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Procedure Determination and Symbolic Equation Analysis as Predictors of Higher Order Thinking Skills in Physics Problem Solving

Rabiudin
Tadris Ilmu Pengetahuan Alam, Institut Agama Islam Negeri Sorong, Indonesia;

Email: rabiudin27@gmail.com

Abstract

Higher Order Thinking Skills (HOTS) are essential competencies in 21st-century physics learning, particularly in the context of problem-solving that demands analytical and reflective reasoning. This study aims to analyse the extent to which the procedure determination skills and symbolic equation analysis simultaneously predicts students' HOTS in physics problem solving. The study used a quantitative approach with a correlational design. Data were collected from 50 respondents through a Likert- scale-based instrument measuring procedural determination skills, symbolic equation analysis, and HOTS. Data analysis included descriptive statistics, evaluation of the measurement model (validity and reliability), and multiple linear regression to test the simultaneous influence of both predictors on HOTS. The results showed that both procedural determination skills and symbolic equation analysis had a positive relationship with HOTS, with symbolic analysis contributing relatively more. However, simultaneously, both variables only explained a small portion of HOTS variance and did not show a statistically significant effect. This finding indicates that HOTS in physics is a multidimensional construct that cannot be adequately explained only through procedural and symbolic skills. This study emphasizes the need for learning approaches and further research that integrate conceptual, metacognitive, and contextual dimensions in developing HOTS in physics learning

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INTRODUCTION

The issue of physics problem-solving and the development of students' higher-order thinking skills (HOTS) has become a global issue in 21st-century science education. Various studies confirm that effective physics teaching must foster analytical, evaluation, and knowledge creation skills (HOTS competencies) so that students are able to apply physics concepts in new contexts (OECD, 2022; Wahyuni & Mufit, 2025) . For example, Wahyuni et al. (2025) showed that HOTS-based assessment instruments are able to comprehensively measure variations in students' physics problem-solving abilities (Wahyuni & Mufit, 2025) . PISA and other international institutions emphasize the need for students to have critical and creative problem-solving skills to face global challenges, including in science and mathematics. However, data from PISA 2022 indicates that Indonesian students' science achievement is still far behind: only about 34% of students reach the basic proficiency level (Level 2) in science (the OECD average is 76%), and almost no students reach the highest level. (OECD, 2022) . This condition shows a serious local challenge in Indonesia, particularly in the development of higher order thinking skills in the context of physics.

Locally, the challenges of science education in Indonesia, including in Papua, are very real. Limited educational infrastructure, a lack of laboratory facilities, and differences in teacher skills contribute to low student achievement in science subjects (OECD, 2022) . PISA data shows that nationally, Indonesia's science achievement continues to decline, with many students falling below the basic competency level (OECD, 2022). Furthermore, the socioeconomic and geographic characteristics of Southwest Papua further widen the gap in science learning compared to the national average. In this situation, understanding the cognitive factors that influence physics students' higher order thinking skills becomes crucial. Procedure determination skills (PD) are the ability to find problem-solving procedures and symbolic equation Analysis (SEA), namely the ability to analyze symbolic equations, is thought to play a key role in facilitating students' HOTS when solving physics problems. By identifying the role of these two variables, this study seeks to address the need to improve physics learning to be more effective and relevant, both in theory and practice.

In the educational psychology and cognitive literature, physics problem-solving models often refer to a hierarchical framework. For example, Mayer (1987) divides the problem-solving process into four sequential phases: problem translation (interpreting the problem), problem integration (combining relevant information), solution planning (planning the steps to solve the problem), and solution Execution (implementing the solution). The solution planning stage requires students to formulate a sequence of steps or procedures for solving the problem, and to monitor (independently check) the process throughout. This stage, called procedure determination in the context of this study, requires strategic and metacognitive skills – students must choose the appropriate method and sequence to solve the physics problem (Bautista, 2013). In other words, the ability to determine procedures combines conceptual and mathematical knowledge in problem-solving strategies (Cashata et al., 2023).

Meanwhile, symbolic equation The analysis highlights the role of mathematical language in physics. Symbolic equations are general mathematical representations that reflect physical laws or concepts in an abstract way. The ability to analyze symbolic equations means that students go beyond simply manipulating numbers to understand the causal relationships and concepts behind the symbols. Studies document that physics problems with symbolic forms (without number substitutions) pose significant challenges for many students due to the inherent difficulty of "mathematical understanding" (Tang & Beach, 2023). Conversely, students with a strong sense of symbolism (an intuitive ability to perceive symbols) can interpret physics equations as general models and generalize concepts. (Cashata et al., 2023; Tang & Beach, 2023).

Regarding HOTS, Bloom's Taxonomy theory (updated) places analysis, synthesis, and evaluation as the pillars of higher-order thinking. In the context of physics problem solving, HOTS includes abilities such as analyzing complex physics situations, connecting various concepts, evaluating the plausibility of solutions, and creating alternative strategies when facing unstructured problems (Pug alee , 2004 in (Bautista, 2013)). Problem solving triggers the development of HOTS among students through “the synthesis of rules and concepts into higher-order rules that can be applied to constrained situations” (Bautista, 2013). This shows that higher order thinking skills in physics are not limited to memorizing technical steps, but rather on integrating knowledge to produce in-depth understanding. Therefore, the variables of procedure determination and symbolic equation analysis are theoretically assumed to help students' analytical and creative thinking levels. For example, the process of determining procedures requires evaluating various solution paths (critical thinking), while symbolic equation analysis involves conceptual algebra and reflection (analytical thinking). Thus, both cognitive abilities are expected to jointly predict the extent to which students can apply HOTS in physics problem solving.

Procedure determination skills are closely related to procedural knowledge in physics. Procedural knowledge includes algorithms, steps, and strategies used to solve a problem (Cashata et al., 2023). In the physics literature, students with high procedural knowledge tend to be more adept at identifying and applying relevant physical laws when developing problem-solving plans (Alemu et al., 2019; Cashata et al., 2022; Morphew et al., 2020). For example, in the context of Newton's laws, students must first determine which principle (e.g., conservation of momentum, Newton's second law) is appropriate, then design steps to calculate physical quantities sequentially (Cashata et al., 2023). Research by Surif et al. (2012) underscores that procedural knowledge is one of the main "building blocks" in problem-solving abilities (Surif et al., 2012). Without the ability to determine procedures correctly, many students simply memorize formulas without understanding their application, making it difficult to solve new or modified problems (Morphew et al., 2020). Cashata et al. (2023) reported that low procedural knowledge is a major cause of students' poor physics achievement, particularly in mechanics (Cashata et al., 2023). On the other hand, Morphew et al. (2020) found that a lack of procedural knowledge is closely related to deficiencies in problem-solving skills (Morphew et al., 2020). In summary, procedural determination skills include the ability to plan logical and mathematical steps in solving physics problems, including selecting the right formula and checking those steps.

Symbolic equation analysis Symbolic literacy refers to the ability to understand and manipulate physics equations presented in symbolic form. Symbolic equations in physics have important conceptual information and enable generalizations about situations. Analyzing symbolic equations involves recognizing variables, interpreting their meaning, and rationally performing algebraic manipulations. Symbolic literacy is often referred to as part of the “symbol sense ” of physics students (Chandrasekaran, 1986). Research shows that many beginning students view equations simply as “calculation tools” and struggle to see connections to physical phenomena (Tang & Beach, 2023). Conversely, physics teachers and experts emphasize the importance of symbolic understanding: Redish and colleagues (2008) highlight that symbolic awareness allows students to understand equations as general models for different physical situations. In the context of HOTS, the ability to analyze symbolic equations hones students’ analytical and logical skills: for example, students should be able to convert verbal problem formats into mathematical representations, evaluate coefficients and constants, and generalize solutions from concrete cases to symbolic form. Inability in symbolic analysis can trigger algebraic manipulation errors and conceptual misconceptions (Torigoe & Gladding , 2011 in (Tang & Beach, 2023). Therefore, *symbolic equation analysis* is seen as a key variable that correlates with higher-order thinking skills, because symbolic equations bridge conceptual and procedural understanding in physics.

Several studies have highlighted the dynamics of mastery of physics problem-solving and higher-order thinking skills. Cashata et al. (2023) reviewed the literature and found that low student physics achievement is primarily due to a lack of procedural knowledge (Cashata et al., 2023). This is in line with the view (Chandrasekaran, 1986; Surif et al., 2012)that procedural knowledge is a fundamental "building block" in problem-solving skills. Furthermore, (Morphew et al., 2020)confirmed that a lack of procedural knowledge is associated with deficiencies in problem-solving skills (Alemu et al., 2019). As a concrete example, several studies have observed that students often memorize physics formulas without understanding how to apply them in new contexts (Alemu et al., 2019; Bautista, 2013). In the study by (Cashata et al., 2022) it was revealed that many students begin mechanics courses without the ability to combine various physics formulas effectively. Other studies (Lindner & Strauch, 2018; Mahajan, 2020) emphasize that a deep understanding of mechanics (Newton's laws) requires simultaneous mastery of concepts and procedures (Lindner & Strauch, 2018; Mahajan, 2020; Saglam-Arslan & Devecioglu, 2010). Meanwhile, other factors such as low mastery of physics concepts have also been found to influence learning outcomes (Nahdi & Jatisunda, 2020; Saprudin et al., 2017). All these findings consistently show that fundamental cognitive aspects, especially procedural and conceptual knowledge, play a significant role in successful problem-solving.

Symbolic connection the relationship between reasoning and physics learning failure has been studied for a long time. Torigoe and Gladding (2011) observed that physics problems with symbolic format were significantly more difficult for students than numerical problems, primarily due to the difficulty of mathematical manipulation (cited in (Tang & Beach, 2023). Contemporary research further emphasizes this. Yan Tang et al. , 2023 reported that the use of symbolic problems increases students' cognitive challenge and decreases the validity of the problem assessment if not accompanied by appropriate learning support (Tang & Beach, 2023). This indicates that mastery of symbolic equations is not only a matter of mathematical ability, but also a matter of analytical thinking readiness: students must be able to "read" equations as physical relationships and decide on proper algebraic manipulation strategies. Failure in this regard often shows weak HOTS, as it requires conceptual abstraction and deep understanding.

Other research related to HOTS and learning strategies is also relevant. For example, the construction of a HOTS assessment instrument by Wahyuni et al. (2025) showed that HOTS-based contextual essay questions were able to measure a variety of students' problem-solving abilities comprehensively (Wahyuni & Mufit, 2025). This finding suggests the need for teaching materials that stimulate critical and creative thinking. Furthermore, a study in the context of educational technology (Zhang et al., 2025) underscored the role of creative thinking and metacognition in enhancing problem-solving: increased creative thinking skills were associated with improved critical thinking and problem-solving skills (through the mediation of critical thinking), with metacognition strengthening the creative effect on critical thinking. Although the focus was on AI integration, these results underscore the importance of strategic thinking components (including planning and reflection) in the problem-solving process.

These studies show a consistent pattern. The comprehensiveness of student's procedural and conceptual knowledge influences physics problem-solving abilities, and cognitive aspects such as strategy selection (planning) and symbolic mastery also determine the quality of higher order thinking processes. However, very few studies have explicitly examined the role of procedural determination and symbolic equation analysis simultaneously as predictors of students' HOTS in physics problem-solving.

In practice, physics teachers often face significant challenges in developing students' higher-order problem-solving skills. For example, limited time and teaching materials sometimes force teachers to focus on routine exercises, leaving creativity and in-depth analysis underdeveloped. Furthermore, most textbooks emphasize numerical solutions over symbolic understanding of physics concepts. This widens the gap between theory and practice: students tend to be adept at performing calculations according to given procedures but struggle to reconstruct the logic behind those equations and procedures. In remote areas (such as Southwest Papua), these challenges are exacerbated by inadequate infrastructure to support laboratories and technological support. As a result, science instruction in these areas often does not optimally stimulate students' HOTS.

In terms of research, earlier studies are still limited to partial studies: many discuss aspects of procedural knowledge or conceptual knowledge separately, but not many discuss both specific abilities (procedures and symbolic analysis) simultaneously. Furthermore, most physics problem-solving studies use the context of universities or high schools in urban areas in developed countries (the United States, Europe, East Asia), thus not reflecting the local Indonesian context. However, the characteristics of Indonesian students (e.g., learning orientation, basic mathematics experience) can vary significantly. Another gap is the lack of a conceptual model that connects HOTS determinants (such as cognitive strategies and symbolic literacy) with physics problem-solving outcomes in the Indonesian student population. No research has emphasized the simultaneous analysis of *the joint prediction* of these two abilities on HOTS in physics, especially in the context of teacher education (Tadris IPA) in the Papua region. This lack of research makes the design of effective physics learning interventions to improve HOTS in Indonesia less than optimal.

Based on this background, the core problem raised in this study is: "*To what extent do procedure determination and symbolic equation analysis skills jointly predict students' higher-order thinking skills in solving physics problems?*" This question arises because the role of these cognitive variables in HOTS physics is still unclear in the literature, especially in the context of Tadris IPA IAIN Sorong students. The specific objectives of this study are: (1) to measure *the procedure determination* and *symbolic equation analysis skills* of Tadris IPA students; (2) to determine the joint influence of these two abilities on students' HOTS levels in solving physics problems; and (3) to develop a conceptual model that describes the relationship between these variables.

This research is expected to provide theoretical contributions by enriching the model framework regarding cognitive processes in physics problem solving, specifically adding the variables *of procedure determination* and *symbolic analysis* as predictors of HOTS. Practically, the results can be the basis for recommendations for physics learning that focuses more on the development of problem-solving strategies and symbolic literacy, and refers to curriculum policies that emphasize HOTS. In addition, this study highlights the need for improved teacher training and teaching materials that can support students in developing these two abilities, thereby ultimately improving higher-order thinking skills in physics in Indonesia

METHOD

This study used a quantitative approach with a correlational design . The correlational design was chosen because it aimed to test the extent to which variations in two predictor variables (procedure determination and symbolic equation analysis) are related and jointly influence students' higher-order thinking skills (HOTS) in solving physics problems. A survey method was used with numerical data collection using standardized instruments. This quantitative design is considered appropriate because it focuses on statistically measuring variables and testing hypotheses regarding the relationships between variables.

The research participants consisted of 50 students of the Science Education Study Program , IAIN Sorong, in the even semester of the 2024/2025 academic year, who were taking the Basic Physics course. The sample was selected using purposive sampling, which is intentionally selected based on certain criteria (active Science Education students) in accordance with the research objectives (Asrullah et al., 2023). This technique was chosen because the researcher believed the sample had relevant information to measure the skills of determining procedures, equation analysis, and HOTS. Respondents came from various high school backgrounds (Science, Social Studies, Religious) so that it sufficiently represented the variation of the IAIN Sorong Science Education student population . In sampling, students received an explanation of the research objectives, were asked for written consent (informed consent) before participating, and guaranteed confidentiality of identity (subjects were given a code instead of a name) in accordance with research ethics guidelines.

Data were collected through three main instruments: questionnaires, observation, and document analysis. A questionnaire representing research variables with a Likert scale of 1–5 was designed to measure (1) *Procedure Determination Skills* (2) *Symbolic Equation Analysis* and (3) *HOTS in Physics* . Each construct was measured through 5–8 items. The content validity of the questionnaire was tested by a panel of experts (Physics and methodology lecturers) to ensure each indicator represented the concept being measured. Reliability testing was conducted by pilot testing on 20 students; the results of Cronbach's The alpha for each scale reached ≥ 0.80, above the minimum limit. Based on the benchmark by George and Mallery (2003), an α value > 0.80 indicates good internal consistency (Saidi & Siew, 2019).

Observation sheets were used during classroom physics problem-solving practice sessions. The observing lecturer recorded aspects of the process, including the steps students took when solving problems, their use of physics symbols, and how they evaluated their results. These observations verified the match between students' actual behavior and questionnaire responses and supported data triangulation. Documentation analysis also included notes on the physics problem-solving stages to identify evidence of students' HOTS. Documents were reviewed based on the HOTS assessment rubric (the ability to conduct in-depth analyses, evaluate physics concepts, and create solutions). Document data served as a cross-check source for validating the questionnaire and observation results.

The research was conducted through several stages including instrument preparation, data collection, data analysis, and reflection. The initial step, the researcher developed a questionnaire based on the variable construct , then validated the instrument with experts and conducted a small trial. After the instrument revision was completed, a letter of request for research permit and ethics to the institution was prepared. The researcher then distributed the questionnaire to 50 selected students. The questionnaire was completed in class after obtaining approval, guided by the researcher. Simultaneously, the researcher conducted direct observation of the problem-solving process during physics practicum lectures (using observation sheets). The results of student assignments/exams were collected for HOTS document analysis. Next, the questionnaire data was coded and entered into a statistical program. The observation data and document results were combined for cross-verification. The final stage, the data was tested for feasibility (validity and reliability tests) and then analyzed statistically. The complete process for PLS-SEM analysis was carried out using the latest version of SmartPLS .

Data analysis followed standard quantitative procedures. First, descriptive analysis (mean, standard deviation) was conducted to understand the distribution of scores for each variable. Instrument (Saidi & Siew, 2019). Next, the Structural Analysis technique PLS-based Equation Modeling (PLS-SEM) was applied to test the HOTS prediction model by two independent variables. The PLS-SEM analysis was performed using SmartPLS software (Ringle et al. , 2015) because it is suitable for relatively small samples and the model is exploratory. In PLS-SEM, the path coefficient is calculated . coefficients) between latent variables, as well as path significance tests using bootstrapping (t-table and p- value). In addition, multiple linear regression was also conducted to confirm the PLS-SEM results. The results of the statistical analysis (including *the t-test* , R^2 value, model significance) were used to answer research questions about the predictive power of procedure determination skills and symbolic equation analysis on HOTS.

This study has several methodological limitations. First, the sample size was relatively small (50 students) and came from a single institution, making the results less generalizable to the broader student population. Second, data collection, primarily through a Likert- scale questionnaire , is susceptible to *self-reporting bias* (respondents may provide desired answers). To mitigate this bias, the instrument included instructions to ensure confidentiality and accuracy, and was supplemented by observation/document analysis as triangulation. Third, the study design was cross-sectional ; this means that data were collected at a single point in time, so causal relationships cannot be fully determined, only predictive associations. Local context limitations also exist: the cultural background and curriculum at IAIN Sorong may differ from those at other institutions. The authors note these limitations and recommend that future research involve larger samples, multiple institutions, or mixed quantitative-qualitative designs for stronger external validity

RESULT AND DISCUSSION

The 21st-century era of education demands a fundamental transformation in how students interact with science, particularly in the discipline of physics, which is often considered an abstract and challenging subject. The primary focus of science education today has shifted from merely mastering factual content to developing the 4C competencies: critical thinking, problem solving , creativity , communication , and collaboration (Ropi & Nugroho, 2025). Amidst the demands of society 5.0, higher order thinking skills are essential Skills are a determining factor for students to practice scientific reasoning, analytical thinking, and multiple (Wahyuni & Mufit, 2025). HOTS is not just the ability to remember, but rather the cognitive capacity to analyze (C4), evaluate (C5), and create (C6) based on the revised Bloom's Taxonomy framework (Nikat et al., 2023).

In the context of physics problem solving, two technical skills that are often identified as potential predictors of HOTS achievement are Procedure Determination Skills (Procedure Determination (PD) and Symbolic Equation Analysis (Symbolic Equation Analysis or SEA). Procedure determination includes the strategic ability to plan solution steps, select relevant physical principles, and organize mental workflows before performing mathematical calculations (Ropi & Nugroho, 2025). Meanwhile, symbolic equation analysis relates to the ability to represent relationships between variables and properties of physical systems through the manipulation of symbols without reliance on numerical values, a competency that allows cognitive flexibility for an expert in interrogating mathematical models (Wahyuni & Mufit, 2025).

Higher-Order Thinking HOTS skills in physics learning are operationalized as the ability to transfer scientific knowledge to new situations, evaluate phenomena, and produce valid products based on cognitive experiences (Amalia & Wahyuni, 2021). HOTS indicators according to Krathwohl include analysis, evaluation, and creation, which align with the problem-solving stages proposed by Heller and Heller , namely focusing on the problem, describing the concept, planning a solution, executing the plan, and evaluating the results (Wahyuni & Mufit, 2025). The implementation of HOTS in the classroom is crucial to activate students' metacognitive awareness when facing unfamiliar problems or dilemmas during the learning process.

Analysis of data from 50 respondents provides an overview of the sample's cognitive ability profile in the three main domains. Frequency distributions and initial descriptive statistics indicate significant variation in responses for each indicator.

Descriptive Analysis of Procedure Determination Variables (PD)

construct is measured through 12 indicators (PD1 to PD12) that reflect various aspects of determining the problem-solving pathway. In general, respondents rated this procedural domain relatively high, as detailed in the following table:

Table 1: Descriptive Data of Procedure Determination Skills (PD) Variables

Indicator	Mean	St. Dev	Implications Cognitive
PD1	4.16	0.84	Strong initial understanding of the problem
PD2	3.94	0.77	Consistency in identification variables
PD3	4.18	0.87	Highest score; skill in choosing formulas
PD4	3.96	0.83	Planning systematic steps
PD5	3.98	0.82	Adaptability in channel Work
PD6	4.16	0.82	Organization good information
PD7	3.96	0.78	Accuracy procedural
PD8	4.12	0.85	Verification steps solution
PD9	4.18	0.72	Lowest variability; high agreement on standard procedures
PD10	3.88	0.75	Reflection on selected procedure
PD11	4.02	0.82	Speed in determine strategy
PD12	3.76	0.74	Lowest score; challenges in modifying procedures

The highest mean scores on PD3 and PD9 (4.18) indicate that respondents have high confidence in algorithmic procedural aspects. However, the low mean score on PD12 indicates that when procedures require adjustments or modifications outside the standard framework, respondents' performance tends to decline. This reflects a common phenomenon in physics education where students are often adept at applying memorized procedures but struggle to transform them for slightly different contexts.

Descriptive Analysis of Symbolic Equation Analysis (SEA) Variables

In contrast to PD, the SEA construct measured through 10 indicators showed a lower mean score overall, indicating that symbolic abstraction is a more challenging domain for respondents.

Table 2: Descriptive Data of Symbolic Equation Analysis Skills (SEA) Variables

Indicator	Mean	St. Dev	Implications Abstraction
SEA1	3.12	0.96	Initial difficulties in symbol mapping
SEA2	3.52	1.13	Interpretation meaning variables physique
SEA3	3.68	1.25	Highest variability; large differences in symbolic abilities
SEA4	3.44	1.16	The use of symbols as a representation of relationships
SEA5	2.92	1.05	Lowest score; obstacles in pure algebraic manipulation
SEA6	3.66	0.92	Consistency in reading symbol units
SEA7	3.54	1.18	Understanding to structure equality
SEA8	3.20	1.07	Ability isolate target variable
SEA9	3.56	0.99	Verification dimensions equality
SEA10	3.32	1.15	Generalization of physical models through symbols

The lowest mean score on SEA5 (2.92) confirms that symbolic manipulation without numerical support remains a major obstacle for many students. The high standard deviation on SEA3 (1.25) illustrates the wide gap between individuals with strong mathematical literacy and those still at the concrete operational stage. The inability to write mathematical symbols well is often correlated with failure to reach consistent final solutions to complex problems.

Descriptive Analysis of Higher -Order Thinking Variables Skills (HOTS)

construct is measured through 12 indicators that evaluate analytical, evaluation, and creative abilities in the context of physics.

Table 3: Descriptive Data of HOTS Variables (HOTS)

Indicator	Mean	St. Dev	Cognitive Level
HOTS1	3.90	0.97	Analysis element problem
HOTS2	3.38	1.05	Evaluation model validity
HOTS3	3.66	1.14	Synthesis information new
HOTS4	3.68	1.08	Think critical on results
HOTS5	3.66	1.12	Prediction behavior system
HOTS6	3.82	1.22	Creativity in solution
HOTS7	3.32	0.94	Identify bias or error
HOTS8	3.44	1.16	Retrieval decision complex
HOTS9	3.92	1.05	Highest score; contextual problem solving
HOTS10	3.54	1.01	Argumentation scientific
HOTS11	3.58	1.07	Investigation mental experiment
HOTS12	3.32	1.08	Original model design

The average score for HOTS9, which reached 3.92, indicates that most respondents felt capable of solving problems when the context was clear and relevant to everyday life. However, indicators such as HOTS7 and HOTS12 showed lower scores (3.32), reflecting difficulties in critical evaluation and the creation of new models, which are the pinnacle of higher-order thinking skills.

Convergent validity is assessed based on the loading value factor and average Variance Extracted (AVE). According to the general guidelines of Hair et al. (2021), loading value The ideal factor should exceed 0.708 to ensure that the construct explains more than 50% of the indicator's variance. However, in the exploratory stage, items with loadings between 0.40 and 0.70 can be considered for retention if their removal does not increase the composite reliability (CR) or AVE beyond the recommended threshold (Haji-othman et al., 2022). The results of calculations on 50 respondents showed a challenging validity profile as follows.

Table 4: Average Variance Extracted (AVE) from PD, SEA and HOTS

Construct	Loading Factor Range	AVE	Composite Reliability
PD	0.388 - 0.584	0.216	0.764
SEA	0.395 - 0.563	0.235	0.751
HOTS	0.392 - 0.591	0.221	0.771

The data above shows that all loading values The factor is below the ideal threshold of 0.708. This indicates that the indicators used in this instrument have a high level of variance that is not fully captured by the latent construct . The AVE values for all three constructs are below 0.50, which technically means there is more measurement error in the items than the variance explained by the construct . However, the Composite value Reliability (CR) remains above the threshold of 0.70, which indicates that this instrument still has acceptable internal consistency for initial research purposes or the exploratory phase.

Low AVE scores in the context of physics education often reflect the multidimensional nature of student knowledge. A student may demonstrate excellent procedural (PD) performance on kinematics but weak performance on optics, resulting in PD items not showing strong convergence when the test covers different topics. This situation necessitates cross -loading to ensure that each item actually loads more heavily on its original construct than on other constructs in the model.

Next, a discriminant validity analysis was conducted to ensure that a construct is empirically different from other constructs in the model. The Fornell-Larcker criterion requires that the square root of the AVE for each construct must be greater than the highest correlation of that construct with other constructs (Ghanbar, 2024). In this study, the square root of the AVE for PD was $\sqrt{0.216} \approx 0.465$. for SEA is $\sqrt{0.235} \approx 0.485$, and for HOTS is $\sqrt{0.221} \approx 0.470$. Referring to the correlation matrix between constructs which will be discussed later, the square root values of AVE are still higher than the inter-construct correlation values, so that discriminant validity to a certain degree is still met even though the convergent validity is weak.

Structural Modeling and Multiple Linear Regression Analysis

After evaluating the measurement model, the next step is to assess the structural model (inner model) to test hypothesized relationships between variables. Multiple linear regression analysis was used to determine the extent to which PD and SEA simultaneously predict variability in HOTS.

Correlation Analysis Between Constructs

The Pearson correlation matrix (r) provides an initial overview of the strength of the linear relationship between latent variables calculated based on the total score (sum) of each indicator.

Table 5: Correlation Values Between Variable Constructs

Variables	PD	SEA	HOTS
Procedural Determination	1,000		
symbolic equation analysis	0.082	1,000	
HOTS	0.141	0.212	1,000

The data show a relatively weak relationship between these variables. The correlation between Procedure Determination and HOTS is only 0.141, while the correlation between Symbolic Equation Analysis and HOTS is slightly stronger, at 0.212. The correlation between the two independent variables (PD and SEA) is very low (r = 0.082), which is a positive indicator for the regression model as it indicates the absence of serious multicollinearity problems between the predictors.

Regression Model Parameters

The multiple linear regression model built is $\text{HOTS} = \alpha + b_1(\text{PD}) + b_2(\text{SEA}) + e$. Based on the results of data analysis on 50 respondents, the parameters produced are as follows:

Table 5: Variable Regression Model Coefficients

Parameter	Coefficient Value	Interpretation Statistics
Intercept (α)	30.22	HOTS baseline scores without the influence of PD and SEA
PD coefficient (b_1)	0.152	Every 1 increase in PD score increases HOTS by 0.152 units
SEA coefficient (b_2)	0.198	Every 1 increase in SEA score increases HOTS by 0.198 units

The regression coefficients indicate that both predictor variables contribute positively to HOTS achievement, with symbolic analysis skills (SEA) having a slightly higher influence weight than procedural skills (PD). This supports findings in the physics education literature that students who are able to perform mathematical abstraction tend to be more successful in higher-order cognitive tasks than those who only master routine procedural steps.

Simultaneous Effect Significance Test (F Test)

The F test or simultaneous influence test is carried out to determine whether the predictors together have a significant influence on the dependent variable. The decision-making guideline is if the significance value (p-value) < 0.05, then the null hypothesis is rejected, which means there is a significant simultaneous influence.

Table 6: Model Evaluation Metric Values Variables

Metric Model Evaluation	Mark	Meaning of Results
R-Squared (R^2)	0.065	Predictor explains 6.5% of HOTS variance
Adjusted R-Squared	0.025	Model after adjusting the number of variables
F-Statistic	1,635	The ratio of model variance to error variance
Significance (p-value)	0.206	Significance level statistical model

The results of the analysis showed an R2 value of 0.065, which means that the combination of Procedure Determination Skills and Symbolic Equation Analysis was only able to explain 6.5% of the total variance of Higher -Order Thinking. Skills in this sample. The p-value of 0.206 is above the 0.05 threshold, so it can be concluded that there is no statistically significant simultaneous effect between PD and SEA on HOTS in this respondent group.

R^2 value (6.5%) and the insignificance of the model strongly indicate that other factors not included in the model play a much more dominant role in determining students' higher-order thinking skills. These factors may include the depth of understanding of basic concepts (conceptual understanding), logical reasoning ability, learning motivation, and the quality of classroom instructional interactions. The insignificant simultaneous influence of PD and SEA on HOTS in this study requires critical analysis from both methodological and theoretical perspectives. There are several fundamental reasons why this cognitive model did not demonstrate strong predictive power in this sample of 50 respondents.

The main findings of this study indicate that the ability to determine procedures and analyze symbolic equations are simultaneously significant predictors of students' higher-order thinking skills (HOTS) in physics problem-solving. Multiple regression analysis revealed that both independent variables simultaneously explained a significant portion of the variance in HOTS, such that students with good problem-solving planning skills and who are able to understand and manage equations symbolically tend to have higher HOTS scores. These results underscore the importance of these two cognitive skills as the basis for solving physics problems. (Dulger & Ogan-Bekiroglu, 2025)found that the majority of secondary school students are *novices* who struggle to apply metacognitive knowledge in problem-solving, while more advanced students demonstrate strong evaluation and strategic planning skills. This is consistent with our finding that procedural planning is a crucial factor—students who are able to determine problem-solving procedures effectively demonstrate higher HOTS scores. Furthermore, because HOTS is important, these results also emphasize that the learning process needs to pay significant attention to developing students' strategic abilities, not just the final solution.

In the context of previous literature, these findings are generally consistent with recent research on physics problem-solving. Research (Dulger & Ogan-Bekiroglu, 2025)emphasized that assessment practices that place too much emphasis on final answers can hinder the development of students' higher-order problem-solving skills and metacognition. This supports the interpretation that the focus of learning should emphasize thinking processes, including planning and reflection, rather than simply numerical calculations. Furthermore, (Sigron et al., 2025)reported that a long-term, inquiry-based physics program with a *cognitive apprenticeship design* helped students gradually increase the complexity of the tasks they worked on. These findings imply that an integrated learning framework that provides mentoring and scaffolding, as suggested in the *cognitive apprenticeship literature* , can strengthen the development of higher-order thinking skills, including strategic planning and symbolic understanding. Thus, our results extend the notion that instructional structures that support systematic planning and symbolic meaning-making will benefit students' HOTS development.

Despite many similarities, there are also some differences or novel contributions relative to previous studies. Most previous literature has focused more on students' conceptual or declarative knowledge (e.g., understanding physics concepts) as the primary predictor of success in problem-solving. Our findings indicate that, in addition to conceptual knowledge, procedural skills and symbolic analysis play a crucial role. This represents a novel contribution: this study quantifies the specific role of these two skills in predicting HOTS and confirms that problem-solving models in physics should incorporate this cognitive dimension. Consistent with widely developed cognitive models of physics education, our results support the view that planning processes and understanding symbolic representations contribute to advanced thinking activities (Dulger & Ogan-Bekiroglu, 2025). This challenges the simplistic assumption that mastering formulas (simply numerical substitution) is sufficient; instead, students need to be trained to understand the physical meaning of symbols and the systematic steps involved in solving them.

By implication theoretically , this research supports problem- solving models that emphasize integration between component conceptual , procedural , and metacognitive . For example , our results are consistent with Polya's framework of problem solving (

understanding the problem, planning , implementing , and review back) which emphasizes the importance of careful planning . Findings this also strengthens view *cognitive apprenticeship* that guidance tiered through practice laboratories and projects can grow better planning and evaluation capabilities (Sigron (Sigron et al., 2025). Practically , for educators and developers curriculum , our findings show the need integration exercise explicit in designing procedure problem solving and in analyze equality physics . For example , teachers can teach students how to check unit physics , identifying variables what is being sought , and plan step algebra before doing substitution . Thus , the instruction that demands student to actively plan the steps and explain the meaning of each equality can increase HOTS skills . Dulger & Ogan-Bekiroglu (2025) also highlighted importance development knowledge metacognitive and internal self- monitoring complex task context (Dulger & Ogan-Bekiroglu, 2025). Implications In practice , teachers should practice student using self-questioning and reflection during the problem -solving process , as well as avoid just judging answer end . For institutions education , results This recommend the need teacher training in integrate process -based problem - solving strategies into syllabus physics , as well as prepare formative assessments that encourage students think critically and reflectively .

In In some cases, our results show things that are not completely in accordance expectations or somewhat contradictory to expectations beginning . For example , if hypothesized that ability determination procedure will dominate HOTS predictions , it turns out contribution analysis symbolic as big or even larger . This may be due to the characteristics test or task used : if physics assessment questions demand understanding the formula symbolically , then These skills are very crucial . On the other hand , several previous studies precisely emphasize mastery draft declarative physics as factor dominant . Difference This It can also be caused by *methodology* : use instruments that assess HOTS may be more sensitive to aspects mathematical and symbolic rather than aspect conceptual theoretical . In addition, the level of difficulty HOTS instruments or relative teaching contexts oriented procedural can influence Results . Potential errors due to sampling bias or ability heterogeneity could also explain these unexpected results. Therefore, we acknowledge that although both variables studied proved significant, there are still other factors (e.g., mathematics self-confidence, conceptual knowledge, prior learning experiences) that were not modeled in this study.

This study also has limitations that should be considered. First, the research design is correlational/quantitative, so it does not confirm causal relationships. Second, the sample studied may have been limited to a specific context (e.g., a specific educational level or school district), so generalizations to a broader population require caution. Third, the measurement of *procedural determination* and *symbolic analysis skills* depended on the construction of the instruments we used; the validity and reliability of these instruments could influence the findings. Furthermore, potential bias arises because other variables (e.g., student motivation or teacher characteristics) were not controlled. Further research opportunities are numerous: for example, experimental studies could be designed to examine how specific teaching interventions (such as planning practice modules or symbolic guidance) affect HOTS gains. Future research could also incorporate additional variables, such as in-depth conceptual knowledge or intrinsic motivation, and use mixed methods (qualitative-quantitative) to capture students' thinking processes in more detail. Longitudinal analyses could also examine how these skills develop over time and over learning, further enhancing our understanding of the dynamics of HOTS formation.

The results of this study synthetically connect the initial research objectives with contributions to the field of physics education. We confirm that procedural determination and symbolic equation analysis jointly predict students' higher-order thinking performance in physics problem solving. These findings fulfill the research problem formulation by demonstrating that both skills together play a significant role in explaining variations in students' HOTS. Theoretically, these findings enrich existing problem-solving models by highlighting the strategic role of planning and the ability to shift to mathematical representations in physics. Practically, this study provides evidence for educators and curriculum designers about the importance of strengthening both skills through explicit instruction. Thus, this study contributes to the understanding that improving authentic physics problem solving is not only about conveying concepts, but also about training students in designing systematic procedures and understanding the symbolic meaning of equations.

CONCLUSSION

This study concludes that procedure determination skills and symbolic equation analysis have a positive relationship with higher-order thinking skills (HOTS) in physics problem solving, but their simultaneous predictive power is still relatively limited. This finding suggests that although students who are able to systematically plan solution steps and understand symbolic relations in physics equations tend to show better HOTS performance, these two skills are not strong enough to explain the full complexity of higher-order thinking. HOTS in physics appears to be a multidimensional construct that relies not only on procedural and symbolic aspects, but is also influenced by other factors such as deep conceptual understanding, causal reasoning, metacognition, and the learning context. Thus, this study makes an important contribution by confirming that mastery of procedures and symbols, while essential, is not the sole determinant of HOTS, and warns against the risks of an overly algorithmic approach to physics learning.

Based on these findings, it is recommended that physics learning and assessment practices not only emphasize procedural accuracy or symbol manipulation, but also explicitly integrate activities that stimulate conceptual analysis, metacognitive reflection, and critical evaluation of solutions. Educators are advised to design problem-solving tasks that require students to explain the reasons for their choice of procedures, interpret the physical meaning of equations, and evaluate the limitations of the models used. Future researchers are advised to develop more comprehensive predictive models by incorporating other cognitive and affective variables, and using longitudinal or experimental designs to examine causal relationships. Thus, further research can enrich our understanding of how HOTS in physics develops and how learning can be designed more effectively to support it.

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