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Enhancing Physics Problem-Solving Skills on Waves through Problem-Based Learning (PBL) Integrated with the Inquiry Method and Polya's Problem-Solving Techniques for Grade 11 Students at Buakhao School

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Abstract

This study investigated the effectiveness of using the Problem-Based Learning (PBL) management process combined with Polya's problem-solving techniques in enhancing students' physics problem-solving abilities and their satisfaction with the learning method. The research aimed to (1) assess the students' ability to solve physics problems after engaging in PBL, with the goal of meeting the 70% performance criterion, and (2) evaluate student satisfaction with the learning approach. The sample group consisted of 33 grade 11 students from Buakhao School during the first semester of the academic year 2024. The research tools included six learning management plans, a multiple-choice test with four sets of ten questions each, and a satisfaction questionnaire with 20 items. Data analysis was performed using mean, standard deviation, and t-tests (one sample). The results showed that (1) students' physics problem-solving abilities significantly improved after the PBL-based instruction with Polya's techniques, surpassing the 70% criterion, with statistical significance at the 0.05 level, and (2) student satisfaction with the PBL approach was at the highest level ($\bar{x} = 4.63$, SD = 0.70).

Keywords: Solving skills in physics problems; problem-based learning; Polya problem solving techniques

1. Introduction

Physics is a branch of science that plays a highly significant role in the development of human cognition. It is a discipline concerned with the study of natural phenomena, emphasizing the discovery of laws to explain occurrences in nature that occur around us or can be observed in daily life (Puangrat, 2016). Due to the inherent nature of physics, which combines philosophical foundations with mathematical complexity to the extent that they are often inseparable, physics instruction necessarily involves two crucial components: experimentation, which fosters accurate understanding of physical principles, and problem-solving, which requires the application of highly abstract mathematical knowledge. This characteristic makes physics a particularly challenging subject, causing many students to struggle with effective comprehension of its content. Moreover, when confronted with problems that differ from those previously encountered, students are often unable to solve them independently (Krerk, 2019).

Physics instructors regard problem-solving as a fundamental skill in the teaching and learning of physics. Students must first be able to comprehend the information provided in the problem statement as well as the specific requirements of the question before they can appropriately select and apply the relevant physics formulas or equations. Without critical and analytical thinking abilities, students are unlikely to solve problems accurately. Moreover, even when students successfully understand the problem, they may still struggle to substitute values correctly into equations, fail to arrive at the correct solution, or make errors in manipulating the equations, resulting in incorrect outcomes. Therefore, to effectively develop students' physics problem-solving skills, instructional practices must employ teaching methods that are aligned with the objectives of the subject, account for individual differences among learners, and ensure content appropriateness. Such approaches should also stimulate students' motivation and foster enthusiasm for learning (Tupsai et.al., 2015).

To address students' deficiencies in physics problem-solving skills, the researchers conducted a study to investigate and select appropriate teaching methods and instructional models. Problem-Based Learning (PBL) has been identified as an instructional approach that actively engages students in understanding authentic problem situations. Through collaborative efforts aimed at exploring and developing solutions, PBL emphasizes the cultivation of learning skills rather than mere knowledge acquisition. In this approach, instructors guide students to encounter real-world problem scenarios and practice systematic problem analysis, thereby fostering clear and comprehensive problem understanding. Additionally, PBL promotes the development of critical thinking abilities and various problem-solving processes (Titsana, 2024). According to Chomsriharat and Polyiem (2024), the integration of Problem-Based Learning (PBL) with questioning strategies can effectively enhance students' engagement and cognitive abilities in science education. Moreover, it was found that the problem-based learning model has a positive impact on students' physics problem-solving abilities, which can be applied in physics instruction to foster and strengthen problem-solving skills (Aulia, Hikmawati, & Susilawati, 2022; Rasyid et al., 2023; Ummah et al., 2023).

Polya's problem-solving technique offers another important pedagogical approach, consisting of four systematic steps: (1) understanding the problem, which enables students to analyze given information, identify relationships, and recognize conditions necessary for problem solution; (2) devising a plan, which helps students determine appropriate methods or principles for problem solving; (3) carrying out the plan, where students perform calculations according to the devised strategy; and (4) looking back, whereby students verify whether the obtained solution is correct and consistent with the problem's requirements. This method fosters systematic and stepwise problem-solving, ultimately enhancing students' problem-solving skills effectively (Polya, 1945; Suanse and Yuenyong, 2023). Extant research provides compelling evidence that the implementation

of Polya's problem-solving process constitutes a highly effective pedagogical approach for enhancing students' physics problem-solving proficiency (Venus, 2019; Thanyarat et al., 2020; Panarin, 2023).

When Problem-Based Learning is integrated with Polya's problem-solving techniques, this combination is anticipated to foster engaging and motivating learning experiences while specifically promoting the development of physics problem-solving skills. This approach allows students to understand the sequential steps involved in the problem-solving process and provides a foundation for tackling physics problems effectively. In this context, the instructor plays a crucial role in guiding and supporting students to improve their problem-solving abilities in physics.

Considering the rationale and problems, the researchers recognize both the existence of these issues and the necessity of developing students' physics problem-solving skills. Consequently, this study aims to design and implement learning activities that integrate Problem-Based Learning (PBL) with Polya's problem-solving technique on the topic of waves for Grade 11 students. Through this instructional approach, students are expected to improve their physics problem-solving skills and develop more positive attitudes toward the learning process.

2. Objectives

1. To examine students' physics problem-solving skills on wave problems through Problem-Based Learning (PBL) integrated with Polya's problem-solving techniques compared to the 70% performance criterion
2. To investigate student satisfaction with the learning management process using Problem-Based Learning (PBL) integrated with Polya's problem-solving techniques.

3. Research Methodology

Population and Sample Group

Population: The population consisted of Grade 11 students at Buakhao School, Kuchinarai District, Kalasin Province, during the first semester of the 2024 academic year, totaling 437 students.

Sample Group: The sample comprised 33 Grade 11/7 students at Buakhao School, Kuchinarai District, Kalasin Province, during the first semester of the 2024 academic year. The sample was selected through cluster random sampling.

Research Instruments

Learning Plans

Six learning management plans on the topic of waves were developed using Problem-Based Learning (PBL) integrated with Polya's problem-solving technique. Each plan was designed for two hours of instruction, totaling twelve hours. The evaluation results indicated that the appropriateness of the learning management plans was rated at the highest level.

Physics Problem-Solving Test

The test designed to assess students' physics problem-solving skills on waves consisted of four sets of multiple-choice questions, with 10 items per set, totaling 40 items. The Index of Item-Objective Congruence (IOC) values ranged from 0.67 to 1.00. Item analysis from the pilot test revealed difficulty indices (p) ranging from 0.20 to 0.77, discrimination indices (r) ranging from 0.20 to 0.60, and an overall reliability coefficient of 0.81.

Student Satisfaction Questionnaire

The questionnaire measuring student satisfaction with the Problem-Based Learning (PBL) approach integrated with Polya's problem-solving technique consisted of 20 items using a five-point Likert scale. The Index of Item-Objective Congruence (IOC) values ranged from 0.67 to 1.00.

Data Collection Procedures

Initial Setup: Prior to the experiment, the researcher explained the research objectives, Problem-Based Learning (PBL) methodology, and Polya's problem-solving techniques to the sample group.

Instructional Sessions: The instructional intervention was implemented through six learning management plans over twelve sessions, with each session lasting two hours. These sessions engaged students in problem-solving activities related to waves using the integrated PBL and Polya approach.

Post-Instruction Test: Upon completion of all six learning management plans, students completed a post-test to assess their physics problem-solving skills, specifically focused on the topic of waves.

Satisfaction Survey: Following the instructional intervention, students completed a satisfaction questionnaire to evaluate their perceptions of the learning process and the effectiveness of the integrated PBL and Polya approach.

Data Collection: All collected data, including post-test scores and satisfaction questionnaire responses, were compiled for subsequent statistical analysis.

Data Analysis

Problem-Solving Skills: To analyze students' physics problem-solving skills on the topic of waves through the learning process integrating Problem-Based Learning (PBL) with Polya's problem-solving technique, post-instruction performance was compared with the 70% criterion using a one-sample t-test.

Satisfaction Analysis: To analyze students' satisfaction levels with the learning process integrating Problem-Based Learning (PBL) with Polya's problem-solving technique, means and standard deviations of satisfaction scores were calculated and interpreted according to established evaluation criteria.

4. Findings and Discussion

4.1 Students' physics problem-solving skills on the topic of waves through the learning process integrating Problem-Based Learning (PBL)

To analyze students' physics problem-solving skills on the topic of waves through the learning process integrating Problem-Based Learning (PBL) with Polya's problem-solving technique, post-instruction performance was compared with the 70% criterion using a one-sample t-test.

Table 1: Results of the Analysis of Students' Physics Problem-Solving Skills on the Topic of Waves

Skills	N	Full score	$\bar{x}$	S.D.	% of Mean	t	Sig (1-tailed)
Posttest	33	40	30.27	1.28	75.68	10.19*	0.0000

From Table 1, the physics problem-solving skills on the topic of waves using Problem-Based Learning (PBL) integrated with Polya's problem-solving technique among 33 Grade 11 students showed a post-instruction average score of 30.27 out of 40 points, equivalent to 75.68%. When comparing students' post-instruction physics problem-solving skills on the topic of waves with the established 70% criterion, the results revealed that post-instruction scores were significantly higher than the criterion at the .05 level of statistical significance.

This outcome may be attributed to the implementation of the PBL approach, which emphasizes stimulating students' understanding of authentic problems, fostering collaboration, encouraging independent inquiry, and guiding solution development. PBL also cultivates analytical thinking and problem-solving skills, enabling students to gain clearer problem understanding and develop systematic thinking processes (Titsana, 2024). Furthermore, the integration of Polya's problem-solving technique, consisting of four essential steps—(1) understanding the problem by analyzing conditions and relationships, (2) devising a plan by selecting appropriate methods or principles, (3) carrying out the plan through calculations and solution implementation, and (4) reviewing results to ensure correctness—provides students with a systematic and structured problem-solving framework. This method effectively enhances problem-solving skills (Polya, 1945).

During implementation, students required considerable time for both problem understanding and problem-solving execution. This was primarily due to difficulty recalling variables from problem statements and shortcomings in performing calculations and solving equations. Test scores measuring physics problem-solving skills revealed that Sets 2 and 3 yielded the lowest average scores (as shown in Table 2). This occurred because equations contained unfamiliar variables, causing confusion and leading to incorrect substitutions and equation manipulation errors. Moreover, students demonstrated insufficient problem analysis, resulting in extended time requirements and necessitating additional teacher guidance.

Notably, students became aware of their assessment performance results in each learning session, which motivated increased engagement with learning activities to achieve improved scores. This finding aligns with Venus (2019), who examined instructional practices using Polya's problem-solving process and its impact on physics problem-solving abilities among Grade 10 students, finding that students' problem-solving abilities significantly exceeded the 70% criterion at the .05 level. Similarly, Thanyarat (2020) investigated problem-solving ability and physics achievement on momentum and collision among Grade 10 students using inquiry-based learning integrated with Polya's problem-solving technique, indicating that students' problem-solving abilities significantly exceeded the 70% criterion at the .05 level. This is also consistent with Chomsriharat and Polyiem (2024), who found that integrating PBL with questioning strategies effectively enhanced students' engagement and cognitive abilities in science learning.

Therefore, Problem-Based Learning integrated with Polya's problem-solving technique proves highly effective in enhancing students' physics problem-solving skills in a systematic and efficient manner.

From Table 2, the individual scores, averages, and percentages of physics problem-solving skills on the topic of waves using Problem-Based Learning (PBL) integrated with Polya's problem-solving technique among 33 Grade 11 students at Buakhao School demonstrated that all students achieved scores of at least 70%, meeting the established criterion. The lowest score was 28 points (70.00%), while the highest score was 33 points (82.50%). These results indicate that the learning process integrating Problem-Based Learning (PBL) with Polya's problem-solving technique can be effectively implemented to develop students' physics problem-solving skills.

Table 2: Individual Analysis Results of Students' Physics Problem-Solving Skills on the Topic of Waves

No.	Problem-solving skill score (10 points per set)				Overall Score	Expressed as a percentage	Passing Criterion (Not less than 70%)
	Set 1	Set 2	Set 3	Set 4			
1	7	8	8	9	32	80.00	Meet the criterion
2	9	8	6	7	30	75.00	Meet the criterion
3	7	8	9	7	31	77.50	Meet the criterion
4	6	8	8	9	31	77.50	Meet the criterion
5	7	7	6	9	29	72.50	Meet the criterion
6	8	8	7	7	30	75.00	Meet the criterion
7	8	6	9	9	32	80.00	Meet the criterion
8	7	7	8	6	28	70.00	Meet the criterion
9	7	7	8	9	31	77.50	Meet the criterion
10	8	7	7	8	30	75.00	Meet the criterion
11	9	8	7	7	31	77.50	Meet the criterion
12	7	8	9	6	30	75.00	Meet the criterion
13	8	7	8	9	32	80.00	Meet the criterion
14	9	8	7	7	31	77.50	Meet the criterion
15	6	7	7	9	29	72.50	Meet the criterion
16	6	7	7	9	31	77.50	Meet the criterion
17	8	7	8	8	31	77.50	Meet the criterion
18	9	8	8	7	32	80.00	Meet the criterion
19	8	7	6	7	28	70.00	Meet the criterion
20	7	7	8	6	28	70.00	Meet the criterion
21	8	6	8	8	30	75.00	Meet the criterion
22	7	8	8	9	32	80.00	Meet the criterion
23	7	7	6	9	29	72.50	Meet the criterion
24	9	8	6	7	30	75.00	Meet the criterion
25	9	7	6	7	29	72.50	Meet the criterion
26	8	7	8	6	29	72.50	Meet the criterion
27	9	7	8	9	33	82.50	Meet the criterion
28	8	8	7	7	30	75.00	Meet the criterion
29	9	7	7	8	31	77.50	Meet the criterion
30	7	7	8	6	29	72.50	Meet the criterion
31	8	8	8	8	30	75.00	Meet the criterion
32	9	7	8	6	30	75.00	Meet the criterion
33	7	7	8	8	30	75.00	Meet the criterion
Mean	8	7	8	8	30.27	75.68	Meet the criterion

4.2 Students' satisfaction levels with the learning process integrating Problem-Based Learning (PBL)

To analyze students' satisfaction levels with the learning process integrating Problem-Based Learning (PBL) with Polya's problem-solving technique, means and standard deviations of satisfaction scores were calculated and interpreted according to established evaluation criteria.

From Table 3, the overall satisfaction of students with the learning process using Problem-Based Learning (PBL) integrated with Polya's problem-solving technique was at the highest level ($\bar{x} = 4.63$, SD = 0.70). When examined by individual items, the item with the highest mean score was "Disclosing the scores obtained from assessments" ($\bar{x} = 5.00$, SD = 0.00). The next highest mean scores were "Using teaching media that promote appropriate learning" ($\bar{x} = 4.85$, SD = 0.50) and "Providing solutions and explanations for answers" ($\bar{x} = 4.85$, SD = 0.43), respectively. The items with the lowest mean scores were

"The instructor delivers knowledge clearly, concisely, and understandably" ($\bar{x}$ = 4.39, SD = 0.95) and "The instructor provides opportunities for students to ask questions and engage in group work to exchange knowledge" ($\bar{x}$ = 4.39, SD = 0.98).

Table 3: Results of Satisfaction Level with the Learning Process Using the Problem-Based Learning (PBL) Process Combined with Polya's Problem-Solving Technique

No.	List	$\bar{X}$	S.D.	Satisfaction level
1	The instructor provides clear, concise, and understandable explanations.	4.39	0.95	high
2	The instructor answers questions clearly according to the students' doubts.	4.45	0.89	high
3	Instructors provide opportunities for learners to ask questions.	4.39	0.98	high
4	The instructor encourages students to think logically and analytically.	4.67	0.64	highest
5	Teaching materials that promote proper learning	4.85	0.50	highest
6	Learning management makes learners dare to think, dare to answer.	4.42	0.95	high
7	Learners have the opportunity to study and learn on their own.	4.76	0.60	highest
8	Learning management makes learners understand the content better.	4.70	0.52	highest
9	Learning allows learners to know how to solve problems systematically.	4.61	0.85	highest
10	It takes time to manage teaching and learning appropriately.	4.73	0.57	highest
11	There are books, textbooks, and the Internet available for searching.	4.79	0.48	highest
12	Encourage learners to apply knowledge to solve problems.	4.64	0.73	highest
13	Encourage learners to think critically and solve problems on their own.	4.70	0.63	highest
14	Work training, group exchange of knowledge between learners.	4.39	0.98	high
15	Learners can apply their knowledge to solve problems in daily life.	4.45	0.99	high
16	The content studied is consistent with the test.	4.76	0.60	highest
17	There are answers and explanations.	4.85	0.43	highest
18	Reveal the score obtained from the measurement	5.00	0.00	highest
19	Provide feedback to lead to self-improvement	4.48	0.89	high
20	The measurement and evaluation of academic performance is clear and fair	4.64	0.81	highest
	Total Average	4.63	0.70	highest

This outcome can be attributed to the PBL process integrated with Polya's problem-solving technique, which emphasized students' active participation, hands-on practice, and physics problem-solving skill development. The learning activities were diverse and

engaging, encouraging critical thinking and problem-solving while fostering students' knowledge, skills, and positive learning behaviors. Consequently, students gained deeper understanding, enhanced long-term retention through practice, and improved skill development. Moreover, the instructional process included interactive elements such as questioning, responding, and clarifying doubts. At the end of each learning session, teachers provided immediate feedback on students' performance, motivating active self-improvement and full engagement in all activities. As a result, students' satisfaction with the instructional process reached the highest level overall. These findings align with Panarin (2023), who investigated physics problem-solving ability using Polya's problem-solving technique integrated with the 5E inquiry-based learning model among Grade 11 students and found that students' overall satisfaction was also at a high level.

5. Conclusion

The development of physics problem-solving skills on the topic of waves through Problem-Based Learning (PBL) integrated with Polya's problem-solving technique among Grade 11 students at Buakhao School revealed that students' post-instruction problem-solving performance significantly exceeded the 70% criterion at the .05 level. Moreover, overall student satisfaction with the instructional process combining PBL and Polya's problem-solving technique was rated at the highest level ($\bar{x}$ = 4.63, S.D. = 0.70). These findings demonstrate that instructional practices designed and implemented through PBL integrated with Polya's method can effectively enhance and strengthen physics problem-solving skills, particularly for wave-related problems among Grade 11 students. This approach enables students to learn more effectively, follow clear and systematic procedural steps, develop durable knowledge retention, and cultivate positive attitudes toward physics learning. The results suggest that this instructional approach should be adapted and applied to other areas of physics education to promote student engagement, foster deeper understanding, and further develop problem-solving skills.

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