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The Impact of Multirepresentation Learning on Students' Ability to Work with Graphs in One-Dimensional Kinematics

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Abstract: Students' low ability to work with graphs remains a problem in physics education. This study aims to apply a multirepresentation approach to improve high school students' ability to work with kinematic graphs. A quasi-experimental control group design was employed to compare the improvement in students' abilities between the experimental and control groups at a senior high school in Malang Regency. Students' ability to work with graphs was measured using a test adapted from the Test of Understanding Graphs in Kinematics (TUGK), consisting of 24 questions grouped into five indicators: (1) directly reading graphs; (2) reading graphs through the interpretation of slope/gradient; (3) reading graphs through the interpretation of the area under the curve; (4) a combination of Indicators 1 and 2; and (5) a combination of Indicators 1 and 3. The analysis results showed that the n-gain value for the experimental class was 0.30 (lower medium), was significantly higher on the $\alpha = 0,05$ scale compared to the control class value of 0.10 (low). The experimental class also showed superior results across all indicators. For basic skills (indicators 1-3), the experimental class obtained n-gain scores ranging from 0.25 to 0.27 (low-medium), while the n-gain for the control class ranged from 0.13 to 0.23 (low). For indicator 4, the experimental and control class achieved n-gain values of 0.19 and 0.01. Meanwhile, Indicator 5 could not be compared because the n-gain for the control class was undefined. Nevertheless, the achievement of experimental group was still not optimal, particularly regarding students' tendency to think "what you see is what you get" (WYSIWYG). The results emphasize that multirepresentational instruction should be complemented with tasks that assist students in linking graphical representations to their physical interpretations.

Keywords: Multirepresentational Learning; One-dimensional Kinematics; Students' Ability to Work with Graphs; Test of Understanding Kinematics in Graphs (TUGK)

Introduction

Physics education still faces various challenges, and one of them is students' low ability to work with graphs (Putri & Sutopo, 2024). Indeed, graphs are extremely important in showing the relationships between different variables in different scientific disciplines, and they are employed in science and mathematics education to support scientific researh, represent functions, explain concept, and summarize quantitative relationship (Binali et al., 2024). Consequently, the skills in creating and interpreting graphs are important and need to be considered in physics learning outcomes (Sarkity et al., 2022). The ability to work with graphs is not only based on the capability to read from graphs but also involves complex cognitive processes. In kinematics, these abilities consist of basic skills such as reading graphs directly, interpreting slopes, and interpreting the area under a curve, as well as advanced skills that combine two or more basic skills to transform one graph into another (Putri & Sutopo, 2024).

One-dimensional kinematics is one of the fundamental topics in mechanics because it serves as the basis of learning further physics topics (Adha & Taqwa, 2024). All skills related to working with graphs can be developed by learning kinematics (Beichner, 1994; Hernández et al., 2021). For example, the slope of the position-time graph represents velocity, while the area under the velocity-time graph represents displacement. The relationship between position, velocity, and acceleration can also be understood through graph analysis without using calculus. Therefore, the ability to work with graphs is a very important competency, but students have not yet fully mastered it, so it often becomes a source of difficulty in learning physics.

Students' limited ability to work with kinematic graphs has been highlighted in several previous studies. According to Putri & Sutopo (2024) only 39% of students were skilled at reading graphs directly, 47% at interpreting slopes, and 37% at determining the area under the curve. These percentages decrease further when students are presented with a combination of skills: 37% can read graphs and determine slopes, and 31% can read graphs and calculate the area under the curve. The results reveal that graphical problems continue to be one of the difficulties encountered by students in linear motion.

One of the approaches that can be implemented in solving the problem is multirepresentational learning, which means learning through different types of representations like verbal explanation, images, tables, mathematical equation, and graphs. This approach has been shown to effectively improve students' conceptual understanding, problem-solving skills, and representational abilities (Munfaridah & Goedhart, 2022; Nikat et al., 2021; Taqwa *et al*., 2023; Kurniasari & Wasis, 2021). Ate et al. (2025) also demonstrated that multirepresentation approach in physics instruction is widely used to improve students' conceptual understanding, problem-solving skills, and representational abilities There are also some researches which try to find the connection between multirepresentation approach and students' graphical abilities. One of such studies conducted by (Hidayah et al., 2019) revealed that kinematics instruction utilizing various representations can improve students' ability to work with graphs. The implementation of this instructional approach had a positive impact, as evidenced by an increase in students' understanding between pretest and posttest results.

In the field of kinematics, the ability to work with graphs is often assessed using the Test of Understanding Graphs in Kinematics (TUGK), developed by Beichner (1994). Currently, TUGK is still considered a relevant and widely used instrument for assessing this ability (Amin et al., 2020; Klein et al., 2021; Putri & Sutopo, 2024). Several research studies have shown that TUGK successfully identifies difficulties experienced by students and university students in connecting graphs with other representations, such as mathematical equations and motion concepts (Royani et al., 2025; Sundari et al., 2023). In addition, other studies have shown that graph interpretation skills can be improved through active learning strategies, such as peer instruction and active (Gok & Gok, 2022; Hernández et al., 2021).

Previous studies have attempted to improve students' ability to work with graphs. However, most of the research has been centered on enhancing the scores of graphing ability without identifying students' specific weaknesses in each indicator. Consequently, information regarding which aspects of graphical representation students find most difficult to understand remains limited. Furthermore, previous research has not extensively integrated a multirepresentation approach as a learning strategy. Based on the research gap, this study aims to implement multirepresentation learning to investigate Indonesian high school students' ability to work with kinematics graphs. Multirepresentational learning is expected to help students enhance their skills in reading, interpreting, and analyzing kinematics graphs, while also providing a detailed overview of the skills that remain challenging for students. Thus, the findings can serve as a basis for improving physics learning strategies at the senior high school level.

Methods

This study employed a quantitative method using a quasi-experimental control group design. In this design, the selection of the experimental and control groups did not involve randomization of subjects. Both the groups were subjected to pretest and posttest; however, the multirepresentational learning approach was implemented only in the experimental group. the intervention multirepresentation learning was applied only to the experimental class, while the control group received conventional instruction (

Table *1*). Subjects in this experiment included the students of Class X-F (experimental group) and Class X-E (control group). There were 36 students in each class. The population of this study consisted of all 10th-grade students at the school.

Table 1. Quasi Experimental Control Group Design

Group	*Pretest*	*Treatment*	*Posttest*
Experiment	O_1	X	P_1
Control	O_2	-	P_2

Keterangan:
X = Multirepresentation Learning
O_1 = *Experimental group: Pretest*
O_2 = *Control Group: Pretest*
P_1 = *Experimental group: Posttest*
P_2 = *Control Group: Posttest*

The pretest and posttest scores have been collected from student answers, with a score of 1 assigned to a correct answer and 0 to an incorrect answer. The improvement in score from the pretest to the posttest can be calculated using normalized gain (n-gain) (Hake, 1998), this is given by $g = \frac{posttest-pretest}{24-pretest}$, where the maximum test score is 24. g is categorized into four categories as shown in Table 2. To ensure the validity of using n-gain, a paired-samples t-test was conducted to compare the pretest and posttest scores within each class. If the test showed a statistically significant difference between the pretest and posttest scores, the use of n-gain scores as a measure of improvement in students' ability to work with graphs was considered valid.

Correlation test was conducted between the pretest scores and n-gain scores to examine the relationship between students' initial ability and their improvement in working with graphs. Pearson's correlation was used because the data were normally distributed and measured on an interval scale. If the test indicated a significant relationship between pretest and n-gain scores, pretest scores were treated as a covariate, and the analysis was continued using Analysis of Covariance (ANCOVA). In this analysis, posttest scores were used as the dependent variable, while the instructional group was used as the independent variable. ANCOVA was conducted to control for the effect of students' initial ability, allowing differences in posttest scores between the groups to be analyzed more accurately.

N-gain was also calculated for each indicator of the problem-solving abilities using graphs to find out the gains from all indicators. g values thus calculated were classified using the criteria shown in Table 3. Also, the analysis was done at the item level using normalized gain calculated using formula $g = \frac{P_{post}-P_{pre}}{1-P_{pre}}$, where P_{pre} is the number of students who answered correctly on the pretest, and P_{post} is the number of students who answered correctly on the posttest. This analysis aims to identify indicators of graphing skills that remain a weakness for students after instruction. The normalized gain scores per item are also categorized into four categories as shown in Table 2.

Table 2. N-Gain Score Distribution

Value Range	Category
$g < 0{,}25$	Low
$0{,}25 \leq g < 0{,}45$	Lower medium
$0{,}45 \leq g < 0{,}65$	Upper medium
$g > 0{,}65$	High

(Sutopo & Waldrip, 2014)

Students' ability to work with graphs was assessed using a test instrument adapted from the Test of Understanding Graphs in Kinematics (TUGK). The original instrument consisted of 26 items, but two items were not included in the test because they were procedural questions that had already been integrated into the Student Worksheet (LKPD). This test assesses several important skills related to the understanding of kinematic graphs; these skills are divided into two main categories: basic skills and combination skills (Putri & Sutopo, 2024). Each of these skill indicators is represented by a specific set of test items, as shown in Table 3.

Table 3. Indicators of Students' Ability to Work with Graphs

Indicator	Question Number
Basic Skills	
(1) Read the graph directly by looking at the coordinate labels and the axes of the graph	3, 8, 11, 16, 22, 23
(2) Interpreting the slope or gradient of a line on a graph	2, 5, 6, 7, 9, 12, 17, 18, 20
(3) Interpreting the area under the curve	1, 4, 15, 21, 24
Combination Skills	
(4) Graph transformation based on a combination of the ability to read graphs and interpret slopes or gradients	10 dan 13
(5) Graph transformations based on a combination of the ability to read graphs and interpret the area under the curve	14 dan 19

(Putri & Sutopo, 2024)

Results and Discussion

The results of the descriptive statistical analysis show that pretest-to-posttest scores increased in both the experimental and control classes, as shown in Table 4. The experimental class showed a greater increase than the control class. This is evident from the average n-gain of 0,30 (lower-medium category) in the experimental class and 0,16 (low category) in the control class. This is evident from the average n-gain of 0,30 (lower-medium category) in the experimental class and 0,16 (low category) in the control class. The results of the skewness analysis for the pretest, posttest, and n-gain data in both classes fell within the range of −1 to 1, indicating that the distributions were normal (Morgan et al., 2004) and that parametric tests could be applied

Table 4. Descriptive Statistics of Pretest, Posttest, and N-gain in the Experimental and Control Group

Statistics	Experiment			Control		
	Pretest	*Posttest*	*N-gain*	*Pretest*	*Posttest*	*N-gain*
Minimum	1	5	0.10	0	2	0
Maximum	8	17	0.56	6	11	0.32
Mean	5.03	10.6	0.30	2.80	6.23	0.16
Std. Deviation	1.91	2.94	0.11	1.43	2.01	0.09
Skewness	-0.28	-0.06	0.27	0.37	0.29	-0.003

The maximum score is on a scale of 24

To ensure the validity of the n-gain method, a comparison was conducted between the pretest and posttest scores in the control and experimental classes using a paired-sample t-test. A p-value of $< 0{,}001$ was obtained, indicating a significant difference at the $\alpha = 0{,}05$ level between the pretest and posttest scores in each class. Therefore, the use of n-gain scores as a measure of improvement in students' ability to work with graphs is valid. Analysis continued with an n-gain difference test between the control and experimental classes using an independent samples t-test. A significant p-value of $< 0{,}001$ was obtained at the $\alpha = 0{,}05$ level. These results indicate a significant difference in the improvement of students' ability to work with kinematic graphs between the experimental and control classes.

Analysis continued with a correlation test between pretest scores and n-gain to determine the relationship between students' initial ability and their improvement in working with graphs. The results of the Pearson correlation test in the control class showed that there was no significant relationship between the pretest scores and n-gain ($r = -0{,}203; p = 0{,}235$). Meanwhile, in the experimental class, a significant positive correlation was found between pretest scores and n-gain ($r = 0{,}452; p = 0{,}006$). Because there was a significant correlation between pretest scores and n-gain in the experimental class, pretest scores were treated as a covariate, and the analysis continued using ANCOVA with the posttest as the dependent variable. ANCOVA results showed that the pretest had a significant effect on the posttest ($F = 48{,}214; p < 0{,}001$). In addition, the class factor also had a significant effect on the posttest ($F = 17{,}207; p < 0{,}001$).

More specifically, an analysis based on indicators of chart-working skills Table 3 yielded the data presented in Table 5. All n-gains in the experimental class tended to be higher than those in the control class, except for indicator 5, for which the n-gain could not be calculated. The subsequent analysis will focus on the improvement per indicator in the experimental class to identify aspects of skill that still require reinforcement.

Table 5. Normalized Gain for Each Graphing Ability Indicator in the Experimental and Control Group

Indicator	N-gain			
	Experiment		Control	
	Mean	Standar Deviation	Mean	Standar Deviation
1	0.25	0.35	0.22	0.18
2	0.26	0.23	0.23	0.20
3	0.27	0.41	0.13	0.33
4	0.19	0.49	0.01	0.30
5	0.31	0.40	NA	NA

NA = *Not Available* (tidak terdefinisi)

Indicator 1: Reading Graphs Directly

The lowest level of basic skill achievement was observed in Indicator 1, as evidenced by the lowest n-gain score compared to the other basic indicators (Table 5). In addition, there were still test items with gain scores in the low and lower-medium categories. Figure 1 presents an example of a test item for this indicator in the low category, where 11 students (30.6%) answered correctly on the pretest. The distribution of answers shows that students chose option A 11.1% of the time, option B 8.3% of the time, option D 41.7% of the time, and option E 8.3% of the time, with option D being the most popular choice.

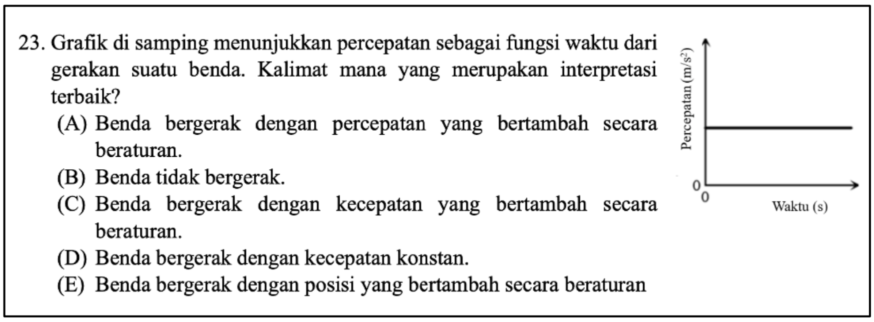

Figure 1. An Example of an Item for Indicator 1 in the upper-medium Category

After learning intervention there was a change in the pattern of the students' responses, since there were more students who had responded correctly in the posttest and their numbers were 8 students (22.2%). This change in the students' responses is detailed in Table 6.

Table 6. Cross-Tabulation of Response Among Students in the Experimental Class for Indicator 1 (Q23)

		A	B	C*	D	E	Total *pretest*
Pretest	A	**2**	0	0	2	0	4
	B	0	**0**	0	3	0	3
	C*	1	0	**4**	6	0	11
	D	0	0	4	**11**	0	15

	E	1	0	0	2	**0**	3
Total *posttest*		4	0	8	24	0	36

Note: The * symbol indicates the correct answer choice.
Cells in bold indicate the student's answers that remained unchanged from the pretest to the posttest.

In this study, multirepresentation learning was designed based on the assumption that constructing graphs progressively from verbal representations to tables and then to graphs can help students develop basic graph interpretation skills, particularly in reading graphs directly. Students were trained to understand relationships among kinematic quantities, construct tables, draw graphs, and determine mathematical equations based on motion phenomena. The experience of transforming between these representations is expected to deepen students' understanding of physics concepts (Sutopo et al., 2020). However, the research findings indicate that this assumption has not yet been fully realized. The n-gain scores on the graph-reading indicator remain relatively low, and for some test items, the increase in the number of students who answered correctly after the instruction was not optimal.

This suggests that the experience of constructing representations progressively is not yet sufficient to ensure that students can transfer their understanding to different situations involving graph interpretation. In other words, students still need more explicit practice in connecting verbal, mathematical, tabular, and graphical representations when solving kinematics problems. This condition may have occurred because the learning activities placed greater emphasis on how graphs are constructed from a given phenomenon, while explicit practice in reading graphs directly remained limited. Although the LKPD involved activities that required students to work with graphs, it did not intensively train students to connect the given graph features with their physical meaning. Consequently, some students still experienced difficulties when faced with questions requiring direct interpretation of graph labels, axes, and types.

Figure 1 shows an example of a test item for Indicator 1, where improvement remains low. This item requires students to read the graph directly, paying attention to the labels and axes, understand its physical meaning, and translate it into a verbal description. The shift in responses shown in (Table 6) indicates that most students still struggle and do not yet have a consistent conceptual understanding. A total of 67% of students still choose option D because they believe that all graphs showing straight lines represent constant motion. They have not yet realized that on an acceleration-time graph, a horizontal line indicates constant acceleration, which causes velocity to change at a constant rate. This error indicates that the relationships among kinematic quantities have not yet been fully understood, and students' understanding is still influenced by the "what you see is what you get" (WYSIWYG). Namely the tendency to interpret graphs based on their visual appearance without considering the variables on the axes or the physical meanings they represent.

These findings indicate that students still have difficulty linking graphical representations to verbal explanations, particularly in the context of acceleration, which is conceptually more complex than speed. These results are consistent with previous research revealing that students' ability to interpret graphs directly which requires translating graphical information into verbal form remains low (Amin et al., 2020). A study by Royani et al. (2025) also shows that students still have difficulty interpreting acceleration graphs because they require a more complex understanding of the relationships among kinematic quantities.

Students who answer correctly demonstrate that they understand graphs as representations of the relationship between two variables, as indicated by the labels on the horizontal and vertical axes. They are able to identify the quantities on each axis and interpret the physical meaning of the graphs. Therefore, there is a need for multirepresentation worksheet that present the relationships between representations in a more comprehensive and systematic manner, and provide students with more opportunities to translate and interpret between representations, which has the potential to help improve their ability to read graphs directly and draw conclusions based on the visual form of the graphs.

Indicator 2: Interpreting the Gradient

Similar to the previous indicator, Indicator 2 still contains test items in the low and lower-medium categories, even negative gains were found. This result is contrary to what has been found in previous studies where the gradient interpretation indicator has higher achievement than other indicators (Putri & Sutopo, 2024). The examples of test questions for this indicator at the low level are shown in Figure 2. Five students (13.9%) answered the item correctly on the *pretest*. The distribution of response choices showed that 5.6% of the students selected option A, 8.3% selected option B, and 52.8% selected option C, being the most frequently selected answer.

2. Gambar di samping menunjukkan grafik kecepatan terhadap waktu gerakan suatu benda. Manakah dari opsi berikut yang sesuai dengan situasi di mana percepatan benda paling negatif?
(A) Pada interval waktu R hingga T
(B) Pada interval waktu T hingga V
(C) Pada waktu t = V
(D) Pada waktu t = X
(E) Pada interval waktu X hingga Z

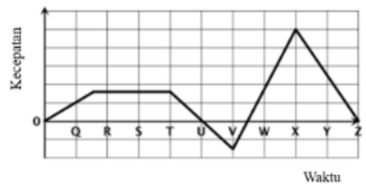

Figure 2. An Example of an Item for Indicator 2 in the low Category

During the learning process, students were trained to determine velocity from the slope of position-time graphs and acceleration from the slope of velocity-time graphs through discussions and LKPD activities. This practice helped some students understand that the slope represents the rate of change of a quantity with respect to time and recognize positive, zero, and negative acceleration. However, the learning activities still focused primarily on identifying the sign of acceleration based on the direction of the line's slope. Students had limited opportunities to compare the magnitude of acceleration based on the steepness of the line or to interpret the physical meaning of changes in slope. Consequently, some students still had difficulty relating the slope of a graph to the magnitude of changes in acceleration.

After learning intervention there was a change in the pattern of the students' responses (

Table 7). Overall, the number of students who answered correctly on posttest increased to 7 students (19.4%). However, 50% of the students selected option C, influenced by the statement in the question referring to the "most negative acceleration." These students relied more heavily on the visual representation and assumed that negative acceleration occurred when the object was at position t = V (the lowest point). This finding is consistent with previous studies showing that students tend to rely more on the height of the graph line than on its slope (Binali et al., 2024; Putri & Sutopo, 2024; Sundari et al., 2023; Susac et al., 2018). In addition, 16,9% of students chose option A because they associated negative acceleration with a high value of velocity, even though the slope of the graph is zero at that interval, meaning the acceleration is also zero. This error indicates that students have not yet fully understood that acceleration is determined by the slope of the velocity-time graph, not by the height of the graph.

Table 7. Cross-Tabulation of Response Among Students in the Experimental Class for Indicator 2 (Q2)

		A	**B**	**C**	**D**	***E**	**Total *pretest***
Pretest	A	**2**	0	0	0	0	2
	B	0	**1**	2	0	0	3
	C	1	3	**11**	0	4	19
	D	1	0	4	**0**	2	7
	E*	2	1	1	0	**1**	5
Total *posttest*		6	5	18	0	7	36

Note: The * symbol indicates the correct answer choice.
Cells in bold indicate the student's answers that remained unchanged from the pretest to the posttest.

Total of 13.9% students chose option B (the time interval from T to V) and 19.4% chose option E (the time interval from X to Z). Students who chose option B generally demonstrated a preliminary understanding of the concept of negative acceleration on a velocity-time (v-t) graph, specifically by identifying the downward-sloping portion of the graph as representing negative acceleration. However, they have not carefully compared the steepness of the graph at each interval, leading them to assume that the interval from T to V represents the most negative acceleration, when in fact the interval from X to Z has a steeper slope and represents the greatest negative acceleration. If students have developed the skill of interpreting the slope of a line, they can determine its gradient without having to master the concept of derivatives in calculus (Putri & Sutopo, 2024).

Students' difficulty in determining the most negative acceleration indicates that they are not yet accustomed to comparing the steepness of negative gradients on velocity-time graphs. Although students have been given examples and exercises involving positive, zero, and negative acceleration, the proportion of exercises involving positive acceleration is relatively greater than those involving negative acceleration. Students' understanding of how to interpret negative slopes may not be as strong as their understanding of positive slopes. As a result, some students still focus more on the y-intercept of the graph than on its slope when determining the magnitude of acceleration. These findings suggest that exercises on interpreting slopes need to be presented in a more varied and repetitive manner, particularly in the context of negative acceleration and comparisons of the steepness of lines.

Overall, Indicator 2 still requires special attention because students have not yet fully understood the meaning of the slope (gradient) of a line on a graph. These findings suggest that exercises that focus solely on the procedure for determining the slope are not sufficient to help students understand the conceptual meaning of the slope as a representation of the rate of change. Therefore, teachers need to emphasize that velocity is represented by the slope of the $x(t)$ graph, and acceleration is represented by the slope of the $v(t)$ graph. In addition, students' mathematical understanding needs to be strengthened specifically, that the slope is expressed as $m = \Delta y/\Delta t$, so that on a position-time graph, $v = \Delta x/\Delta t$, and on a velocity-time graph, $a = \Delta v/\Delta t$. With this emphasis, it is hoped that students will be able to relate physics concepts to the mathematical representations of the graphs.

Indicator 3: Interpreting the Area Under the Curve

Pada indikator 3, skor *n-gain* merupakan yang tertinggi di antara keterampilan dasar (**Error! Reference source not found.**), menunjukkan adanya peningkatan pemahaman siswa dalam memaknai luas daerah di bawah grafik sebagai representasi besaran fisis, seperti jarak tempuh, perpindahan, atau perubahan kecepatan. Peningkatan tersebut tampak pada butir soal nomor 4 (**Error! Reference source not found.**) yang memperoleh kategori gain tinggi. Pada soal tersebut, siswa diminta menentukan jarak tempuh lift selama tiga detik pertama berdasarkan grafik kecepatan-waktu. Untuk menjawab dengan benar, siswa harus memahami bahwa jarak diperoleh dari luas daerah di bawah grafik pada interval 0-3 s yang berbentuk segitiga, sehingga dapat dihitung menggunakan rumus luas segitiga. Temuan ini berbeda dengan penelitian sebelumnya yang melaporkan bahwa sebagian besar siswa masih belum mampu memaknai luas daerah di bawah kurva sebagai cara langsung (*shortcut*) untuk menentukan besaran fisis tersebut (Bajracharya et al., 2023; Putri & Sutopo, 2024; Sundari et al., 2023).

For Indicator 3, the n-gain score was the highest among the basic skills (Table 5), indicating an increase in students' understanding of interpreting the area under a graph as a representation of physical quantities, such as distance traveled, displacement, or change in velocity. This is shown by question number 4 (Figure 3), which received a "high gain" rating. In this question, students were asked to determine the distance traveled by the elevator during the first three seconds based on a velocity-time graph. To answer correctly, students had to understand that the distance is calculated from the area under the graph for the 0-3 s interval, which is triangular in shape and can therefore be calculated using the formula for the area of a triangle (Bajracharya et al., 2023; Putri & Sutopo, 2024; Sundari et al., 2023).

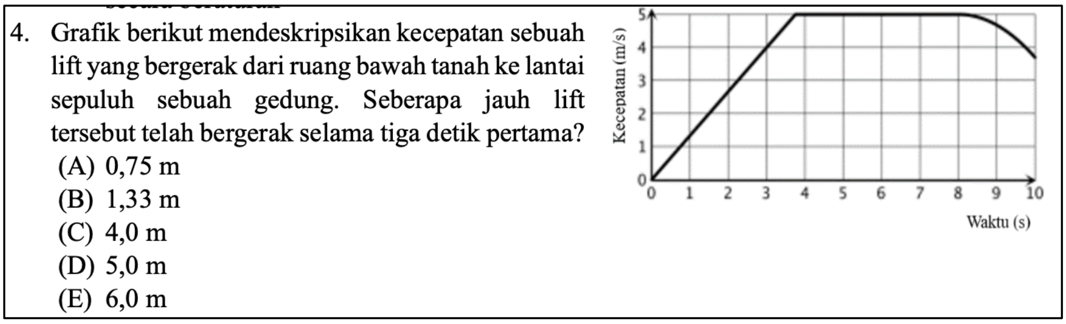
4. Grafik berikut mendeskripsikan kecepatan sebuah lift yang bergerak dari ruang bawah tanah ke lantai sepuluh sebuah gedung. Seberapa jauh lift tersebut telah bergerak selama tiga detik pertama?
(A) 0,75 m
(B) 1,33 m
(C) 4,0 m
(D) 5,0 m
(E) 6,0 m

Figure 3. An Example of an Item for Indicator 3 in the low Category

The result of this change can be observed from question 4 (Figure 3), where the normalized gain score attained was 0.59 (upper-medium group). From the pre-test, only 7 learners (19%) got it right (option E), while 81% of the total picked the wrong option, especially option C. This is made possible through LKPD learning activities that directly teach students how to find the area under a curve by way of systematic approaches, including identifying time intervals, determining the shape of a plane figure, finding its area, as well as linking this process to physical phenomena like displacement and velocity. These types of systematic and repetitive exercises allow students to see the relationship between geometry and physics, thus showing that direct instruction is useful in improving students' graphing skills.

Table 8. Cross-Tabulation of Response Among Students in the Experimental Class for Indicator 3 (Q4)

		A	B	C	D	E*	Total *pretest*
Pretest	A	**0**	0	1	0	2	3
	B	0	**1**	1	0	6	8
	C	1	1	**2**	2	9	15
	D	0	0	1	**0**	2	3
	E*	0	0	1	1	**5**	7
Total *posttest*		1	2	6	3	24	36

Note: The * symbol indicates the correct answer choice.
Cells in bold indicate the student's answers that remained unchanged from the pretest to the posttest.

An analysis of three basic skills for interpreting graphs shows that they are interrelated and must all be mastered for students to be able to interpret graphs correctly. In many cases, students are required not only to master a single skill but also to combine them. For example, transforming a position-time graph into a velocity-time graph requires the ability to read graphs and interpret the slope as velocity, whereas transforming an acceleration-time graph into a velocity-time graph requires the ability to read graphs and understand that the area under the curve represents a change in velocity. The research findings indicate that indicators (4) and (5), which involve a combination of these skills, still show low to lower-medium achievement levels. Therefore, the subsequent discussion focuses on questions that require the integration of two graph interpretation skills.

Indicator 4: Graph Transformation Based on Gradient

For Indicator 4, graph transformation based on a combination of the ability to read graphs and interpret slopes or gradients the combined skills assessed by this indicator showed the lowest achievement. Figure 4 presents an example of a test item for this indicator. Based on the pretest results, only 16.7% of students answered correctly (option B), while the majority of students chose option A (63.9%), followed by option D (16.7%) and option E (2.8%).

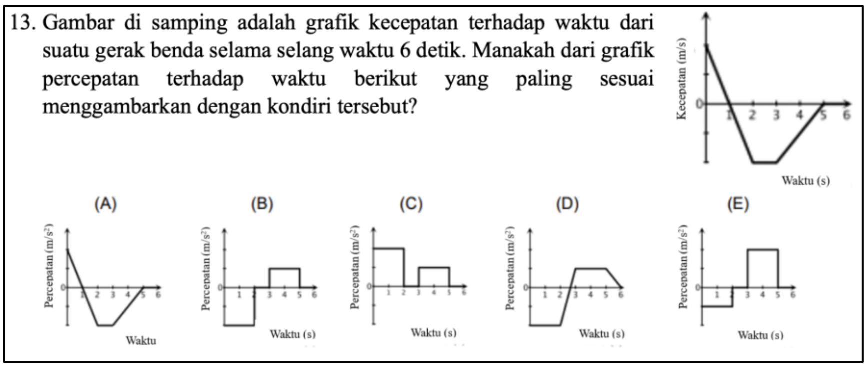

Figure 4. An Example of an Item for Indicator 4 in the low Category

As is shown in Table 9, the pattern of responses from the students changed after the lesson. The number of students who answered correctly increased to 15 (41.7%). This shift primarily came from students who had previously chosen options A and D but then switched to option B. Nevertheless, some students still selected incorrect answers, with 10 students (27.8%) choosing option D and 4 students (11.1%) choosing option E on the posttest. This shows that improvement in this particular indicator has not been consistent, and there have been difficulties in plotting the graph accurately.

Table 9. Cross-Tabulation of Response Among Students in the Experimental Class for Indicator 4 (Q13)

		A	B*	C	D	E	Total *pretest*
Pretest	A	**5**	9	0	7	2	23
	B*	0	**3**	1	1	1	6
	C	0	0	**0**	0	0	0
	D	1	3	0	**1**	1	6
	E	0	0	0	1	**0**	1
Total *posttest*		6	15	1	10	4	36

Note: The * symbol indicates the correct answer choice.
Cells in bold indicate the student's answers that remained unchanged from the pretest to the posttest.

Students' ability to work with graphs declines when they are asked to transform one graph into another, a task that combines the skills of reading graphs and interpreting slopes. This can be seen by the n-gain scores for the combination of indicators 1 and 2, which are lower than the scores for each indicator individually (Table 5). This difficulty is particularly evident in indicator 4, which requires the simultaneous integration of several skills. This finding is consistent with previous research indicating that combining multiple graph-interpretation skills requires a more complex thought process and is one of the main challenges students face (Amin et al., 2020; Klein et al., 2021).

Problems associated with this indicator may imply that the students have not managed to combine their skills of interpreting graphs with those of analyzing slopes while transforming graphs (Binali et al., 2024; McDermott, Rosenquist, & van Zee, 1987; Putri & Sutopo, 2024). Analysis of the answers provided by the students during the pretest reveals that transforming information from the speed-time graph is still a problem for the students. These results are consistent with previous research indicating that students' ability to interpret information based on graphs remains relatively low (Amin et al., 2020; Royani et al., 2025). Following the instructional intervention, a shift in students' responses toward the correct option on item 13 was observed (Figure 3), indicating an improved understanding that acceleration is determined by the slope of the velocity-time graph, not by the visual shape of the graph.

Before the lesson, some students still relied on the similarity of graph shapes (what you see is what you get), so they chose graphs that resembled the original graph. Others had understood that acceleration changes, but were not yet able to accurately determine its value and sign. After the lesson, more students were able to represent each segment of the velocity graph as the corresponding constant acceleration.

Nevertheless, the majority of students still chose the incorrect answer. This indicates that students are not yet able to process graphical information conceptually. Graph transformations require the ability to read the axes and labels, understand the meaning of the slope, and relate that information to the new graph. The error in option C shows that students recognized constant acceleration but still made a mistake in determining the magnitude and sign of the acceleration. This indicates that the understanding of the gradient as acceleration is not yet consistent.

In the 0-2 s interval, the gradient of the velocity graph is negative, so the acceleration should be a constant negative value. Students' errors in identifying the acceleration graph are consistent with the findings of McDermott (1987) and Putri & Sutopo (2024), which indicate that students still struggle to connect the shape of a graph with the physical meaning of motion. Upon closer inspection, options B and E have similar graph shapes. The difference between the two graphs lies in the acceleration values for the 0-to-2-second time interval and the 3-5s time interval. Students are likely to give the wrong answer if they cannot interpret this information based on the slope of the velocity-time graph. In addition, students must understand that the slope of the velocity-time graph is directly related to the value of acceleration. The steeper the slope of the line, the greater the acceleration. Students' lack of precision in comparing the slopes of the lines in these two intervals caused some of them to choose option E. On the velocity-time graph, the slope of the line in the 0-2s interval appears steeper than that in the 3-5s interval. This indicates that the acceleration in the 0-2s interval is greater in magnitude and more negative than that in the 3-5s interval. This finding is consistent with previous research showing that students still experience difficulties in interpreting the slope of a velocity-time graph to determine the magnitude and direction of acceleration, therefore this aspect requires attention in the learning process (Ayop & Ismail, 2019; Bajracharya et al., 2023; Putri & Sutopo, 2024; Susac et al., 2018).

The low scores on this indicator suggest that multirepresentation learning has not yet fully succeeded in developing students' ability to transform graphs. Although students have been trained to determine positive, zero, and negative slopes by analyzing velocity-time graphs in the worksheets, these exercises still focus on identifying slopes procedurally. Students have not had much practice converting velocity-time graphs into acceleration-time graphs or other forms of representation. As a result, when faced with problems that require the integration of multiple skills, students still tend to rely on visual similarities rather than on the relationships between representations and their physical meanings.

Throughout the course, students have actually been trained to determine positive, zero, and negative acceleration by analyzing the slope of the velocity-time graph in the worksheet on uniformly accelerated motion. One of the exercises provided is similar in context to question 13, in which students are asked to determine whether several statements are true or false based on a velocity-time graph. In this activity, students are guided to understand that a positive slope indicates positive acceleration, a zero slope indicates zero acceleration, and a negative slope indicates negative acceleration or deceleration. However, the exercises provided still place greater emphasis on identifying the gradient value procedurally and do not yet include exercises that explicitly ask students to transform a position-time graph into a velocity-time graph or a velocity-time graph into an acceleration-time graph. As a result, when students are presented with graph transformation problems involving several intervals with positive, negative, and zero slopes, some students still tend to focus on the visual similarity of the graphs rather than on the relationships between the physical quantities they represent.

Indicator 5: Graph Transformation Based on the Area Under the Curve

However, the performance on indicators 1 and 3 showed better n-gain scores than the other indicators (Table 5). Although this indicator involves combined skills, students' improvement on this indicator was greater than on indicator 4. This suggests that students have a stronger understanding of interpreting the area under a curve than of the slope when transforming a graph. Figure 5 presents an example of a test item for this indicator with a normalized gain in the upper-medium category. Based on the pretest results, only 3 students (8,3%) answered correctly (option B), while the remaining 93% of students chose the incorrect answer. The distribution of answers shows that the majority of students chose option C.

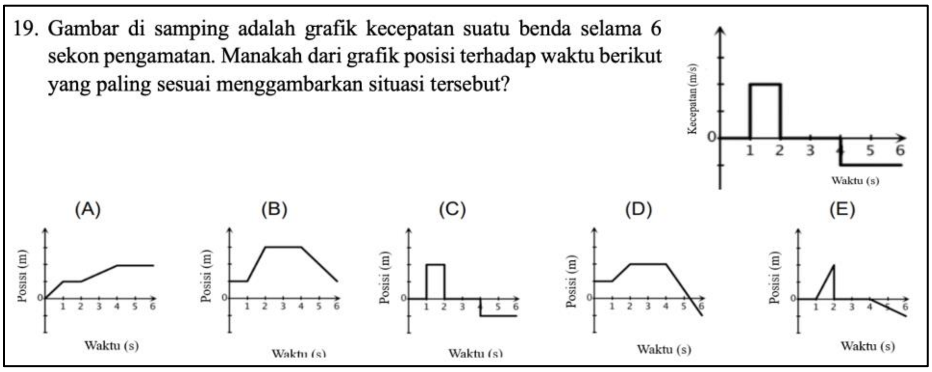

Figure 5. An Example of an Item for Indicator 4 in the upper-medium Category

As can be seen from Table 10 below, after the lesson, there was a change in the students' answers. Specifically, there were 18 (50%) students who gave the correct answer. This is because the students who had picked option C switched to option B. On the other hand, in the posttest, there were some students who had picked the wrong answers, specifically, 9 students (25%) picked option A, 3 (8.3%) picked option C, 2 (5.6%) picked option D, and 4 (11.1%) picked option E.

Table 10. Cross-Tabulation of Response Among Students in the Experimental Class for Indicator 5 (Q19)

		A	B*	C	D	E	Total *pretest*
Pretest	A	**1**	3	0	1	0	5
	B*	1	**1**	0	0	1	3
	C	5	12	**2**	1	2	22
	D	2	1	0	**0**	1	4
	E	0	1	1	0	**0**	2
Total *posttest*		9	18	3	2	4	36

Note: The * symbol indicates the correct answer choice.
Cells in bold indicate the student's answers that remained unchanged from the pretest to the posttest.

This improvement is supported by learning activities and worksheets that explicitly train students to calculate the area under a curve through systematic, step-by-step procedures. Structured and repetitive practice helps students understand the relationship between geometric representations and physics concepts. As a result, when asked to transform a graph based on the area under the curve, students were better prepared than when asked to perform gradient-based transformations. In number 19 (Figure 5), students not only interpreted the area under the curve but also related it to the position of the graph in each answer choice. Therefore, solving this problem requires the ability to integrate information from the velocity graph with the concept that the area under the curve represents a change in position. If these two skills are not properly combined, students are likely to choose the wrong answer.

Based on an analysis of the responses, most students were unable to answer correctly in the early stages. A total of 61% of students chose option C because they focused more on the visual form of the graph than on analyzing its physical meaning (what you see is what you get). As a result, the graphs they selected tended to resemble the original graph. After instruction, about 50% of students switched to the correct answer, with 33% of them believed to have come from the group that previously experienced this effect. This shift indicates an increase in understanding, although some students still choose the incorrect answer. For example, 25% of students chose option A because they believed that the position begins to change as soon as the velocity increases, without realizing that as long as the velocity is zero, the object's position remains constant. This indicates that students have understood the relationship between positive velocity and changes in position, but have not yet fully realized that zero velocity is represented by a horizontal line on a position-time graph. Thus, students' understanding remains partial because it focuses more on the moving part of the object than on the initial condition when the object is at rest.

Another error was made by the 11% of students who chose option E. These students were unable to correctly relate the velocity-time graph to the position-time graph. In the problem, the object moves at a constant positive velocity and then comes to a stop (zero velocity) without ever moving in the opposite direction. However, the position graph for Option E actually decreases after reaching a certain point, indicating that the object is moving back in its original direction (negative velocity), even though this condition is not shown on the velocity graph. This error likely arises because students assume that when velocity becomes zero, the position returns to the starting point, or they are still confusing the concepts of velocity and position. In fact, when velocity is zero, the object's position remains constant. Although there was an improvement in Indicator 5, some students still had difficulty integrating the relationships between physical quantities on graphs with different variables. This finding is consistent with previous research showing that proficiency in this indicator remains relatively low and often poses a challenge for students (Amin et al., 2020; Putri & Sutopo, 2024; Susac et al., 2018).

The implications of these findings suggest that instruction should include more exercises that explicitly require students to transform one type of graph into another. It is not enough for students to simply be trained to construct graphs based on a given phenomenon; they also need to become accustomed to converting position-time graphs into velocity-time graphs, velocity-time graphs into acceleration-time graphs, and vice versa. These exercises are important so that students can understand the relationships among kinematic quantities in a more integrated way, particularly in interpreting the slope and the area under the curve as representations of physical quantities. Thus, students' ability to work with graphs depends not only on the visual similarity of the graphs but also on their conceptual understanding of the relationships among these representations.

Based on the discussion presented, the application of TUGK instrument in the context of high school physics instruction indicates that students' ability to work with kinematic graphs still needs to be strengthened. This is reflected in the difficulty level of the questions, which remain in the "difficult" category, particularly for questions that require the simultaneous integration of several graph-interpretation skills. From these results, we conclude that there is still difficulty among the students when it comes to working with graphs including their interpretation and conceptualization. Therefore, learning strategies are needed that not only emphasize the process of constructing graphs based on phenomena but also provide scaffolding and more intensive practice in explicitly and consistently connecting various graphical representations so that students' ability to work with graphs can develop more comprehensively.

Conclusion

Results of this study indicate that multirepresentation instruction is more effective than conventional instruction in improving students' ability to work with graphs in one-dimensional kinematics. This is evidenced by the higher n-gain scores of the experimental class, both overall and for each indicator, although these scores still fall within the lower-medium category. Analysis also shows that students' initial ability still influences the magnitude of their improvement. However, even after controlling for the effect of initial ability, multirepresentation instruction still has a significant effect on students' n-gain.

Among the basic skills, the smallest improvement was observed in the indicator for reading graphs directly, followed by interpreting slopes, while the greatest improvement was observed in interpreting the area under the curve. Among the combined skills, the improvement tended to be smaller, particularly in indicators that integrate the ability to read graphs with interpreting slopes. These findings indicate that students still have difficulty when they must combine several graph interpretation skills simultaneously.

Overall, this study shows that multirepresentation learning can improve students' ability to work with graphs; however, this improvement is not consistent across all skill areas. Students still experience difficulties, particularly on tasks that require the integration of multiple skills. These findings indicate that the ability to work with graphs depends not only on mastery of individual basic skills, but also on the ability to connect and consistently apply them across various representations of kinematics. These findings reinforce the notion that difficulties in working with graphs of linear motion remain a common challenge for high school students.

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