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POLYA'S FRAMEWORK IN PHYSICS: ELEVATING ANALYTICAL THINKING AND ACADEMIC ACHIEVEMENT AMONG STUDENTS

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Abstract

This quasi-experimental study investigates the pedagogical effectiveness of Polya's structured problem-solving framework in enhancing analytical thinking and academic achievement in high school physics. The research focused on tenth-grade students studying linear motion and free fall and used a one-group pretest-posttest design to evaluate cognitive and affective outcomes. The empirical results reveal a highly significant improvement in post-instruction physics learning achievement ($p < .001$) with a substantial effect size (Cohen's $d = 1.59$), successfully exceeding the rigorous 60% curriculum mastery criterion ($p < .05$). Concurrently, the students' analytical thinking abilities demonstrated marked, statistically significant growth ($p < .001$). Beyond cognitive gains, the structured intervention fostered highly positive attitudes toward the physics curriculum, with students reporting increased interest, determination, and academic responsibility. These findings strongly affirm that systematically integrating Polya's four-step heuristic effectively supports metacognitive regulation, mitigates traditional problem-solving deficits, and consistently drives superior academic performance in complex scientific disciplines, providing a robust pedagogical model for contemporary physics education.

Keywords: Analytical Thinking, Physics Achievement, Metacognitive Regulation, Polya's Problem-Solving Framework, Pedagogical Effectiveness

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Introduction

Physics, as a foundational branch of science, explores and explains natural phenomena. These include fundamental questions such as why objects fall to Earth, how matter undergoes phase transitions, how rainbows form, or the atmospheric optics responsible for the red hue of the setting sun. The evolution of concepts, theories, principles, and laws in physics has spanned centuries, leading to its classification into diverse subfields, including mechanics, waves, sound, light, electricity and magnetism, thermodynamics, atomic physics, nuclear physics, and particle physics. Mastery of physics provides profound insights into matter, energy, their intricate interactions, and the fundamental forces that govern the natural world. The systematic acquisition of physics knowledge relies on rigorous observation, controlled experimentation, and the meticulous collection and analysis of empirical data (Mansfield & O'Sullivan, 2020; Bashim, 2025).

A significant pedagogical challenge consistently observed in physics problem-solving classrooms is students' inability to accurately delineate the knowns and unknowns in a given problem. This often manifests as difficulty correctly identifying and substituting variables and judiciously selecting appropriate equations for computation. Such analytical deficits are recurrently evident in their assessment performance. These struggles may stem from the inherent conceptual complexity of physics topics, the extensive repertoire of mathematical equations required, and a perceived lack of student initiative or engagement in independently refining their problem-solving skills. Consequently, students frequently demonstrate inadequate problem-solving and analytical skills essential for examinations, resulting in academic outcomes generally considered unsatisfactory (Kingsdorf & Krawec, 2014).

Prompted by the identified background and the challenges articulated above, this study explores learning management strategies specifically designed to cultivate analytical thinking skills. The core intervention centers on George Polya's four-step problem-solving heuristic: (1) Understanding the Problem, (2) Devising a Plan, (3) Carrying out the Plan, and (4) Looking Back. This systematic approach aims to influence students' cognitive behaviors and strengthen their analytical proficiencies. Consequently, the researcher focused on integrating Polya's problem-solving framework to foster analytical thinking among Mathayomsuksa 4 (Grade 10) students, with a particular focus on equations for linear motion and free fall. The overarching aim is to generate practical insights that can inform and enhance pedagogical practices in physics education for student development.

Literature Review

To establish a robust conceptual framework for evaluating the pedagogical efficacy of Polya's problem-solving process on tenth-grade physics students, this study synthesizes four core theoretical dimensions: systematic problem-solving, analytical thinking, learning achievement, and student attitudes. George Polya's foundational framework (1945) outlines four sequential cognitive stages—understanding the problem, devising a plan, carrying out the plan, and looking back—that systematically align with metacognitive regulation. In complex physics education, where mastery demands integrating abstract variables, this structured approach helps students translate declarative knowledge into logical, self-regulated action. Concurrently, analytical thinking, defined as the higher-order capacity to disaggregate components and articulate cause-and-effect relationships, is essential for precisely defining knowns and unknowns in physics problems. Wang et al. (2025) empirically demonstrated that instructional activities designed to foster such systematic reasoning significantly enhance analytical competencies.

Ultimately, true learning achievement in physics transcends rote memorization of formulas; it requires rigorous application of conceptual knowledge, which Polya's method logically supports through its cognitive pathways (Hasnor et al., 2013; Negash et al., 2022). Furthermore,

because physics is often perceived as inherently challenging and computationally intense, students frequently experience diminished academic self-efficacy. However, research robustly indicates that successful, structured problem-solving experiences can effectively mitigate this anxiety. By framing complex problems as manageable through clear, systematic steps, pedagogical interventions actively cultivate long-term confidence and highly positive affective and cognitive attitudes toward science education (Chen et al., 2020; Ma, 2023). Synthesizing these theoretical insights confirms that integrating Polya's heuristic into linear motion and free-fall instruction is a promising strategy for simultaneously developing analytical proficiency, fostering positive attitudes, and improving academic performance among high school students.

Research Hypotheses

Based on the synthesized theoretical framework, this study posits four primary hypotheses about integrating Polya's problem-solving process. First, tenth-grade students' post-instruction learning achievement in equations for linear motion and free fall will be significantly higher than their pre-instruction achievement at the .001 level of statistical significance. Second, this post-instruction achievement will significantly exceed the established 60% mastery criterion at the .05 level. Third, students' post-instruction analytical thinking abilities will significantly improve over their pre-instruction baseline at the .001 significance level. Finally, it is hypothesized that students will exhibit a high level of positive attitude towards the Physics 1 curriculum following the systematic implementation of this pedagogical intervention.

Research Conceptual Framework

The conceptual framework, as illustrated in Figure 1, delineates the pedagogical effect of instruction based on Polya's problem-solving approach on students' learning achievement, analytical thinking ability, and attitudes toward physics. In this model, the problem-solving steps are applied systematically as instructional procedures rather than independent variables.

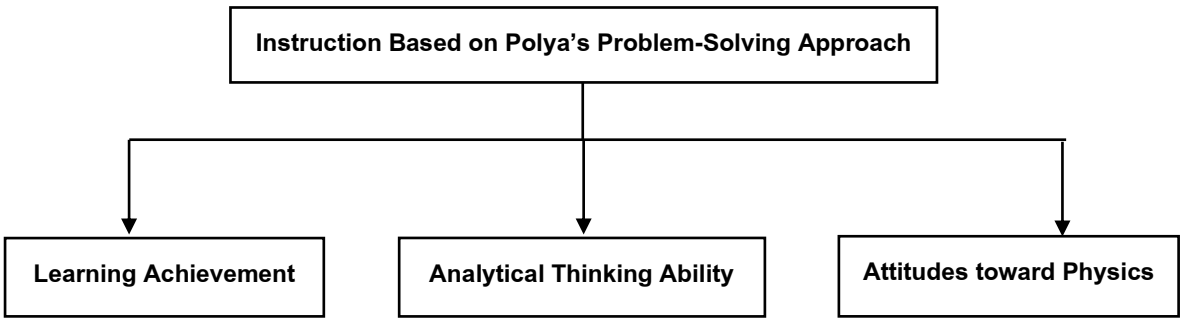

Figure 1 The Research Conceptual Framework

Research Methodology

Participants and Pedagogical Intervention

This quasi-experimental research utilized a one-group pretest-posttest design to investigate the pedagogical impact of Polya's problem-solving framework. The target population comprised 57 tenth-grade students enrolled at Khanom Pittaya School, Nakhon Si Thammarat Province, during the second semester of the 2025 academic year. Using purposive sampling, one classroom of 30 students was selected as the experimental cohort based on foundational characteristics representative of the broader population. The pedagogical intervention consisted of 12 instructional hours guided by four meticulously structured lesson plans focused on linear motion and free fall. During this phase, educators integrally applied Polya's four-step heuristic to foster systematic analytical thinking and logical problem-solving strategies.

Data Collection and Analytical Procedures

To rigorously evaluate the intervention's efficacy, data collection followed a systematic process. Initially, students completed a pre-test comprising a standardized learning

achievement assessment and an analytical thinking ability test to establish baseline cognitive capabilities. Following the 12-hour instructional phase, a parallel post-test was administered to quantify academic and analytical growth. Additionally, students completed a five-point Likert-scale questionnaire to gauge their affective responses and attitudes toward the physics curriculum. The compiled data were analyzed using inferential statistics; a dependent-samples t-test evaluated pre-to-post improvements in both learning achievement and analytical thinking, while a one-sample t-test assessed whether post-instruction scores significantly exceeded the stipulated 60% curriculum mastery criterion. Descriptive statistics, including means and standard deviations, were used to interpret students' overall positive attitudes toward the instructional process.

Ethical Considerations

This research received formal ethical clearance from the Research Ethics Committee of the Faculty of Education, Physics Department, Nakhon Si Thammarat Rajabhat University. The ethics certificate, bearing number 025/2569, was issued and approved on February 20, 2026. The researcher adhered to ethical research principles by safeguarding the rights and well-being of all participants. This involved introducing the study to the sample group, clearly explaining its objectives, detailing the research methodology, outlining the potential benefits of participation, and explicitly confirming that the study posed no harm or foreseeable risks to the participants. Furthermore, all participants had full autonomy to consent to or decline participation, with the assurance that their decision would have no adverse implications. All collected data were treated with strict confidentiality and used exclusively for the stated research purposes. The research findings would be presented in aggregate form, and participants retained the right to withdraw from the study at any point before its conclusion without obligation to provide a reason.

Research Results

The analysis of empirical data concerning the analytical thinking abilities and attitudes toward Physics 1 among tenth-grade students, following the implementation of Polya's problem-solving framework, yielded the following key findings:

Pre- and Post-Instruction Learning Achievement

As presented in Table 1, the comparative analysis of learning achievement scores demonstrated a statistically significant improvement from pre-instruction to post-instruction. Post-instruction scores ($M = 12.83$, $SD = 2.09$) were significantly higher than pre-instruction scores ($M = 8.37$, $SD = 2.27$), with a highly significant statistical difference at $t(29) = 8.74$, $p < .001$. The observed effect size (Cohen's $d = 1.59$) was notably large, indicating both the statistical and practical significance of Polya's problem-solving instruction on students' learning achievement.

Table 1 Comparison of Physics Learning Achievement on Equations for Linear Motion and Free Fall of Mathayomsuksa 4 Students Before and After Instruction

Testing	N	$\bar{X}$	S.D.	t	df	Cohen's d
Post -test	30	12.83	2.09	8.735**	29	1.59
Pre-test	30	8.37	2.27			

** P < .001

Mastery Criterion Evaluation

Table 2 presents results comparing post-instruction learning achievement with a predetermined 60% mastery criterion. The mean post-instruction score for students ($M = 12.83$, equivalent to 64.17%) was statistically significantly higher than the 60% criterion, $t(29) = 2.18$, $p < .05$. The moderate effect size (Cohen's $d = 0.40$) indicates that students' learning outcomes consistently exceeded the minimum competency standard set by the curriculum.

Table 2 Comparison of Post-Instruction Physics Learning Achievement on Equations for Linear Motion and Free Fall of Mathayomsuksa 4 Students with the 60% Criterion

Experimental Group	N	60% Criterion	$\bar{X}$	S.D.	t	Cohen's d
Posttest	30	60	64.17 (12.83 points)	10.43	2.18*	0.40

* P < .05

Enhancement of Analytical Thinking Ability

Table 3 shows a substantial increase in students' analytical thinking ability after the instructional intervention. Post-instruction scores (M = 30.11, SD = 3.28) were significantly higher than pre-instruction scores (M = 21.09, SD = 2.43), with a highly significant statistical difference at t(29) = 14.52, p < .001. The remarkably large effect size (Cohen's d = 2.65) unequivocally demonstrates the significant practical impact of Polya's problem-solving instruction on students' cognitive development.

Table 3 Comparison of Students' Analytical Thinking Ability in Physics 1 on Equations for Linear Motion and Free Fall Before and After Instruction

Testing	N	$\bar{X}$	S.D.	t	Cohen's d
Post -test	30	30.11	3.28	14.52**	2.65
Pre-test	30	21.09	2.43		

** P < .001

Student Attitudes Toward Physics Instruction

An examination of students' attitudes towards Physics 1, specifically regarding equations for linear motion and free fall, revealed highly positive sentiments after the intervention. As detailed in Table 4, the mean score for interest or curiosity in learning was high (M = 3.69, SD = 0.96). Similarly, the mean score for responsibility, determination, patience, and perseverance was high (M = 3.75, SD = 0.99). The overall mean attitude score encompassing both behavioral objectives was 3.72 (SD = 0.98), consistently interpreted as a high level of positive attitude.

Table 4 Students' Attitudes Toward Learning Physics 1 After Instruction Using Polya's Problem-Solving Process

Behavioral Objectives	$\bar{X}$	S.D.	Interpretation
Interest or curiosity in learning	3.69	0.96	High
Responsibility, determination, patience, and perseverance	3.75	0.99	High
Overall	3.72	0.98	High

Conclusion and Discussion

Elevating Physics Learning Achievement and Mastery

The empirical results unequivocally demonstrate the effectiveness of Polya's problem-solving process in enhancing students' knowledge and conceptual understanding. Post-instruction learning achievement was statistically significantly higher than pre-instruction scores (p < .001) with a very large effect size (Cohen's d = 1.59). Specifically, the "Understanding the Problem" step enables students to clearly analyze problem statements, identify key information, and define unknowns—foundational skills vital for systematically connecting variables in physics. This aligns with Pimdee et al. (2024), who reported that active, problem-based learning approaches foster systematic analytical thinking and lead to higher academic outcomes. Furthermore, students' post-instruction achievement significantly surpassed the 60%

curriculum mastery criterion ($p < .05$). This structured engagement allows students to appropriately connect theoretical knowledge with practical applications, mirroring the findings of Chookhampaeng et al. (2025), which emphasize that step-by-step problem-solving approaches significantly promote deeper problem comprehension and mastery beyond baseline standards.

Development of Analytical Thinking Abilities

Students' analytical thinking abilities exhibited substantial, statistically significant growth post-instruction ($p < .001$, Cohen's $d = 2.65$). This profound improvement indicates that integrating Polya's process effectively cultivates higher-order cognitive skills. From a procedural perspective, Polya's sequential steps promote metacognitive regulation; during the planning and execution stages, students use strategic techniques such as selecting appropriate equations, establishing relationships between variables, and systematically sequencing calculations. These outcomes strongly align with Memıs & Ergun (2023) and Yapatang & Polyiem (2022), who found that structured, inquiry-based, and cooperative problem-solving frameworks significantly improve students' analytical reasoning and mathematical problem-solving capabilities. This underscores the need to design learning activities that intentionally foster critical thinking to optimize educational effectiveness.

Cultivation of Positive Academic Attitudes

Beyond cognitive gains, the instructional intervention successfully cultivated a high level of positive attitude toward Physics 1. Students demonstrated strong interest, curiosity, responsibility, and perseverance throughout the learning process. These affective improvements align with Pratiwi et al. (2023), who found that structured, engaging instructional activities boost student motivation more than conventional methods. Furthermore, as supported by the unidimensional attitude metrics established by Kind et al. (2007), a systematic approach helps students see complex physics problems as manageable. By breaking challenges down into clear, structured steps, Polya's framework fosters self-confidence and promotes enduring positive attitudes toward scientific learning (Dookurong et al., 2025).

Pedagogical Implications and Future Research

Ultimately, integrating Polya's problem-solving process into high school physics instruction is a highly effective pedagogical approach that enhances academic achievement, analytical thinking, and positive affective outcomes. Educators should actively incorporate this systematic method to cultivate higher-order thinking and support metacognitive regulation. Future research should employ more robust experimental designs with dedicated control groups to establish definitive causal relationships. Additionally, expanding the demographic sample across diverse educational contexts and utilizing qualitative methods—such as think-aloud protocols—would yield richer insights into students' metacognitive strategies and specific cognitive pathways during complex problem-solving.

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