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Enhancing Students' Higher-Order Thinking Skills in Mathematics

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Abstract

This study explores the possible effects of incorporating Polya's Problem-Solving Method on Bukidnon State University Secondary Laboratory School (SLS) students' academic performance in Mathematics. This intervention study is intended to untangle significant information that will inform the educational field to understand SLS students' academic performance. This study aims to analyze whether incorporating Polya's Problem-Solving Method improves the students' academic performance in mathematics and perception towards problem solving. A quantitative one-group pretest-posttest research design approach was employed using survey questionnaires. The results show that incorporating Polya's Problem-Solving Method significantly improved students' academic performance and demonstrated increased Higher Order Thinking Skills in solving mathematical problems. The findings suggest that integrating Polya's Problem-Solving Method into the curriculum can promote autonomous learning and enhance higher-order thinking Skills in Grade 7 students. Further research is recommended to explore the effectiveness of combining this method with other instructional strategies to improve students' problem-solving skills and academic achievement.

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Introduction

Mathematics education is vital in developing critical thinking and problem-solving skills that students can use to navigate the technology-driven world. Learners need to develop higher-order thinking Skills (HOTS) in mathematics, for it fosters their mastery of the concepts and their application to real-life situations. The modern mathematics classroom's main problem is that it requires HOTS as its fundamental skill.

Higher-Order Thinking Skills (HOTS) encompass cognitive processes that enable individuals to analyze, evaluate, and create. These skills are crucial in mathematics, where problem-solving involves logical reasoning, pattern recognition, and strategic thinking. Students with higher-order thinking skills are more successful (Tanujaya, B., et. al., 2017). It shows that students who develop strong HOTS in mathematics demonstrate better academic achievement and adaptability. However, HOTS is not readily available among students (Mustapha et al, 2019). Despite efforts to improve mathematics education, students continue to face difficulties in problem-solving. Word problems are among the most challenging problems that mathematics learners encounter (Verschaffel, L., et. al., 2020). Traditional teaching methods emphasizing rote learning over critical thinking contribute to this issue. Students often rely on memorization rather than understanding, limiting their ability to apply mathematical concepts to real-world situations.

George Polya's Problem-Solving Method offers a structured approach to mathematical problem-solving. Comprising four stages – understanding the problem, devising a plan, carrying out the plan, and looking back – this method facilitates logical reasoning, critical thinking, and reflection. Research suggests that incorporating Polya's method can enhance students' mathematical understanding, confidence, and HOTS.

Several studies have examined the impact of Polya's method on students' problem-solving skills. For example, Gulam and Arenas (2024) observed a significant improvement in Grade 9 students' problem-solving abilities after applying Polya's method, which supports the current study's findings on its positive impact. Similarly, Gopinath and Lertlit (2022) noted moderate improvements in Grade 7 students' problem-solving skills after using Polya's method. However, they suggested continued instructional support was necessary to achieve higher performance levels. While these results show promising improvements, some studies present contradictory findings.

Adegoke (2015) found no statistically significant difference in students' pre-test and post-test scores after using Polya's method in physics, indicating that it may not always yield substantial gains. Similarly, Wickramasinghe and Valles (2015) reported initial improvements in students' performance in statistics. Still, the impact did not last over time, raising questions about the long-term sustainability of Polya's method. Despite these mixed results, the method's ability to improve problem-solving skills remains a key focus for educators, and its application to mathematics education continues to be explored.

This research explored the possible effects of incorporating Polya's Problem-Solving Method on Bukidnon State University Secondary Laboratory School (SLS) students' academic performance in Mathematics. This intervention study was intended to untangle significant information that will inform the educational field's understanding of SLS students' academic performance. This study aimed to analyze whether incorporating Polya's Problem-Solving Method improves the students' academic performance in mathematics.

Action Research Questions

This action research aimed to examine the Grade 7 students' Mathematics problem-solving performance using Polya's problem-solving strategies as a formative assessment method at Bukidnon State University Secondary Laboratory School, Malaybalay City. This study ought to uncover answers to the following questions:

1. What is the level of students' perception of problem solving before and after being exposed to Polya's problem-solving strategies?
2. What is the academic performance of students in mathematics before and after being exposed to Polya's problem-solving strategies?
3. Is there a significant difference in students' perceptions of problem-solving before and after being exposed to Polya's problem-solving strategies?
4. Is there a significant difference in the academic performance of students in mathematics before and after being exposed to Polya's problem-solving strategies?

Method

Research Design

To achieve the study's objectives, the researchers employed a one-group pre-test-post-test research design. This design examined the significant difference between students' academic performance and perception in mathematics before and after incorporating Polya's Problem-Solving method.

Research Participants

This study's participants were the Grade 7 students of Bukidnon State University Secondary Laboratory School (BukSU SLS) for S.Y. 2024-2025. The overall goal was to examine the Grade 7 students' academic performance and perception in mathematics before and after incorporating Polya's Problem-Solving Method.

Research Locale

This study was conducted at the Bukidnon State University Secondary Laboratory School, located at EduHub, Casisang, Malaybalay City, Bukidnon. The Secondary Laboratory School is an integral part of the esteemed College of Education and encompasses a comprehensive range of grade levels. The school mentioned above offers junior high school from Grades 7, 8, 9, and 10 and the STEM Strand in Senior High School.

Research Instruments

This study utilizes a two-part questionnaire. The first part is a 40-item mathematics exam developed by the researchers based on the Revised Bloom's Taxonomy with emphasis on higher-order Thinking Skills (HOTS). The test's specifications table was based on the Department of Education's curriculum guide for the MATATAG Curriculum Grade 7 Mathematics. The questionnaire was pilot tested on grade 8 students of BukSU SLS, and Cronbach's alpha, 0.9080, was determined to identify the level of internal consistency.

Table 1 shows the scoring guide on students' performance in Mathematics before and after the intervention, using the range of scores of the students in the first part of the questionnaire.

Table 1. Scoring Guide on Students' Performance in Mathematics before and after the Intervention

Range of Score	**Interpretation**
27-30	Very High Performance
25 - 26	High Performance
24	Average Performance
22 - 23	Low Performance
Below 22	Very Low Performance

The second part of the questionnaire is a survey about students' Perceptions of The Effectiveness of Polya's Problem-Solving Method, adapted and modified from the study of In'am (2014). Table 2 shows the scoring guide for the students' perceptions of the effectiveness of Polya's Problem-Solving Method before and after the intervention.

Table 2. Scoring Guide for the Students' Perception on the Effectiveness of Polya's Problem Solving Method before and after the Intervention

Range of Mean	**Interpretation**
4.20 - 5.00	Very High Perception
3.40 - 4.19	High Perception
2.60 - 3.39	Moderate Perception
1.80 - 2.59	Low Perception
1.00 - 1.79	Very Low Perception

Results and Discussion

Level of Students' Perception of the Effectiveness of Problem Solving when exposed to Polya's Problem-solving Strategies before and after Intervention

Table 3 pertains to the level of perception of students towards problem solving before and after the intervention. Before the intervention, it was found that most of the students try to understand the problem first, its goal, and the main idea before answering the problem. This is observed with the statements that garnered the highest accumulated mean: Statement 4. I try to understand a problem before I try to solve it with a mean of 4.62 and a standard deviation of 0.539; Statement 1. I try to understand the goal of a problem before answering the problem with a mean of 4.4048, SD of 0.587, and Statement 10. I try to find the main idea before solving the problem with a mean of 4.43 with an SD of 0.668. On the other hand, Statements 3, (*I know how many problems that I can accomplish.)*, 15 (*I almost always know how many problems I can solve.)*, both 9 (*I try to solve a problem based on the plan I have made*) and 16 (*I examine the accuracy of the results after solving problems.*) accumulated the lowest mean scores among the statements given with means of 3.38, 3.43, and 3.86 and Standard Deviations of 0.936, 0.966, and 1.026 respectively.

After the intervention, Statement 1 (*I try to understand the goal of a problem before answering the problem.*) garnered the highest mean of 4.64 with SD of 0.577, followed by Statement 10 (*I try to find the main idea before solving the problem.)* with a mean of 4.55 and SD of 0.705, and Statement 4 (*I try to understand a problem before I try to solve it.)* with a mean of 4. 5238 and SD of 0.634. On the other hand, Statement 15 (*I almost always know how many problems I can solve.)* garnered the lowest accumulated mean of 3.48 with SD of 0.943, followed by Statement 3 (*I know how many problems that I can accomplish.*) with a mean of 3.71 and SD of 0.918, and Statement 16 (*I examine the accuracy of the results after solving problems.*) with a mean of 4.02 and SD of 0.924. This result signifies that after the intervention, the students still try to understand the problem first, its goal, and the main idea before solving a given problem. Moreover, they are having difficulty knowing how many problems they can solve and examining the accuracy of the results after solving a problem.

Table 3. Mean and Standard Deviation of Students' Perception towards Problem Solving

	Pre-Test			**Post Test**		
Statement	**Mean**	**SD**	**QI**	**Mean**	**SD**	**QI**
1. I try to understand the goal of a problem before answering the problem	4.41	0.587	Very High	4.64	0.577	Very High
2. I think of the meaning of a problem before I start to answer the problem.	4.14	0.683	High	4.31	0.680	Very High
3. I know how many problems that I can accomplish.	3.38	0.936	High	3.71	0.918	High
4. I try to understand a problem before I try to solve it.	4.62	0.539	Very High	4.52	0.634	Very High
5. I always make plan before solving problems	3.91	1.055	High	4.31	0.749	Very High
6. I try to determine what to be required in solving problems.	4.14	0.783	High	4.26	0.798	Very High
7. I realize about the importance of planning my action	4.05	0.962	High	4.19	0.943	High
8. I choose and organize proper information to solve the	4.12	0.942	High	4.33	0.754	Very High

problem						
9. I try to solve a problem based on the plan I have made	3.86	1.117	High	4.26	0.857	Very High
10. I try to find the main idea before solving the problem	4.43	0.668	Very High	4.55	0.705	Very High
11. I make certain to understand what to do and how to implement	4.05	0.882	High	4.33	0.650	Very High
12. I determine the ways to solve the problem	4.31	0.749	Very High	4.45	0.772	Very High
13. I realize that each solution should be reviewed.	4.10	1.078	High	4.26	0.767	Very High
14. I examine the solution I have made.	4.19	1.042	High	4.41	0.885	Very High
15. I almost always know how many problems I can solve.	3.43	0.966	High	3.48	0.943	High
16. I examine the accuracy of the results after solving problems.	3.86	1.026	High	4.02	0.924	High
Overall	4.06	0.514	High	4.25	0.498	Very High

Furthermore, before the intervention, the overall mean was 4.06 and the standard deviation was 0.514, implying that the students agreed with the given statements, which also signifies that they have a high level of perception towards problem solving. After the intervention, the overall mean score was 4.25 and the standard deviation was 0.498, implying that the students strongly agree with the statements, which also signifies that they have a very high level of perception towards problem solving. This means that incorporating Polya's Problem-Solving Method helped increase the perception of students in problem-solving.

Some research highlights challenges and limitations in the universal effectiveness of Polya's method. Saifurrisal's recent finding (2022) is that the students made gross errors at each stage of Polya's process, almost predominantly when they execute the plan and review the solution, with the error rate at 64%. Such observation means that the vast majority of students have not completely internalized the intended benefits of the instructions. However, they still have to face learning limitations, which minimize the ultimate effect of the method on problem-solving accuracy and confidence. Similarly, the studies by Effiom and Abdullahi (2021) indicated that the effectiveness of Polya's strategy on the performance of senior secondary students in algebraic word problems varied as a function of prior knowledge, problem difficulty, and quality of instruction. They warned that Polya's method alone will not be adequate for all learners and that other teaching methods must be supplemented.

The present study and supporting literature assert that Polya's problem-solving strategies positively affect students' perception and problem-solving skills. However, that literature goes on to show a gap in the ongoing challenges that still pose variability in outcomes. This calls for adaptive instructional designs incorporating Polya's method with other pedagogical methods for developing diverse learners' strong and accurate problem-solving skills. .)

Level of Students' Performance before and after Incorporating Polya's Problem-solving Method

Table 4 shows the level of students' performance before incorporating Polya's Problem-Solving Method in terms of the pre-test. It indicates that one (1) student or 2.38 % of the students had very high performance, two or 4.76 % had an average performance, 4 or 9.53 % had a low performance, and 35 or 83.33 % had very low performance. The overall mean score of students' academic performance on the pre-test was 17.45 with a standard deviation of 5.181, implying a very low performance. After the intervention, it is indicated in the table that nine (9) students or 21.43 % had an outstanding performance, six or 14.29 % had a very satisfactory performance, five (5) students or 11.90 % had satisfactory performance and likewise had a fairly satisfactory performance, and 17 or 40.48 % of the students did not meet the expected performance. The overall mean score of students' academic performance on the post-test was 23.26 with a standard deviation of 4.665, implying a fairly satisfactory performance.

Table 4. Mean, Standard Deviation, and Frequency Distribution of Students' Academic Performance in Mathematics Before and After the Intervention

Range	Pre Test		Post Test		Interpretation
	Frequency	%	Frequency	%	
27-30	1	2.38	9	21.43	Very High Performance
25 - 26	0	0	6	14.29	High Performance
24	2	4.76	5	11.90	Average Performance
22 - 23	4	9.53	5	11.90	Low Performance
Below 22	35	83.33	17	40.48	Very Low Performance
Total	42	100	42	100	
	Mean = 17.45 SD = 5.181 58.17% (Does not meet expectations)		Mean = 23.26 SD = 4.665 76. 54 % (Fairly Satisfactory)		

The findings indicate that the Grade 7 students, before the intervention, did not meet the expected performance. This was in line with the findings of Inah and Anditung (2021) that students taught geometry by traditional lecture methods had lower performance than those taught geometry with Polya's Problem-Solving Strategy. A parallel report by Nasir and Syartina (2022) indicated low initial achievement scores of students in solving mathematical story problems before the application of Polya's method, thus highlighting the inadequacies of conventional methods of teaching problem-solving skills. While some studies supported these findings, others seemed to contradict them. Adegoke (2015), for instance, explored the use of Polya's problem-solving model in physics instruction; in this study, it was found that students' pre-test scores were not significantly low. This led to the suggestion that students might already possess some basic skills in problem-solving, thus contradicting the assumption that one needs to provide a structured intervention all the time. Wickramasinghe and Valles (2015) also examined using Polya's method in statistics and noted that the students did not perform extremely poorly in the pre-test. They argued that some experience with problem-solving approaches reduces the necessity for an extra intervention.

Furthermore, the findings signify that the Grade 7 students performed fairly satisfactorily after being exposed to Polya's problem-solving method. This finding is consistent with Gopinath and Lertlit (2022), who implemented Polya's four-step problem-solving model with grade 7 students and observed improvement in problem-solving skills; however, overall performance remained at a moderate level, thereby suggesting that instructional support continues to be needed for enhanced proficiency. Likewise, Gulam and Arenas (2024) showed that although there were noteworthy improvements in the problem-solving performance of Grade 9 students after the application of Polya's Method, their overall achievement indicated the necessity of reinforcement to achieve higher performance level and while the results are encouraging, some studies also dispute the effectiveness of the intervention.

Adegoke (2015) does not report an increase in the students' post-test scores after using Polya's method in physics. The study suggested that this method may not be universally applicable across all subjects and not to all students. Similarly, Wickramasinghe and Valles (2015) reported that while Polya's method initially presented a better performance in statistics, the effect did not last over time, and traditional teaching methods produced similar accomplishments.

Comparison of Students' Level of Perception before and after the Intervention

Table 5 shows the paired t-test of the pre-test and post-test scores of the treatment. As evidenced by the students' t-test ($t\ (42) = -6.03, p < 0.001$). Additionally, Cohen's d of 0.603 indicates that students' average level of perception towards problem solving after the intervention is 0.603 standard deviations greater than their level of perception towards problem solving before being exposed to Polya's Problem Solving Method. This finding indicates a substantial change in the students' perception of problem solving before and after the intervention. Specifically, the mean difference between the pre-test and post-test scores was - 0.19, with a standard error of 0.032.

Table 5. Paired t-test Comparison of Students' Perception towards Problem Solving

	t-value	df	MD	SED	p	Cohen's d
Pretest−Posttest	- 6.03	15	-0.19	0.032	0.000	0.603

These findings are consistent with previous research supporting the effectiveness of Polya's problem-solving strategies. Gulam and Arenas (2024) reported that after the integration of Polya's four-step method, students had greatly enhanced problem-solving performance with extraordinary post-test scores in understanding the problem (mean = 6.02) and in developing a plan (mean = 5.77). This study has confirmed that Polya's method helps the students to develop structured thinking and problem-solving skills. In the same manner, the study conducted by Yapatang, L. & Polyiem, T. (2022) proved that the combination of cooperative learning and Polya's problem-solving process significantly develops grade 9 students' mathematical problem-solving abilities, with statistically significant gains in the understanding, planning, executing, and reflecting phases. Those studies affirm that Polya's strategies positively impacted their perception and problem-solving ability and agree with the improvements noted in the present study.

Comparison of Students' Performance before and after the Intervention

Table 6 shows the paired t-test of the pre-test and post-test scores of the treatment. As evidenced by the students' t-test ($t\ (42)\ =\ -8.04, p\ <\ 0.001$). Additionally, Cohen's d of 1.18 indicates that the average academic performance of students after the intervention is 1.18 standard deviations greater than their academic performance before exposure to Polya's Problem Solving Method. This finding indicates a substantial change in the students' performance before and after the intervention. Specifically, the mean difference between the pre-test and post-test scores was -5.81, with a standard error of 0.722. The null hypothesis was rejected, stating that there is no significant difference between the pre-test and post-test scores of students' performance in Mathematics when exposed to Polya's problem-solving method. Consequently, the intervention significantly impacted the measured variables. Results showed marked improvement in students' performance by implementing Polya's Problem-Solving Method. They can be backed up by a study by Gulam and Arenas (2024) that employed a one-group pretest-posttest design assessing the effect of Polya's four-step process on the mathematics performance of Grade 9 students. They showed a huge improvement in problem-solving ability quantified statistically through pre-test and post-test comparison of scores ($t - value = -8.04, p < 0.05$), thus indicating that the intervention helped improve the students' mathematical problem-solving skills.

Table 6. Paired T-test Comparison of Students' Academic Performance in Mathematics

	t-value	**df**	**MD**	**SED**	**p**	**Cohen's d**
Pretest−Posttest	- 8.04	41	-5.81	0.722	0.000	1.18

Some researchers contradict these findings. According to Adegoke (2015), the difference between pre-test and post-test scores was not statistically significant, indicating that Polya's method has not been effective in the expected manner in physics. Moreover, Wickramasinghe and Valles (2015) found initial improvement in students' scores; however, in the long term, the statistical significance concerning the intervention seemed feeble, making one think that Polya's method would not be a sustainable teaching approach.

Conclusion

Based on the findings of the study, the following conclusions were drawn:

1. Before the intervention, the students had a high level of perception in problem-solving. Meanwhile, after the intervention, the students showcased a very high level of perception in problem solving.
2. When not exposed to Polya's Problem-Solving Method, students' performance in mathematics did not meet expectations, but it was fairly satisfactory after the intervention.
3. Polya's Problem-Solving Method increased the level of perception of students towards problem solving.
4. There is a significant difference between the pre-test and post-test scores of students' mathematics

performance when exposed to Polya's problem-solving method.

5. Polya's Problem-Solving method effectively enhances students' Higher-Order Thinking Skills (HOTS) and eventually improves their academic performance in mathematics.

Recommendations

Based on the conclusions, the following recommendations are formulated:

1. Implement a structured, step-by-step problem-solving approach to enhance students' mathematical problem-solving skills.
2. Implementing Polya's problem-solving method in mathematics classes is highly recommended to enhance students' higher-order thinking skills.
3. Further research could be conducted to assess the effectiveness of other alternatives, along with Polya's Problem-Solving Method, to enhance the students' academic performance, critical thinking, and problem-solving skills.

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