



## Enhancing Polytechnic Students' Conceptual Understanding of Kinematics Through Instruction That Integrates Metacognitive Guidance

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### Abstract

This study aims to analyze changes in the conceptual understanding of polytechnic students following the implementation of instruction that integrates metacognitive prompts into kinematics material, as well as to describe students' metacognitive behaviors during the learning process. The study employed a one-group pretest–posttest pre-experimental design involving 32 first-semester students in the Road and Bridge Engineering Technology (TRKJJ) program at Ketapang State Polytechnic. Data were collected through conceptual understanding tests, diagnostic tests, metacognitive prompt sheets, and metacognitive behavior observation sheets. Conceptual understanding data were analyzed using normalized gain, the paired-samples t-test, the Wilcoxon signed-rank test, and Cohen's  $d_z$  effect size, while metacognitive behavior was analyzed descriptively based on the aspects of planning, monitoring, and evaluating. The results showed that the mean conceptual understanding score increased from 14.47 (36.17%) on the pretest to 29.38 (73.44%) on the posttest. The mean N-gain value of 0.59 falls into the moderate category. The difference between pretest and posttest scores was significant based on the paired-samples t-test ( $t(31) = 38.24$ ,  $p < 0.001$ ) and consistent with the Wilcoxon test ( $p > 0.001$ ). The effect size was Cohen's  $d_z = 6.76$ . Among the metacognitive behaviors, monitoring received the highest mean score ( $M = 3.20$ ), followed by planning ( $M = 2.80$ ) and evaluating ( $M = 2.60$ ). These findings indicate an increase in conceptual understanding following instruction that integrated metacognitive prompts, accompanied by a predominance of monitoring behavior during the learning process. However, because the study used a design without a control group, this increase cannot be fully attributed to the metacognitive prompts.

**Keywords:** Conceptual understanding; Kinematics; Metacognitive prompts; Polytechnic education; Physics education

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## INTRODUCTION

Kinematics is one of the fundamental concepts in physics that must be understood conceptually by early-level students, including those in vocational education. Understanding kinematics is not only related to the ability to perform mathematical calculations but also encompasses the ability to interpret representations and connect various forms of representation with physical phenomena. In learning kinematics, students need to understand the relationship between position, velocity, and acceleration and be able to interpret information presented in the form of equations or graphs. Various studies indicate that students still experience difficulties and misconceptions in understanding kinematic concepts, particularly when connecting mathematical representations, graphs, and physical phenomena (Mutrofin Rozaq & Prihatiningtyas, 2024; Haryanto & Budhi, 2025; Admoko & Suliyanah, 2023; Kamil et al., 2022). These difficulties indicate that the ability to solve problems procedurally is not always accompanied by adequate conceptual understanding (Taryati & Tarsidi, 2025).

Various approaches have been developed to address difficulties in conceptual understanding in physics learning, including the use of simulations, inquiry-based learning, peer instruction, and various interactive learning strategies (Siantuba et al., 2023; Fakoya et al., 2023). Although these approaches can help increase student engagement and understanding, they have not specifically incorporated the process of regulating students' thinking as an explicit part of learning. In this context, metacognition plays a crucial role because it relates to an individual's ability to plan strategies, monitor thinking processes, and evaluate the outcomes of their thinking (Bambang Widjajanto et al., 2025). One form of implementing these strategies is metacognitive prompts—structured questions or instructions designed to encourage students to become aware of and regulate their thinking processes during learning. Through metacognitive prompts, students are guided not only to seek answers but also to consider how a problem is understood, what strategies are used, and whether the results obtained align with the concepts applied.

The need for strategies that support regulatory thinking is also evident in the teaching of kinematics in vocational education. Initial observations of 32 first-semester students in the Road and Bridge Construction Engineering Technology (TRKJJ) program at the Ketapang State Polytechnic indicate that their conceptual understanding of kinematics still needs to be strengthened. The results of the initial diagnostic assessment showed that some students had difficulty reading position–time graphs, determining acceleration based on velocity–time graphs, and distinguishing between constant velocity and zero acceleration conditions. Students also demonstrated difficulty in explaining the relationships between kinematic variables in a structured manner. These findings indicate that the ability to perform basic calculations is not always accompanied by the ability to interpret graphical representations and explain the physical meaning of the results obtained.

This issue is particularly important in the context of vocational education because learning at polytechnics requires students not only to master procedures but also to understand the concepts underlying their application. The ability to interpret graphs and connect various representations is a crucial part of understanding physical phenomena related to engineering. Therefore, learning strategies are needed that not only provide problem-solving practice but also help students develop awareness of the thinking processes used during problem-solving. However, research on the explicit application of metacognitive prompts in kinematics instruction within the context of vocational education remains limited. Research on metacognition has been conducted primarily in the context of general education or academic higher education settings (Zakiya & Falamy, 2024; Mardova et al., 2025). This gap highlights the need for further study on how metacognitive strategies can be applied in physics instruction within the context of vocational education.

This study was conducted to bridge that gap by integrating metacognitive prompts into graph-based kinematics instruction. Metacognitive prompts were used to encourage students to engage in three main processes—planning, monitoring, and evaluating—while solving kinematics problems. During the planning stage, students were guided to identify information and determine solution strategies; during the monitoring stage, students examined their reasoning process and the consistency of their interpretations with the information on the graphs; and during the evaluating stage, students reassessed their answers and the strategies they had used. This approach is expected to help students establish more consistent connections between graphical representations and physics concepts and to increase their awareness of their thinking processes during learning (Ciptaningtyas et al., 2022; Muthmainnah et al., 2024).

Based on this gap, this study aims to analyze the effectiveness of using metacognitive prompts in improving polytechnic students' conceptual understanding of kinematics. Specifically, this study aims to: (1) analyze students' conceptual understanding prior to the implementation of instruction integrating metacognitive prompts; (2) analyze changes in students' conceptual understanding following instruction; and (3) describe students'

metacognitive behaviors—including planning, monitoring, and evaluating—during the learning process. This study is expected to provide empirical insights into the application of metacognitive strategies in physics instruction within the context of vocational education, particularly to support conceptual understanding of kinematics based on graphical representations

## METHOD

This study employed a pre-experimental design using a one-group pretest–posttest model to analyze changes in students' conceptual understanding following instruction that integrated metacognitive prompts. The study was conducted in the Road and Bridge Construction Engineering Technology (TRKJJ) program at the Ketapang State Polytechnic, Indonesia, during the 2024/2025 academic year. The research subjects consisted of 32 first-semester students enrolled in the Basic Physics course. Subjects were selected using convenience sampling because the students were from the same class.

The research procedure consisted of five stages, as shown in Figure 1. In the initial stage, students took a diagnostic test and a conceptual understanding pretest to identify their prior knowledge and difficulties regarding kinematics concepts, particularly position–time and velocity–time graphs. Next, students participated in three learning sessions that integrated metacognitive prompts into the solving of conceptual kinematics problems. The prompts were designed based on three metacognitive processes: planning, monitoring, and evaluating. During the learning sessions, students' metacognitive behaviors were observed using observation sheets and their written responses to the prompts. After the intervention was completed, students took a posttest to measure changes in their conceptual understanding.

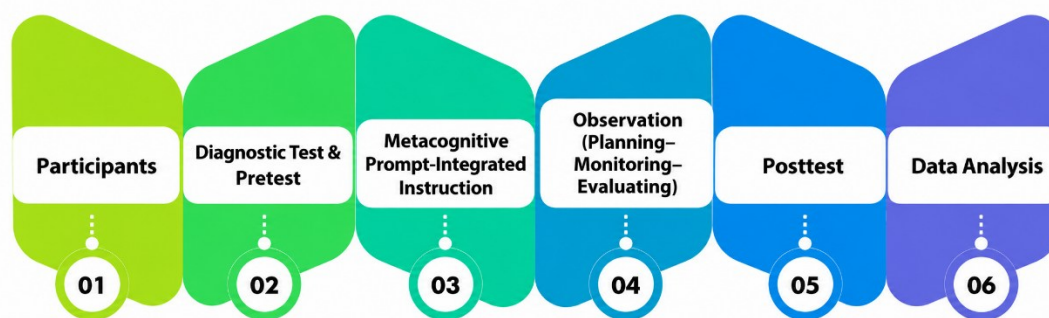


Figure 1. Research Flowchart

Data were collected using four instruments: a conceptual understanding test, a diagnostic test, a metacognitive prompts sheet, and a metacognitive behavior observation sheet. The conceptual understanding test consisted of 10 items, each scored on a scale of 0–4, for a maximum score of 40. The test was used to measure students' ability to interpret position–time graphs, velocity–time graphs, and the relationships between position, velocity, and acceleration. The diagnostic test consisted of five conceptual questions and was used to identify students' initial difficulties. The metacognitive prompts sheet contained questions representing planning, monitoring, and evaluating, while the observation sheet was used to document metacognitive behaviors during learning. The instruments were reviewed by experts in physics education to ensure content validity. The conceptual understanding test had a CVR of 0.82 and a Cronbach's  $\alpha$  internal consistency of 0.78, while the observation sheet showed inter-rater agreement with a Cohen's  $\kappa$  of 0.78.

The data were analyzed using descriptive and inferential statistics. The increase in conceptual understanding was calculated using normalized gain (N-gain):

$$g = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}}$$

where  $S_{\text{post}}$ ,  $S_{\text{pre}}$ , and  $S_{\text{max}}$  represent the posttest score, pretest score, and maximum score, respectively. N-gain values were categorized as low ( $g < 0.30$ ), moderate ( $0.30 \leq g < 0.70$ ), and high ( $g \geq 0.70$ ). The Shapiro–Wilk test was used to examine the distribution of the score differences. Differences between pretest and posttest scores were analyzed using a paired-samples t-test and re-examined using the Wilcoxon signed-rank test. Effect sizes were calculated using Cohen's  $d_z$ . The observational data were analyzed descriptively to describe the aspects of planning, monitoring, and evaluating.

## RESULTS AND DISCUSSION

### Students' Conceptual Understanding Before the Intervention

The results of the initial assessment indicate that students' conceptual understanding of kinematics material is still relatively low. Based on the pretest results for 32 students, the average score was 14.47 out of a maximum score of 40, with a standard deviation of 2.00. This score is equivalent to 36.17% of the maximum score. Individual scores on the pretest ranged from 10 to 18.

At the item level, the average pretest scores ranged from 1.22 to 1.75 out of a maximum score of 4. The lowest averages were found on items S6 and S8, at 1.22 each, while the highest average was found on item S9, at 1.75. These results indicate that students' initial abilities still vary across the various aspects of kinematics concept understanding that were measured.

### Changes in Conceptual Understanding

After participating in instruction that integrated metacognitive prompts, the average posttest score increased to 29.38 out of a maximum score of 40, with a standard deviation of 2.94. This score is equivalent to 73.44% of the maximum score. Students' posttest scores ranged from 23 to 34. Thus, there was an increase in the average score of 14.91 points, from 36.17% on the pretest to 73.44% on the posttest.

**Table 1.** Descriptive statistics for pretest and posttest scores

| Statistics                  | Pretest | Posttest | Difference              |
|-----------------------------|---------|----------|-------------------------|
| N                           | 32      | 32       | 32                      |
| Mean                        | 14,47   | 29,38    | 14,91                   |
| SD                          | 2,00    | 2,94     | 2,20                    |
| Minimum                     | 10      | 23       | 8                       |
| Maksimum                    | 18      | 34       | 19                      |
| Percentage of Maximum Score | 36,17%  | 73,44%   | 37,27 percentage points |

All students achieved higher posttest scores than their respective pretest scores. The individual score differences ranged from 8 to 19 points, with an average increase of 14.91 points and a standard deviation of 2.20.

### Changes Based on Test Items

Changes in conceptual understanding were also evident across all test items. Table 2 presents the average pretest and posttest scores, score increases, and N-gain for each item.

**Table 2.** Changes in conceptual understanding scores by test item

| Item | Pretest Mean | Posttest Mean | Increase | N-gain |
|------|--------------|---------------|----------|--------|
| S1   | 1,50         | 2,91          | 1,41     | 0,56   |
| S2   | 1,53         | 2,72          | 1,19     | 0,48   |
| S3   | 1,44         | 2,97          | 1,53     | 0,60   |
| S4   | 1,38         | 2,66          | 1,28     | 0,49   |
| S5   | 1,47         | 2,94          | 1,47     | 0,58   |
| S6   | 1,22         | 2,75          | 1,53     | 0,55   |
| S7   | 1,63         | 3,13          | 1,50     | 0,63   |
| S8   | 1,22         | 3,06          | 1,84     | 0,66   |
| S9   | 1,75         | 3,00          | 1,25     | 0,56   |
| S10  | 1,34         | 3,25          | 1,91     | 0,72   |

All items showed an increase in scores from the pretest to the posttest. The largest absolute increase was observed in S10, at 1.91 points, followed by S8 at 1.84 points. Based on N-gain, the highest value was also observed in S10 at 0.72, while the lowest value was observed in S2 at 0.48.

When grouped by the aspects being measured, items S1–S4, which relate to the interpretation of position-time graphs, showed an increase of 1.19–1.53 points. Items S5–S8, which relate to velocity-time graphs, showed an increase of 1.47–1.84 points. Meanwhile, items S9–S10, which integrate several kinematic representations, showed an increase of 1.25–1.91 points.

### Normalized Gain

The improvement in conceptual understanding was further analyzed using normalized gain (N-gain). Calculations were performed at the individual level based on each student's pretest and posttest scores. The average individual N-gain was 0.59, with a range of 0.35–0.76. Based on the N-gain categories, 28 students (87.5%) fell into the moderate category and 4 students (12.5%) fell into the high category. No students fell into the low category..

**Table 3.** Distribution of students by N-gain category

| N-gain Category | Number | Percentage |
|-----------------|--------|------------|
| Low             | 0      | 0,0%       |
| Moderate        | 28     | 87,5%      |
| High            | 4      | 12,5%      |
| Total           | 32     | 100%       |

When N-gain was calculated based on the group's average score, the value obtained was 0.58. Meanwhile, the value of 0.59 represents the average N-gain calculated beforehand for each student. Since the research analysis focused on changes at the individual level, the average individual N-gain value of 0.59 was used in reporting the research results.

### Statistical Analysis of Differences Between the Pretest and Posttest

Since the pretest and posttest scores were obtained from the same students, the analysis was conducted using a paired t-test. The normality assumption was tested for the difference scores between the posttest and pretest. The results of the Shapiro–Wilk test indicated that the difference scores were not normally distributed, with a W value of 0.905 and a p-value of 0.008.

Therefore, in addition to the paired-samples t-test, a Wilcoxon signed-rank test was also conducted as a nonparametric analysis. The results of the Wilcoxon test indicated a significant difference between the pretest and posttest scores ( $W = 0$ ;  $p < 0.001$ ).

The paired-samples t-test also revealed a significant difference between the pretest and posttest scores, with  $t(31) = 38.24$ ;  $p < 0.001$ . The mean difference in scores was 14.91 points, with a 95% confidence interval of 14.11–15.70.

**Table 4.** Results of The Analysis of Differences Between Pretest and Posttest Scores

| Analysis                      | Values                        |
|-------------------------------|-------------------------------|
| Mean difference               | 14,91                         |
| SD of difference              | 2,20                          |
| 95% CI                        | 14,11–15,70                   |
| Shapiro–Wilk                  | $W = 0,905$ ; $p = 0,008$     |
| Paired-samples <i>t</i> -test | $t(31) = 38,24$ ; $p < 0,001$ |
| Wilcoxon signed-rank          | $W = 0$ ; $p < 0,001$         |
| Cohen's <i>dz</i>             | 6,76                          |

The results of both tests showed consistent findings: posttest scores were higher than pretest scores. The effect size, calculated based on the standard deviation of the score difference, yielded a value of Cohen's  $dz = 6.76$ .

### Students' Metacognitive Behavior

Students' metacognitive behaviors during learning were analyzed based on three aspects: planning, monitoring, and evaluating. The observation results showed average scores of 2.80 for planning, 3.20 for monitoring, and 2.60 for evaluating.

**Table 5.** Average Metacognitive Behavior Scores

| Aspect     | Average |
|------------|---------|
| Planning   | 2,80    |
| Monitoring | 3,20    |
| Evaluating | 2,60    |

The monitoring aspect received the highest average score, followed by planning and evaluating. These results indicate that during the learning process, monitoring behavior had a higher observed score than the other two metacognitive aspects.

However, based on the available data in the form of aggregate scores, these results cannot yet be used to conclude that monitoring showed the greatest improvement throughout the learning process. The available data only supports the statement that the observed score for monitoring was the highest among the three aspects.

### Discussion

The results of the study indicate that students' conceptual understanding of kinematics prior to instruction was still relatively low. The average pretest score of 14.47 out of a maximum of 40 (36.17%) indicates that students do not yet have an adequate understanding of the kinematics concepts being assessed. These difficulties were particularly evident in the ability to interpret graphical representations and relate the characteristics of the graphs to the corresponding physical quantities (Royani et al., 2025). On several items, students achieved relatively low initial scores, particularly on items related to the interpretation of velocity–time graphs. This indicates that students' ability to solve kinematics problems depends not only on their mastery of mathematical procedures but also on their ability to understand the physical meaning of the representations used (Nurhidayat et al., 2023). These findings are consistent with previous research showing that students often struggle to interpret kinematic graphs, particularly in understanding the meaning of the graph's slope and the relationship between velocity and acceleration (Wati, 2024). Thus, the results of the initial assessment provide a basis for the conclusion that kinematics instruction needs to place greater emphasis on the process of interpretation and the relationships between representations, rather than solely on calculation procedures (Taqwa et al., 2025).

The increase in scores after instruction indicates a change in students' conceptual understanding. The average score rose from 14.47 on the pretest to 29.38 on the posttest, or from 36.17% to 73.44% of the maximum score. This increase of 14.91 points indicates that students were able to achieve higher scores after participating in instruction that integrated metacognitive prompts. These results are further supported by the normalized gain analysis, which yielded an average individual N-gain of 0.59, with 28 students falling into the moderate category and 4 students into the high category. These findings suggest that changes in understanding did not occur only in a small subset of students but were evident across all study participants. However, since the study employed a one-group pretest–posttest design without a comparison group, this improvement should be interpreted as a change in understanding resulting from the instructional intervention, rather than as causal evidence that the change was solely attributable to metacognitive prompts (Lee et al., 2026).

Statistically, the difference between the pretest and posttest scores also showed significant results. The paired-samples t-test yielded  $t(31) = 38.24$ ,  $p < 0.001$ , with a mean difference of 14.91 points and a 95% confidence interval of 14.11–15.70. Since the Shapiro–Wilk test on the score differences yielded  $W = 0.095$  and  $p = 0.008$ , the analysis was also examined using the Wilcoxon signed-rank test (Tapio, 2025). The results of the Wilcoxon test

showed  $W = 0$  with  $p < 0.001$ , indicating that the conclusion regarding a change in scores remains consistent when analyzed using a nonparametric approach. The effect size calculated based on the difference scores yielded Cohen's  $d_z = 6.76$ . The magnitude of the effect size indicates that the difference between pretest and posttest scores was relatively large in the study sample (Panjeh et al., 2023). However, the magnitude of the effect size does not in itself prove a causal relationship between metacognitive prompts and improved understanding, as the study design did not include a control group (Shear & Briggs, 2024).

An improvement in understanding was also evident across all test items. The average score increased for items S1–S10, although the magnitude of the increase varied from item to item. In the position–time graph interpretation item group (S1–S4), the increase ranged from 1.19 to 1.53 points. In the velocity–time graph group (S5–S8), the increase ranged from 1.47 to 1.84 points. Meanwhile, items that integrated multiple kinematic representations (S9–S10) showed an increase of 1.25 to 1.91 points. This pattern indicates that changes in scores are not limited to a single type of representation but occur across various aspects of kinematic understanding as measured by the instrument. The pattern of improvement across the various item groups suggests that learning that integrates multiple forms of representation can help students connect the characteristics of graphs with the underlying kinematic concepts (Orillo & Mistades, 2024).

A relatively large increase was observed in items S8 and S10. Item S8 showed an increase of 1.84 points with an N-gain of 0.66, while item S10 showed an increase of 1.91 points with an N-gain of 0.72. These values represent the highest increases among the ten items analyzed. This pattern is interesting because both items require students to use the relationships among kinematic components in a more integrated manner (Aminuddin et al., 2024). The improvement on these two items may indicate that activities asking students to examine information on graphs and relate it to physics concepts support the solution of problems requiring more than one step of interpretation (Su, 2026). However, since the study did not employ qualitative analysis of students' responses to each item, this interpretation should be viewed as a possible explanation for the data pattern, rather than as direct evidence regarding the mechanisms of changes in understanding (Ammer & Alnasser, 2025).

The role of metacognitive prompts in learning can be understood through their function as questions or instructions that support the process of regulating thinking (Guo, 2022). In the context of interpreting kinematic graphs, students need to identify relevant information, select appropriate conceptual relationships, examine their reasoning steps, and ensure that their answers are consistent with the given representations (Koswojo et al., 2026). Metacognitive prompts can direct students' attention to these processes by asking them to plan their approach, monitor the problem-solving process, and evaluate their answers (Shin et al., 2023). Thus, prompts not only guide students toward the final answer but also provide an opportunity to reflect on the thinking process used (Wang et al., 2024). This explanation aligns with the characteristics of metacognitive prompts as a form of cognitive scaffolding that can help students direct and regulate their thinking processes while solving problems (Ciptaningtyas et al., 2022; Muthmainnah et al., 2024).

The results of the observation of metacognitive behavior provide additional information regarding the learning process. The monitoring aspect received the highest average score of 3.20, followed by planning at 2.80 and evaluating at 2.60. The predominance of monitoring scores can be attributed to the nature of the learning activities, which required students to check whether their problem-solving process aligned with the information in the graphs (Janssen & Lazonder, 2024). When interpreting position-time and velocity-time graphs, students need to verify whether the relationship between the slope of the graph, changes in values, and physical quantities has been correctly understood (Prada Núñez et al., 2022). Such verification activities have the potential to make monitoring behavior more frequently observed during the problem-solving process (Paramata et al., 2026). However, since the available observational data

consists of aggregate scores, these results only indicate that monitoring has the highest observed score and cannot yet be used to conclude that monitoring has shown the greatest improvement over time.

Conversely, the lower evaluation score—2.60—indicates that the evaluation aspect received the lowest observation score compared to planning and monitoring. This difference can be attributed to the characteristics of the problem-solving process. Conceptually, monitoring involves examining understanding and thought processes during problem-solving, whereas evaluation involves reassessing the strategies, processes, and results obtained (Chen et al., 2025). Therefore, the research findings suggest that evaluation activities could receive more explicit attention in the learning process. Prompts at the final stage of problem-solving can be designed to ask students to review their answers, provide reasons for their answers, and explain whether the results obtained are consistent with the characteristics of the graph and the physics concepts used (Marthaliakirana et al., 2022).

These results indicate that metacognitive prompts have the potential to support a learning process that is oriented not only toward obtaining answers but also toward examining the thinking process (Fazilova et al., 2026). In graph-based kinematics learning, students need to connect the shape of a graph with its physical meaning (Sakellariou & Hatzikraniotis, 2025). For example, interpreting a position–time graph requires an understanding that the slope is related to velocity, whereas interpreting a velocity–time graph requires an understanding that the slope is related to acceleration (Çoban & Salar, 2023). When prompts ask students to explain their reasoning, examine the information used, or reevaluate their answers, students gain a framework for examining these relationships (Vo et al., 2024). Thus, improved scores on various items can be understood in the context of learning that provides students with greater opportunities to regulate their reasoning processes (Benek & Şekercioğlu, 2026).

The research results also show that the improvement was not uniform across all students. Individual N-gain scores ranged from 0.35 to 0.76, with most students falling into the moderate category. This variation indicates that students responded differently to the implemented learning approach. These differences may be related to variations in prior knowledge, previous learning experiences, and each student's ability to use prompts to regulate their thinking processes (Safhira et al., 2026). Therefore, although the overall trend in score changes was positive, the research results do not indicate that all students achieved the same level of improvement (Pape, 2025). These findings imply that the use of metacognitive prompts can be developed in a more adaptive manner by taking into account the needs of students with varying levels of prior understanding.

The findings of this study are particularly relevant in the context of vocational education. Learning at polytechnics requires students not only to obtain numerical answers but also to understand the concepts underlying their application in vocational fields (Zheng, 2024). The ability to interpret graphs, understand relationships between physical quantities, and explain the reasoning behind a decision is an essential part of problem-solving skills applicable in engineering contexts (Niyomufasha et al., 2024). Therefore, integrating metacognitive activities into physics instruction can serve as an approach to help students develop the habit of reflecting on their thought processes when addressing conceptual problems. In the context of this study, the application of metacognitive prompts to kinematics material provides an example of how such strategies can be integrated into physics instruction in vocational education (Sijmkens et al., 2024).

The research findings also have practical implications for instructional design. Metacognitive prompts can be incorporated at various stages of problem-solving. During the planning stage, students can be asked to identify available information, determine relevant concepts, and plan a solution strategy (Eticha et al., 2025). During the monitoring stage, students can be asked to check whether their interpretation of the graph and the steps taken to solve the problem align with the concepts of kinematics (Dulger & Ogan, 2025). During the

evaluating stage, students can be asked to review their answers, provide justifications, and explain how their answers align with the characteristics of the graph (Punia et al., 2022). Based on the observation results in this study, strengthening the evaluation stage is relevant because this aspect received the lowest average score. Thus, the distribution of prompts can be designed to be more balanced so that students not only become accustomed to monitoring their thought processes but also reflect on the results and strategies used (Wang et al., 2024).

Although the results show significant changes, they must be interpreted with several limitations in mind. First, the study used a one-group pretest–posttest design without a control group. Therefore, the increase in scores cannot be fully attributed to the metacognitive prompts, as other factors—such as practice with the questions, learning experiences during the intervention, peer interactions, or the repeated measurement process—may also contribute to the changes in scores (Bierer et al., 2025). Second, the same instrument was used for both the pretest and posttest, so the possibility of a testing effect must be considered (DeBerry et al., 2023). Third, the number of participants was relatively limited and drawn from a single class at a single vocational education institution; thus, generalizing the results to a broader population of polytechnic students should be done with caution. Fourth, the metacognitive behavior data, which is available in the form of aggregate scores, does not yet allow for a longitudinal analysis of the development of planning, monitoring, and evaluating skills across each learning session.

These limitations also point the way for future research. Subsequent studies could employ a control group or a quasi-experimental design with a comparison group to obtain stronger evidence regarding the contribution of metacognitive prompts to improved conceptual understanding (Kongkaew et al., 2025). Research involving a more diverse range of participants and institutions is also needed to test the applicability of these strategies in different vocational education contexts. Additionally, the use of alternative instruments for the posttest or measurement designs that can mitigate the testing effect should be considered (Puimège et al., 2025). Qualitative analysis of student responses could also be used to identify changes in types of reasoning, misconceptions, and metacognitive strategies that emerge during learning (Utama et al., 2025). Thus, future research could provide a deeper understanding of the mechanisms by which metacognitive prompts support the development of conceptual understanding.

Overall, the study shows an increase in students' conceptual understanding after participating in a kinematics course that integrated metacognitive prompts. This improvement is evident from changes in average pretest and posttest scores, individual N-gains, and improvements across all measured items. Statistical analysis indicates that the difference between pretest and posttest scores is significant, and this conclusion remains consistent when examined using the Wilcoxon test. In the observational data, “monitoring” received the highest average score, while “evaluating” received the lowest. These findings suggest that instruction that provides students with opportunities to examine their own thinking processes has the potential to support graph-based kinematics learning (Osman et al., 2026). However, given the limitations of the study design, these results are best understood as evidence of improved understanding following the implementation of instruction that integrates metacognitive prompts, rather than as standalone causal evidence.

## CONCLUSION

Based on the research findings, it can be concluded that instruction incorporating metacognitive prompts leads to improved conceptual understanding of kinematics among polytechnic students. Prior to the instruction, students' conceptual understanding was still relatively low, particularly in interpreting motion graphs and understanding the relationships among kinematic quantities. After participating in the instruction, conceptual understanding scores increased significantly, from an average of 14.47 (36.17%) on the pretest to 29.38 (73.44%) on the posttest, with an N-gain value of 0.59 in the moderate category.

In addition to the improvement in conceptual understanding, observation results showed that metacognitive behaviors emerged during the learning process. The monitoring aspect received the highest average score (3.20), followed by planning (2.80) and evaluating (2.60). These results indicate that monitoring of the thinking process was observed more frequently than planning and evaluation. Meanwhile, the relatively lower score for evaluating suggests a need to strengthen reflection and evaluation of answers and problem-solving strategies.

## RECOMMENDATION

Physics instructors at polytechnics are advised to systematically integrate metacognitive prompts, particularly in material that involves various representations. Reflective activities during the evaluation stage also need to be strengthened. Future research is recommended to include a control group, a larger number of participants, and to involve different subject matter and vocational education institutions in order to obtain stronger evidence and test the generalizability of the findings.

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## AUTHOR CONTRIBUTIONS STATEMENT

| Name of Author   | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|------------------|---|---|----|----|----|---|---|---|---|---|----|----|---|----|
| Firmanilah Kamil | ✓ |   | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  |    | ✓ | ✓  |
| Nely Kurnila     |   | ✓ |    | ✓  |    | ✓ |   | ✓ | ✓ | ✓ | ✓  | ✓  |   |    |

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

## ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

## DATA AVAILABILITY

The data that support the findings are available from the corresponding author, FK, upon reasonable request.

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