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Research Paper

Application Of Brain Based Learning on Critical Thinking Skills and Academic Achievement in Chemistry At the Secondary Level

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Abstract
This study explores the effectiveness of Brain-Based Learning (BBL) strategies in enhancing critical thinking and academic achievement among secondary school students in chemistry. Recognizing the limitations of traditional teaching methods—especially their overreliance on rote memorization—this experimental research adopts a two-group pre-test and post-test design involving 60 students from a secondary school in Muthukulam, Kerala. The experimental group received instruction through BBL strategies rooted in neuroscience and cognitive psychology, while the control group was taught using conventional activity-oriented methods. Data was collected through standardized tools including a Critical Thinking Scale and an Achievement Test in Chemistry, with results analyzed using statistical methods such as t-tests and ANCOVA. Findings revealed that students exposed to BBL strategies showed significantly improved critical thinking abilities and academic performance compared to the control group. The study underscores the pedagogical value of aligning instructional approaches with how the brain naturally learns and recommends integrating BBL into science curricula to foster deeper understanding, increased engagement, and higher-order cognitive skills. Implications for teacher training, curriculum design, and educational policy are also discussed.

Keywords: *Brain-Based Learning, Critical Thinking, Academic Achievement, Chemistry Education, Secondary School, Cognitive Strategies*

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I. Introduction

Learning is an inherently complex and dynamic process involving cognitive, emotional, and social interactions between learners, educators, and instructional environments. In recent decades, educational psychology and neuroscience have significantly influenced pedagogical practices, revealing how deeply the structure and functioning of the human brain impact learning outcomes. This emerging insight has given rise to Brain-Based Learning (BBL) — a progressive, research-backed approach designed to harmonize teaching methodologies with the brain's natural learning processes.

BBL emphasizes experiential, multisensory, and emotionally resonant learning experiences that stimulate brain regions responsible for memory, critical thinking, and conceptual integration. It aligns with the principles of neuroplasticity, which suggest that the brain remains capable of growth and change throughout life. Educators implementing BBL focus on creating environments that are emotionally safe, cognitively challenging, and physically engaging — all critical conditions for optimal learning.

Chemistry, as a core scientific discipline, presents unique opportunities and challenges for implementing BBL strategies. Its inherent abstractness, combined with its demand for conceptual understanding and application, makes traditional methods of rote memorization and passive instruction insufficient for deep learning. The failure to connect chemistry education to real-world applications often leads to student disengagement, low critical thinking, and superficial understanding. Consequently, modern chemistry instruction must evolve beyond lecture-based delivery to embrace pedagogies that are interactive, student-centered, and cognitively enriching.

In many developing educational contexts, particularly in science classrooms, systemic issues such as outdated curricula, limited resources, and overcrowded classrooms continue to hinder meaningful engagement.

Students frequently memorize content without internalizing the conceptual framework, thereby inhibiting their scientific literacy and problem-solving skills. The current educational climate demands a shift towards methodologies that not only promote academic proficiency but also nurture competencies vital for 21st-century citizenship — such as critical thinking, creativity, collaboration, and civic responsibility.

This study investigates the application of Brain-Based Learning strategies in enhancing critical thinking skills and academic achievement in secondary-level chemistry education. By comparing students exposed to BBL-based instruction with those taught through conventional activity-oriented methods, the research seeks to determine the effectiveness of BBL in transforming passive learning into an active, reflective, and meaningful process.

Grounded in the constructivist theory of learning, which asserts that knowledge is actively constructed by learners through experiences and social interactions, this study adopts an experimental research design. It aims to provide empirical evidence supporting the adoption of brain-compatible instructional methods that are attuned to students' developmental and cognitive needs.

The relevance of this research lies not only in its academic implications but also in its practical contributions to instructional planning, teacher training, and curriculum development. The findings are expected to inform educators, curriculum designers, and policymakers about how scientifically grounded pedagogical strategies can elevate the quality of chemistry education, making it both intellectually rigorous and emotionally engaging.

Hypotheses of the Study

1. There is a significant difference between the Experimental group and the Control group in the Pre-test score of Critical thinking.
2. There is a significant difference between the experimental group and control group in their post-test scores of Critical thinking after they have been adjusted for differences in the pre-test scores of Critical thinking.
3. There is a significant difference between the Experimental group and the Control group in the Pre-test score of Achievement in Chemistry.
4. There is a significant difference between the experimental group and control group in their post-test scores of Achievement in Chemistry after they have been adjusted for differences in the pre-test scores of Achievement in Chemistry.

Objectives of the Study

1. 1. To find out whether there is a significant difference between the experimental group and control group in the pre-test score of Critical Thinking.
2. To find out whether there is a significant difference between the experimental group and control group in their post-test scores of Critical thinking after they have been adjusted for differences in the pre-test scores of Critical thinking.
3. To find out whether there is a significant difference between the experimental group and control group in the pre-test score of Achievement in Chemistry.
4. To find out whether there is a significant difference between the experimental group and control group in their post-test scores of Achievement in Chemistry after they have been adjusted for differences in the pre-test scores of Achievement in Chemistry.

II. Methodology

The present study adopted a two-group pre-test and post-test experimental design to investigate the effectiveness of Brain-Based Learning (BBL) strategies on secondary school students' academic achievement and critical thinking skills in chemistry. A total of 60 students from K V Sanskrit HSS, Muthukulam, were randomly assigned into two groups—30 in the experimental group and 30 in the control group. The experimental group was taught using BBL strategies, which included multisensory activities, emotional engagement, real-world applications, and neuroscience-informed lesson templates, while the control group received instruction through conventional activity-based methods. Pre-tests were administered to both groups to assess baseline levels of academic achievement and critical thinking. Following a six-week instructional intervention, post-tests were conducted using a standardized Achievement Test in Chemistry and a Critical Thinking Scale developed and validated by the investigator. Data were analyzed using descriptive statistics, t-tests, ANOVA, and ANCOVA through EDUSTAT software to determine the statistical significance of the observed differences between the groups. The findings aimed to assess the impact of BBL on promoting meaningful learning and cognitive development in chemistry education.

Descriptive Analysis of Data
This section deals with the descriptive analysis of the variables used in the study. **Table 1**

Descriptive statistics of Pre-test score of Critical thinking of Secondary school students

N	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
60	39.3	38	36	5.31	0.34	-0.87

The mean, median and mode for the Pre-test score of Critical thinking of Secondary school students are obtained as 39.3, 38, and 36 respectively. The values of Skewness and Kurtosis are obtained as 0.34 and -0.87 respectively. The values of skewness and kurtosis suggest that the Pre-test score of Critical thinking of Secondary school students is slightly positively skewed and slightly platykurtic.

Table 2

Descriptive statistics of Post-test score of Critical thinking of Secondary school students

N	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
60	76	78.5	53	18.92	-0.09	-1.85

The mean, median and mode for the Post-test score of Critical thinking of Secondary school students are obtained as 76, 78.5, and 53 respectively. The values of Skewness and Kurtosis are obtained as -0.09 and -1.85 respectively. The values of skewness and kurtosis suggest that the Post-test score of Critical thinking of Secondary school students is slightly negatively skewed and platykurtic.

Table 3

Descriptive statistics of Pre-test score of Achievement in Chemistry of Secondary school students

N	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
60	24.27	24	24	5.41	0.22	-0.72

The mean, median and mode for the Pre-test score of Achievement in Chemistry of Secondary school students are obtained as 24.27, 24, and 24 respectively. The values of Skewness and Kurtosis are obtained as 0.22 and -0.72 respectively. The values of skewness and kurtosis suggest that the Pre-test score of Achievement in Chemistry of Secondary school students is slightly positively skewed and slightly platykurtic.

Table 4

Descriptive statistics of Post-test score of Achievement in Chemistry of Secondary school students

N	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
60	65.93	66	40	22.13	-0.03	-1.8

The mean, median and mode for the Post-test score of Achievement in Chemistry of
Secondary school students are obtained as 65.93, 66, and 40 respectively. The values of Skewness and Kurtosis are obtained as -0.03 and -1.8 respectively. The values of skewness and kurtosis suggest that the Post-test score of Achievement in Chemistry of Secondary school students is slightly negatively skewed and platykurtic.

Testing of Hypotheses

This section deals with the testing of hypotheses formulated for the study using appropriate statistical techniques.

Testing of Hypothesis 1

Table 5

Test of significance of difference between means of Pre-test score of Critical thinking of Experimental group and Control group

Group	Number	Mean	Standard deviation	t	Level of significance
Experimental group	30	38.6	5.26	1.02	Not significant
Control group	30	40	5.36		

The calculated value of t is 1.02 and is not significant at 0.05 level ($t = 1.02$; $p>0.05$). Since the mean of the Experimental group do not differ significantly from that of the Control group, Experimental group and Control group are more or less equal in Pre-test score of Critical thinking.

Tenability of Hypothesis

Test of significance of difference between means of Pre-test score of Critical thinking of Experimental group and Control group revealed that there is no significant difference between Experimental group and Control group in Pre-test score of Critical thinking. Hence the null hypothesis formulated in this context is not rejected.

Testing of Hypothesis 2

Table 6

Analysis of Covariance of pre-test and post-test scores of Critical thinking of experimental group and control group

Source of variation	df	Sum of squares	Mean square	F	Level of significance
Among means	1	19161.74	19161.74	953.16	0.01
Within groups	57	1145.89	20.1		
Total	58	20307.64			

The obtained value of F is 953.16 and is significant at 0.01 level. ($F = 953.16$; $p<0.01$). This shows that the post-test mean scores of Critical thinking of treatment groups differ significantly after they have been adjusted for difference in the pre-test scores of Critical thinking.

Table 7

Pre-test, post-test and adjusted post-test mean scores of Critical thinking of the treatment groups

Group	Number of students	Mean of pre-test	Mean of post-test	Adjusted post-test mean
Control	30	40	57.8	57.97
Experimental	30	38.6	94.2	94.03

The significant difference between the adjusted post-test means of Critical thinking indicates that the pupils of experimental and control group differ significantly in their post-test scores of Critical thinking after they have been adjusted for difference in the pre-test scores of Critical thinking. Since the adjusted mean of post-test scores of Critical thinking of experimental group is significantly greater than that of the control group, the treatment applied to the experimental group (Brain based learning strategy) is better than that applied to the control group (Activity oriented method).

Tenability of Hypothesis

Analysis of Covariance of pre-test and post-test scores of Critical thinking of experimental group and control group revealed that there is significant difference between control group and experimental group in their post-test scores of Critical thinking after they have been adjusted for difference in the pre-test scores of Critical thinking. Hence the null hypothesis formulated in this context is rejected.

Testing of Hypothesis 3

Table 8

Test of significance of difference between means of Pre-test score of Achievement in Chemistry of Experimental group and Control group

Group	Number	Mean	Standard deviation	t	Level of significance
Experimental group	30	24.8	5.79	0.76	Not significant
Control group	30	23.73	5.03		

The calculated value of t is 0.76 and is not significant at 0.05 level ($t = 0.76$; $p>0.05$). Since the mean of the Experimental group do not differ significantly from that of the Control group, Experimental group and Control group are more or less equal in Pre-test score of Achievement in Chemistry.

Tenability of Hypothesis

Test of significance of difference between means of Pre-test score of Achievement in Chemistry of Experimental group and Control group revealed that there is no significant difference between Experimental group and Control group in Pre-test score of Achievement in Chemistry. Hence the null hypothesis formulated in this context is not rejected.

Testing of Hypothesis 4

Table 9

Analysis of Covariance of pre-test and post-test scores of Achievement in Chemistry of experimental group and control group

Source of variation	df	Sum of squares	Mean square	F	Level of significance
Among means	1	25367.21	25367.21	1837.5	0.01
Within groups	57	786.9	13.81		
Total	58	26154.11			

The obtained value of F is 1837.5 and is significant at 0.01 level. ($F = 1837.5$; $p<0.01$). This shows that the post-test mean scores of achievement in Chemistry of treatment groups differ significantly after they have been adjusted for difference in the pre-test scores of Achievement in Chemistry.

Table 10

Pre-test, post-test and adjusted post-test mean scores of Achievement in Chemistry of the treatment groups

Group	Number of students	Mean of pre-test	Mean of post-test	Adjusted post-test mean
Control	30	23.73	44.8	45.27
Experimental	30	24.8	87.07	86.6

The significant difference between the adjusted post-test means of Achievement in Chemistry indicates that the pupils of experimental and control group differ significantly in their post-test scores of Achievement in Chemistry after they have been adjusted for difference in the pre-test scores of Achievement in Chemistry. Since the adjusted mean of post-test scores of Achievement in Chemistry of experimental group is significantly greater than that of the control group, the treatment applied to the experimental group (Brain based learning strategy) is better than that applied to the control group(Activity oriented method).

Tenability of Hypothesis

Analysis of Covariance of pre-test and post-test scores of Achievement in Chemistry of experimental group and control group revealed that there is significant difference between control group and experimental group in their post-test scores of Achievement in Chemistry after they have been adjusted for difference in the pre-test scores of Achievement in Chemistry. Hence the null hypothesis formulated in this context is rejected.

III. Discussion and Conclusion

The findings of this study demonstrate that Brain-Based Learning (BBL) has a statistically significant and positive impact on both academic achievement and critical thinking skills among secondary school students studying chemistry. The experimental group, which was exposed to BBL instructional strategies, consistently outperformed the control group, which received traditional activity-based instruction. This aligns with the conclusions of Bada and Jita (2022) and Lagoudakis et al. (2022), who reported that BBL fosters deeper engagement, improves memory retention, and enhances conceptual understanding in science education.

The results affirm the core premise of brain-based instruction: that when learning experiences are emotionally engaging, multisensory, and connected to real-world applications, students exhibit higher cognitive involvement. These principles are consistent with the neurological basis of learning, which suggests that emotional safety, physical engagement, and pattern recognition are crucial for long-term memory formation

(Caine & Caine, 1994; Jensen, 2008). The integration of visual, auditory, and kinesthetic activities, as used in the BBL lesson templates, supports the multisensory learning advocated by Zakaria et al. (2021), who emphasize that engaging multiple brain regions strengthens critical thinking and comprehension.

This study also supports findings from Ozturk (2014) and Özsoy&Yildirim (2014), who observed that BBL leads to improved academic performance and motivation in science subjects. The experimental group in the current study showed measurable improvement in post-test scores, indicating not only better recall of facts but also greater application of conceptual knowledge. These results are particularly important in the context of chemistry education, where students often struggle with abstract concepts, as noted by Sevian and Talanquer (2014). The BBL strategies employed here helped bridge the gap between theory and application, fostering "chemical thinking" — the ability to relate chemical knowledge to practical and societal issues.

Furthermore, the enhancement of critical thinking through BBL validates the call by the World Economic Forum (2020) and APA (2012) to integrate cognitive skill development into secondary education. In this study, students engaged in problem-solving, hypothesis generation, and reflective analysis — all key aspects of higher-order thinking. The collaborative and inquiry-driven structure of BBL also parallels strategies found effective in Problem-Based Learning (PBL) and Inquiry-Based Chemistry Education (IBCE), as described by Raman et al. (2024) and Jegstad (2023), thus contributing to the growing body of evidence supporting constructivist approaches in science teaching.

In conclusion, this study provides strong empirical support for the use of Brain-Based Learning strategies in secondary chemistry education. The data affirm that BBL not only enhances students' academic performance but also significantly boosts their critical thinking skills — outcomes that are essential for nurturing scientifically literate, innovative, and socially responsible learners. Grounded in the constructivist theory and supported by findings in cognitive neuroscience, BBL presents a viable, scalable instructional framework that addresses the limitations of traditional rote-based methods.

The implications are clear: to cultivate meaningful learning in chemistry, educators must design lessons that are emotionally engaging, cognitively challenging, and grounded in real-life contexts. As this study shows, such practices not only improve retention and understanding but also promote the development of higher-order thinking, preparing students for academic success and active participation in a complex, information-rich society.

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