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Brain-Based Learning Model to Improve Mathematical Reflective Thinking Ability in Trigonometry : An Experimental Study

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Abstract: This study aims to analyze the effect of applying the Brain-Based Learning (BBL) model on students' mathematical reflective thinking ability in trigonometric ratio material. The research employed a quasi-experimental method with a Nonequivalent Control Group Design, involving two 10th-grade classes at a public high school in Purwakarta,—one as the experimental class and the other as the control class. Data were collected through pretest and posttest using a mathematical reflective thinking ability test instrument. Since the data were not normally distributed, hypothesis testing was conducted using the Wilcoxon Signed-Rank and Mann-Whitney U tests. The Wilcoxon test showed a significance value of <0.01, indicating a significant improvement in the experimental class after the intervention. The Mann-Whitney test also revealed a significance value of <0.01, indicating a significant difference between the experimental and control classes. These results demonstrate that the BBL model significantly enhances students' mathematical reflective thinking ability, particularly in mastering trigonometric ratio material.

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Introduction

Mathematics plays a central role in various aspects of human life, from technological advancement to cognitive development (Agbata et al., 2024; Hayati & Jannah, 2024). This field of study not only drives innovation but also contributes significantly to the development of thinking abilities. In line with this importance, Regulation No. 22 of 2016 concerning the Process Standards for Basic and Secondary Education and Regulation No. 20 of 2016 concerning the Graduate Competency Standards explicitly emphasize the need to develop higher-order thinking competencies. In this regard, one essential cognitive skill in mathematics is mathematical reflective thinking ability. In line with Noverienda Armelia et al. (2021), mathematical reflective thinking ability is one of the high-level thinking skills required to solve mathematical problems effectively.

Mathematical reflective thinking ability is a structured cognitive process based on knowledge, experience, and reasoning to address ambiguity and complexity in mathematics (Kholid et al., 2021). This ability involves three key stages: an initial reaction to the problem situation (reacting), elaboration and comparison of information (comparing/elaborating), and reflection on the steps taken (contemplating) (Utomo et al., 2021).

In the learning process, mathematical reflective thinking ability helps learners to move from one experience to another, from theory to practice with a better understanding of connections and relationships (Puig et al., 2020). This process not only results in a more comprehensive understanding, but also makes the subject matter more relevant to students

(Simacon & Veloria, 2022). Mathematical reflective thinking ability allows students to develop appropriate problem-solving strategies quickly (Muntazhimah et al., 2021). So that by thinking mathematical reflectively, students can build a more comprehensive and contextual understanding of the learning material.

However, several studies have reported that students' reflective mathematical thinking remains low (Febrianty et al., 2024; Nabilah, 2023). Many learners tend to mimic teachers' solutions without critically analyzing the process (Zahra et al., 2021). Research by Putra & Hakim (2023) further highlights that students struggle to identify core mathematical components or connect concepts to real-world problems. They have not been able to identify the components and relate their knowledge of mathematics to the problems they are facing. Furthermore, research conducted by showed that students often had difficulty understanding the meaning of the given problem, showing low mathematical reflective thinking ability skills. Furthermore, Veronika et al. (2024), also observed gender-based disparities, where both male and female students scored low in elaboration and contemplation despite slight differences in initial reactions. Students male had a higher percentage of indicators reacting (75%) compared to female students (57%), but on the elaborating and contemplating, both showed low values, which were about 50% for men and 43% for women.

In the initial observations made by the researcher on students and teachers, it was shown that the learning carried out was still focused on the teacher and used the conventional model in conducting learning, which relied on whiteboards and markers as the medium and lectures as the method of delivery, when the interview was conducted it was known that the teacher rarely asked questions to reflect on the ability of his students, so that students were only limited to understanding how to operate a formula but did not able to understand its use in daily life.

Trigonometry is one of the challenging subjects for students. Many students make mistakes when working on trigonometry problems that focus on the formula for the sum and difference of two angles (Panimbarini, 2022). This difficulty is not only caused by weak conceptual understanding, but also by the lack of opportunities to reflect on the problem-solving strategies they use. Trigonometry was chosen in this study because of the nature of its concepts and the breadth of its applications, which naturally support the development of mathematical reflective thinking ability. As a branch of mathematics that deals with triangle measurement, trigonometry involves understanding the relationships between angles and side lengths, requiring spatial reasoning, diagram interpretation, and context-based decision making (Herlina Wati & Chandra Dhewy, 2022; Walidah et al., 2022). Its real-world applications—such as in construction, transportation, and navigation—require students to go beyond procedural knowledge and adopt a reflective approach in solving problems (Mukles et al., 2024).

Considering the gaps identified in prior research and observations, it is essential to initiate effective interventions aimed at enhancing students' mathematical reflective thinking ability. One potential strategy involves providing targeted learning activities that stimulate specific brain regions responsible for the cognitive skills intended for development (Hayes & Ayu Sumekar, 2017). In this context, the reflective brain plays a crucial role, as it governs high-level thinking processes such as analysis, critical evaluation, and self-reflection. As noted by (Barbara K & Given, 2007) the reflective brain enables individuals to assess underlying assumptions and internal understanding. When properly trained, this brain function can significantly strengthen students' capacity for reflective mathematical reasoning.

So that when the reflective brain is trained appropriately, it can maximize the ability to think mathematically.

An effective approach to nurturing the reflective brain is through the implementation of the Brain-Based Learning (BBL) model (Oktaviani et al., 2023) and (Barbara K & Given, 2007) BBL activates five interconnected brain systems—emotional, social, cognitive, physical, and reflective—during the learning process. According to Funa et al. (2024a) BBL is grounded in how the brain naturally receives, processes, and interprets information. By aligning instruction with these neurological processes, BBL fosters an engaging and interactive learning environment. Such an approach not only supports deeper understanding but also enhances students' motivation and involvement (Munfarokhah, 2020).

Specifically, in trigonometry, BBL can guide students through each stage of mathematical reflective thinking ability. In the reacting phase, emotional and physical engagement through activities like brain gym or real-life problem scenarios helps students connect personally with the material. During the comparing/elaborating stage, collaborative discussions and guided exploration encourage them to analyze and compare different solution paths. Finally, in the contemplating stage, structured reflection tasks, such as journaling or peer explanation, allow students to review the logic behind their steps and refine their mathematical reasoning. By aligning these activities with the natural learning processes of the brain, BBL creates an environment where students not only engage actively but also think critically and reflectively about mathematical concepts, particularly abstract and contextual ones such as trigonometric comparison.

While several studies have explored the general impact of BBL on cognitive outcomes (Binar, 2024; Dwi Cahyani et al., 2023; Funa et al., 2024b; Lagoudakis et al., 2022; Lilis Susanti, 2023; Oktaviani et al., 2023; Rahmawati et al., 2024), few have specifically examined its role in enhancing students' reflective mathematical thinking in trigonometric topics. This research aims to bridge that gap by analyzing the effectiveness of the BBL model in improving students' mathematical reflective thinking ability in trigonometric comparison. The study is expected to offer insights into innovative teaching strategies that can improve mathematics learning outcomes.

This study is in line with No. 22 of 2016, which emphasizes the importance of learning that fosters student independence and active engagement. In this regard, mathematical reflective thinking ability serves as a foundation for deep learning, enabling students to build understanding through reflection and meaningful experiences. The findings of this study are expected to contribute to the development of innovative instructional strategies that foster active student engagement, and to serve as a foundation for designing neuroscience- and technology-based learning to meet future educational challenges.

Research Method

This research adopted a quasi-experimental design featuring a non-equivalent control group (Sugiyono, 2019). Students in the experimental group were instructed using the Brain-Based Learning (BBL) approach, while the control group received conventional teaching. The design was selected due to practical constraints in educational settings, where random assignment is often unfeasible. The sample in this study was selected using purposive sampling technique. According to Sugiyono (2019), purposive sampling technique is a method of taking samples from data sources with special considerations. Class selection is carried out by considering the equality of characteristics, namely both classes have a relatively balanced level of academic ability based on previous mathematics scores, and are

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guided by the same teacher, so that it is relevant to use in experimental designs that do not allow full randomization. Two classes were selected, grade ten as the research sample, one class as the experimental group, and one class as the control group. There are 31 students in each class.

This research was carried out in several stages. The first stage is the preparation stage, where a literature study is carried out related to the BBL learning model and mathematical reflective thinking ability skills. Furthermore, the researcher conducted an initial observation to see the learning carried out and the alignment of the material which will then be used as an instrument to test mathematical reflective thinking ability skills and make a teaching module using the BBL method.

To assess students' mathematical reflective thinking ability, the researchers designed a descriptive test focused on trigonometric comparison material. A descriptive test was created with three items that aligned with the indicators of mathematical reflective thinking ability —reacting, comparing, and contemplating—as outlined by Surbeck e (1991) Each question presented real-life scenarios that required students to analyze situations, propose logical and systematic solutions, and formulate conclusions.

Before implementation, the test instrument and teaching module were validated for content and reliability by a panel of experts, including two university lecturers and one mathematics teacher. A small group of students also participated in a pilot test to ensure clarity and appropriateness. During the implementation phase, both the experimental and control groups were administered a pretest to gauge their initial mathematical reflective thinking ability. The instructional intervention was conducted over three sessions. The experimental group followed the BBL stages, while the control group continued with traditional instruction. After the intervention, a posttest was administered to both groups to measure learning gains.

Data analysis in this study was performed using SPSS version 26. The first step involved conducting assumption tests, which included the normality test and the homogeneity test. The normality test was carried out using the Shapiro-Wilk method, as the sample size was fewer than 50. The purpose was to determine whether the data followed a normal distribution. The result showed a significance value (Sig.) less than 0.05, indicating that the data were not normally distributed.

Next, a homogeneity test was conducted using Levene's Test to determine whether the variances of the experimental and control groups were equal. The result showed a Sig. value greater than 0.05, indicating that the groups were homogeneous. According to Sugiyono (2019), testing for homogeneity is essential to ensure that both groups have equivalent conditions before the treatment is applied. Due to the non-normal distribution but homogeneous variance, non-parametric tests were chosen for hypothesis testing (Sugiyono, 2019). The Wilcoxon Signed-Rank Test was used to analyze pretest and posttest differences within each group, as it is suitable for paired non-normal data. The Mann-Whitney U Test was applied to compare posttest results between the experimental and control groups, appropriate for two independent non-normal samples.

Results and Discussion

Prerequisite Test

Before conducting further analysis to test the hypothesis, a number of prerequisite tests were performed. Prerequisite tests were conducted to ensure that the data used met certain assumptions and that the selected analysis method was appropriate for the

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characteristics of the data. Preliminary statistical checks, including tests for normality and variance homogeneity, were conducted to ensure the suitability of further analyses. The results of the prerequisite tests are described below.

Tests of Normality

	Kelas	Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Kemampuan berpikir reflektif matematis	Pre-Test Eksperimen	.246	31	<,001	.816	31	<,001
	Post-Test Eksperimen	.179	31	.013	.840	31	<,001
	Pre-Test Kontrol	.223	31	<,001	.890	31	.004
	Post-Test Kontrol	.167	31	.028	.884	31	.003

a. Lilliefors Significance Correction

Figure 1. Normality Test

To determine the appropriate statistical tests, normality and homogeneity assessments were conducted first. All pre-test and post-test data in the experimental class and control class had significance values (Sig.) below 0.05 in the Kolmogorov-Smirnov and Shapiro-Wilk normality tests. This indicated the need for non-parametric tests, as the data were not normally distributed, as shown in Figure 1.

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Kemampuan berpikir reflektif matematis	Based on Mean	.336	1	60	.564
	Based on Median	.304	1	60	.584
	Based on Median and with adjusted df	.304	1	58.646	.584
	Based on trimmed mean	.337	1	60	.564

Figure 2. Homogeneity test

Meanwhile, the homogeneity test using the Levene test yielded a significance value of 0.564, which is above the threshold of 0.05. Therefore, it was concluded that the data had homogeneous variance, as shown in Figure 2.

Hypothesis Test

The normality test results indicate that the data does not have a normal distribution. Therefore, non-parametric statistical tests were used to further analyze the data (Sugiyono, 2019). In addition, the homogeneity test results showed that the variances of the two data groups were homogeneous. As a result, the research hypothesis was tested using the Wilcoxon and Mann-Whitney tests. The results of the hypothesis testing are described as follows.

Test Statistics[a]

	Pos test Ekperimen - Pre test Ekperimen
Z	-4.864[b]
Asymp. Sig. (2-tailed)	<,001

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

Figure 3. Wilcoxon Test

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Figure 3 shows the Wilcoxon Signed-Rank test for the experimental group produced a significance value of less than 0.01, suggesting a statistically significant improvement between the students' mathematical reflective thinking ability scores before and after the intervention in the experimental group. This result supports the conclusion that the BBL-based instruction had a considerable impact on enhancing students' mathematical reflective thinking ability.

Test Statistics[a]

	Kemampuan berpikir reflektif matematis
Mann-Whitney U	242.000
Wilcoxon W	738.000
Z	-3.370
Asymp. Sig. (2-tailed)	<,001

a. Grouping Variable: Kelas

Figure 4. The Mann-Whitney Test

In addition, the Mann-Whitney test was conducted to determine whether the post-test results affected reflective mathematical thinking skills in trigonometric comparison material between the experimental class and the control class. Based on Figure 4. Similarly, the Mann-Whitney U test comparing posttest scores of the two groups yielded a significance value below 0.01, confirming a meaningful difference favoring the BBL group. performance between the experimental and control groups after the intervention. Therefore, the hypothesis stating that Brain-Based Learning significantly improves mathematical reflective thinking ability is supported by empirical evidence.

Discussion

Applying the BBL model significantly contributed to the development of students' mathematical reflective thinking ability, particularly within the context of trigonometric comparisons. The positive impact observed through statistical tests confirms the effectiveness of BBL in promoting deeper thinking and analysis, supporting the main objective of this research. From a theoretical perspective, these results are consistent with BBL theory which emphasizes that learning that corresponds to the natural workings of the brain will be more effective in supporting higher-level thinking processes, including reflection, analysis, and evaluation (Caine & Caine, 1994). The application of the 12 principles of BBL, which integrates a comfortable learning environment, physical activity through brain gym, and educational games that stimulate students' curiosity and active involvement, has been proven to be able to create a conducive learning environment to foster mathematical reflective thinking ability skills. These results are in line with Permana & Kartika (2021) findings that show that the application of BBL is able to significantly improve mathematical understanding compared to conventional methods.

Furthermore, these findings also support the results of studies that Akcay (2023) combining BBL with metacognitive techniques enhances the quality of the learning process by facilitating structured reflection and improved retention such as organizing the learning process in terms of active thinking. Learning that combines aspects of a comfortable learning environment, physical movements that stimulate brain activity, and educational play that involves multi-sensory is proven to create a more meaningful learning experience. This contributes to the formation of stronger inter-neuronal connections, supports long-term memory retention, and enhances students' ability to reflect, evaluate, and develop problem-solving strategies independently.

In the aspect of the environment when learning in the experimental classroom found a noisy atmosphere because one class was divided into two with a thin partition, but the researcher worked around so that the volume of the teacher's voice could be heard by students and the classroom conditioning, and from the visual aspect of the classroom which was predominantly white, the researcher also aligned the color of the PPT with a white background and yellow accents as decorations, Yellow was chosen because it can increase curiosity and give a cheerful impression.(Mourin et al., 2024)

Meanwhile, the application of brain gym as a short physical activity during learning showed a positive impact in reducing tension, as well as maintaining students' focus, especially after intensive discussions. These findings support research that (Herawati et al., 2024) states that brain gyms are effective in increasing oxygen supply to the brain, improving students' memory, concentration, and mental readiness to receive new material. so as to support the mathematical reflective thinking ability process more optimally.

In terms of educational games, the implementation of games such as trigonometry jumping and corner captains not only makes the learning atmosphere more enjoyable, but also strengthens the understanding of concepts through physical and cognitive activities at the same time. The application of Quizalize as a digital-based educational media also adds a variety of interactive learning experiences. These findings are in line with research that (Fitri & Zaeni, 2020) states that brain-based educational game-based learning is able to increase student engagement and support in-depth understanding of concepts.

The novelty of this research lies in the application of Brain Based Learning designed on trigonometry comparison material, which has been known as one of the mathematics topics that is quite complex and challenging for students. By placing learning outcomes at the C5 (evaluation) and C6 (creating) levels, students are not only encouraged to understand concepts, but also develop the ability to evaluate, develop new strategies, and reflect on their own thought processes. In addition, the model is designed by utilizing the Quizalize application, which provides an interactive and fun learning experience through quizzes that can assess students' understanding directly, thus facilitating increased learning motivation and monitoring the development of students' abilities in real-time.

Compared to previous research such as that conducted by (Kaewkumsai & Phusee-orn , 2024) , these findings reinforce that brain-based learning models are effective in encouraging better analytical thinking, problem-solving, and decision-making. However, the novelty of this research lies in the combination of learning strategies that not only optimize brain function, but also integrate a systematic approach through regular reflection at each end of learning, where students are invited to evaluate their own strategies, find weaknesses, and devise alternative solutions.

The implications of this study show that Brain Based Learning has great potential to be adopted more widely in Indonesia, especially in mathematics learning that requires strong reflective and analytical thinking. More so, the flexibility of this model allows for further development through integration with artificial intelligence (AI) and neuroscience-based technologies to create an adaptive learning platform capable of tailoring learning approaches to each student's cognitive and emotional profile. The synergy between BBL and AI-based deep learning in the future is expected to be able to provide a more personalized, adaptive, and effective learning experience in developing essential mathematical reflective thinking ability skills in the digital era.

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In addition to its long-term potential, BBL also offers immediate implications that can be implemented in current mathematics instruction. Specifically, to enhance mathematical reflective thinking ability in trigonometric ratio material, teachers can design modules that align each stage of BBL with stages of mathematical reflective thinking ability. For example, the lesson can begin with a short brain gym and a real-life problem involving angle of elevation to trigger reacting. Then, during the comparing/elaborating phase, students may work in groups to analyze and compare multiple solution strategies using diagrams or manipulatives. Finally, in the contemplating phase, students write reflective journals or present their reasoning processes to the class. These steps can be implemented in a single lesson or expanded across a weekly cycle. By embedding these practices, teachers not only facilitate multisensory engagement but also gradually build students' ability to reflect deeply and critically in mathematical contexts, especially in abstract topics like trigonometry.

Conclusion

The results of this study conclude that the implementation of the Brain-Based Learning model significantly improves students' mathematical reflective thinking ability. Students who experienced BBL-based instruction demonstrated stronger capabilities in elaborating ideas, connecting mathematical concepts, and evaluating their problem-solving processes compared to those who were taught using traditional methods. These findings affirm that teaching methods aligned with natural brain function—especially those involving multisensory activities, emotional involvement, and structured reflection—are effective in developing mathematical reflective thinking ability. Thus, the BBL model can serve as an innovative and impactful alternative for mathematics instruction, particularly for complex subjects such as trigonometric comparisons.

Recommendation

The implementation of the Brain-Based Learning (BBL) model in trigonometric comparison material requires relatively complex instructional procedures and a longer duration to ensure that all stages of the model can be effectively executed. Developing students' reflective mathematical thinking skills also demands a continuous and iterative learning cycle to produce more substantial improvements. Although the model in this study incorporated the use of the Quizalize application, the integration of interactive learning technologies was not fully optimized due to infrastructural limitations and technical readiness in the school setting. Therefore, it is recommended that future research explore the implementation of the BBL model over an extended period, cover a broader range of mathematical topics, and enhance the integration of digital learning tools to more effectively support students' reflective learning processes.

Based on the research findings, it is recommended that mathematics teachers begin to adopt the Brain-Based Learning (BBL) model, particularly for content that requires conceptual and mathematical reflective thinking ability. Teachers can develop teaching modules that incorporate activities aligned with the three stages of mathematical reflective thinking ability reacting through contextual problem triggers or brain gym activities, comparing/elaborating through group discussions, concrete manipulatives, and educational games, and contemplating through reflective journals or evaluation of problem-solving steps. These activities not only support multisensory and emotional engagement but also enhance conceptual understanding and promote reflective habits.

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To support sustainable implementation, schools are encouraged to provide professional development on neuroscience-based BBL strategies and facilitate teacher learning communities for sharing best practices. Further research is also recommended to explore the application of BBL in other mathematical topics and levels, as well as its potential in digital or collaborative learning environments.

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