathematics with activities based on the BBL approaches and principles. The mathematics motivation scale and observation (field notes) were used to collect quantitative and qualitative data simultaneously. Data were analysed using one-way repeated measure ANOVA and thematic analysis. The researchers revealed that BBL significantly affects students' IM to learn and perform in mathematics. After qualitative analysis, it was found that visual story-telling, role-playing, i-Think maps, back-to-board, and Kick Me Poison Box are the most effective BBL-based activities which keep them engaged, provide emotional support and contribute to students' IM to learn and perform in mathematics. The teachers were suggested to develop BBL-based activities to teach mathematics and to influence students' psychology in the schools.

Keywords:

Neuroscience, Brain-Based Learning, School Psychology, Intrinsic Motivation, Visual Story-Telling

Introduction

Neuroscience with its relevance and functions has emerged as a powerful field of research with immense potential to revolutionise various disciplines (Amjad et al., 2022a; Palser et al., 2022). School psychology is one such field that benefits significantly from integrating neuroscience (Baker et al., 2021; Benson et al., 2019). As our understanding of the brain and its cognitive processes expands, educators and school psychologists have begun

to recognise neuroscience's profound implications on enhancing student learning, well-being, and overall educational outcomes (Tortella et al., 2021). This research paper aimed to explore the impact of neuroscience (Brain-Based Learning) in the field of school psychology, examining how the application of BBL principles can inform and improve educational practices. By integrating neuroscience findings into instruction, intervention, and assessment, school psychologists can enhance their ability to address the diverse needs of students and create more effective learning environments.

The objective of maximising students' cognitive, social, and emotional growth is at the heart of educational psychology (Immordino-Yang et al., 2019). Brain-Based Learning (BBL) provides valuable insights into the underlying neural mechanisms that govern these processes (Jailani, 2021). By understanding the brain's structure, functioning, and flexibility, school psychologists can introduce interventions and educational strategies that align with the biological foundations of learning and development (Wilcox et al., 2021). The BBL approach can greatly benefit intervention strategies to support students' learning and well-being (Baratali & Zardeini, 2023). By identifying the neural processes associated with specific learning difficulties or behavioural challenges, school psychologists can provide interventions to target these underlying neural mechanisms (Sanetti & Collier-Meek, 2019). The BBL offers valuable insights into how children's brains acquire, process, and retain information (Li & Lan, 2022). Understanding brain functions associated with attention, memory, motivation, and emotional regulation can guide educators in designing instructional strategies that capitalise on these processes (Drigas & Karyotaki, 2019).

From elementary school through university, mathematics is now an integral course for students (Oljayevna & Shavkatovna, 2020). In the Pakistani school system, it is considered a compulsory subject (Amjad et al., 2022b). Most students think that mathematics is complicated for students since it requires them to learn formulas (Das, 2019), carefully follow examples (Udjaja et al., 2018), and work with sometimes less interesting subject matter (Appelgate & Jurgenson, 2022). Although memorising extensive mathematical notations is a common perception of mathematical ability (Pascual, 2022), Nematillayevna (2021) argues that what matters is learning how to apply those notations effectively when faced with a challenge.

Mathematics significantly impacts our personal and professional lives, and its essential for individual and national economic development (Maass et al., 2019). Its multidisciplinary nature aids a country's scientific and technological progress (Bano et al., 2018). Mathematics supports engineering, physics, sociology, chemistry, and arts (Weeden et al., 2020). It profoundly impacts scientific and technological advancements, from research to products and business methods (Engelbrecht et al., 2020). Given its broad influence, mathematics is vital in modern curricula (Alayont, 2022). Tokac et al. (2019) recommend providing students with resources through mathematics education to succeed in today's advanced nations.

According to Khan et al. (2020), Pakistani students show less performance in mathematics as compared to other school-level subjects. Overall, it was also found that students' arithmetic ability to perform in mathematics was not good, which led to decreasing motivation to learn and perform in mathematics. It was also found that students between the ages of four and eight perform poorly globally in mathematics. According to Stojanović et al. (2021), teachers' ability to teach, the calibre of the pupils, and their motivation all play a significant role in how well students achieve in mathematics. Additionally, it is clear from the literature that students struggle academically in mathematics classes because they lack motivation.

Influence of BBL on Learning and Motivation

The BBL is based on the principles of Neuroscience, which was first used in American schools in the 1990s (Ferreira & Rodríguez, 2022). From the tiniest cellular level to the greatest cerebral circuits, neuroscience explores how the brain works to learn and remember things (Glaser et al., 2019). Teachers must understand how to teach using what scientists have discovered about the brain to learn in a way compatible with their brain. Applying the ideas and methods found through research on the brain is necessary for teaching in a way that is in harmony with the brain (Ferreira & Rodríguez, 2022). Understanding how the brain functions, what influences the brain, and the educational consequences of these insights have changed over time (Tan & Amiel, 2022). One of the BBL's founders, Caine and Caine (1991), stated the following approaches based on 12 BBL principles.

Relaxed Alertness: Triana and Zubainur (2019) suggest that a peaceful and attentive atmosphere should be provided when students are given a difficult task. For successful problem-solving, students must be relaxed and engaged. Saleh and Mazlan (2019) argue that a challenging learning atmosphere with minimal physical risk is essential to ensure students learning.

Orchestrated immersion: It is related to immerse students physically, mentally, and emotionally in a topic to support learning (Saleh & Mazlan, 2019). Triana and Zubainur (2019) argue that students can use their methods to solve problems, helping them remember the principles. Critical thinking and acquiring new information are essential for learning.

Active processing of experience: To foster learning, Triana and Zubainur (2019) suggest creating environments like small discussion groups that motivate students to engage with the material. Saleh and Mazlan (2019) added that it enables students to internalise information, value it, make connections, and form relevant opinions or decisions.

Motivation for Mathematics Learning

Several factors and types of motivation affect mathematics learning motivation (Hung et al., 2019). Wilkie and Sullivan (2018) suggest techniques to influence internal and external motivation. IM happens when a person is motivated to succeed by themselves. Extrinsic motivation (EM) is external and easier to cultivate for mathematics study than IM. External sources like instructors' motivation and peers' approval of a positive learning environment can strengthen EM. IM is more difficult to develop. El-Adl and Alkharusi (2020) argue that IM leads to self-satisfaction as students strive for learning success. IM happens when students find personal value in something and recognise its potential benefits. Weidinger et al. (2017) found that IM rises at the start of school but decreases in the early years. Some students experience a more significant drop than others, while some show no decrease. Learners' IM is based on meeting their needs for competence, instruction, and teaching activities (Ryan & Deci, 2016). Good grades should motivate students to learn, while poor grades can reduce their sense of intellectual ability and IM. Corpus and Wormington (2014) found that lower scores in elementary school correlated with lower IM.

BBL and Students' Intrinsic Motivation

Neuroscience-based teaching approach (BBL) have educational applications and have been used to study student motivation (Al-Balushi & Al-Balushi, 2018), academic performance (Amjad et al., 2022b), and problem-solving skills (Pohan et al., 2020). Mekarina and Ningsih (2017) found that BBL is an effective teaching approach for mathematics and can enhance students' motivation and performance. BBL helps students use the right part of the brain to learn and perform in mathematics. This enables them to make the most of their brains to understand mathematics concepts. Yu and Singh (2018) studied the relationship between teachers' teaching strategies and students' mathematics learning motivation. SEM analysis revealed a positive relationship between teachers' teaching strategies, self-efficacy, and motivation.

BBL and students' IM to learn and perform in mathematics are interconnected concepts with great promise for transforming the educational landscape. BBL emphasises aligning teaching strategies with the brain's natural learning processes (AlAkayleh & Al-Zoubi, 2023), while IM refers to students' internal drive and interest in learning (Bai et al., 2021). When BBL principles are applied effectively in mathematics instruction, they can intensely impact students' IM (Solihatin & Syahrial, 2019). Here are some key points to explore the relationship between BBL and IM in mathematics:

Engaging Learning Experiences: BBL promotes active and experiential learning, meaningfully allowing students to explore and engage with mathematical concepts. Students' curiosity is piqued by incorporating hands-on activities, real-world problem-solving, and interactive experiences, fostering a more profound interest and IM to delve into the subject (El-Adl & Saad, 2019).

Personalised Learning: BBL recognises the uniqueness of each student's brain and learning style. By tailoring instruction to individual needs and preferences, students feel more autonomy and ownership over their learning journey. This sense of control and personalisation can ignite IM as students' experience and as a sense of accomplishment in mastering mathematical challenges (Baratali & Zardeini, 2023).

Positive Emotional Climate: BBL has shown that emotions play a crucial role in learning and memory. A brain-based approach to mathematics instruction creates a positive and supportive learning environment where students feel safe to take risks, make mistakes, and embrace challenges. When students experience positive emotions in the classroom, it enhances their IM to learn and perform in mathematics (Baratali & Zardeini, 2023).

Meaningful Relevance: BBL advocates connecting new knowledge and existing experiences. By demonstrating the practical relevance of mathematics in everyday life, careers, and various fields of study, students can see the significance of learning mathematics, increasing their IM to learn and perform in the subject (Apeh & Iyiegbuniwe, 2021).

Mastery and Growth Mindset: BBL supports the idea of a mastery and growth mindset. Students are encouraged to see effort and perseverance as the path to improvement rather than fixating on grades or performance. This mindset fosters IM as students become more focused on the joy of learning and the satisfaction of personal development rather than external rewards (Hofer, 2022).

Challenging but Manageable Tasks: BBL advocates for presenting challenges that are neither easy nor difficult. By providing students with appropriately challenging mathematical tasks, they experience a state of flow where they are fully engaged and immersed in the learning process. This flow state enhances students' IM and fosters a love for mathematics (Apeh & Iyiegbuniwe, 2021).

Research Objective

Many researchers in Pakistan have employed different teaching strategies to increase students' motivation to learn mathematics (Farooq et al., 2020; Talpur et al., 2021). Why pupils fail to acquire higher grades at all levels, particularly at the elementary level, is still a concern (Mushtaq, 2021). The authors, in the present mixed-methods' study investigated how the BBL affects eighth graders' IM to learn and perform in mathematics. The researchers developed a null hypothesis based on the study aim that BBL had no significant effect on elementary-level pupils' IM to learn and perform in mathematics. The researchers also developed a research question to explore which teaching activities could enhance students' IM to learn and perform in mathematics at the elementary level.

Methods

The authors intended to study the influence of BBL-based intervention on students' IM to learn and perform in mathematics on a deeper level. Therefore, an in-depth study of the phenomenon was designed using mixed-methods research. The pragmatic research philosophy guided the present study. The problem under investigation was explored using quantitative and qualitative approaches.

Research Design

The research design of the study was convergent parallel. In this design, researchers collected quantitative and qualitative data simultaneously and independently. The results from both data sets were then compared and contrasted to identify any convergence or differences. The researchers used an experimental-based quantitative investigation during the different phases of the study. It was an 18-week experimental study that had three different stages. The experimental phase was carried out to investigate the change in applied behaviour analysis (A-B-A) in students' IM to learn and perform in mathematics. It was carried out in three stages of equal length (6 weeks). In the first stage A (baseline phase), students were taught eighth-grade mathematics using the traditional lecture method. In the second stage B (treatment phase), the students were taught mathematics using activities based on BBL principles. In the third stage of study A (withdrawal phase), the researchers withdrew the intervention, and students were again taught mathematics using the traditional lecture method.

Study Content

In the present mixed-methods investigation, elementary-level students were taught nine units overall. In the baseline phase, they were taught units (1-3) named "Operation on Sets," "Real Numbers," and "Number System." During the treatment phase, they were taught units (4-6) named "Financial Arithmetic," "Polynomials," and "Factorization, Simultaneous Equations." In the withdrawal phase, they were taught the three units (7-9) named "Fundamentals of Geometry," "Practical Geometry," and "Areas of Volumes.". It is evident that public school teachers typically teach mathematics with traditional lecture method using whiteboard practice only. Based on the nature of lower IM among Pakistani students to learn and perform in mathematics, the researchers in the current study deployed BBL-based teaching in the treatment phase.

Participants

The participants of the current mixed-methods study were elementary-level students. These students were considered based on the argument that elementary-level students show less motivation to learn and perform in mathematics. The researchers selected a school using convenience sampling and selected all the eighth-grade students enrolled in a public secondary school in the Kasur district. The total number of students in eighth grade was 39, who were taught in a single class section as per the standardised student-teacher ratio (40/1). Single class section was selected as study sample and single-subject research was designed to measure the influence of BBL-based teaching on students' IM to learn and perform in mathematics.

Data Collection Tools

The researchers used two data collection tools simultaneously to collect data in the present study. The authors developed an observation guide to take field notes on students' IM in the class. The observation guide was designed using the different aspects related to the students' IM. To collect quantitative data, Mathematics Motivation Scale (MMS) developed by Zakariya and Massimiliano (2021) was used during all study phases. It was developed on a five-point Likert scale with options ranging from strongly disagree (1) to strongly agree (5). It had different items to measure students' IM to learn and perform in mathematics. The IM of the study respondents was measured using quantitative items like "If I can, I want to get better grades in this class than most of the other students." The reliability of the MMS was ensured using Cronbach's Alpha, and it ranged from .73 to .86, which was satisfactory to use, according to Hair et al. (2021).

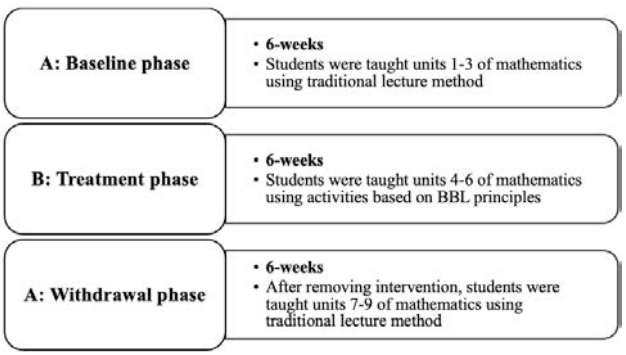
Procedure

The researchers deployed mixed-methods approaches in the current single-subject A-B-A experimental study. It was carried out in three phases. In the first stage A (baseline), the researchers taught the first three units of eighth-grade mathematics with

the traditional lecture method and measured their IM to learn and perform in mathematics three times using the MMS at the regular interval of two weeks. Meanwhile, the researchers also took field notes according to the observation guide. In the treatment phase (B), the researchers taught units 4-6 with the help of activities based on the BBL principles. To get the BBL intervention's effect, all the activities were designed by following the BBL approaches; a) relaxed alertness, b) orchestrated immersion, and c) active processing and 12 principles of BBL. The researchers devised brainstorming activities to improve class engagement and students' social and emotional involvement. They were given various mathematical problems to solve and discuss with their classmates. Students were assigned different roles to play in role-playing activities to improve their understanding of various concepts related to financial mathematics, polynomials, and factorisation, simultaneous equations. In one of the exercises, students were given the roles of judge, lawyer, and petitioner for the division of inherited property according to Islamic laws after the death of a father who left behind three sons, a daughter, and a widow. In the following units, students were given different maps, sketches, tree maps, and flowcharts to think, relate, and identify the correct solutions for teaching ideas linked to factorisation and other functions of algebraic expressions. The researchers devised activities based on the students' visual imagery to teach distinct views from the unit covering topics concerning simultaneous linear equations. Short videos, simulations, and images about simultaneous linear equations were shown to them. During the intervention phase (B), the researchers measured students' IM to learn and perform in mathematics at the regular interval of two weeks. The authors also took field notes after observing their engagement and participation in the activities based on BBL principles. In the withdrawal phase A, the researchers withdrew the BBL-based intervention. Students were again taught with the lecture method. The authors took field notes for qualitative data, while quantitative data was measured using MMS at regular intervals of two weeks.

Figure 1

Phase-Wise Study Progression



In Figure 1, the researchers presented the phase-wise study progression. During each stage, three measurements for IM to learn and perform in mathematics were taken using MMS and filed notes.

BBL's founders, Caine and Caine (1991), presented 12 BBL principles. The authors developed teaching activities for treatment phase (B) in this investigation based on the 12 principles. The detail of the activities is presented in Table 1.

Ethical Considerations

In this experimental investigation, the researchers meticulously adhered to established research ethics for the adolescent respondents. Informed consent was obtained from all participating respondents and their parents, signifying their voluntary agreement to participate in the study. After recruitment into the investigation, the participants underwent a comprehensive briefing, acquainting them with the research procedures, study duration, and the prescribed code of ethics. All participants were assured of anonymity to protect their personal information, as neither their names nor locations were disclosed, mitigating any risk of confidentiality breaches. The experiment took place in natural settings, devoid of any interventions or activities that could potentially cause harm to the participants. The activities conducted during the study were thoughtfully aligned with the prevailing school culture and education calendar, ensuring seamless integration into the participants' daily routines. Each activity was precisely organised to fit within a time frame of 45 minutes. Considering linguistic diversity, a bilingual version of the research instrument, comprising both English and Urdu, was employed for quantitative data collection. This thorough modification made it easier for the participants to understand each item and provide meaningful and precise responses.

Data Analysis

In this paper, the authors deployed MMS to collect quantitative data and field notes to collect students' qualitative responses during an 18-week study. The quantitative data was analysed using the SPSS (Version 26) software, and qualitative data were analysed using the NVivo (Version 12 pro) software. The researchers deployed one-way repeated measure ANOVA to find the influence of BBL-based instruction on students' IM to learn and perform in mathematics. The qualitative data was analysed using the thematic data analysis technique by following the six-stage guidelines of Braun and Clarke (2006). The interpretation of the analysis is presented below.

Results

After the data analysis, quantitative and qualitative

Table 1

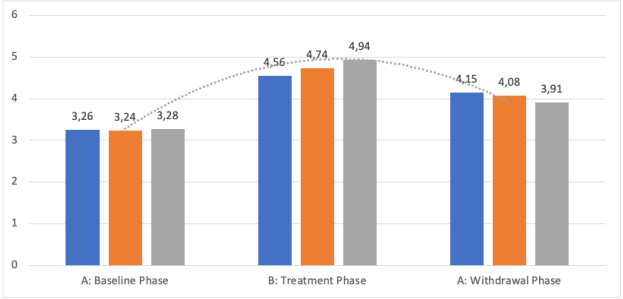
List of Activities and Features Based on BBL Principles

Treatment/Activity	Features	BBL Principles
Visual Story-telling	• Visual imagery • Picture metaphor	• The brain understands and remembers best when facts and skills are embedded in natural spatial memory. • Learning always involves conscious and unconscious processes. • Appropriate environment, music, and aroma excite rain activity. • Each brain is unique.
Role Play	• Emotion in learning • Kinesthetic • Auditory	• A positive climate stimulates brain function. • Learning is enhanced by challenges and inhibited by threats. • Learning engages whole physiology. • Each brain is unique.
Back to Board	• Kinesthetic • Brainstorming • Verbal	• The search for meaning is innate. • The search for meaning comes through the brain patterning process. • Learning always involves conscious and unconscious processes. • Learning engages whole physiology. • Complex and active experiences involving movement stimulate brain development. • Each brain is unique.
Kick Me Poison Box	• Making connection • Develop meaning • Thinking through analogies	• The search for meaning is innate. • Learning always involves conscious and unconscious processes. • Learning always takes place in two memory approaches, retaining facts, skills, and procedures or making sense of experience. • The brain can quickly grasp and remember facts and skills embedded in its memory space. • Each brain is unique.
i-THINK Map	• Brainstorming • Visual imagery • Demonstration of students' understanding	• The brain is unique and a parallel processor. • Learning always takes place in two memory approaches, retaining facts, skills, and procedures or making sense of experience.

data results are presented and interpreted below. The researchers collected data nine times during the current mixed-methods longitudinal experimental study. The mean scores for students' IM to learn and perform in mathematics are presented below.

Figure 2

Effect of BBL on Students' IM to Learn and Perform in Mathematics



In Figure 2, the researchers presented the results of quantitative data to explore the effect of BBL on students' IM to learn and perform mathematics during the study phases. In the baseline phase (*A*), when students were taught with the traditional lecture method, their scores (M_1 = 3.26, M_2 = 3.24, M_3 = 3.29) were lesser than the scores during the treatment phase (*B*) (M_4 = 4.56, M_5 = 4.74, M_6 = 4.94) when they were taught mathematics using the activities bases on BBL principles. In the withdrawal phase (*A*), when the researchers withdrew from the BBL-based intervention, the scores (M_7 = 4.15, M_8 = 4.08, M_9 = 3.91) showed a decline from the treatment phase (*B*). It was found that the increase in mean scores in the treatment phase (*B*) and the decrease in the mean score during the withdrawal phase (*A*) were owed to the BBL-based intervention.

A one-way repeated measure ANOVA was utilised to test the null hypothesis. The mean scores of distinct phases within the study were examined at a significance level of .001. This analysis assumes homogeneity of variance among the differences observed among study phases. The results of the assumption of sphericity are displayed in Table 2.

Table 2 displays the results of Mauchly's test, indicating a significant violation of the assumption of sphericity (Mauchly's W = .000 < .001). In such cases, the adjusted sphericity procedure is warranted. Given that the value of adjusted sphericity exceeds .75, Huynh-Feldt's correction was employed to interpret the outcomes of the BBL on students' IM to learn and perform in mathematics below.

The assumption of sphericity was assessed and found to be 132.71, higher than the value of .75. Consequently, Huynh-Feldt's correction was applied to analyse the differences in mean values for students' IM across nine measurements within three phases. The impact of BBL on eighth-graders' IM during the intervention phase was examined, and post-Huynh-Feldt's correction, the sphericity-adjusted F-statistic was found to be $F(2.95) = 111$, with a p-value of 0.000 ($p < .001$). The effect size, represented by partial eta squared ($\eta p2$), was calculated to be .75, signifying a statistically significant impact of the BBL activities on students' IM to learn mathematics, meeting the criteria set by Latoszek (2020) for statistical significance. Consequently, it can be inferred that the BBL-based activities, including visual imagery, role play, i-Think map, and brainstorming, had a significant effect on students' IM to learn and perform in mathematics throughout the treatment phase (B), specifically in learning financial arithmetic, polynomials, and factorisation related topics.

In this part of the results, the researchers presented the analysis for the qualitative data. The researchers took field notes daily during all the study phases by following the observation guidelines. After applying thematic data analysis, the authors found the following themes.

Class Engagement and Interaction

The researchers found that when the students were taught using the traditional lecture method, students showed poor class management in the baseline phase. They were less interactive and most of the time passive in class. It was also found that few of the students never asked a question to the teacher or peers. While in the treatment phase, they were more engaged. Perhaps, it was the effect of activities designed based on BBL principles. In this phase, students showed enthusiasm and interest, and quantitative results showed that they got the highest IM to learn and perform in mathematics during this phase. In the withdrawal phase, the researchers observed that students' class engagement and interaction decreased from the baseline phase. Although it remained better than the baseline phase, it significantly reduced from the treatment phase. When the authors matched the data triangulation results, it was concluded that both types of data support each other and validate the influence of BBL-based teaching on students' IM to learn and perform

Table 2

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Intrinsic motivation	.000	288.775	35	.000	.340	.369	.125

Table 3

Mean and Standard Deviation Values and Tests of Within-Subjects Effects

Variable	M	SD	N	df	Sphericity assumed	*Effect*	*F ratio*	Sig.	Partial Eta Squared
Week 2	3.26	.607	39	2.95	132.71	IM	111	.000	.75
Week 4	3.24	.669	39						
Week 6	3.29	.648	39						
Week 8	4.56	.348	39						
Week 10	4.74	.275	39						
Week 12	4.94	.125	39						
Week 14	4.15	.420	39						
Week 16	4.08	.427	39						
Week 18	3.91	.624	39						

in mathematics. It showed that activities such as visual story-telling, role-playing, i-Think maps, back-to-board, and Kick Me Poison Box effectively increased students' IM during the treatment phase.

Emotional Support

The authors found that the emotional support of students was lowest during the baseline phase, and it enhanced dramatically during the treatment phase. In the withdrawal phase, it was although better than the baseline phase but significantly decreased from the treatment phase. This fluctuation of emotional support in class was owed to implementing BBL-based teaching. The teacher taught them such activities, which were designed for the BBL principles, and these principles focus on emotional attachment. It was found that when they were part of the groups' activities, they showed an empathetic attitude toward each other. After triangulating the data for validation, it was investigated that activities such as role-playing, visual story-telling, i-Think maps, and back-to-board are effective activities for students' emotional support and contributed to increasing students' IM during the treatment phase.

Discussion

The present mixed-methods study aimed to examine the impact of BBL on students' IM to learn and perform in mathematics. During the research, participants were exposed to traditional lecture-based instruction in the baseline and withdrawal phases, while the treatment phase entailed BBL-based activities and principles. The study's results revealed a significant enhancement in students' IM when exposed to the BBL approach, attributing this improvement to the intervention during the treatment phase. Concerns over enhancing students' motivation in mathematics have long occupied educators and stakeholders (Farooq et al., 2020; Mushtaq, 2021; Talpur et al., 2021), revealing the positive impact of the BBL teaching approach on students' IM in mathematics, particularly significant. Wilkie and Sullivan (2018) posited that IM plays a pivotal role in overall motivation, strengthening efforts toward achieving academic goals, especially in mathematics.

The literature strongly indicates that students' inadequate motivation contributes to a high rate of mathematics failure (Heyder et al., 2020). In this context, the current study offers a promising explanation by proposing BBL-based activities to enhance students' IM and, consequently, their likelihood of academic success. Froiland and Worrell (2016) support this claim, highlighting that intrinsically motivated students outclass in various educational events, displaying sharp passion, challenge-seeking tendencies, greater participation, and enhanced performance. The thematic analysis also supports the argument that when students were taught mathematics with BBL-based activities, they felt more passion and energy to solve mathematical problems.

An essential consideration is the students' classroom engagement, with motivation being critical. Motivated students actively contribute to class work, enthusiastically engaging in tasks and fulfilling deadlines (Musu-Gillette et al., 2015). Embracing BBL-based activities in mathematics instruction can encourage students' motivation by addressing their needs in terms of competency, teaching, and pedagogical experiences, thereby fostering academic achievement and the attainment of favourable grades. Qualitative analysis showed that when BBL-based interventions were applied in the class, it enhanced their class engagement and participation. It further supported the quantitative findings, significantly increasing students' IM during treatment.

Ryan and Deci (2016) reinforce the relationship between motivation and academic achievement, asserting that successful educational outcomes are a powerful motivator for students. Conversely, lower scores may undermine students' confidence in their intellectual abilities and lead to demotivation. In this context, BBL emerges as a valuable approach to nurturing motivation, enabling students to achieve higher scores and find fulfilment in their academic pursuits. Thus, it can be argued that BBL is an effective approach with the potential to enhance students' IM and engage them in class participation. Their passion, energy, and interest in solving mathematical problems increased when they were taught with the help of BBL-based activities.

The research findings, determined through one-way repeated measure ANOVA, conclusively demonstrate that BBL-based activities significantly influence students' IM to learn and perform in mathematics. These results validate the findings of Mekarina and Ningsih (2017), who support the efficacy of BBL as a teaching strategy, enhancing both motivation and mathematical proficiency among students. Furthermore, the estimated marginal mean score highlights a positive relationship between the BBL-based teaching approach and students' IM to learn and perform in mathematics, supporting the study findings of Yu and Singh (2018) in their investigation of the interplay between teachers' strategies and students' motivation for mathematics learning. Additionally, Effendi and Marlina (2021) emphasise the potential of the BBL model to elevate students' motivation in mathematical communication, aligning with the present study's outcomes.

Thus, this research digs into the field of educational exploration, revealing the remarkable potential of BBL to ignite students' IM in the pursuit of mathematical

learning and performance. The findings emphasise the significance of incorporating the BBL approach in mathematics education to unlock students' full potential and pave the way for academic excellence. As educators and stakeholders embark on the path ahead, may these insights serve as a guiding light to invigorate the hearts and minds of future learners, fostering a generation of motivated individuals poised for success in their mathematical endeavours. Hence, it can be argued that the implications of neuroscience in school can effectively affect students' psychology.

Conclusion

The authors performed the convergent parallel study using experimental conditions. Students overcame the fear and concerns about enhancing students' IM to learn and perform in mathematics which has challenged teachers over the decades. Academia also believes that students' IM is one of the crucial aspects for students' success in school psychology. The current study was designed to investigate the effect of BBL on students' IM to learn and perform mathematics at the elementary level. During the intervention phase of the study, the researchers developed mathematics learning activities based on the approaches and principles of BBL. The visual analysis presented a comparison in all stages of the study, which revealed that the increase in IM during the treatment phase (B) was due to the intervention provided to students for mathematics learning. The decline in IM during the withdrawal phase (A) further supported the study's findings that the results started decreasing when the intervention was withdrawn. The qualitative data also supported the quantitative data findings when data triangulation was performed. Thus, the current study concluded that BBL significantly affects students' IM to learn and perform in mathematics.

Limitations, Study Implication, and Future Research

The present investigation had certain limitations. Being a mixed-methods study, the researchers employed an experimental setting on a single subject (A-B-A) with a relatively smaller sample size and confined to a specific region encompassing one school and class. While the A-B-A design effectively addresses potential threats like history and maturation by equalising the duration of all study phases, concerns arise regarding the generalizability of the results to a broader context. Moreover, the repetitive use of the same measurement tool (MMS) for data collection at two-week intervals might introduce potential biases in communicating results. Additionally, the study's budget constraints necessitated the creation of BBL-based activities using cost-effective, non-elaborate materials to foster a conducive environment for students' engagement with mathematical concepts. These limitations could potentially restrict the scope and applicability of the current study.

Despite these limitations, the study's findings have practical implications for students and teachers at the elementary school level. Adopting a classroom environment that emphasises BBL may foster a sense of comfort and ease for teachers and students, potentially alleviating the stress associated with achieving higher academic scores. The investigation demonstrated a significant increase in students' IM to comprehend and apply mathematical concepts, highlighting the potential of BBL as a valuable approach for enhancing students' class participation, engagement, and retention.

While the current study provides valuable insights, it also suggests further exploration. Future researchers may consider employing only a qualitative approach to thoroughly assess the impact of BBL-based activities on students' IM in learning and performing mathematics. They can deploy semi-structured interviews or focused group discussions to explore teachers' and students' dispositions and applications of BBL-based interventions. The current findings could be replicated by designing experimental studies utilising alternative designs beyond the A-B-A. Such endeavours would contribute to a more comprehensive understanding of BBL strategies' potential benefits and effectiveness in mathematics education.

References

AlAkayleh, S. S., & Al-Zoubi, A. M. (2023). The Effectiveness of a Program Based on Brain-Based Learning in Acquiring Mathematical Skills among Students with Learning Difficulties in Math. *Resmilitaris*, *13*(3), 3076-3082.

Alayont, F. (2022). A Case for Ethics in the Mathematics Major Curriculum. *Journal of Humanistic Mathematics, 12*(2), 160-177. https://doi.org/10.5642/jhummath.CXSI3022

Al-Balushi, K. A., & Al-Balushi, S. M. (2018). Effectiveness of Brain-Based Learning for Grade Eight Students' Direct and Postponed Retention in Science. *International Journal of Instruction, 11*(3), 525-538. https://doi.org/10.12973/iji.2018.11336a

Amjad, A. I., Habib, M., & Saeed, M. (2022b). Effect of brain-based learning on students' mathematics performance at the elementary level. *Pakistan Journal of Social Research, 4*(03), 38-51. https://doi.org/10.52567/pjsr.v4i03.684

Amjad, A. I., Tabbasam, U., & Abbas, N. (2022a). The Effect of Brain-Based Learning on Students' Self-Efficacy to Learn and Perform Mathematics: Implication of Neuroscience into School Psychology. *Pakistan Languages and Humanities Review*, *6*(3), 683-695.

Apeh, H. A., & Iyiegbuniwe, O. A. (2021). Effects of brain-based learning strategies on secondary school students' motivation to learn in Federal Capital Territory, Abuja, Nigeria. *International Journal of Research*, *10*(5), 19-32. https://doi.org/10.5861/ijrse.2021.5057

Appelgate, M. H., & Jurgenson, K. (2022). How engagement with mathematics in an integrated STEM lesson evolved over four years. *Investigations in Mathematics Learning, 14*(1), 63-86. https://doi.org/10.1080/19477503.2021.2023965

Bai, S., Hew, K. F., Sailer, M., & Jia, C. (2021). From top to bottom: How positions on different types of leaderboards may affect fully online student learning performance, intrinsic motivation, and course engagement. *Computers & Education*, *173*, 104297. https://doi.org/10.1016/j.compedu.2021.104297

Baker, D. H., Vilidaite, G., Lygo, F. A., Smith, A. K., Flack, T. R., Gouws, A. D., & Andrews, T. J. (2021). Power contours: Optimising sample size and precision in experimental psychology and human neuroscience. *Psychological Methods*, *26*(3), 295. https://doi.org/10.1037/met0000337

Bano, M., Zowghi, D., Kearney, M., Schuck, S., & Aubusson, P. (2018). Mobile learning for science and mathematics school education: A systematic review of empirical evidence. *Computers & Education, 121*, 30-58. https://doi.org/10.1016/j.compedu.2018.02.006

Baratali, M., & Zardeini, A. Z. (2023). Identification of curriculum objectives of brain-based education and positive education. *Journal of Fundamentals of Mental Health*, *25*(2), 69-79.

Benson, N. F., Floyd, R. G., Kranzler, J. H., Eckert, T. L., Fefer, S. A., & Morgan, G. B. (2019). Test use and assessment practices of school psychologists in the United States: Findings from the 2017 National Survey. *Journal of School Psychology*, *72*, 29-48. https://doi.org/10.1016/j.jsp.2018.12.004

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Caine, R. N., & Caine, G. (1991). Making connections: Teaching and the human brain. ERIC.

Corpus, J. H., & Wormington, S. V. (2014). Profiles of intrinsic and extrinsic motivations in elementary school: A longitudinal analysis. *The Journal of Experimental Education, 82*(4), 480-501. https://doi.org/10.1080/00220973.2013.876225

Das, K. (2019). Role of ICT for Better Mathematics Teaching. *Shanlax International Journal of Education*, *7*(4), 19-28. https://doi.org/10.34293/education.v7i4.641

Drigas, A., & Karyotaki, M. (2019). Executive Functioning and Problem Solving: A Bidirectional Relation. *Int. J. Eng. Pedagog.*, *9*(3), 76-98. https://doi.org/10.3991/ijep.v9i3.10186

Effendi, K. N. S., & Marlina, R. (2021). The effect of motivation towards mathematical communication in mathematics learning with brain-based learning model. *Jurnal Program Studi Pendidikan Matematika, 10*(2), 808-819. https://doi.org/10.24127/ajpm.v10i2.3488

El-Adl, A. M., & Saad, M. A. E. (2019). Effect of a brain-based learning program on working memory and academic motivation among tenth grade Omanis students. *Online Submission*, *8*(1), 42-50.

El-Adl, A., & Alkharusi, H. (2020). Relationships between self-regulated learning strategies, learning motivation and mathematics achievement. *Cypriot Journal of Educational Sciences, 15*(1), 104-111. https://doi.org/10.18844/cjes.v15i1.4461

Engelbrecht, J., Llinares, S., & Borba, M. C. (2020). Transformation of the mathematics classroom with the internet. *ZDM, 52*(5), 825-841. https://doi.org/10.1007/s11858-020-01176-4

Farooq, S., Tatlah, I. A., & Butt, I. H. (2020). Role of Peer Tutoring on the Intrinsic Motivation of Student Teachers in Pakistan: An Experimental Investigation. *Pakistan Social Sciences Review, 4*(1), 381-388. https://doi.org/10.35484/pssr.2020(4-I)30

Ferreira, R. A., & Rodríguez, C. (2022). Effect of a science of learning course on beliefs in neuromyths and neuroscience literacy. *Brain Sciences, 12*(7), 1-14. https://doi.org/10.3390/brainsci12070811

Froiland, J. M., & Worrell, F. C. (2016). Intrinsic motivation, learning goals, engagement, and achievement in a diverse high school. *Psychology in the Schools, 53*(3), 321-336. https://doi.org/10.1002/pits.21901

Glaser, J. I., Benjamin, A. S., Farhoodi, R., & Kording, K. P. (2019). The roles of supervised machine learning in systems neuroscience. *Progress in Neurobiology, 175*, 126-137. https://doi.org/10.1016/j.pneurobio.2019.01.008

Hair Jr, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021). *Partial least squares structural equation modeling (PLS-SEM) using R: A workbook*. Springer. https://doi.org/10.1007/978-3-030-80519-7

Heyder, A., Weidinger, A. F., Cimpian, A., & Steinmayr, R. (2020). Teachers' belief that math requires innate ability predicts lower intrinsic motivation among low-achieving students. *Learning and Instruction, 65*, 1-39. https://doi.org/10.1016/j.learninstruc.2019.101220

Hofer, B. K. (2022). Teaching Educational Psychology to Undergraduates. Routledge. https://doi.org/10.4324/9781138609877-REE100-1

Hung, C. Y., Sun, J. C. Y., & Liu, J. Y. (2019). Effects of flipped classrooms integrated with MOOCs and game-based learning on the learning motivation and outcomes of students from different backgrounds. *Interactive Learning Environments, 27*(8), 1028-1046. https://doi.org/10.1080/10494820.2018.1481103

Immordino-Yang, M. H., Darling-Hammond, L., & Krone, C. R. (2019). Nurturing nature: How brain development is inherently social and emotional, and what this means for education. *Educational Psychologist*, *54*(3), 185-204. https://doi.org/10.1080/00461520.2019.1633924

Jailani, M. (2021). Developing Arabic Media Based on Brain-Based Learning: Improving Mufrodat in School. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, *6*(2), 349-361. https://doi.org/10.24042/tadris.v6i2.9921

Khan, R. M. G. B., Chachar, G. B., & Abro, I. A. (2020). Mathematics Achievement of Grade VIII Students Based on International Standardized Test (TIMSS) in an Urban Context of Sindh, Pakistan. *In 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET),* 1-4. https://doi.org/10.1109/iCoMET48670.2020.9074110

Latoszek, B. B. V. (2020). Treatment effectiveness of Novafon local vibration voice therapy for dysphonia treatment. *Journal of Voice, 34*(1), 7-14. https://doi.org/10.1016/j.jvoice.2018.05.009

Li, P., & Lan, Y. J. (2022). Digital language learning (DLL): Insights from behavior, cognition, and the brain. *Bilingualism: Language and Cognition*, *25*(3), 361-378. https://doi.org/10.1017/S1366728921000353

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The role of mathematics in interdisciplinary STEM education. *ZDM, 51*(6), 869-884. https://doi.org/10.1007/s11858-019-01100-5

Mekarina, M., & Ningsih, Y. P. (2017). The effects of brain-based learning approach on motivation and students achievement in mathematics learning. *Journal of Physics: Conference Series, 895*(1), 1-6. https://doi.org/10.1088/1742-6596/895/1/012057

Mushtaq, T. (2021). A Critical Evaluation of PEELI Project Run by the Punjab Government of Pakistan and British Council. *International Journal of Academic Research in Business and Social Sciences, 11*(3), 1080-1098. https://doi.org/10.6007/IJARBSS/v11-i3/8656

Musu-Gillette, L. E., Wigfield, A., Harring, J. R., & Eccles, J. S. (2015). Trajectories of change in students' self-concepts of ability and values in math and college major choice. *Educational Research and Evaluation, 21*(4), 343-370. https://doi.org/10.1080/13803611.2015.1057161

Nematillayevna, J. M. (2021). Formation of methodological competencies of future mathematics teachers in the field of quality assessment of education. *Asian Journal of Multidimensional Research, 10*(6), 67-71. https://doi.org/10.5958/2278-4853.2021.00504.8

Oljayevna, O., & Shavkatovna, S. (2020). The Development of Logical Thinking of Primary School Students in Mathematics. *European Journal of Research and Reflection in Educational Sciences*, *8*(2), 235-239.

Palser, E. R., Lazerwitz, M., & Fotopoulou, A. (2022). Gender and geographical disparity in editorial boards of journals in psychology and neuroscience. *Nature Neuroscience*, *25*(3), 272-279. https://doi.org/10.1038/s41593-022-01012-w

Pascual, E. A. (2022). Getting the Answer Exactly Right: Dealing with Math Misconception. *Getting the Answer Exactly Right: Dealing with Math Misconception, 93*(1), 306-310. https://doi.org/10.47119/IJRP100931120222745

Pohan, A. M., Asmin, A., & Menanti, A. (2020). The effect of problem-based learning and learning motivation of Mathematical problem-solving skills of class 5 students at SDN 0407 Mondang. *Budapest International Research and Critics in Linguistics and Education (BirLE) Journal, 3*(1), 531-539. https://doi.org/10.33258/birle.v3i1.850

Ryan, R. M., & Deci, E. L. (2016). Facilitating and hindering motivation, learning, and well-being in schools: Research and observations from self-determination theory. *Handbook of Motivation at School*, 96-119. Routledge.

Saleh, S., & Mazlan, A. (2019). The effects of brain-based teaching with i-think maps and brain gym approach towards physics understanding. *Jurnal Pendidikan IPA Indonesia, 8*(1), 12-21. https://doi.org/10.15294/jpii.v8i1.16022

Sanetti, L. M. H., & Collier-Meek, M. A. (2019). Increasing implementation of science literacy to address the research-to-practice gap in school psychology. *Journal of School Psychology*, *76*, 33-47. https://doi.org/10.1016/j.jsp.2019.07.008

Solihatin, E., & Syahrial, Z. (2019). The effects of Brain-based learning and Project-based learning strategies on student group mathematics learning outcomes student visual learning styles. *Pedagogical Research*, *4*(4), em0047. https://doi.org/10.29333/pr/5949

Stojanović, J., Petkovic, D., Alarifi, I. M., Cao, Y., Denic, N., Ilic, J., ... & Milickovic, M. (2021). Application of distance learning in mathematics through adaptive neuro-fuzzy learning method. *Computers & Electrical Engineering, 93*, 1-12. https://doi.org/10.1016/j.compeleceng.2021.107270

Talpur, N., Kalwar, T., & Talpur, M. J. (2021). Computer-assisted Language Learning in Pakistani Context During COVID-19 Pandemic. REiLA: *Journal of Research and Innovation in Language, 3*(3), 210-225. https://doi.org/10.31849/reila.v3i3.6908

Tan, Y. S. M., & Amiel, J. J. (2022). Teachers learning to apply neuroscience to classroom instruction: a case of professional development in British Columbia. *Professional Development in Education, 48*(1), 70-87. https://doi.org/10.1080/19415257.2019.1689522

Tokac, U., Novak, E., & Thompson, C. G. (2019). Effects of game-based learning on students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning, 35*(3), 407-420. https://doi.org/10.1111/jcal.12347

Tortella, G. R., Seabra, A. B., Padrão, J., & Diaz-San Juan, R. (2021). Mindfulness and other simple neuroscience-based proposals to promote the learning performance and mental health of students during the COVID-19 pandemic. *Brain sciences*, *11*(5), 1-20. https://doi.org/10.3390/brainsci11050552

Triana, M., & Zubainur, C. M. (2019). Students' Mathematical Communication Ability through the Brain-Based Learning Approach Using Autograph. *Journal of Research and Advances in Mathematics Education, 4*(1), 1-10. https://doi.org/10.23917/jramathedu.v4i1.6972

Udjaja, Y., Guizot, V. S., & Chandra, N. (2018). Gamification for elementary mathematics learning in Indonesia. *International Journal of Electrical and Computer Engineering (IJECE), 8*(6), 3860-3865. https://doi.org/10.11591/ijece.v8i5.pp3860-3865

Weeden, K. A., Gelbgiser, D., & Morgan, S. L. (2020). Pipeline Dreams: Occupational Plans and gender differences in STEM major persistence and completion. *Sociology of Education*, *93*(4), 297-314. https://doi.org/10.1177/0038040720928484

Weidinger, A. F., Steinmayr, R., & Spinath, B. (2017). Math grades and intrinsic motivation in elementary school: A longitudinal investigation of their association. *British Journal of Educational Psychology, 87*(2), 187-204. https://doi.org/10.1111/bjep.12143

Wilcox, G., Morett, L. M., Hawes, Z., & Dommett, E. J. (2021). Why educational neuroscience needs educational and school psychology to effectively translate neuroscience to educational practice. *Frontiers in Psychology*, *11*, 618449. https://doi.org/10.3389/fpsyg.2020.618449

Wilkie, K. J., & Sullivan, P. (2018). Exploring intrinsic and extrinsic motivational aspects of middle school students' aspirations for their mathematics learning. *Educational Studies in Mathematics, 97*(3), 235-254. https://doi.org/10.1007/s10649-017-9795-y

Yu, R., & Singh, K. (2018). Teacher support, instructional practices, student motivation, and mathematics achievement in high school. *The Journal of Educational Research, 111*(1), 81-94. https://doi.org/10.1080/00220671.2016.1204260

Zakariya, Y. F., & Massimiliano, B. (2021). Development of Mathematics Motivation Scale: A Preliminary Exploratory Study with a Focus on Secondary School Students. *International Journal of Progressive Education, 17*(1), 314-324. https://doi.org/10.29329/ijpe.2021.329.20