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Fostering conceptual understanding in mathematics through brain-based learning with crossword puzzle media

Leni Agustina Daulay[1*], Dede Zulfikar[2], Hizmi Wardani[3], Haira Fitri[4]
[1*,2,4]Program Studi Tadris Matematika, Institut Agama Islam Negeri (IAIN) Takengon, Aceh 24519, Indonesia
[3]Program Studi Pendidikan Matematika, Universitas Muslim Nusantara Al-Washliyah, Sumatera Utara 20147, Indonesia
[1*]agustina_leni@yahoo.com, [2]dedezulfikar11@gmail.com, [3]hizmiwardani@umnaw.ac.id, [4]haiafitri123@gmail.com

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*Corresponding author

Abstract:
This study aimed to foster seventh-grade students' conceptual understanding in mathematics, particularly in algebra, through the Brain-Based Learning (BBL) model supported by crossword puzzle media. Conceptual understanding is essential for mastering higher-level mathematics, highlighting the need for effective instructional strategies. A quasi-experimental design with a nonequivalent control group was employed, involving two classes randomly selected from the 2024/2025 seventh-grade population using a spin wheel application. Students' conceptual understanding was assessed via essay tests and analyzed using Welch's t-test on normalized gain (N-Gain) scores. The experimental group achieved a significantly higher mean N-Gain (M = 0.66) compared to the control group (M = 0.41) at the 0.05 significance level. The findings reveal a clear and meaningful difference between the groups, backed by strong statistical evidence $t(33.731) = -4.324$, $p < 0.001$, Cohen's $d = 1.31$), indicating that Brain-Based Learning with crossword puzzle media significantly enhanced students' conceptual understanding compared to conventional instruction. However, the study is limited by a small sample from a single school and the exclusion of specialized classes, which may affect generalizability. These findings suggest that integrating Brain-Based Learning with interactive media can effectively foster deeper mathematical understanding.

Keywords: Brain-Based Learning, Crossword Puzzles, Conceptual Understanding

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Introduction

While studying Mathematics is supposed to improve one's ability to think logically, solve problems, and discipline the intellect, the world over, students are still struggling with problems of conceptual understanding and have to resort to rote memorization rather than understanding the material on a deeper level, as has been documented by PISA and TIMSS (Mullis et al., 2011; OECD, 2019). This inability to think conceptually limits the students' scope and ability to adapt and apply the learning to new situations, increase self-efficacy, and overall confidence in the domain of learning Mathematics

(Hidayat & Iksan, 2015; Killpatrick et al., 2010). Brain-Based Learning (BBL) applies neuroscience principles to instructional design, integrating them more closely with instructional approaches. According to Jensen (2008), most learning occurs when there is orchestrated immersion, relaxed alertness, and active engagement. Similarly, Caine & Caine (2019) state that emotion, context, and multiple representational forms are necessary to deliver meaningful learning.

Empirical data support the benefits of BBL in mathematics. Suarsana et al. (2018) reported that BBL improved junior high students' understanding of polyhedra concepts. Triana et al. (2019) found that BBL, combined with the Autograph software, enhanced students' mathematical communication. In high school, BBL improved the learning of quadratic functions and student satisfaction. A meta-analysis by Amjad et al. (2022) and Funa et al. (2024) showed very large overall effect sizes for BBL on conceptual understanding across grades and subjects. In addition, studies show that BBL can foster mathematical creativity even at the elementary level, laying the foundation for junior high school students (Adiansha et al., 2021; Yulian & Hayati, 2019).

The use of varied instructional media strengthens learning by integrating multiple representations, motivating students, and supporting active recall. Crossword puzzles, in particular, encourage the retrieval and connection of key terms and concepts, promoting long-term retention and active engagement (Khaedar & Alam, 2023; Susanti et al., 2019). Recent studies also show that crossword puzzle-based media can improve students' critical thinking and conceptual mastery in mathematics (Cholily et al., 2023). Moreover, crossword puzzles have been shown to enhance knowledge retention (Torres et al., 2022).

The integration of crossword puzzles serves as a strategic cognitive scaffold for mathematical problem solving. As Sweller (2011) describes, managing cognitive load is vital for schema construction. Crossword puzzles facilitate this by requiring students to engage in active retrieval practice, which Karpicke & Roediger (2008) identify as a critical component for moving information from short-term to long-term memory. In algebra, this retrieval process allows students to bridge the gap between recognizing a term and applying it within a complex problem-solving context. By decoding clues and identifying conceptual relationships within the grid, students essentially practice the initial stages of Polya's problem-solving framework, specifically in understanding the problem and establishing connections between known and unknown variables.

From a cognitive perspective, crossword puzzles constitute retrieval-based learning activities that align strongly with Brain-Based Learning principles. Retrieval practice stimulates neural pathways, consolidates memory, and reinforces associations between mathematical terms and procedures (Karpicke & Roediger, 2008). When students solve mathematical crossword clues, they actively recall prior knowledge, analyze relationships between terms, and integrate new information with existing schemas. This process fosters deeper conceptual comprehension rather than rote memorization and supports the elaboration and incubation stages described in Brain-Based Learning (Caine & Caine, 2019; Carr et al., 2011; Jensen, 2008). The game-like format also reduces extraneous cognitive load while increasing germane load for schema construction, consistent with Cognitive Load Theory (Sweller, 2011).

From a cognitive perspective, crossword puzzles are retrieval-based learning activities. They align with Brain-Based Learning principles. Retrieval practice stimulates neural pathways, consolidates memory, and reinforces associations between mathematical terms and procedures. When students solve mathematical crossword clues, they retrieve prior knowledge and analyze relationships between terms. They also integrate new information with existing understanding. This process of active recall fosters deeper conceptual comprehension rather than rote memorization. It aligns with the engagement and elaboration stages described in Brain-Based Learning (Caine & Caine, 2019; Jensen, 2008).

Despite positive outcomes, gaps remain. Most studies treat Brain-Based Learning as a stand-alone approach, with few systematically integrating it with retrieval-based media such as crossword puzzles. Additionally, prior research has emphasized adjacent constructs rather than directly targeting conceptual understanding. Evidence from Indonesian junior high schools, particularly Grade VII, where students transition to algebraic reasoning, also remains limited. This study aims to determine the specific effect of Brain-Based Learning, when supported by crossword puzzle media, on students' conceptual understanding in Grade VII at SMP Negeri 2 Takengon. The hybrid design aligns crossword activities with Brain-Based Learning phases to enhance recall, elaboration, and consolidation.

Research Method

A quasi-experimental design with a nonequivalent control group assessed intervention effects in real classrooms where full randomization was not feasible (Creswell & Creswell, 2018; Sugiyono, 2020). The experimental group received mathematics instruction using Brain-Based Learning with crossword puzzles. The control group received direct instruction. Pretests and posttests measured conceptual understanding.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	BBL + crossword puzzle media	O_2
Control	O_3	Direct instruction	O_4

The population consisted of three seventh-grade classes at SMP Negeri 2 Takengon: VII-1 (31 students), VII-2 (21 students), and VII-3 Binaan (32 students). Class VII-3 Binaan was excluded because it is a special coaching class with a modified learning schedule, additional academic support, and distinct student characteristics. Including it would introduce confounding variables and threaten internal validity, given non-comparable instructional conditions and academic profiles (Creswell & Creswell, 2018). Only the two regular classes (VII-1 and VII-2), which follow the same curriculum, schedule, and assessment standards, were eligible for random assignment via a spin wheel (VII-1 as the experimental condition, VII-2 as the control). It ensured group equivalence while minimizing bias (Buch et al., 2021). Pretest means were comparable (Control: M = 9.66, Experimental: M = 10.41), supporting initial equivalence. Seventh-grade students were selected because this level marks the first formal encounter with algebraic concepts and the critical transition from arithmetic to algebraic thinking.

The conceptual understanding test consisted of five open-ended essay items aligned with indicators of conceptual understanding (restating concepts, providing examples, classifying, applying formulas, and solving problems in new situations). Open-ended items better capture the depth of reasoning than multiple-choice formats. Content validity was checked by three experts: two mathematics lecturers and one junior high math teacher. They used Aiken's V index (average V = 0.83, all items > 0.7, valid). The instrument was tested with 30 students outside the sample and showed good internal consistency (Cronbach's α = 0.85, reliable). Crossword puzzle activities were built into all seven phases of Brain-Based Learning. This approach matches neuroscience principles.

Table 2. Integration of Crossword Puzzle Media in Brain-Based Learning Phases

Preparation	Activate Prior Knowledge	Brief Warm-up Crossword on Basic Terms
Initiation	Orchestrated immersion	Introduce the full puzzle as an engaging hook
Elaboration	Active processing & multiple representations	Group solving with clue analysis
Incubation	Reflection & neural replay	Individual reflection on solved clues
Verification	Check understanding	Peer review of crossword answers
Deepening	Consolidation & application	Create your own clues linking concepts
Celebration / Reflection	Emotional closure & metacognition	Share insights and self-assessment

This mapping ensures retrieval practice occurs at optimal moments for memory consolidation. Descriptive statistics summarised performance. Inferential analyses included: (1) Normality (Shapiro-Wilk), (2) Homogeneity (Levene's), (3) Normalized Gain (N-Gain), and (4) Hypothesis testing via independent samples t-test (Welch's adjustment for unequal variances) on N-Gain scores using SPSS 21.

Research Result

1. Descriptive Analysis

a. Conceptual Understanding Scores in the Control and Experimental Groups

Students' conceptual understanding was studied through a pretest taken before the intervention and posttests given after. Below is an informative statistical summary of the scores obtained from both the control and experimental classes.

Table 3. Summary of Pretest and Posttest Scores for Control and Experimental Groups

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Pretest Control	21	0.00	22.86	9.66	7.58
Posttest Control	21	5.71	77.14	46.39	21.55
Pretest Experimental	31	0.00	25.71	10.41	7.61
Posttest Experimental	31	37.14	97.14	68.94	15.38

The posttest means for the experimental and control groups were M = 68.94 and M = 46.39, respectively. Although the control group posttest mean is significantly lower than that of the experimental group, it is worth noting that, as is shown in Table 3, the two groups had the same mean pretest scores. It demonstrates that the experimental group's improvement in conceptual knowledge was the result of the educational intervention involving the BBL and crossword puzzles.

b. Average N-Gain Scores for Control and Experimental Groups

N-Gain scores were used to gauge the development in learners' understanding of mathematical concepts before and after the intervention. The mean scores were calculated employing SPSS 21. The summary statistics describing the N-Gain results of the control and experimental groups are provided below.

Table 4. Summary of Normalized Gain (N-Gain) Statistics

Group	N	Minimum	Maximum	Mean	Std. Deviation
Control	21	0.03	0.75	0.41	0.23
Experimental	31	0.37	0.97	0.66	0.16

The experimental group showed higher gains (M = 0.66) than the control (M = 0.41). Post-hoc item analysis indicated the largest gains in the application of the problem-solving indicator, where crossword clues directly supported retrieval and conceptual linkage.

c. N-Gain Analysis per Indicator of Conceptual Understanding

To address the specific impact of the BBL-crossword intervention, a detailed analysis of N-Gain scores was conducted for each indicator of conceptual understanding. This breakdown provides insight into which cognitive areas experienced the most significant development.

Table 5. Comparison of N-Gain Scores per Indicator

Indicator of Conceptual Understanding	Control Group (N-Gain)	Experimental Group (N-Gain)	Difference
Restating concepts	0.45	0.62	0.17
Classifying objects	0.42	0.64	0.22
Applying formulas (Problem Solving)	0.36	0.72	0.36
Solving problems in new situations	0.41	0.66	0.25

Table 5 shows that the experimental group outperformed the control group across all indicators. Notably, the highest N-Gain in the experimental group was achieved in the applying concepts or algorithms to problem solving indicator (0.72), which falls into the "High" gain category. In contrast, the control group's highest gain was only 0.45 in "Restating concepts". It suggests that while traditional instruction is somewhat effective for basic recall, the BBL model with crossword puzzles is significantly more effective for higher-order conceptual application.

2. Prerequisite Test for Analysis

Before hypothesis testing, the data were examined through normality and homogeneity tests to determine the suitability of parametric statistical procedures.

a. Normality Test

An assessment of the normality of the N-gain scores was conducted before proceeding with hypothesis testing to determine whether the data could be analysed using parametric methods. The normality analysis was performed using SPSS 21. Given that the sample size was fewer than fifty participants, the Shapiro-Wilk test was applied.

Based on this test, data from the pretest and posttest are deemed normally distributed if the significance value (Sig.) exceeds 0.05, while a Sig. value below 0.05 indicates that the data are not normally distributed. The normality test results for both the control and experimental groups are shown in the table below.

Table 6. Results of Normality Test for Control and Experimental Groups

Group	Kolmogorov-Smirnov Statistic	Df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Control	0.181	21	0.072	0.926	21	0.115
Experimental	0.136	31	0.150	0.945	31	0.116

b. Homogeneity Test

Following the normality assessment, Levene's test was employed to evaluate the equality of variances between the control and experimental groups. Homogeneity of variance was assumed if $p > 0.05$, whereas a p-value < 0.05 indicated non-homogeneous variances. The results of this test are summarized in Table 7.

Table 7. Results of the Homogeneity Test for Control and Experimental Groups

Levene Statistic	df1	df2	Sig.
5.106	1	50	0.028

Table 7 shows that Levene's Test yielded a p-value of 0.028, indicating unequal variances between the groups; therefore, Welch's t-test was used as an alternative to the independent samples t-test.

3. Hypothesis Testing

To explore whether the experimental and control groups differed significantly in conceptual understanding, an independent-samples t-test was initially considered. However, since Levene's test revealed unequal variances, the more robust Welch t-test was used instead. All statistical analyses were performed using SPSS version 21, and the results are presented in Table 8.

Table 8. Independent Samples Test for N-Gain Scores

Assumption	T	Df	Sig.(2−tailed)	Mean Difference	95% Confidence Interval
Equal variances not assumed (Welch)	-4.324	33.731	< 0.001	-0.24868	[-0.36559, -0.13177]

An independent-samples Welch's t-test was performed on the normalised gain (N-Gain) scores because the assumption of homogeneity of variances was violated (Levene's test, p = 0.028). The analysis revealed a statistically significant difference between the experimental and control groups: $t(33.731) = -4.324$, $p < 0.001$, with a mean difference of −0.24868. The effect size was very large (Cohen's d = 1.31). Therefore, the null hypothesis was rejected. Beyond statistical significance (p < 0.001), the Cohen's d was 1.31, indicating a very large effect size. It indicates that the average student in the experimental group outperformed approximately 90% of the students in the control group, demonstrating the substantial practical utility of the BBL-crossword intervention in a real-world classroom setting. These results indicate that the Brain-Based Learning model supported by crossword puzzle media significantly improved seventh-grade students' conceptual understanding of algebraic operations compared to conventional direct instruction.

Discussion

The findings of this study indicate that the Brain-Based Learning (BBL) model supported by crossword puzzle media significantly improved seventh-grade students' conceptual understanding of algebra compared to conventional direct instruction. The experimental group achieved a higher normalized gain (N-Gain) score (M = 0.66) than the control group (M = 0.41), with a very large practical effect size (Cohen's d = 1.31). The very large effect size (Cohen's d = 1.31) demonstrates that the intervention not only produced a statistically significant difference but also had a strong practical impact on students' algebraic conceptual understanding. This result confirms that integrating crossword puzzles into the BBL framework yields meaningful gains beyond traditional teaching methods.

This improvement can be attributed to aligning crossword activities with BBL phases, particularly elaboration, incubation, and deepening. The effectiveness of the crossword puzzle within the BBL framework can be explained through Cognitive Load Theory. By presenting algebraic terms as puzzles, the intervention reduces extraneous load (boredom/anxiety) and increases germane load through retrieval practice. Neuroscientifically, the visual-spatial nature of crosswords stimulates the hippocampus, facilitating the consolidation of abstract algebraic rules into long-term memory. This 'fun' yet challenging retrieval process triggers dopamine release, which enhances neural plasticity and strengthens the synaptic connections needed for complex problem-solving. Crossword puzzles serve as retrieval-based learning tools that stimulate neural pathways, reinforce associations between mathematical terms and procedures, and promote long-term memory consolidation through hippocampal replay (Carr et al., 2011; Karpicke & Roediger, 2008). More specifically, the visual-spatial features of crossword puzzles, including grid layouts, intersecting letter patterns, and visual cues, engage both visual and verbal processing. These activities are linked to slower memory decline and may support hippocampal-dependent memory by promoting repeated retrieval and visual-spatial integration (Pillai et al., 2011; Torres et al., 2022).

In addition, the intervention reduced extraneous cognitive load while increasing germane load for schema construction, in line with Cognitive Load Theory (Sweller, 2011). The game-like, low-threat format of crossword puzzles minimised unnecessary mental effort, allowing students to focus on meaningful conceptual connections. The violation of the homogeneity assumption (p = 0.028) indicates that the variances between the two groups differ significantly. This disparity suggests that while the control group maintained a more uniform (yet lower) performance, the experimental group experienced a wider range of improvement. Specifically, the BBL model with crossword puzzles likely allowed high-achieving students to excel significantly faster, while still supporting lower-achieving students, thereby widening the distribution of scores compared to the more 'stagnant' distribution in the direct instruction class.

Post-hoc item analysis further revealed that the largest gains occurred in the application of the problem-solving indicator, where crossword clues directly supported conceptual linkage and transfer. These results are consistent with previous studies by Asfar et al. (2022), Made Suarsana et al. (2018), and Wiantara et al. (2020) and extend them by explicitly mapping crossword activities to BBL phases and linking outcomes to both neuroscience principles and Cognitive Load Theory.

From a pedagogical perspective, junior high school mathematics teachers can adopt this hybrid approach to facilitate students' transition from arithmetic to algebraic thinking. Crossword puzzles in the elaboration and deepening phases increase student engagement, collaboration, enthusiasm, and self-efficacy while creating an emotionally safe learning environment (Freeman & Wash, 2013; Syafmen & Indri, 2023). Reflective activities during the incubation phase further allow students to reconstruct meaning and address misconceptions.

Despite these positive outcomes, the study has several limitations. First, it was conducted in a single school with only two regular classes (N = 52), which limits the generalizability of the findings. Second, potential teacher effects may have influenced the results if different instructors facilitated the groups. Third, the exclusion of the VII-3 Binaan class, although necessary to maintain comparability in curriculum, schedule, and student characteristics, may reduce applicability to diverse learner populations that 25 require additional academic support. Fourth, implementing all seven BBL phases with crossword media was time-intensive. Future research should involve larger, multi-school samples, randomized designs, long-term retention measures, and mixed-methods approaches to explore student learning processes and scalability across different contexts.

Conclusion

This study demonstrates that, within the specific context of seventh-grade algebra instruction at the participating school, the Brain-Based Learning (BBL) model, integrated with crossword puzzles, significantly improved students' conceptual understanding compared to conventional direct instruction. The substantial effect size (d = 1.31) indicates that this hybrid approach effectively facilitated active retrieval and conceptual linkage among the students studied. While these findings suggest that neuroscience-aligned strategies can enhance mathematical learning, the results are bounded by the specific school environment and topic. Future research is encouraged to investigate the scalability of this model across diverse student populations and different mathematical domains to validate its pedagogical utility.

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