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# Tracking Problem-Solving Behavior in One-Dimensional Kinematics: A Study of Physics Education Undergraduates

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**Abstract**

A qualitative study was employed to explore undergraduate Physics Education students' behavior during problem-solving of one-dimensional kinematics. Six undergraduate students from Physics Education program were chosen as the participants. The main data for this research were gathered through the think-aloud technique, which involved recording participants' verbalizations, transcribing, and coding the data. This analysis was further supported by observations, interviews, and students' written responses. The study identified twenty-four distinct behaviors commonly exhibited by students when solving problems related to one-dimensional kinematics. These behaviors included initial reading, repeated reading, strategic reading, organizing information, clarifying the problem context, drawing a visual representation, recalling relevant knowledge, identifying the goal, selecting the appropriate formula, identifying the variable, developing the plan, formulating a sub-plan, linking the concept, considering the formula, considering the variable, checking the plan, checking the computation, estimating the answer, recognizing error, evaluating the plan, reflecting on themselves, performing basic calculation, performing algebra, and presenting or writing down the solution. These behaviors were categorized into eight broader groups, which allowed for a clearer interpretation of students' behavior during problem-solving. The eight categories of behavior revealed in this study align with Polya's four-step problem-solving model and Schoenfeld's theory of metacognition. The results offer meaningful insights into the ways students interpret, plan, and evaluate solutions to physics problems. The findings also provide important implications for physics education by offering insights that lecturers can use to design learning instruction that explicitly supports the development of students' problem-solving skills. Future research is suggested to design targeted interventions that support the development of expert-like problem-solving in undergraduate physics education based on the results of this study.

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## INTRODUCTION

Problem-solving has been identified as one of the key skills required in the 21st century (González-pérez & Ramírez-montoya, 2022; Maries & Singh, 2023; Rachmawati et al., 2024) with the Organization for Economic Co-operation and Development (OECD) emphasizing its importance for both students and the broader population (OECD, 2025). Conceptually, problem solving involves a set of cognitive and metacognitive processes used to analyze unfamiliar tasks, formulate strategies, and implement them to achieve a solution (Ovadiya, 2025; Wu et al., 2024). In educational contexts, problem-solving plays a pivotal role across various domains of learning. It helps students deal with unfamiliar problems, analyze complex situations, integrate knowledge from different disciplines, make informed decisions, and apply it effectively to achieve goals (Zhang et al., 2025). Problem-solving is also closely interconnected with other essential 21st-century competencies, including critical thinking, creativity, communication, and collaboration. Effective problem-solving requires students to evaluate information critically, find alternative strategies, communicate their reasoning, and often collaborate with others to refine plans and validate results. Consequently, the development of problem-solving skills contributes simultaneously to the broader set of competencies required for academic success, workplace readiness, and lifelong learning (González-pérez & Ramírez-montoya, 2022; OECD, 2025). Its importance is especially clear in physics education, where students are expected to apply conceptual understanding, make assumptions, formulate equations, and use both quantitative and qualitative reasoning to interpret physical phenomena (Sarkingobir & Bello, 2024; Tschisgale et al, 2025). For undergraduate students majoring in physics education, the ability to solve physics problems is not only crucial for understanding physical concepts and supporting their own learning but also for their future roles as educators tasked with fostering these competencies in future learners.

Kinematics was chosen as the topic of this research because it is typically one of the first topics introduced in introductory physics courses at various educational levels. This is due to its fundamental concepts—such as units, position, velocity, and acceleration—which are essential and recur across nearly all areas of physics (Yennita et al., 2023). Mastery of problem-solving in kinematics is crucial, as a weak understanding in this area can hinder students' overall success in learning physics (Hitier & González-Martín, 2022). Kinematics, especially one-dimensional motion, serves as a fundamental domain where students begin to develop and demonstrate their problem-solving skills (Sundari et al., 2023). Despite its introductory nature, many undergraduate students struggle with kinematics problems (Rabiudin et al., 2023; Tatira, 2024). Previous studies have reported that students frequently encounter difficulties in identifying relevant variables, distinguishing between velocity and acceleration, interpreting motion graphs, and selecting appropriate kinematic equations when solving one-dimensional motion problems (Rabiudin et al., 2023; Tatira, 2024; Yennita et al., 2023). Research has also shown that many students can perform mathematical manipulations but fail to connect equations with the underlying physical concepts, resulting in incorrect or incomplete solutions (Hitier & González-Martín, 2022). These findings suggest that students' challenges extend beyond conceptual understanding and involve deficiencies in the problem-solving process itself.

Previous research has pointed out that students' struggles with successfully tackling physics problems are often linked not just to conceptual misunderstandings but also to unproductive cognitive behaviors and ineffective strategies during problem-solving processes (Iwuanyanwu, 2025). This is partly because existing instructional methods often overlook the development of these behaviors, as instruction tends to emphasize obtaining correct numerical answers through algorithmic procedures rather than explicitly teaching students how to analyze problems, select strategies, monitor their thinking, and evaluate their solutions (Good et al., 2024). To address these limitations, researchers have recommended instructional approaches that explicitly promote problem-solving processes, such as metacognitive scaffolding, which encourages students to explain their reasoning, evaluate alternative solution paths, reflect on their thinking, and engage actively in constructing knowledge (Ovadiya, 2025). Effective development of problem-solving skills depends on recognizing how to approach problems, the strategies chosen, the way to respond to the challenges, understanding the steps involved to reach a solution, and how to reflect on the process (Schoenfeld, 2016). Consequently, there is increasing interest in examining problem-solving behaviors, which refer to the observable actions and decision-making strategies employed by individuals while solving a problem. Observable problem-solving behaviors may include identifying known and unknown variables, constructing diagrams or representations, selecting relevant equations, checking the consistency of units, revising solution strategies when encountering difficulties, monitoring intermediate results, and evaluating the plausibility of final answers (Wu et al., 2024). Such behaviors provide valuable insights into how students approach and regulate their problem-solving processes and can reveal differences between successful and unsuccessful problem solvers (Tari et al., 2025; Tschisgale et al., 2025).

Previous research in physics education has investigated students' cognitive behavior and strategies during problem-solving, often drawing on frameworks such as Polya's four-step model. (Pólya, 1957) and Schoenfeld's theory of metacognition (Schoenfeld, 1985), which are among the most frequently cited in studies on problem solving. Polya proposed four key steps: understanding the issue, formulating a plan, executing the plan, and checking the results by looking back at the answer. (Pólya, 1957). Pólya highlighted that problem-solving skills are not innate but can be developed through effective teaching and learning. Schoenfeld's problem-solving phases, analysis, implementation, and verification (Schoenfeld, 1985) closely resemble the steps outlined in Polya's problem-solving framework. Studies on problem-solving behavior, steps, strategies, and similar aspects have been conducted across various fields and contexts, such as Türkoğlu & Yalçınalp (2024), who analyzed how university students approached geometry problems using eye-tracking data, Evans et al., (2025) explored how middle school students with learning disabilities engage in problem-solving tasks. Tschisgale et al., (2025) investigated the differences in the physics problem-solving strategies between individuals with high and low performance levels. The results showed that low-performing individuals tended to demonstrate less structured approaches, whereas high-performing individuals employed more organized and methodical strategies (Tschisgale et al., 2025).

Although several studies have explored students' problem-solving performance in physics, few have examined the behavioral processes underlying their solution attempts, particularly in the domain of one-dimensional kinematics. There remains a need for studies that capture students' problem-solving behaviors in more observable, task-based settings, especially at the undergraduate level in teacher education programs. This study aims to investigate the problem-solving behavior exhibited by undergraduate physics education students as they solve one-dimensional kinematics tasks. Understanding these behaviors could offer deeper insights into students' cognitive development and inform instructional practices to improve both problem-solving skills and physics teaching strategies.

## METHODS

This research employed a descriptive qualitative research design to explore students' problem-solving behavior while they solved one-dimensional kinematics problems. Data collection involved several methods, including the think-aloud protocol, retrospective interviews, observations, and analysis of students' written responses. The think-aloud technique served as the primary method. It was also complemented by the other approaches to ensure the data remained well-grounded and to enhance the overall credibility of the findings.

In the think-aloud process, participants were instructed to verbalize their thoughts while working through the problems. Simultaneously, non-participant observation was carried out, allowing the researcher to monitor participants' actions and their engagement with the task without interference. Field notes were taken during this stage to help formulate interview questions aimed at clarifying specific behaviors during problem-solving—particularly when ambiguous terms like "this" or "that" were used, which are not easily interpreted through verbal protocols alone. The interview was conducted after each participant completed the problem while verbalizing their thoughts. The participants were questioned about their action or their thoughts during the problem-solving process, for example, 'How did you find the solution to that problem?' or 'Why did you use............(the action, strategy, or method) to solve the problem?' This method is referred to as a retrospective interview, which is one of the most widely used strategies to complement think-aloud data. Each participant's answer sheet was also reviewed and compared with the think-aloud recordings, allowing the researcher to visually trace and better understand the students' problem-solving processes.

The research involved six first-year undergraduate students from the physics education program. Each participant gave their informed consent and agreed to participate by signing the consent documents. First-year students were selected to reduce the possibility of insufficient prior knowledge related to the target concept, one-dimensional kinematics, a topic covered in the Basic Physics course, which is typically taken by Physics Education students during their first semester at university. The participants were chosen after they solved two one-dimensional kinematics problems. They were chosen based on criteria that they have adequate problem-solving skills in one-dimensional kinematics and are capable of articulating their thoughts clearly.

For this research, eight one-dimensional kinematics problems were piloted with undergraduate students of the physics education program. The eight problems were adapted from university physics books (Halliday et al., 2014; Hecht & Bueche, J, 2006; Young & Freedman, 2012). The pilot test was guided by the criteria: (1) first-year students should be able to clearly determine whether their solution is correct or incorrect; (2) the problem should permit multiple approaches, allowing students to explore alternative methods if one strategy proves unsuccessful; and (3) the problem should have an appropriate level of difficulty for the participants. The seven selected problems that met the criteria (Table 1) were used for three different purposes: two problems were used to select the participants of this study; two problems were prepared for a warm-up session, where the session was used to help participants become familiar with the think-aloud and provided an opportunity to check the audiotaping process; and the last three problems were used for the think-aloud session. The seven problems are shown in Table 1, listed in the order they were used.

Table 1 One-dimensional kinematics problems

| Used for | Problem |
|---|---|
| Selection of participant | To avoid being hit by a missile from a marine ship, a submarine has to be at least 2500 meters underneath the surface of the ocean. A submarine and a marine ship can only measure the distance in the water using an ultrasound scan by measuring the time for the sound to travel forth and back. When the marine ship detects an echo of the ultrasound coming back in 4 seconds, it fires a missile at the submarine underneath. Do you think the submarine will be hit? (The speed of ultrasound in the water is 1500 m/s) |
| | A high-speed train enters a station traveling at 100 meters per second and can decelerate at a maximum rate of −5.0 meters per second squared until it comes to a full stop. (a) What is the shortest possible time it would take for the train to come to rest once it begins to decelerate? (b) Could the train safely stop within the limits of a platform that is 0.80 kilometers in length? |

| | |
|---|---|
| Warm-up session | The gate of your school closes at 07.30 am. If you are cycling from your house to the school, which is 3.0 km away at a velocity of 5.0 m/s, what is the latest time you should start cycling if you don't want to be late for school?<br><br>Joni is cycling at a velocity of 2.0 m/s, Gari is skating at an acceleration of 2.0 m/s$^2$ from rest, and Tomi is riding at a deceleration of 5.0 m/s$^2$ from a velocity of 10 m/s. At a distance of 10.0 m, who will reach the finishing line last? |
| Think-aloud | Nia, Rani, Sinta, and Ayu are preparing to take part in a team-based science relay, where each member is responsible for completing a 100-meter segment. Nia can cover 100 meters in 25 seconds. Rani has previously completed an 800-meter track in 160 seconds, and Sinta once ran 1500 meters in 500 seconds. The record of the 100 m x 4 relay in school is 89.9 s. Bella is the first runner of the team, followed by Cindy and Dahlia. Assuming each participant runs at their typical speed as previously stated, and Ayu is assigned as the final runner, what is the minimum speed Ayu must maintain to finish the race at least 0.1 seconds faster than the existing record?<br><br>A truck started from rest and traveled eastward, reaching a constant velocity of 50.0 m/s after 20.0 seconds. At the same time, a car began accelerating westward from the same location with an acceleration of 4.0 m/s$^2$ over a span of 10.0 seconds. In an attempt to overtake a vehicle ahead, the car entered the same lane as the truck. At the moment they were 500.0 meters apart and heading toward each other, both drivers applied their brakes immediately. The truck required 10.0 seconds to come to a complete stop, while the car needed only 5.0 seconds. Based on this information, is a collision between the two vehicles unavoidable? Explain your reasoning.<br><br>Ari went to her cousin's apartment on the 15th (count from ground floor, first floor, second floor, and so on). Which way will be faster for Ari:<br>a. Using stairs in the situation: Ari's velocity of running up the stairs is 4.0 m/s for the first 10.0 s. And he decelerates at 0.2 m/s$^2$ after that.<br>b. Using a lift in a situation: the velocity of the lift is 6.0 m/s or $1\frac{1}{2}$ floors per second, as the height of each floor is 4.0 m. And he always have to wait for 10.0 s for the lift to come to the ground floor. |

The data were analyzed following Miles et al. (2014) qualitative data analysis, which included three steps: reducing the data by coding and categorizing, displaying the data in a table, and drawing a conclusion. Once data collection was complete, the researcher organized the large volume of information obtained from audio recordings of the think-aloud sessions and retrospective interviews, field notes taken during observation, and the answer papers of the participants. The recorded materials were transcribed into typed documents for analysis. The next phase involved coding the data, beginning with initial coding. In this stage, the think-aloud transcripts were reviewed using gerunds—action verbs that captured specific behaviors reflected in participants' verbalizations. Each segment coded corresponded to a distinct behavior. However, during this process, some codes were found to be vague or overly general, making them less meaningful for interpreting students' actions during problem-solving. While a code might represent a single behavior, it did not always reflect a relevant or clearly defined action. For instance, the behavior labeled "Reading" was often observed to occur alongside other actions, such as reading while writing down information or paraphrasing a problem statement. This indicated that some codes required further refinement and differentiation. As the analysis progressed, the researcher revisited the transcripts and developed more precise coded behavior. When the think-aloud transcript contained unclear or ambiguous statements, the researcher cross-referenced the data with observation field notes and retrospective interview transcripts. Additionally, if further clarification of a student's behavior was necessary, information from the participants' answer sheets was also consulted.

Once all student transcripts were coded, similar codes were grouped into broader categories. For each problem solved by each participant, the categories of behavior identified in the think-aloud transcripts were compiled and displayed to outline the range of behaviors students demonstrated while solving one-dimensional kinematics problems, as shown in Table 2.

Table 2 Sample of coded transcript

| Excerpt From | Excerpt | Codes of behavior | Categories of behavior |
|---|---|---|---|
| *Not** | *Lina carefully read each part of the problem and wrote down key details using physics symbols as she read each sentence.* | Strategic reading (organizing the information) | Reading |
| TA** | Nia can cover a distance of 100 meters in 25 seconds. The goal is to beat the current record. What is the total distance for the team to complete? Does each runner need to complete 400 meters? | Strategic reading (restate) | |
| *Not* | *Lina repeated the reading* | Repeated reading | |
| TA | Ah.. I see, since it's a relay, each runner covers 100 meters. | Strategic reading (restate) | |
| TA | Assuming each participant runs at their typical speed as previously stated, and Ayu is assigned as the final runner, what is the minimum speed Ayu must maintain to finish the race at least 0.1 seconds faster than the existing record? | Repeated reading | |
| TA | Beating the current record by 0.1 seconds | Strategic reading (restate) | |
| TA | What needs to be found is the speed at which Ayu is running, right? | Identifying the Goal | Planning |
| TA | The formula for velocity........ *s* per *t* | Selecting the Appropriate Formula | |
| TA | Her distance is also 100 meters, like the others, isn't it? How do we calculate her time? | Considering the next move | Analyzing |
| TA | I guess I need to figure out the others' velocity first | Developing a plan | Planning |
| TA | Nia.... § 100/25 = 4 | Performing basic calculation | Calculating |
| TA | Rani.....800/160 = 5 | | |
| TA | Sinta...... hers is 3. | | |
| TA | Still, that value is for a different distance—I'm looking for the time over 100 meters | Formulating the sub-plan | Planning |
| TA | Nia.....*v is s divided by t* | Performing algebra | Calculating |
| TA | So, time is calculated by dividing distance by speed. | | |
| TA | Thus, Nia is 25 s | | |
| TA | Oh right, Nia's time is provided because she runs the same distance. | | |
| TA | Rani.... 100/5 = 20 | Performing basic calculation | |
| TA | Sinta.....100/3 = 33.3 | | |
| TA | So, to find Ayu's, I need to add the others' times first. | Formulating the sub-plan | Planning |
| TA | 25+20+33.3........78,3 | Performing basic calculation | Calculating |
| TA | Next..... | | |

| Excerpt From | Excerpt | Codes of behavior | Categories of behavior |
|---|---|---|---|
| TA | 89.9...........89.9 - 78.3......11.6 | | |
| TA | So Ayu has 11.6 seconds left to finish. | | |
| TA | Then Ayu's velocity *(wrote the formula)* | Performing basic calculation | |
| TA | 100 divided by 11.6........8.62 | | |
| *Not* | *Once she figured out Ayu's time, Lina reviewed her answer while comparing it to the original problem* | Checking the computation | Checking |
| TA | I might have made an error—can I revisit it and make corrections? | Recognizing Error | Reflecting |
| **Ob***** | **Yes** | | |
| TA | As they intend to break the record by at least 0.1 seconds, their final time should be 89.8. | Recognizing Error | Reflecting |
| TA | So.... 89,8 - 78.3 is 11.5 | Making a simple calculation | Calculating |
| TA | 100 /11.5 is 8.69 | | |
| TA | The answer is 8.69 m/s | Present the answer | Answering |

* Field notes: observation excerpt
**Think-aloud excerpt
*** Observer's spoken words

In total, 18 behavior sequences were analyzed from six participants, each of whom solved three one-dimensional kinematics problems. This dataset allows for the examination of individual differences in behavioral variations across multiple problem-solving instances. The identification of these behavioral patterns is expected to provide evidence that can inform the development of instructional strategies aimed at improving students' physics problem-solving skills.

## RESULT AND DISCUSSION

The results of the data analysis reveal behavioral differences among participants for each problem-solving task. Each participant also demonstrated different behaviors when faced with different problems. These behavioral data were then combined and organized sequentially according to the problem-solving steps. The data analysis reveals twenty-four distinct behaviors that students exhibited during their problem-solving process of one-dimensional kinematics. These behaviors were subsequently grouped into eight categories based on their functional similarities and roles within the problem-solving process. This categorization allowed for a clearer interpretation of students' behavior during problem-solving. Table 3 outlines the problem-solving behaviors demonstrated by undergraduate students while addressing problems in the one-dimensional kinematics topic. Notably, not all behaviors were demonstrated uniformly by all participants; they were identified based on the behaviors of six participants while solving the problems. The behaviors are not arranged in chronological order, as students' problem-solving processes do not always follow a linear sequence.

Table 3 Problem-solving behavior in one-dimensional kinematics topic

| Categories of Behavior | Codes of Behavior | Description |
|---|---|---|
| Reading | Initial Reading | Students initially read the entire problem statement as a standalone action |
| | Repeated reading | Students revisited the problem either to deepen their understanding or to extract clues by re-reading certain parts during the problem-solving process. |
| | Strategic Reading | While reading, the student simultaneously attempted to comprehend the problem by rephrasing it, creating visual |

| Categories of Behavior | Codes of Behavior | Description |
|---|---|---|
| | | representations (e.g., drawings), organizing details, or performing direct calculations based on given data. |
| Comprehending | Organising Information | Students arranged the provided information while analyzing the problem, such as by underlining, taking notes, or formatting it into a structured list. |
| | Clarify the problem context | Students tried to grasp the problem context by expressing the problem in their own words or by converting it into alternative forms, symbols, or representations. |
| | Drawing a visual representation | Students created a sketch or diagram to better visualize and understand the problem scenario. |
| | Recalling Relevant Knowledge | Students documented relevant prior knowledge, including remembered formulas. |
| Planning | Identifying the Goal | Students rephrased the problem's objective to clarify what was being asked. |
| | Selecting the Appropriate Formula | Students selected an appropriate formula they believed was suitable for solving the problem. |
| | Identifying the variable | Students determined which variables needed to be included in the chosen equation. |
| | Developing the plan | Students devised a step-by-step plan for how to approach and solve the problem. |
| | Formulating sub-plan | Students developed brief strategies or intermediate plans between successive calculations. |
| Analysing | Linking the concept | Students made an effort to identify or connect relevant physics concepts to the problem at hand. |
| | Considering the Formula | Students thoughtfully considered potential formulas by aligning them with the known variables in the problem. |
| | Considering the Variable | Students thoughtfully considered which particular variables were appropriate to apply in the equation while performing the calculation. |
| Checking | Checking the plan | Students reviewed their plan by analyzing their current progress and checking which variables had been identified and used. |
| | Checking the computation | Students verified their computations to determine whether the calculations were correct and if the desired outcome had been achieved. |
| | Estimating the answer | Students speculated about the possible answer or outcome of the problem by suggesting a potential solution. |
| Reflecting | Recognising Error | Upon recognizing an error, the student attempted to understand the mistake and determine how to correct it. |
| | Evaluating the plan | Students reflected on their plan and made adjustments when necessary to improve the problem-solving approach. |
| | Reflecting themselves | Students commented on their own performance or behavior during the problem-solving task. |
| Calculating | Performing basic Calculation | Students performed numerical calculations without engaging in further reasoning or decision-making processes. |
| | Performing Algebra | Students conducted algebraic manipulations to rearrange equations in a way that simplified solving the problem |
| Answering | Presenting or writing down the solution | Students concluded the problem-solving task by providing a final answer |

Findings showed that '*Reading'* was coded as the first behavior of all the participants. Within the 'reading' category, four distinct behaviors are identified: reading, rereading, and reading with strategy. '*Comprehending'* includes behaviors that reflect students' efforts to understand the problem context before attempting to solve it. Students were observed organizing the given information by underlining, listing, or rewriting it. They also reworded the problem statements using different expressions or representations to make sense of the situation. Some students created sketches to visualize the scenario, while others recalled and wrote down relevant prior knowledge, such as formulas or concepts. In the '*Analyzing'* category, students demonstrated conceptual reasoning by relating physics concepts, evaluating formulas, and selecting appropriate variables. '*Checking'* behaviors included monitoring the accuracy of plans, verifying calculations, and speculating on possible answers. The '*Reflecting'* category captured students' recognition of errors, revisions of their approach, and self-evaluative comments. '*Calculating'* behaviors encompassed performing arithmetic and algebraic operations essential to executing the solution. Last, they wrote '*Answering'* code as students concluded the problem-solving process and presented a solution to the problem. These categories of behavior highlight the diverse and often non-linear nature of students' problem-solving processes.

The findings of this study indicate that each student's problem-solving process is unique. Students employ different strategies depending on the nature of the problem and the specific context. Differences in behavior were observed in the same student depending on the nature of the problem-solving situation, highlighting the dynamic and individualized nature of their approaches. This is consistent with Dostál's assertions in his article on the theory of problem-solving (Dostál, 2015). When individuals are confronted with a problem, they engage their cognitive processes to assess its cause and determine appropriate strategies for resolution (Brooks, 2022). They consider what tools or knowledge they have, how to use them effectively, and which strategy might work best. The way a person thinks through the problem and how they perceive its difficulty, whether it seems hard, easy, or in between, affects the kind of behavior they choose to show (Xie & Moss, 2025). The uniqueness of each person's experience with the problem is reflected in their problem-solving behavior, highlighting variations in individual traits and levels of understanding.

This study identified eight categories of behaviors typically displayed by students while solving problems in the one-dimensional kinematics topic. These behaviors function in a dynamic and repetitive sequence. These findings align with the idea that problem-solving is a complex cognitive process involving multiple stages that do not always occur in a fixed sequence. As Molnár and Greiff (2023) have highlighted, the non-linear and iterative nature of problem-solving involves students continuously shifting between one step and another step, such as understanding the problem, devising a plan, executing procedures, and reflecting on outcomes. Moreover, the iterative and non-linear nature of the behaviors observed is supported by Evans et al.'s study (Evans et al., 2025), which found that students often revisit earlier stages as they encounter difficulties or develop new insights. The eight behavior categories of the students during the problem-solving process revealed in this study align with Pólya's four-step problem-solving model and Schoenfeld's theory of metacognition. The behaviors categorized under *Reading*, *Comprehending*, *Planning*, and *Analyzing* reflect the early phases of Pólya's problem-solving model, which emphasizes understanding the problem and devising a plan before execution (Pólya, 1957). All participants in this study demonstrated engagement in this category of behavior. Meanwhile, the *Checking* and *Reflecting* categories correspond to metacognitive regulation processes identified by Schoenfeld, where learners assess and reflect on their performance throughout the problem-solving process (Schoenfeld, 1985). Four of the six students demonstrated checking behaviors, and only three students demonstrated reflecting behavior. The presence of self-reflective behaviors such as recognizing errors and commenting on one's performance also supports the role of metacognition in effective problem solving, as highlighted in studies by Rahayuningsih et al., (2021). The engagement of participants in checking and reflecting behaviors influenced the outcome of their problem-solving performance. Participants who demonstrated checking and reflecting behaviors were found to be more successful in solving the problems compared to those who did not. This finding is consistent with previous studies that categorized checking and reflecting behaviors as forms of metacognition, which play a crucial role in an individual's success in the problem-solving (Arianto & Hanif, 2024; Del

Olmo-Muñoz et al., 2024; Halmo et al., 2024). These results suggest that enhancing students' ability to shift flexibly between cognitive and metacognitive strategies may improve their problem-solving performance in physics contexts.

Behaviors categorized under reading and comprehending are intended to facilitate understanding of the problem or task. This constitutes a crucial strategy in problem-solving. As Sinaga et al., noted, a proper understanding of the problem serves as the foundation for deciding on the appropriate actions and subsequent steps needed to resolve the issue (Sinaga et al., 2023). Therefore, students must thoroughly understand the problem before making informed decisions to find the right solution. All of the participants demonstrated the integration of problem-related information by constructing sketches and organizing formulas according to their prior knowledge. This aligns with the study conducted by Tschisgale et al., (2025) which highlights the problem representation phase as the stage where the problem solver formulates assumptions and idealizations while pinpointing the key physics concepts pertinent to the problem. Every student interprets the initial task differently due to variations in their conceptual understanding (Kellar & Heron, 2025). It was also observed that most of the participants determined the formula by matching the known variables in a problem with equations that contain those variables, rather than focusing on the underlying physics principles. This method is known as the Rolodex approach (Bunce et al., 1991). The Rolodex approach was also observed in previous studies that observed that students in their first year of a physics program commonly used the Rolodex approach—attempting to identify and apply a memorized equation by matching it to the variables provided in the problem (Eryilmaz-Toksoy, 2022; Ogilvie, 2009).

The problem-solving behaviors observed in this study are consistent with previous research and even align with the problem-solving framework proposed by the OECD, which is based on the work of several cognitive psychologists and consists of four stages: (1) exploring and understanding, (2) representing and formulating, (3) planning and executing and (4) monitoring and reflecting (OECD, 2013). Undergraduate students who learn kinematics and engage in one-dimensional kinematics problems need to know the effective problem-solving behavior and know when to use it during the process. Guiding students in physics through clearly defined problem-solving behaviors can enhance their ability to tackle problems effectively. When such structured approaches are introduced, students are encouraged to analyze the problem thoroughly before beginning calculations and to verify their solutions afterward. The categorization of student behaviors in this study not only provides a detailed lens for understanding how undergraduates approach physics problems but also suggests that instruction in problem-solving should not only emphasize conceptual and procedural knowledge but also incorporate explicit teaching of planning, monitoring, and reflection strategies. Integrating guided prompts such as planning, reviewing, and reflecting during problem-solving tasks can help students engage in more intentional and effective cognitive processes.

The findings of this study have important implications for physics instruction, particularly in teacher education programs. Since successful problem solvers were more likely to engage in checking and reflecting behaviors, lecturers and physics teachers should explicitly incorporate these behaviors into classroom activities rather than assuming that students will develop them independently. For example, instructors can provide structured prompts that encourage students to explain their reasoning, verify intermediate calculations, evaluate the plausibility of their answers, and reflect on alternative solution strategies. Think-aloud activities, guided problem-solving worksheets, and reflective questioning can also be used to make students' cognitive and metacognitive processes more visible. By emphasizing not only the correctness of answers but also the quality of the problem-solving process, instruction may better support the development of students' problem-solving competence in physics.

Furthermore, the results of this study offer a behavioral perspective that can inform instructional design, assessment tools, and teacher professional development programs aimed at improving students' problem-solving competence. Future research could explore how these behaviors vary across different topics in physics or evolve with targeted intervention, thereby extending the applicability of the framework across broader learning contexts.

## CONCLUSION

This study provides a detailed analysis of the problem-solving behaviors demonstrated by physics education undergraduates when tackling one-dimensional kinematics problems. The findings reveal that students engage in a wide range of cognitive and metacognitive behaviors, including reading, comprehending, planning, analyzing, checking, reflecting, and calculating. These behaviors reflect a non-linear and iterative problem-solving process, aligning with established models such as Polya's problem-solving steps and the metacognitive frameworks proposed by Schoenfeld and others. The categorization of student behaviors offers a practical framework for understanding how students interpret, plan, execute, and evaluate problem-solving tasks. The findings of this study have important implications for physics education, particularly in the development of instructional strategies that explicitly foster students' problem-solving skills. By identifying specific behaviors demonstrated during problem-solving, lecturers can design learning activities that guide students through systematic stages of understanding problems, planning solutions, monitoring progress, and evaluating results. For example, instructors may incorporate structured problem-solving worksheets that prompt students to identify known and unknown variables, construct representations such as diagrams or sketches, justify the selection of equations, and evaluate the reasonableness of their answers. The findings also highlight the importance of checking and reflecting behaviors, which were more frequently demonstrated by successful problem solvers. Therefore, teachers should provide opportunities for students to review their solutions, identify possible errors, explain their reasoning, and reflect on alternative solution strategies. Classroom practices such as think-aloud activities, guided questioning, peer discussion, and reflective journals may help make students' cognitive and metacognitive processes more explicit and support the development of more effective problem-solving habits. However, this study is limited by the small number of undergraduate physics education student participants from a single institution, which may restrict the generalizability of the findings to broader contexts. In addition, the study focused only on one-dimensional kinematics problems, so the identified behaviors may differ in other areas of physics involving more complex concepts or mathematical representations. Finally, the use of the think-aloud technique relied on participants' ability to verbalize their thoughts, meaning that some cognitive processes may not have been fully captured during data collection. Therefore, future studies are recommended to involve larger and more diverse participants, investigate different physics topics, and combine qualitative and quantitative approaches to obtain a more comprehensive understanding of students' problem-solving behavior. Further research may also focus on developing and evaluating targeted interventions that support the development of expert-like problem-solving skills in undergraduate physics education.

## CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

## AUTHOR CONTRIBUTIONS STATEMENT

SRT led the study by conceptualizing the research, developing the tracking methodology, and writing the original manuscript. FH assisted with data collection from the undergraduate participants and the preliminary coding of behavior patterns. FaH provided academic supervision and contributed to the critical revision of the manuscript. All authors reviewed and approved the final version.

## AI DISCLOSURE STATEMENT

During the preparation of this work, the authors utilized ChatGPT solely for the purpose of grammar correction and linguistic refinement. Following the use of this tool, the authors critically reviewed, edited, and verified the content to ensure its scientific accuracy. The authors assume full accountability for the integrity, originality, and overall content of this publication.

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