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Mathematical Thinking Of Elementary School Students In Geometry Through 4C-Based Problem-Based Learning

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Abstract
Background*: Mathematical thinking to foster skills and abilities in learning mathematics which include the ability to think critically, logically, creatively, and reflectively in solving mathematical problems. The Problem-Based Learning model has become a cornerstone due to the students' involvement in solving mathematical problems. Therefore, further approaches are required to develop students' conceptual understanding, procedural skills, and geometry problem solving skills. This study compares the 4C-based Problem-Based Learning with Problem-Based Learning without 4C on geometry material for grade IV elementary school students.*
Materials and Methods*: This study employed a quasi-experiment with a Non-equivalent Control Group Design. The research sample consisted of two groups: the experimental group of 25 students from class IVA, who received learning with 4C-based Problem-Based Learning and the control group of 25 students from class IVB, who received learning with Problem-Based Learning without 4C. Data was collected through pre-tests and post-tests, then analysed with t-tests and N-Gain tests.*
Results*: The t-test result showed a significant improvement in mathematical thinking in the experimental group compared to the control group. The mean score of N-gain test indicated moderate improvement (0.434) for the experimental group and low (0.204) for the control group. The 4C-based Problem-Based Learning was proven to help students identify problems, make generalizations, and develop more flexible problem-solving strategies in geometry.*
Conclusion*: The 4C-based Problem-Based Learning has a significant effect on improving mathematical thinking of elementary school students in learning geometry.*
Key Words: *Mathematical Thinking, Problem-Based Learning, 4C, Geometry.*

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I. Introduction

Geometry is widely regarded as one of the most challenging mathematical disciplines for students to comprehend. In the context of elementary education, teaching mathematics with the emphasis on geometry, often focuses on the students' abilities in solving geometric problems; however, many fourth-grade students encounter significant obstacles in overcoming challenges related to geometry, thus requiring educators to facilitate the opportunities for improving higher-order cognitive skills. The challenges and obstacles faced by fourth-grade students in learning geometry present many challenges which significantly impact the students' understanding on spatial concepts.

The non-interactive learning methods often lead to students memorizing formulas for geometric calculation, thereby limiting the students' opportunities for active conceptual exploration. Moreover, many students demonstrate difficulties in learning basic concepts, which may be attributed to various factors, namely instructional methodologies, educational resources constraints, or even the students' attitude towards mathematics itself. Such challenges not only bring detrimental effects on their academic performances, but also potentially undermine their confidence and enthusiasm for further academic pursuits. (Riyadi, D.D., & Supriatna, E. 2025).

Students commonly struggle to understand geometric concepts. These abstract concepts can be simplified through problem-solving scenarios. Elements like inadequate meaningful learning experiences, resulting from a lack of diverse instructional methodologies, often lead to students feeling demotivated. The research conducted by Fauzi and Arisetyawan (2020) shows that students are facing difficulties in applying the concepts, principles and verbal problem-solving strategies related to geometric content in elementary education.

Implementing pedagogy strategies which are more dynamic along with exploration can improve students' conceptual understanding, while conventional methodology often restricts their involvement in educational process. (Smith & Jones, 2020).

The improvement on meaningful learning experiences can be facilitated through the integration of concrete manipulative and interactive technology, which helps students to visualize geometrical principles.

Previous research has revealed that the integration of these resources in mathematical instruction is highly important in enhancing students' understanding (Clements & Sarama, 2020).

Problem-Based Learning that incorporated the 21st century competences, particularly the 4C framework (critical thinking, creativity, communication, and collaboration), plays an important role in improving the mathematical analysis ability. The framework of 4C-based PBL grants the students to actively engage with contextual problems, implementing the critical thinking skills in solving mathematical challenges, collaborating effectively in group settings, and articulating mathematical concepts coherently.

Problem-Based Learning is a learning approach emphasizing on solving authentic, complex problems, with the aim to develop the 21st century skill known as the 4C: Communication, Collaboration, Critical Thinking, Creativity. The main principle of 4C-based PBL is to provide contextual challenges which stimulates students' active engagement, encouraging them to hold a discussion and collaborate in teams. Consequently, 4C-based PBL not only strengthens the academic concepts, but also cultivate essential competencies for learners. Problem-Based Learning has shown increase not only in mathematical cognitive skills, but also their collaborative and communicative skills, thereby establishing a more integrated learning environment (Smith & Johnson, 2020). The incorporation of 4C-based PBL competencies in teaching mathematics promotes deep learning and equip students for pragmatic problem-solving attempts (Nguyen & Tran, 2022). The integration of PBL with the 21st century competences, such as critical analysis and collaborative engagement has significantly improved students' participation and understanding in Mathematics (Lee, 2021).

Mathematical thinking entails the ability to recognize patterns, make generalizations, and implement systematic strategies to solve problems. Mathematical. "Mathematical thinking is essential for problem-solving and involves recognizing patterns and making generalizations." (Smith, 2020). Mathematical thinking encompasses several important aspects, namely: critical, logical, creative, and reflective thinking. The main component of mathematical thinking according to Kilpatrick, Swafford dan Findell (2021) include conceptual understanding, procedural skills, adaptive thinking, productive disposition, and strategic competence (Ngu dan Phan, 2024).

The importance of these five components in achieving mathematical proficiency is not only related to technical skills in solving math problems, but also involves students' engagement in the process. The importance of mathematical thinking in learning elementary geometry: mathematical thinking plays a crucial role in teaching plane shapes to elementary students as it enables them to gradually understand geometry concept at a deeper level, develop the problem-solving skills, and enhance their critical and creative thinking skills. A systematic review emphasizes the importance of correlating various types of mathematical thinking to improve students understanding in geometry. (Fachrudin dan Juniati 2023)**.**

In the context of learning plane shapes, mathematical thinking allows students to link geometrical shapes with real-life situations, develop strategies in solving problems related to area and perimeter, and establish logical arguments about the properties of plane shapes. Reasoning in solving geometrical problems serves as a means for students to recognize shapes, identify properties, and analyse relationships between geometrical objects (Aziz, Juniati, & Wijayanti, 2020). Therefore, the implementation of learning approaches that encourage mathematical thinkings, such as 4C-based PBL, is very important in building the geometric competences of elementary school students.

The problem formulation in this research is what is the of 4C-based PBL on elementary school students' mathematical thinking in geometry subject. The research objective is to analyse the impact of 4C-based PBL on students' mathematical thinking.

Based on the review above, the research hypothesis can be formulated as:
Null Hypothesis (H_0): There is no significant difference in elementary school students' mathematical thinking abilities in geometry subject between the group taught with 4C-based Problem-Based Learning and the group taught with Problem-Based Learning without 4C.
Alternative Hypothesis (H_1): There is a significant difference in elementary school students' mathematical thinking abilities in geometry subject between the group taught with 4C-based Problem-Based Learning and the group taught with Problem-Based Learning without 4C.

II. Material And Methods

Study design: Quantitative research approach with quasi-experimental design. The research was conducted on two groups: the experimental group who received learning with 4C-based Problem-Based Learning and the control group who received learning with Problem-Based Learning without 4C.

Study Location: The research was conducted during the learning process of the fourth-grade students at Public Elementary School 3 Peusangan, Bireuen Regency, Aceh Indonesia.

Study Duration: The research was conducted in January – February 2025.

Sample size: 50 students from class IV A and IV B.

Sample size calculation: The population in this study consisted of all fourth-grade students, comprising 4 parallel classes with a total of 106 students. The research sample was determined by using purposive sampling technique. The size of sample for each group is 25 students, for both experimental group and control group.

Inclusion criteria
1. Students who have previously studied geometry subject, specifically regular and irregular polygons, as well as calculating the area and perimeter of plane shapes.
2. The minimum passing grade for mathematics subject at school is 70.
3. Pre-test scores are compared with post-test scores to evaluate the effect of learning method.
4. post-test scores from the experimental and control group are compared to find out the differences.

Exclusion criteria:
1. Students who have never studied geometry subject, specifically regular and irregular polygons, as well as calculating the area and perimeter of plane shapes.
2. Students who have never received 4C-based Problem-Based Learning.
3. Students who did not participate in either the pre-test or post-test for regular and irregular polygons or calculating the area and perimeter of plane shapes.

Procedure methodology

After receiving the written approval, the well-designed instruments were used to collect data on the rate of students' ability before and after the learning process, for both control and experimental class. These instruments consisted of pre-test, post-test, and observation of learning activities, mathematical thinking scale questionnaire, and interviews. All research instruments were used sequentially, starting from the pre-test before learning process, continued with observation on learning activities, followed by post-test before the class was completed, interviews after the learning process was finished by selecting three students based on their academic ability (high, medium, and low). The research questionnaire was given to all students who became the research sample.

Statistical analysis

Data analysis techniques, to ensure the data were normally distributed with homogeneous variances, normality and homogeneity tests were employed. To assess the differences between pre-test and post-test scores between the experimental and control group, t-tests were used (paired sample t-test & independent sample t-test). Meanwhile, N-gain test was employed to measure the effectiveness of mathematical thinking improvement in each group.

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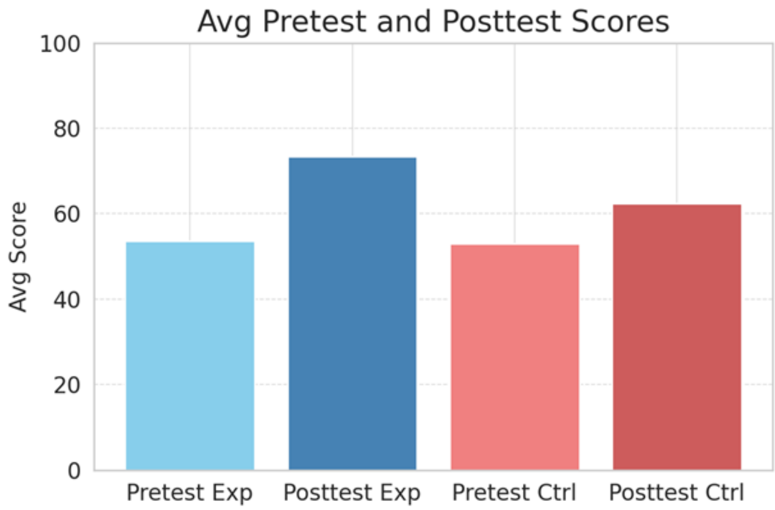
III. Result

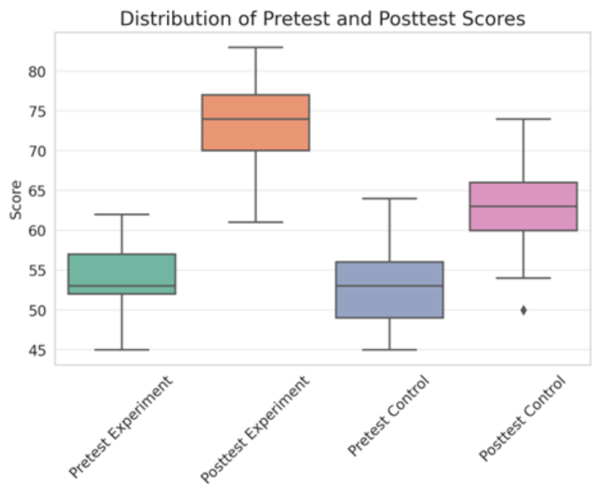
The following are the research findings obtained from the experimental group in Class IV A and the control group in Class IV B. Data collection for both groups was subjected to a normality test using the Shapiro-Wilk method to ensure that the data followed a normal distribution:
Experimental Pre-test: p =0.388 (normal data)
Experimental Post-test: p =0.297 (normal data)
Control Pre-test: p =0.880 (normal data)
Control Post-test: p =0.919 (normal data)

As all p-values were greater than 0.05, it can be concluded that the entire dataset follows a normal distribution. A bar chart was used to illustrate the improvement in the average pre-test and post-test scores for both the experimental and control groups.



To examine the similarity of variance between the experimental and control groups:
Pre-test: p = 0.961 (homogeneous variance)
Post-test: p = 0.818 (homogeneous variance)

A distribution chart of pre-test and post-test scores, along with a boxplot, were used to compare the score distributions between the experimental and control groups.



Considering all obtained p-values were greater than 0.05, the data exhibited homogeneous variance. Consequently, the data met the assumptions of normality and homogeneity, allowing it to be used for further t-test analysis.

Statistical Analysis Results

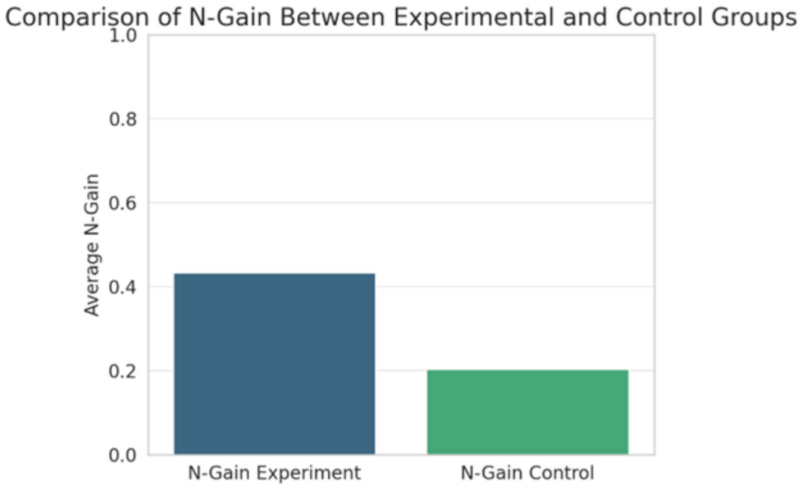
A t-test was performed to determine whether there were significant differences between pre-test and post-test scores within each group, as well as between the experimental and control group post-tests.
Experimental Group T-Test (Pre-test vs Post-test): $p = 1.93\times10^{-20}$ (Significant Difference)
Control Group T-Test (Pre-test vs Post-test): $p = 1.08\times10^{-14}$ (Significant Difference)
Independent T-Test (Post-test Experimental vs Post-test Control): $p = 2.40\times10^{-8}$(Significant Difference)

Interpretation:

The increase in post-test scores compared to pre-test scores in both groups was highly significant. The experimental group showed a greater improvement than the control group, as indicated by the significant difference in post-test scores between the two groups.
The effectiveness of score improvement after the learning process was assessed using the N-Gain test.

Group	Mean N-Gain	Category
Experimental	**0.434**	**Moderate**
Control	**0.204**	**Low**

A bar chart was used to illustrate the N-Gain scores for both the experimental and control groups, showing the mean N-Gain score of each group to highlight the effectiveness of the learning improvement.



Interpretation:

The implementation of 4C-based Problem-Based Learning (PBL) in the experimental group was found to be more effective than the control method, as evidenced by the higher N-Gain scores. However, the effectiveness fell within the moderate category, indicating room for further improvement through additional strategies. Overall, 4C-based PBL effectively enhanced the mathematical thinking of students, showing a significant improvement compared to PBL without 4C. Based on the statistical analysis conducted, the following results were obtained regarding the research hypothesis:

Independent T-Test (Post-test Experimental vs. Post-test Control) shows p-value = 2.40×10^{-8}, which is far below the significance threshold of 0.05. This confirms a significant difference between the experimental group (4C-based PBL) and the control group (PBL without 4C).

Hypothesis Decision:

The p-value was below 0.05, leading to the rejection of the Null Hypothesis (H_0) and the acceptance of the Alternative Hypothesis (H_1). This confirmed a significant difference in mathematical thinking abilities of the students between the experimental group and the control group.

Implication:

The 4C-based PBL model has been shown to be more effective than PBL without 4C in enhancing the mathematical thinking of students in geometry learning. These results supported the use of the 4C-based PBL method as an innovative learning approach to improve the mathematical thinking skills of elementary students. Furthermore, the finding of this study strengthened the argument that implementing 4C-based PBL has a positive impact on the understanding and mathematical thinking skills of elementary students.

IV. Discussion

The purpose of this study was to evaluate the effectiveness of the 4C-based Problem-Based Learning model in enhancing elementary students' mathematical thinking in the topic of geometry. The proposed hypothesis was tested using both a t-test and N-Gain analysis, which were compared the pre-test and post-test results between the experimental group (which used 4C-based PBL) and the control group (which used PBL without the 4C approach).

The paired t-test results indicated a significant improvement in the mathematical thinking of students after the intervention in both groups. The experimental group showed a substantial increase with a p-value of 1.93×10^{-20}, while the control group also experienced a significant improvement with a p-value of 1.08×10^{-14}.However, when an independent t-test was conducted to compare the post-test scores between the two groups, the p-value obtained was 2.40×10^{-8}, which was far smaller than the significance threshold of 0.05. This confirmed that there was a significant difference between the experimental and control groups, with the experimental group achieving higher post-test scores than the control group. As a result, the null hypothesis (H_0), which stated no significant difference in mathematical thinking between the two groups, was rejected, while the alternative hypothesis (H_1), which confirmed a significant difference, was accepted.

Furthermore, the results of the N-Gain test indicated that the effectiveness of score improvement in the experimental group was higher than in the control group. The experimental group achieved a mean N-Gain of 0.434, classified as moderate, while the control group recorded a mean N-Gain of 0.204, categorized as low. These findings demonstrated that 4C-based PBL was more effective in enhancing the mathematical thinking of students compared to PBL without 4C. This result aligned with previous studies stating that 4C-based PBL can improve conceptual understanding, critical thinking skills, and creativity of the students in solving mathematical problems. (Hmelo-Silver, 2004; Savery, 2015).

Overall, the results of this study supported the implementation of 4C-based PBL as an innovative learning strategy for improving the mathematical thinking of students in geometry learning. Although the level of effectiveness remained in the moderate category, this findings indicate that a learning approach emphasizing communication, collaboration, critical thinking, and creativity can help students develop a better understanding of geometric concepts. Therefore, teachers may consider using 4C-based PBL as a more interactive approach to mathematics learning in elementary school.

V. Conclusion

Based on the findings and data analysis of this study, it can be concluded that 4C-based Problem-Based Learning (PBL) approach significantly enhances the mathematical thinking of elementary students in geometry learning. The t-test results revealed a clear distinction between the experimental and control groups after the treatment, with the experimental group showing a higher post-test score. Furthermore, the N-Gain analysis showed that the effectiveness of improving mathematical thinking was greater in the experimental group compared to the control group, which was moderate for the experimental group and low for the control group.

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