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The Effect of the Application of the Brain-Based Learning (BBL) Model on Mathematical Reflective Thinking Ability Trigonometry Comparative Material

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Abstract (English)
Students' mathematical reflective thinking skills are still relatively low, especially in trigonometric comparison material, which requires in-depth understanding and the ability to evaluate and reflect on the steps taken to solve problems. Initial classroom findings suggest that instruction continues to rely heavily on lecture-based techniques, with limited student-centered engagement. Previous research has not specifically examined the effect of applying the Brain-Based Learning (BBL) model on mathematical reflective thinking skills in trigonometric ratio material, so this study aims to analyze the effect of applying the BBL model on students' mathematical reflective thinking skills in trigonometric ratio material. The method used was a quasi-experiment with a Nonequivalent Control Group Design, involving two 10th-grade classes at a high school, namely an experimental class and a control class. Data were obtained through pretest and posttest using a mathematical reflective thinking ability test instrument. Hypothesis testing used the Wilcoxon and Mann-Whitney tests because the data were not normally distributed. The Wilcoxon test results showed a significance value of <0.01, indicating a significant difference between the pretest and posttest results in the experimental class. The Mann-Whitney test showed a significance value of <0.01, indicating a significant difference between the experimental class and the control class after the treatment. Consequently, the use of the BBL model was shown to significantly enhance students' reflective mathematical thinking, particularly in mastering trigonometric ratio material.

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Introduction

Mathematics plays a pivotal role in various dimensions of human life, including technological advancement and cognitive development (Agbata et al., 2024; Hayati & Jannah, 2024). This scientific field propels modern technological progress and contributes significantly to enhancing human cognitive abilities. As stipulated by Permendikbud Number 36 of 2018, mathematics education endeavors to foster advanced thinking competencies. Consequently, the primary objective of mathematics instruction is to equip students with higher-order thinking skills, alongside proficiency in numerical concepts.

Reflexive thinking skills, which are essential for learning mathematics, are one of the highest levels of thinking skills. This is in line with Noverienda Armelia et al. (2021) stating that Reflective thinking is one of the high-level thinking skills needed to solve mathematical problems. Mathematical reflective thinking ability is a term for reflective thinking in a mathematical context. Mathematical reflective thinking is a thought process that is based on

knowledge, experience, and problem-solving skills to overcome the ambiguity or confusion associated with mathematical problems (Kholid et al., 2021). This ability involves the stages of reaction to the problem (reacting), elaboration of information (comparing/elaborating), and reflect on the steps taken (contemplating)(Utomo et al., 2021).

In the learning process, mathematical reflective thinking 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 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 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.

One of the materials that requires the ability to think mathematically, is trigonometric comparison material. This material discusses the relationship between the angle and the length of the sides in a right triangle, as well as their application to various contextual problems such as elevation angle and depreciation angle. Trigonometry is one of the most challenging subjects for students. Many students make mistakes when working on questions on trigonometry that focus on the formula for the number and difference of two angles (Panimbarini, 2022). As a result, students often memorize formulas without understanding concepts in depth or how they can be applied in the real world.

Considering the gaps identified in prior research and observations, it is essential to initiate effective interventions aimed at enhancing students' mathematical reflective thinking. 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

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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).

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' reflective thinking in trigonometric comparison. The study is expected to offer insights into innovative teaching strategies that can improve mathematics learning outcomes.

Research Methods

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. As an alternative, purposive sampling was used to select two Grade 10 classes—one as the experimental group and the other as the control group each consisting of 31 students.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 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 skills and make a teaching module using the BBL method.

The research was conducted in several stages. The initial phase involved a literature review to understand the BBL model and its relationship with mathematical reflective thinking. This was followed by preliminary classroom observations to evaluate current teaching practices and align the lesson materials with reflective thinking indicators. Based on this alignment, the researchers developed test instruments and a teaching module tailored to the BBL framework.

To assess students' reflective thinking in mathematics, 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 reflective thinking—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

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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 reflective thinking abilities. 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 collection was carried out through pretest and posttest assessments. Prior to hypothesis testing, the data were analyzed for normality and homogeneity. The normality tests revealed that the data did not follow a normal distribution, although homogeneity was confirmed. As a result, nonparametric tests were employed for hypothesis testing. The Mann-Whitney U test was used to compare the experimental and control groups, while the Wilcoxon Signed-Rank test was used to evaluate within-group improvements before and after the intervention (Sugiyono, 2019).

Research and Discussion Results

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 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

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Kelas	Statistic	df	Sig.	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.

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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 testing 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.

Uji Hypothesis

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

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' reflective thinking 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 abilities.

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

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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 reflective thinking in mathematics is supported by empirical evidence.

Discussion

Applying the BBL model significantly contributed to the development of students' reflective thinking, 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 reflective thinking 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 enhance 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 reflective thinking process more optimally.

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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 reflective thinking skills in the digital era.

Conclusion

Based on the analysis using the Wilcoxon and Mann-Whitney tests, it can be concluded that the implementation of the Brain-Based Learning model has a significant impact on improving students' mathematical reflective thinking abilities. 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. Thus, the BBL model can serve as an innovative and impactful alternative for mathematics instruction, particularly for complex subjects such as trigonometric comparisons.

Suggestion

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.

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