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IDENTIFY RESOURCES ACTIVATED BY STUDENTS WHEN SOLVING STRAIGHT MOTION KINEMATICS PROBLEMS WITH DIFFERENT REPRESENTATION

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ABSTRACT

This research aims to explore kinematic resources in linear kinematics by utilizing different forms of problem representation. The study was conducted by administering 15 reasoned multiple-choice questions to 146 high school students from three districts in Central Sulawesi, Indonesia. The research instrument covers topics in linear kinematics, including distance, displacement, speed, and velocity, presented through diagrammatic representations, graphs, and mathematical equations. The students' written answers were analyzed both quantitatively and qualitatively. Quantitative analysis was conducted to determine descriptive statistics from the data, while qualitative analysis identified the resources students activated when solving these questions. The findings reveal that the various resources students activate include Phenomenological Primitives (P-Prims), Conceptual Resources, and Procedural Resources. Procedural Resources are more frequently activated when students solve problems presented as mathematical equations. In contrast, in response to visual representations such as diagrams and graphs, students tend to activate "What You See Is What You Get" (WYSIWYG) as P-Prims.

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INTRODUCTION

Kinematics is a fundamental concept in physics that is crucial to understand thoroughly (Aththibby et al., 2021; Rahayu & Purwanto, 2013; Sutopo et al., 2020). As one of the fundamental principles of physics, kinematics has been extensively studied in the field of physics education to uncover misconceptions (Hasbullah et al., 2018; Jufriadi et al., 2021) and students' difficulties in solving problems related to this concept (Amaliah et al., 2021; Puspitaningtyas et al., 2021). These difficulties include challenges in understanding graphs (Bollen et al., 2017; Maries & Singh, 2015), describing speed and acceleration (Taqwa & Rivaldo, 2018), and distinguishing between distance and displacement (Anugraheni & Handhika, 2018; Jufriadi & Andinisari, 2020).

This research employs misconception theory (Broadfoot et al., 2020), which focuses solely on students' incorrect or non-expert conceptions (Sabo et al., 2016). However, this theory is insufficient in explaining how misconceptions develop in students' understanding (Docktor & Mestre, 2014). Therefore, alternative theories are needed to more effectively map the structure of students' understanding.

An alternative theory that can be utilized is Resource Theory. In contrast to misconception theory, Resource Theory views understanding as comprising small, dynamic components called "Resources" that are context-dependent (Kustusch, 2016; Sayre & Wittmann, 2008). Several studies using this theory have found that students who fail to solve physics problems often rely on naïve and irrelevant knowledge (Nadhor & Taqwa, 2020). Research using Resource Theory has identified several types of resources activated when solving physics problems, including Phenomenological Primitives (P-Prims) (DiSessa, 1993; Juliyanto & Siswanto, 2021), Conceptual Resources (Hansen et al., 2021; Jelicic et al., 2017), and Procedural Resources (Wittmann & Black, 2015).

To date, research utilizing Resource Theory in the field of physics education has predominantly highlighted resources on topics such as motion dynamics (Hansen et al., 2021; Harrer et al., 2013; Meiliani et al., 2021), electricity (Meredith & Marrongelle, 2008; Richards & Etkina, 2013; Richards et al., 2020; Taqwa et al., 2023), temperature and heat (Abraham et al., 2021; Alesandrini et al., 2022), and fluid pressure (Young & Meredith, 2017). However, more research is still needed to explore resources in the context of kinematics, particularly linear kinematics.

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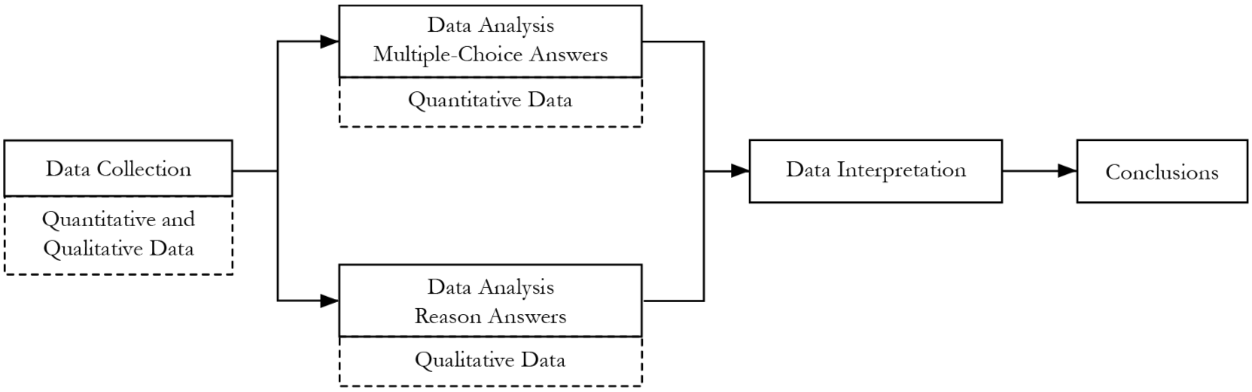


Figure 1. Research flow.

Given the need for more in-depth research on linear kinematics using Resource Theory, this study aims to identify the resources students utilize to solve problems in this area. To trigger the activation of various types of resources (P-Prims, Conceptual Resources, and Procedural Resources), this research employs questions with different representations of physics problems (Khatin-Zadeh et al., 2023), including graphical representations, diagrams, and mathematical equations.

METHOD

This study employs a non-experimental research design using a mixed-methods approach. The data collected in this research is both quantitative and qualitative, gathered simultaneously through various research instruments. The research flow is illustrated in Figure 1. The research instrument consists of 15 reasoned multiple-choice questions on the topic of linear kinematics, presented through graphical representations, diagrams, and mathematical equations. This instrument was adapted from previously developed tools, including the Force Concept Inventory (FCI), specifically Question 19, the Test of Understanding Graphs in Kinematics (TUG-K), specifically Question 4, and two questions from the research conducted by Ibrahim and Rebello (2012).

The research instrument was tested for validity and reliability. Validity and reliability tests were conducted using product moment statistical analysis techniques and Cronbach's Alpha via IBM SPSS Statistics 23. The results of the correlation coefficient calculation indicated that $r_{\text{count}} > r_{\text{table}}$ (with $r_{\text{table}} = 0.1367$), confirming that the 15 questions are valid. Additionally, the reliability test yielded a value of 0.77, indicating acceptable reliability. A more detailed description of the questions is provided in Table 1.

The subjects of this research were 146 high school students from three districts in Central Sulawesi, Indonesia. The participants were students in grades 10th and 11th during the even semester of the 2022/2023 academic year. All participants were given the research instrument, consisting of the multiple-choice questions.

The students' responses to the multiple-choice questions were analyzed using descriptive statistics to determine the means and standard deviations of the data. This quantitative analysis was employed to assess student understanding through the scores obtained. Meanwhile, the qualitative analysis of the students' reasoning behind their answers aimed to identify the resources they activated when solving the physics problems.

Table 1. Sub-topic problems and r value ($r_{\text{table}} = 0.1367$).

Sub-topic	Problem	Forms of Representation	Number of Question	r
1	Determines distance based on position information	Diagram	6	0.508
		Mathematical	4	0.571
		Graph	5	0.592
2	Determines distance based on velocity information	Diagram	9	0.409
		Mathematical	8	0.563
		Graph	7	0.642
3	Determines the displacement containing the turning point based on velocity information	Diagram	15	0.472
		Mathematical	13	0.534
		Graph	14	0.333
4	Determines average speed based on position information	Diagram	1	0.643
		Mathematical	2	0.406
		Graph	3	0.453
5	Determines acceleration based on velocity information	Diagram	11	0.486
		Mathematical	10	0.436
		Graph	12	0.436

RESULTS

The quantitative analysis results, presented in descriptive statistical data, reveal students' understanding of the topic of kinematics. These descriptive statistics can be observed in Table 2, which highlights the differences in average scores obtained by grade 10th and grade 11th students across sub-topic problems related to straight-motion kinematics. Notably, grade 10th students have slightly higher scores than grade 11th students in three sub-topics. The difference in average scores between these two grades ranges from 0.11 to 0.24. However, the most significant score difference is observed in sub-topic 4, with a difference of 0.75.

Additionally, the percentage of correct answers was calculated to determine the distribution of correct responses in kinematics. These results are shown in Figure 2, which demonstrates a notable difference in the percentage of correct answers between grade 10th and grade 11th students. Both groups showed difficulty solving questions on the topic of instantaneous speed using position information. As indicated in Figure 2, the percentages of correct answers for this topic range between 12% and 27%. This problem topic is covered in Question 1, 2, and 3, as detailed in Figure 3.

The qualitative analysis conducted in this study revealed that in Question 1, where students achieved the lowest percentages (12% and 14% correct answers), as shown in Figure 2, students activated Phenomenological Primitives (P-Prims), Conceptual Resources, and Procedural Resources. Specifically, students activated the resource "position is equal to instantaneous speed", also known as "same means same". This interpretation was directly derived from students' reasoning based on the motion diagram representation, as presented in Figure 4.

Based on the students' reasoning (see Figure 4), it is evident that students interpreted the positions depicted in the object's motion diagram as indicative of instantaneous speed. Therefore, they concluded that when two positions are the same, the instantaneous speed must also be the same. Similarly, in Question 3 (see Figure 3), students employed similar resources, as illustrated in Figure 5. Here, students inferred that the curve on the $x-t$ graph represents the object's motion trajectory, leading them to conclude that intersecting curves indicate the same position for two objects.

Table 2. Result of descriptive analysis.

Statistics	**Sub-topic 1**		**Sub-topic 2**		**Sub-topic 3**		**Sub-topic 4**		**Sub-topic 5**	
	10th	**11th**	**10th**	**11th**	**10th**	**11th**	**10th**	**11th**	**10th**	**11th**
N	82	64	82	64	82	64	82	64	82	64
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	3	3	3	3	3	3	3	3	3	3
Mean	0.96	1.08	1.27	1.08	0.60	0.83	1.23	0.50	1.30	1.14
Std. Dev.	1.09	1.01	0.93	0.93	0.87	0.98	0.88	0.71	0.96	0.89

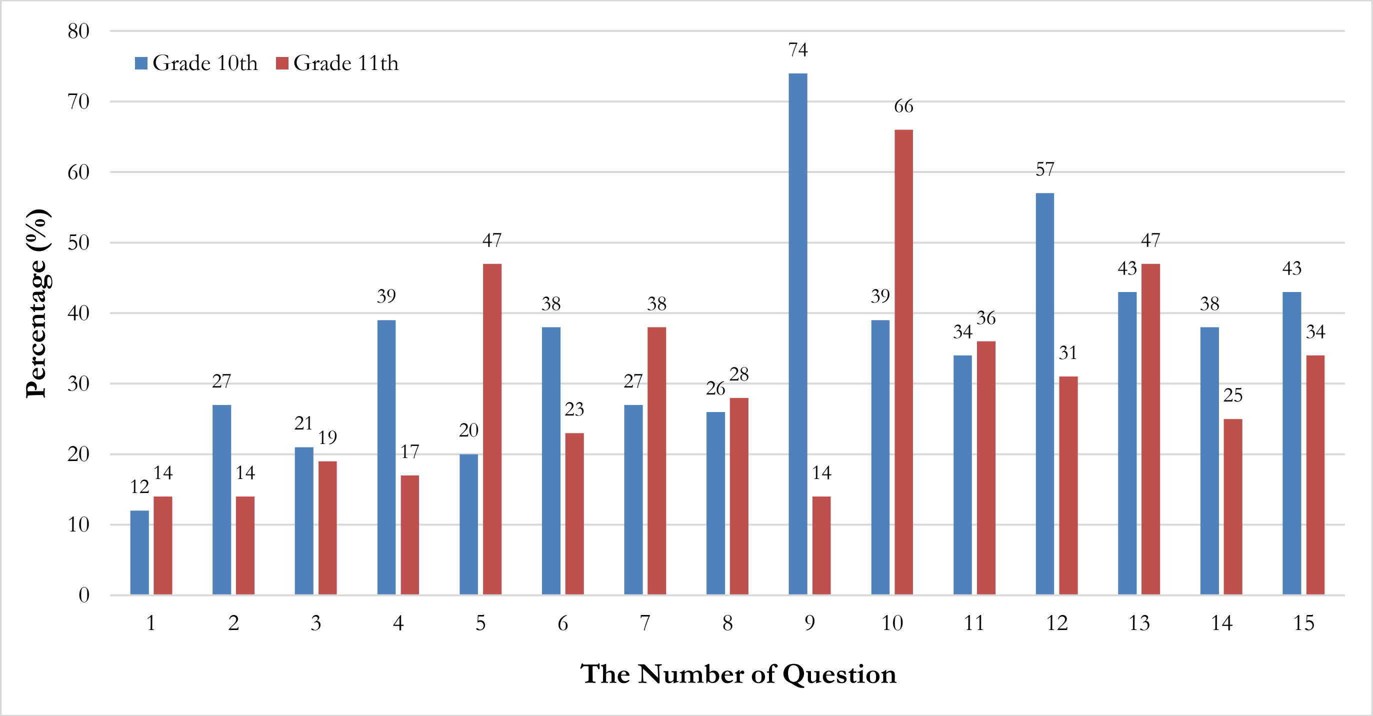
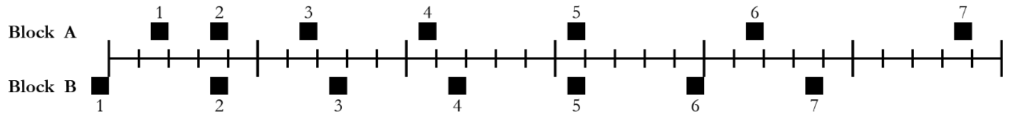


Figure 2. Distribution of correct answers.

1. Two blocks (Blocks A and B) move to the right in a straight path. The position of each block for each equal time interval from 1st second to the 7th second is sequentially depicted by the numbered boxes in the image below.



Do the two blocks ever have the same speed?

- a. Never
- b. Never, namely at position $t = 2$
- c. Once, namely at position $t = 2$ and $t = 5$
- d. Once, namely sometime between the time interval $t = 3$ to $t = 4$
- e. Other: ……………………………….

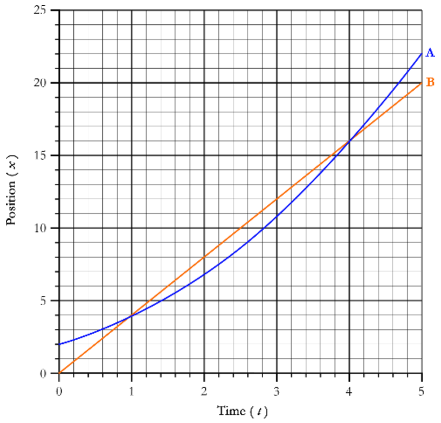
2. It is known that 2 blocks (Blocks A and B) are moving in a straight path. Block A moves in a straight line and changes uniformly. The position of each block meets the following equeation.

Block A: $x(t) = t^2 + t + 1$
Block B: $x(t) = 4t$

Do the two blocks ever have the same speed?

- a. Never
- b. Never, namely at position $t = 1$
- c. Never, namely at position $t = 1.5$
- d. Never, namely at position $t = 3$
- e. Other: ……………………………….

3.

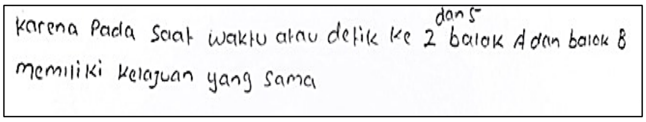


The following graph shows the position of two objects (object A and object B) moving in a straight path during 5 seconds of observation.

Based on the graph, do the two objects ever have the same speed?

- a. Never
- b. Never, namely at position $t = 1$
- c. Once, namely at position $t = 1$ and $t = 4$
- d. Once, namely sometime between the time interval $t = 2$ to $t = 3$
- e. Other: ……………………………….

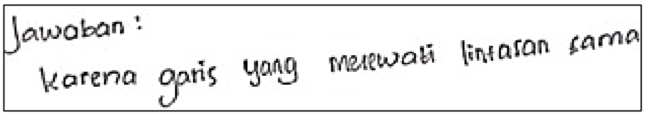
Figure 3. Question items sub-topic 4 (Questions 1, 2, and 3).



Karena Pada Saat waktu atau detik ke 2 dan 5 balok A dan balok B memiliki kelajuan yang sama

Because at the 2nd and 5th seconds, block A and block B have the same speed

Figure 4. Sample of students' reasons for question number 1.

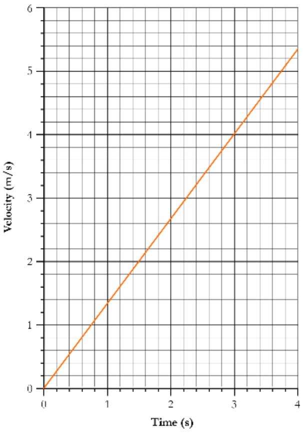


Jawaban :
Karena garis yang melewati lintasan sama

Because the lines pass through the same path

Figure 5. Sample of students' reasons for question number 3.

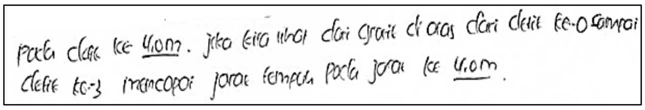
7.



An elevator moves from the basement to the tenth floor of a building. The mass of the lift is 1000 kg and the lift moves as shown in the $v - t$ graph.
How far does the elevator in the first 3 seconds (from second is 0 to second is 3)?

a. 1.33 m
b. 4.0 m
c. 6.0 m
d. 12.0 m
e. Other: ………………………………

Figure 6. Question item number 7.



pada data ke <u>4,0 m</u>. jika kita lihat dari grafik di atas dari detik ke-0 sampai detik ke-3 mencapai jarak tempuh pada jarak ke <u>4,0 m</u>.

If seen from the graph above, from the 0th second to the 3rd second, the distance reached a distance of 4.0 m

Figure 7. Sample of students' reasons for question number 7.

Table 3. List of resources that students activated.

Resources	Sub-topic 1	Sub-topic 2	Sub-topic 3	Sub-topic 4	Sub-topic 5
WYSIWYG as P-Prims	▪ Position is the same as the distance	▪ Velocity is the same as the distance	▪ Velocity is the same as displacement	▪ Position is equal to the instantaneous speed (same means same)	▪ Velocity is the same as acceleration
Conceptual Resource (CR)	▪ Relationship between initial position and final position to the distance	▪ Relationship between initial position and final position to the distance	▪ Relationship between initial position and final position to the displacement ▪ Relationship between change in velocity to the acceleration	▪ Relationship between initial position and final position to the instaneous speed	▪ Relationship between change in velocity to the acceleration
Procedural Resource (PR)	▪ Calculate the difference ▪ Adding up ▪ Multiply 2 quantities ▪ Formulate equations ▪ Determines the gradient of the line ▪ Determine the area under the curve ▪ Substitute the t value ▪ Formulate equations ▪ Calculating scale lines	▪ Calculate the difference ▪ Adding up ▪ Multiply 2 quantities ▪ Formulate equations ▪ Determines the gradient of the line ▪ Determine the area under the curve ▪ Substitute the t value ▪ Formulate equations ▪ Calculating scale lines ▪ Determining integrals	▪ Calculate the difference ▪ Adding up ▪ Multiply 2 quantities ▪ Formulate equations ▪ Substitute the t value ▪ Formulate equations	▪ Formulate equations ▪ Substitute the t value ▪ Formulate equations	▪ Calculate the difference ▪ Substitute the t value ▪ Determining derivatives

These examples highlight that students often provide answers based directly on their interpretations of question representations, particularly in visual formats such as motion diagrams and graphs. This tendency indicates an activation of the "What You See Is What You Get" (WYSIWYG) principle by students. Furthermore, students' reliance on WYSIWYG was also evident in solving problems with visual representations across other sub-topics, such as in Question 7 (see Figure 6), where students interpreted speed values on a graph as distance (see Figure 7) and used this interpretation as the solution or answer to the given problem.

In response to the problem representations discussed earlier, students often interpret them naively, focusing on identifying quantities or variables directly as the answer or solution without linking them to broader physics concepts. This tendency reflects the activation of P-Prims, which involve students' naive ideas that resist reduction and deeper explanation (Redish, 2004). Therefore, in these instances, the WYSIWYG interpretations activated by students fall under the category of P-Prims. More broadly, several resources activated by students are categorized by problem sub-topic, as illustrated in Table 3, which demonstrates that students effectively utilize various resources when solving assigned problems. Specifically regarding procedural resources, the findings indicate that 1–2 resources are exclusively activated depending on the form of problem representation. For example, in diagrammatic representations, students employ the resource of "calculating scale lines", while in graphical representations, they utilize "determining the gradient of the line", and in mathematical representations, they employ "determining derivatives". These resources highlight how students adapt their problem-solving strategies based on the specific context presented in each representation format.

DISCUSSION

The results of the quantitative analysis indicate that the differences in understanding between grade 10th and grade 11th students are not as pronounced as expected. This contrasts with previous findings by Amaliah et al. (2021), which suggested that grade 11th students tend to have a better grasp of kinematics than grade 10th students. Besides the misconceptions and difficulties encountered by students, other factors such as students' experiences in solving problems related to the topic and the representation of the questions influence the understanding between the two groups (Tural, 2015).

This research also demonstrates that even when students mistakenly arrive at the correct answer, they still activate various types of resources. Students consistently succeeded in activating a range of resources while solving kinematics problems. These resources include Phenomenological Primitives (P-Prims), Conceptual Resources, and Procedural Resources. Several resources were activated repeatedly by students (see Table 3), particularly procedural resources such as the "calculate difference" resource, which was utilized by students across all problem sub-topics. This finding aligns with the results of Wittmann and Black (2015), who identified procedural resources as part of a problem-solving strategy that can be employed by many students and activated repeatedly in various situations.

Additionally, some procedural resources are found exclusively in specific forms of representation. For instance, in problems related to determining distance based on position information using graphical representation, students activate the resource "determine the area under the curve". This indicates that students understand mathematically that the area under the curve of an $x-t$ graph represents the total distance traveled by a moving object.

Moreover, in problems concerning determining distance based on velocity information using mathematical representation, students utilized the resource "determining integrals". This shows that students understand that by integrating the equation $v(t)$, they obtain the equation $x(t)$. They then used the resource "substitute the t value" to obtain accurate position information, followed by the resource "relationship between initial position and final position to the distance" to find the correct solution. This demonstrates a coherent understanding of how to approach and solve kinematics problems using mathematical integration and the relationship between position and velocity.

Another resource that students activate is P-Prims, which manifest as naïve ideas or interpretive responses to the form of problem representation. Most P-Prims identified in this research are highly context-dependent. For instance, when students are faced with the sub-topic of determining acceleration based on velocity information, they often translate the information given in the problem directly into an answer. An example is the resource "velocity is the same as acceleration", which students activate when solving such equations. This phenomenon occurs across all problem sub-topics, for instance, when the problem is based on position information, students often use the position data as their solution. This also indicates that P-Prims are related to the "What You See Is What You Get" (WYSIWYG) context, where students interpret the given information as direct answers to the problems. Students activate WYSIWYG as P-Prims particularly when they encounter questions with visual representations, such as graphs and diagrams. This finding aligns with Elby (2000), who stated that this resource is closely related to students' interpretive strategies. When students see a form of representation that presents visuals, they often generate naïve ideas that lack a connection to physics concepts.

The explanations above demonstrate that most resources need to be activated in the appropriate context, which often leads to students failing to find the correct solution to the given physics problem. P-Prims have become the resource that most contributes to students' failure to solve physics problems, particularly in the context of WYSIWYG. As a response to the form of problem representation, the activation of WYSIWYG leads to students incorrectly interpreting the problem representations.

This indicates that the difficulties experienced by students when solving physics problems are not due to a lack of knowledge about the necessary concepts. Instead, student failure is more often caused by fragmented knowledge. When attempting to solve problems, students tend to use irrelevant knowledge due to a lack of understanding of the context that corresponds to the required concept or formula (Nadhor & Taqwa, 2020).

In this research, students were analyzed on how they solve physics problems using various forms of representation. Differences in student responses when dealing with the given problem topics illustrate how students understand, process, and relate existing information to new knowledge. This also highlights the challenges of teaching physics topics, especially kinematics, to students (Wittmann & Black, 2015).

The findings indicate that students often lack a mature understanding of fundamental concepts such as position, distance, displacement, speed, velocity, and acceleration. This aligns with Hammer (2000) explanation regarding students' initial understanding, which presents difficulties when they encounter physics problems. To address these findings, teachers need to be prepared to guide and direct the activation of various resources in the correct contexts. Teachers can enhance learning by encouraging students to broaden their perspectives on moving objects. They can also help students refine their knowledge by asking them to describe the movement of objects in greater detail (Sabo et al., 2016). This approach can aid students in developing a more integrated and accurate understanding of kinematics.

CONCLUSION

Based on the results of this research, it can be concluded that students are capable of simultaneously activating Phenomenological Primitives (P-Prims), Conceptual Resources, and Procedural Resources when solving physics problems. P-Prims represent students' naïve ideas, Procedural Resources are the solution strategies used by students, and Conceptual Resources are directly related to physics concepts. Among all the activated resources, the activation of P-Prims, particularly in the form of "What You See Is What You Get" (WYSIWYG), is the primary reason students fail to solve physics problems correctly. Additionally, different forms of problem representation influence the activation of student resources. Visual representations (such as diagrams and graphs) significantly impact the activation of P-Prims, while the representation of mathematical equations influences the activation of Procedural Resources. Meanwhile, the activation of Conceptual Resources is closely related to the specific problem topics addressed in the questions. These findings highlight the need for targeted teaching strategies to guide students in appropriately activating and applying their knowledge resources in various contexts.

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AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study, data collection, analysis, interpretation, writing, and revision of the manuscript. All authors approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declares no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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