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Improving Students' Mathematics Learning Outcomes through Polya's Computational Approach and Problem-Solving Approach

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Abstract

This study aims to analyze the improvement of students' mathematics learning outcomes through the application of the Computational Thinking approach and the Polya problem-solving approach. This study used a quasi-experimental method with a Non-Equivalent Control Group Design. The subjects were 28 students of class VIII A of SMP Negeri 4 Pasuruan as the experimental group and 23 students of class VIII B as the control group. The instruments used were pretest and posttest tests on the data centering material. Data analysis was carried out using the Wilcoxon Signed Rank test because most of the data were not normally distributed. The test results showed a significant improvement in both groups after treatment. However, the improvement achieved by students in the Computational Thinking group was higher than that of the Polya group. This proves that Computational Thinking is more effective in encouraging students to think systematically, analytically, and reflexively in solving mathematical problems.

Keywords: Learning outcomes, Computational Thinking, Improvement, Polya, Wilcoxon Signed Rank

INTRODUCTION

Mathematics is a field of study that plays a significant role in fostering logical, critical, and systematic thinking skills in students (Gholami, 2024; Lenawati, 2022). However, many students still struggle to understand mathematical concepts and solve problems sequentially, particularly in organizing problem-solving steps, writing down information obtained and asked questions, transforming problems into mathematical models, solving problems, and checking answers (Lein, 2020). This situation highlights the need for a learning approach that can stimulate systematic and structured thinking skills (Amalina & Vidákovich, 2023; Wolff, 2020).

A fairly popular and widely implemented approach is the Polya problem-solving approach (Cheng, 2023; Yapatang & Polyiem, 2022). This approach emphasizes four stages of problem-solving: understanding the problem (Risnawati, 2018), planning a strategy, implementing the plan, and checking again (Anggraini & Fauzan, 2020; Reinke, 2022). Several studies have shown that implementing Polya's stages helps students become more focused, directed, and thorough in solving math problems (Ernawati, 2020; Yapatang & Polyiem, 2022; Erna Yayuk & Husamah, 2020). Furthermore, developments in 21st-century education have also introduced a new approach, namely computational thinking (Lehmann, 2025). Through this approach, students are trained to break down complex problems into simpler components, recognize patterns, build algorithms, and generalize (Papadakis, 2022).

Computational Thinking (CT) plays a crucial role in solving mathematical problems because the problem-solving process requires specific steps (Tsarava, 2019). By implementing CT, students become accustomed to thinking abstractly and logically, following algorithmic flows, and solving problems according to CT-related indicators ((Jocius, 2021; Nouri, 2020; Tang, 2020). A literature review found that approximately 20 research articles demonstrated the positive influence of computational thinking on students' mathematical problem-solving abilities, as well as improving their mathematical reasoning and creativity.

The demand for developing learning approaches that are expected to help optimize students' abilities in the digital era strengthens the relevance of comparing two approaches to solving mathematical problems, namely Polya and computation (Kampylis, 2023; J. Sung, 2022), as the basis for this research. This comparison also opens up opportunities for the integration and development of more effective and contextual approaches to mathematics learning, resulting in learning designs that stimulate students' critical, logical, and creative thinking skills (Atmojo, 2020; Olsson & Granberg, 2024; E Yayuk, 2020). This research uses statistical material, specifically data centering. This material is close to students' daily lives, such as reading data and drawing conclusions from information (Aryanti, 2021). However, many students still have difficulty organizing and interpreting data correctly. Therefore, the application of the Polya approach and computation to this material is considered highly relevant. The research subjects focused on junior high school students, because at this level students are in the development stage of thinking from concrete to abstract, so it is important to provide an approach that can guide them to think systematically. The research location was a junior high school in Pasuruan City, taking into account the teachers' need for various learning methods and school support in improving the quality of education, especially in mathematics.

RESEARCH METHOD

This research is a quantitative research with an experimental approach, specifically a quasi-experimental design (Leon, 2023). The model used is an Unequal Control Group Design. The characteristic of this design is the presence of two groups, Group A and Group B, both of which are processed using pretests and posttests (B. Sung, 2021; Yamada, 2024) quantitative. However, the selection of subjects in each group is not random, but based on pre-existing conditions.

2.1. Research Population and Sample

A population in research is defined as the entire area encompassing objects or subjects with certain characteristics determined by the researcher in accordance with the research objectives, so that conclusions can be drawn from the population (Siyoto & Sodikh, 2015). (Arikunto, 2010) also explains that a population is all research subjects, while a sample is a selected subset of the population considered representative of the population's characteristics. Based on this understanding, the population in this study is all eighth-grade students of SMP Negeri 4 Pasuruan who possess characteristics consistent with the research focus. A sample refers to a number of individuals from the population selected through specific procedures to represent the entire population.

Of the eight classes, two classes were selected with nearly identical or similar average scores. The purpose of this selection was to minimize initial differences between the two classes, thus ensuring more objective and valid analysis results. The sample in this study consisted of two classes: the class treated with Hsu's computational thinking approach and the class treated with Polya's problem-solving method as the control class. This study used a purposive sampling collection technique, a sampling technique that considers and determines specific criteria, specifically based on students' relatively similar abilities, so that differences can be observed after the treatment. The independent variable, namely learning with a computational thinking approach, and the bound variable, namely problem-solving skills. The test used in this study was a written test consisting of descriptive questions. The steps in implementing this test were a pretest, administering the treatment by completing worksheets, and then conducting a final assessment using a posttest.

2.2. Research Instrument

The research instrument consisted of a learning outcome test, including a pretest and a posttest, to measure student achievement before and after the treatment. The questions in this test were structured based on the competency indicator grid for the material focused on in the study. Before use, all questions are submitted to expert judgment to determine content and construct validity. Experts evaluate whether the items align with the indicators and measurement objectives, and whether the language and context of the questions are clear and appropriate for students. This expert validation approach has been widely used in educational research, for example, in the development of test instruments to measure students' mathematical reasoning (Jannah & Rahayu, 2022).

2.3 Research Procedure

The research procedure involved three phases: Pre-Intervention, Intervention, and Post-Intervention.

a. Pre-Intervention Phase: In the initial phase, both groups (experimental and control) were given a pretest using a test instrument validated by experts. This pretest served to measure students' initial abilities and ensure that the initial baseline of both groups could be compared validly and fairly.
b. Intervention Phase:
Following the pretest, treatment was administered according to the research design. The experimental class received a specific method/learning method aligned with the research objectives, while the control class received conventional learning without intervention. The treatment was administered for a specified period according to the research design.
c. Post-Intervention Phase: After the treatment was completed, both groups were given a posttest using the same test instrument. The results of this posttest then served as the basis for evaluating improvements or differences in learning outcomes between the experimental and control groups, allowing for direct analysis of the intervention's effects through changes in scores.

2.4. Data Analysis Techniques

In this study, data analysis was conducted by comparing the pretest and posttest results between the experimental and control classes. The collected data were first subjected to prerequisite tests for normality and homogeneity. Hypothesis testing was then conducted using the Mann-Whitney test to determine whether there were significant differences between the two groups after the treatment. This technique allows researchers to determine the extent to which the treatment affected student learning outcomes in a valid manner and in accordance with the characteristics of the data obtained.

RESULT AND DISCUSSION

Result

This section presents the results of quantitative and qualitative data analysis, followed by an in-depth discussion of the effect of the Computational and Polya Problem-Solving Approaches on Improving Student Mathematics Learning Outcomes.

3.1. Descriptive Analysis Results, Prerequisite Tests, and Hypothesis Test Results (Effectiveness Comparison)

This research was conducted at SMP Negeri 4 Pasuruan, involving two classes. This research was conducted at SMP Negeri 4 Pasuruan, involving two sample classes. Class A consisted of 28 students who received computational thinking-based learning, while Class B consisted of 23 students who were taught using the Polya problem-solving approach. The research data consisted of pretest and posttest results, which were analyzed according to the indicators of each variable.

Before conducting the hypothesis testing, the data were first tested for normality using the Shapiro-Wilk test, because the sample size was less than 50 and the data were on an interval scale. The analysis results showed that in class A, both the pretest ($W = 0.9089 < 0.924$) and posttest ($W = 0.7912 < 0.924$) were not normally distributed. Conversely, in class B, the pretest data ($W = 0.9256 > 0.914$) were normally distributed, but the posttest data ($W = 0.0209 < 0.914$)

were not normally distributed. Thus, only class B's pretest met the assumption of normality. Because most of the data were not normal, hypothesis testing continued using nonparametric statistics.
Meanwhile, for class B, which was taught using the Polya problem-solving method, the pretest normality test results showed that the calculated W value was 0.9256, while the table W value was 0.914. Because the total W value was greater than the calculated W value (W count > W table), it can be concluded that class B's pretest data was normally distributed. However, unlike the posttest, the test results showed that the calculated W value was 0.0209, lower than the W table value of 0.914, indicating that the posttest data for Class B were not normally distributed. From these four results, it can be concluded that only one group of data was normally distributed, namely the Class B pretest. The other three groups of data (Class A pretest and posttest, and Class B posttest) were not normally distributed. Therefore, in subsequent hypothesis testing, non-parametric statistics were used, as they did not meet the assumption of normality.
The next step was to conduct a Wilcoxon signed-rank test. The Wilcoxon signed-rank test was conducted first to analyze changes in pretest and posttest scores in each group separately. This aimed to ensure that the treatment provided improved mathematical problem-solving skills within the groups.

Table 1. Wilcoxon Signed-Rank Test for the Computational Approach Group

No.	Komputasional		Selisih (d)	|d|	Rank	Rank	
	Pretest	Posttest				Positif	Negatif
1	75	100	25	25	1	1	
2	50	90	40	40	2,5	2,5	
3	67	100	33	33	2,5	2,5	
4	26	75	49	49	7	7	
5	67	100	33	33	7	7	
6	50	75	25	25	7	7	
7	50	100	50	50	7	7	
8	75	100	25	25	7	7	
9	17	56	39	39	7	7	
10	75	100	25	25	7	7	
11	57	74	17	17	11,5	11,5	
12	50	100	50	50	11,5	11,5	
13	50	100	50	50	13	13	
14	26	66	40	40	14	14	
15	50	100	50	50	15	15	
16	50	67	17	17	16,5	16,5	
17	75	100	25	25	16,5	16,5	
18	59	70	11	11	18,5	18,5	
19	75	100	25	25	18,5	18,5	
20	50	91	41	41	20	20	
21	59	95	36	36	21	21	
22	25	68	43	43	22	22	
23	50	95	45	45	24,5	24,5	
24	34	90	56	56	24,5	24,5	
25	35	100	65	65	24,5	24,5	
26	75	100	25	25	24,5	24,5	
27	50	87	37	37	27	27	
28	34	75	41	41	28	28	
		Jumlah Rank				406	0
W hitung	0						

Table 2 Wilcoxon Signed-rank Test for the Polya Approach Group

No.	Polya		Selisih (d)	|d|	Rank	Rank	
	Pretest	Posttest				Positif	Negatif
1	75	100	25	25	1,5	1,5	
2	50	25	-25	25	1,5		-1,5
3	75	100	25	25	3	3	
4	59	83	24	24	4	4	
5	67	70	3	3	6	6	
6	59	83	24	24	6	6	
7	42	66	24	24	6	6	
8	75	100	25	25	10,5	10,5	
9	50	93	43	43	10,5	10,5	
10	0	75	75	75	10,5	10,5	
11	27	50	23	23	10,5	10,5	
12	27	65	38	38	10,5	10,5	
13	25	56	31	31	10,5	10,5	
14	25	78	53	53	14	14	
15	59	75	16	16	15	15	
16	43	75	32	32	16	16	
17	34	83	49	49	17	17	
18	0	48	48	48	18	18	
19	59	56	-3	3	19		-19
20	34	75	41	41	20	20	
21	50	100	50	50	21	21	
22	75	100	25	25	22	22	
23	59	84	25	25	23	23	
		Jumlah Rank				255,5	-20,5
W hitung	20,5						

Discussion

4.1 Analysis of Improvement in the Polya and Computational Approaches

Pretest and posttest results show that both approaches positively impacted student learning outcomes. However, the improvement achieved by students using the computational thinking approach was more pronounced. For example, in the aspect of problem identification, many students initially struggled to detail the question's question, but after learning with the computational approach, they were able to write down relevant information and connect it to solution strategies. In the Polya group, this ability also improved, but not as strongly as in the computational group (Tsarava, 2019).

The ability to identify problems remained a challenge for most students in both groups initially. Some students, such as Aira QM and Ayu DL in the computational group, were unable to accurately detail the question in the pretest. After the treatment, the computational group experienced significant improvement, indicated by students' ability to write down the questions, select relevant data, and connect them to the solution steps. This aligns with the opinion (Cousins, 2020; Nurbaya, Hudi, Nurmalasari, & Amalia, 2021) that the first step in problem solving is to understand the problem properly, because without a clear understanding, students will have difficulty moving on to the next stage. In the Polya group, identification skills also improved, although not as significantly as in the computational group. Some students, such as M Billy SS and M Faqih A, still struggled due to the burden of lengthy solution procedures. Therefore, it can be concluded that the computational approach resulted in more equitable problem identification.

Regarding accuracy indicators, pretest results showed that students in both groups still frequently mis-written percentages or skipped steps in calculating averages and medians. After treatment, the computational group experienced significant improvements in accuracy, as demonstrated by Abira KZ and Andini C, who were able to be more careful in selecting data and correctly writing down the calculation process and final results. Although the Polya group also improved, errors were still found, such as incorrect data substitutions by Arya DRM and Nadiah AZ. Quantitatively, the computational group's posttest average was higher (86.1) than the Polya group's (73.6). These results support Supiarmo (2021) who stated that computational thinking can improve students' accuracy and logic in problem-solving.

The calculation ability indicator also improved in both groups. The computational group improved from a pretest average of 50.5 to 86.1 on the posttest, while the Polya group's score increased from 45.6 to 73.6. This improvement was not only demonstrated quantitatively; Aira QM and Ayu DL, who initially only wrote the median, were able to complete all calculation components by the posttest: mean, median, mode, and percentage. On the other hand, in the Polya group, some students, such as Rasyafa KA and Rebecca GAP, only partially completed the problem components. Research by Hsu (2018) supports this finding, stating that computational thinking can help students develop more accurate and comprehensive mathematical calculation skills.

In the reflection indicator, pretest results indicated very low proficiency because only a few students were able to reassess the solution steps. After treatment, the computational group showed significant improvement. Many students, such as M Zamroni and Nadira AP, began to explain whether the strategies they used could be applied to other problems. Meanwhile, in the Polya group, despite some improvement, some students still struggled to evaluate the lengthy and procedural solution steps. These results are supported by the opinion of Markandan (2022) who emphasized that computational thinking can foster metacognitive awareness so that students are better able to assess the chosen solution strategy.

Error analysis also supported the previous results. In the computational group, errors in writing the sequence of steps and performing calculations decreased significantly after treatment. Conversely, in the Polya group, although the number of errors decreased, many students still made errors calculating percentages, copying data, or failing to complete all problems. Therefore, the computational-based approach was more effective in minimizing errors while encouraging students to solve problems comprehensively.

In general, both approaches successfully improved students' mathematics learning outcomes. However, the computational approach demonstrated superiority in almost all aspects, from precision, systematic steps, completeness of answers, reflection, and error reduction. These results align with research by Augie, A., Nurhayati, N., & Susanti, D (Mirheidari, 2019; Yu, 2021), which emphasized the need for teachers to implement learning strategies that involve computational thinking skills because they can train students to think systematically and analytically and solve complex problems in mathematics.

4.2 Comparison with Conventional Learning

The results showed that both the computational thinking approach and conventional learning improved student learning outcomes, but the improvement was significantly stronger in the group learning with the computational approach. While conventional learning, which generally relies on procedural explanations and practice exercises, such as in the Polya siswa model (Ernawati, 2020; Riyadi, 2021), does experience progress, it is not as dramatic as that seen in the group guided through the computational stages. For example, in problem identification skills, students in the conventional learning group still tend to struggle to detail important information and connect it to problem-solving strategies, while students in the computational group experienced a significant jump in ability. The conventional approach, which emphasizes lengthy, procedural steps, leaves some students confused about determining what to ask, as seen in students like M Billy SS and M Faqih A. The computational group, on the other hand, was able to write down relevant information more systematically.

In terms of accuracy, conventional learning also showed improvement, although common errors such as incorrect data substitution or missed calculation steps remained. This contrasted with the computational group, which showed significantly higher accuracy gains, bolstered by the achievements of students like Abira KZ and Andini C, who began to be more careful in selecting data and consistently write down their calculation processes. Quantitatively, the computational group's posttest average reached 86.1, while the conventional learning group only achieved 73.6. A similar pattern was seen in arithmetic skills: although both groups improved, conventional learning still left students unable to complete only partial problem components, in contrast to the computational group, where almost all students were able to complete the mean, median, mode, and percentage.

A striking difference was also evident in reflection skills. In conventional learning, students did show progress, but still struggled to reassess lengthy and procedural solution steps. Meanwhile, students in the computational group demonstrated more mature reflection skills, as illustrated by M Zamroni and Nadira AP, who began to relate the strategies they used to other problems. Furthermore, error analysis clarified that the conventional approach still resulted in various errors in calculating percentages, copying data, and solving problems completely, while the computational approach significantly reduced errors due to its more structured and systematic thinking process.

Overall, conventional learning still had a positive impact on learning outcomes, but it was not as effective as the computational thinking approach, which proved superior in improving accuracy, completeness, reflection, and reducing student errors in completing math assignments. This finding aligns with research by Augie, Nurhayati, and Susanti (2023), which emphasized that integrating computational thinking skills into learning helps students think more systematically, analytically, and effectively in solving complex problems advantages not fully achieved through conventional learning.

CONCLUSION

Based on the results of a study conducted on eighth-grade students at SMP Negeri 4 Pasuruan, it can be concluded that there was a significant improvement in mathematics learning outcomes in both groups, both those taught using the Computational Thinking approach and those taught using the Polya problem-solving approach. Therefore, the alternative hypothesis (H_1), which states that there is an improvement in learning outcomes between students' pretest and posttest scores, is accepted.

The improvement in learning outcomes was more pronounced in the Computational Thinking group, indicating that this approach is more effective in training students to think systematically, analytically, and reflectively than the Polya approach. Therefore, the application of Computational Thinking is recommended as a mathematics learning strategy to improve students' problem-solving abilities.

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