

## STUDENTS' ABILITY IN SOLVING PHYSICS PROBLEMS ON NEWTONS' LAW OF MOTION

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**Abstract:** The ability to solve physics problems is one of the goals in learning physics and a part of the current curriculum demands. One of the physics problems that are often the focus of attention in learning is Newton's law of motion. When solving physics problems on Newton's law of motion, students need to utilize various aspects of certain abilities and rules. The purpose of this study was to reveal how the students utilized aspects of the abilities and rules in problem-solving. The study was conducted by providing physics problems on Newton's law of motion to 105 high school students. The result showed that most students were able to write equations, solutions, and system of units correctly for each problem. However, students' ability to determine the coordinate axes, depicts free-body diagrams, forces representation, and determine the resultant forces and direction of motion was unsatisfactory. Students tended to refer to the mathematical formulations in solving the problems. Therefore, physics learning that requires students to actively learn collaboratively, peer instruction, and procedural thinking can be used as an alternative learning strategy to overcome said problems.

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**Keywords:** Problem-solving, free-body diagrams, representation of forces.

### INTRODUCTION

The ability to solve problems is one of the goals in learning physics. This is stated in the existing curriculum in Indonesia nowadays, one of the competencies that must be achieved by students in learning physics is problem-solving (Kemendikbud, 2016). Some researchers argue that the students' ability in problem solving is an important goal in learning science, including physics (Duschl, Schweingruber, & Shouse, 2007; Gok, 2015; Hong, Chen, Wong, Hsu, & Peng, 2012) because problem-solving is an important cognitive activity in the learning process (Bogard, Liu, & Chiang, 2013; Jonassen, 2000; Kim, 2012), and these abilities are related to aspects of knowledge, thinking skills, and reasoning abilities (Chang, 2010). In addition, problem-solving is one of the current 21st-century skills (Arends, 2012; Kay, 2010). Problem-solving is recognized as a major goal, teaching strategy, and evaluation

technique in physics learning (Heller, Keith, & Anderson, 1992; Huffman, 1997). This fact shows that problem-solving ability is one of the important skills to be developed in learning physics.

Problem-solving is a thinking process that one applies in order to achieve goals different from the state of origins (Lovett, 2002). Problem-solving is one of the higher-order thinking skills (Kelly, 2005; Slavin, 2018) that can be seen as a cognitive process for obtaining a particular goal when the desired solution is not known (Santrock, 2011). Based on cognitive views, problem-solving is a cognitive and innovative process that can help to develop effective strategies to solve everyday problems (Moreno, 2010). In problem-solving, students must apply their knowledge and skills to achieve specific goals (Robertson, 2016) and use certain abilities and rules to solve problems (Mason & Singh, 2010). Problem-solving requires various cognitive components, i.e.

information, concepts, rules, and principles (knowledge domain); information networks, concept networks, and mental models (structural knowledge); arguments, analogies, and inference (implicative skills); metacognition skills; and motivational components (Jonassen & Tessmer, 1996). Teachers believe that problem solving is an important and useful skill for students in learning and thinking as a complex cognitive activity (Sabella & Redish, 2007).

One of the physics learning materials in senior high school is about the dynamics of motion. Dynamics of motion discusses the motion of an object by considering the cause of the motion. The material discussed in the dynamics of motion is about Newton's law. Students often experience difficulties when solving problems related to the dynamics of motion. Some students have difficulty in solving problems related to force (Carson & Rowlands, 2005; Matthews, 2009; Rowlands, Graham, Berry, & McWilliam, 2007) and the concept of acceleration (Coelho, 2010; Tasar, 2010). The results of the study by (Narjaikaew, 2013) showed that some students did not understand the concept of motion and force. The concept of motion and force is described as the motion of an object that is always caused by force, no force acts on a still object, and that the force influences the velocity of an object. The results of other studies showed that students' ability in solving physics problems on Newton's law of motion was unsatisfactory (Tasar, 2010; Yilmaz & Yalcin, 2012).

The ability to solve the physics problem of Newton's law is one of the goals in learning physics. For that reason, an assessment instrument is needed to measure that ability. The assessment instrument should require students to organize, select, and apply complex procedures (Slavin, 2018). Kocakullah (Kocakulah, 2010) has developed an assessment instrument to measure

students' ability to solve the problems on Newton's law of motion. The assessment instrument has been used to assess several aspects of the ability whose components include: identifying coordinate axes, drawing free-body diagrams, representing forces, determining the direction of motion based on resultant forces, write the equations and solutions, and write the system of units. The assessment instrument is based on seven steps to solve the physics problems on Newton's law of motion as suggested by Serway and (Serway & Beichner, 2000) and adapted to the problem-solving strategy developed by (Gaigher, Rogan, & Braun, 2007).

The free-body diagram is an important part of physics learning on mechanics (Serway & Jewett, 2014; Young, Freedman, & Ford, 2016) and a representation of forces acting on objects (Van den Berg & Huis, 1998). Teachers believe that free-body diagrams and forces representations are useful in learning (Wendel, 2011). The use of free-body diagrams can develop students' abilities in formulating equations of motion (Fisher, 1999). With free-body diagrams, students are aware that Newton's law of motion shows the interrelationships between vectors so that students learn to determine the resultant of forces acting on the objects and determine the acceleration of motion (Flores, Kanim, & Kautz, 2004). Students who have the ability to draw free-body diagrams are significantly capable of problems solving (Malone, 2008; Rosengrant, Van Heuvelen, & Etkina, 2009). A free-body diagram can be used to reinforce students' understanding and extend knowledge about weight, force, and vector of forces. In addition, it can help to diagnose the accuracy of motion concepts due to forces. Thus, it can be said that the free-body diagram is related to the representation of forces acting on the object, the resultant forces, and the direction of motion of the object which is all related to the student's ability to solve

the physics problems on Newton's law of motion.

Students' ability to solve physics problems can be assessed using assessment instruments. The assessment instrument developed by Kocakullah is able to reveal various aspects and levels of students' ability to solve problems (Kocakulah, 2010). However, the assessment instrument has not been widely used by teachers or researchers. For that reason, this study will assess the students' ability to solve the problems of Newton's law of motion using that assessment instrument. The purpose of this study is to reveal the students' ability to solve the problems of Newton's law of motion in terms of the ability to identify coordinate axes, draw free-body diagrams, represent forces, determine the direction of motion force, write equations and solutions, and write the system of units.

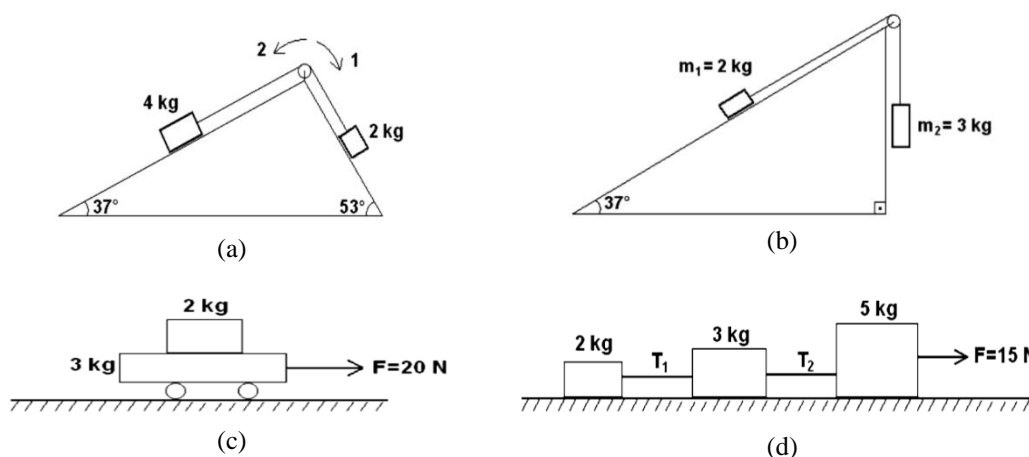
**METHOD**

This research was descriptive research. Herdiansyah states that descriptive research is scientific research that aims to understand a phenomenon experienced by the subject of research, such as behavior, motivation, perception, and activity (Herdiansyah, 2010). With qualitative descriptive research, researchers describe or explain the variables studied through the data obtained from the research, then

analyze and conclude them (Semiawan, 2010). Descriptive research is generally done by collecting information about the status of a situation systematically and accurately, i.e., the natural state of the research conducted (Arikunto, 2003).

The research was conducted at State Senior High School 4 Jember. The respondents of the research were 105 students of tenth grade. The research stages included: 1) determining the site of study based on several considerations, 2) making the instrument of research, i.e., the test on Newton's law of motion adapted from the test developed by Kocakullah (Kocakulah, 2010), 3) collecting the research data by giving the test on students, 4) analyzing test result data to find out students ability in solving problems, 5) drawing conclusions on the results of data analysis.

The test used was adapted from the assessment instrument and rubric to measure the problem-solving skills developed by Kocakullah (Kocakulah, 2010). The test consisted of 4 items, where the students were given a mechanical system and students were assigned to determine the dynamic quantities, i.e., the direction of motion, acceleration, tension, and the magnitude of the coefficient of friction. The mechanical system is shown in Figure 1.



**Figure 1.** The mechanical systems contained in the test.

In Figure 1a (question no. 1), there were two objects on the incline, the two objects connected by a massless string. Students were assigned to determine the direction of motion and acceleration of objects. In Figure 1b (question no. 2), there were two blocks connected by a massless string, one block on the incline and the other hanging vertically. Students were assigned to determine the acceleration of the system and the force of the string. In Figure 1c (question no 3), there was a block on the train. Students were assigned to determine the minimum coefficient of friction between the carriage and the block so that the blocks stayed still on the train. In Figure 1d (question 4), there were three blocks connected by a massless string and pulled by force. Students were assigned to determine the acceleration and tension.

Data analysis was performed using tabulation to adjust the scoring table in assessment rubric (Kocakulah, 2010). The first step was to calculate the number of students according to the scores obtained on each aspect of ability. This stage was done to find out how many students were

able to solve the physics problem on Newton's law of motion in each aspect and each item. The results were then analyzed and concluded. In addition, the analysis was also done to see the correlation between aspects of ability by looking at the pattern of answers.

## RESULTS AND DISCUSSION

### Students Ability in Identifying Axes

The proportion of students in identifying coordinate axes when solving Newton's law of motion problems was shown in Table 1. It appears that students' ability in identifying coordinate axes was unsatisfactory. Most of the students drew mechanical systems without coordinate axes. The rest of the students drew the coordinate axes on objects in the system but were incomplete or wrong. Only 1 student was able to draw the coordinate axes completely in answer to the problem no. 3. Only 4 students drew complete and correct answer but on a certain object only, i.e., the answer to the problem no. 3 and no. 4.

**Table 1.** The composition of students' ability to identify axes

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
Axis for each object in the system was drawn completely and correctly	15	0	0	1	0
Axes for some objects in the system were drawn completely and correctly	10	0	0	4	4
Axis for each object in the system was drawn incompletely or mistakenly	5	42	37	39	50
Axes for some objects in the system were drawn incompletely or mistakenly	3	2	2	1	10
No work is done	0	61	66	60	41

Although some students drew the coordinate axes, they were generally incomplete or incorrect. The common mistake was to identify the coordinate axes of the object in the incline, i.e., the object in the problem no. 1 and no. 2. Some students did not even draw the coordinate axes for the object. For objects in the horizontal plane, i.e., in problems no. 3 and no. 4, some students drew the coordinate

axes completely but incorrectly, especially on the writing of symbols and the direction of the coordinate axis. The motion dynamics of the objects in the horizontal plane allowed students to identify the direction of the coordinate axes. Students mentioned that they were familiar with the coordinate axes of the Cartesian system, in which the x-axis was horizontal, and the y-axis was in the vertical direction.

### Students Ability in Drawing Free-Body Diagrams

The proportion of students in drawing free-body diagrams is shown in Table 2. It appears that there were generally four groups of students according to their ability aspects. The first group, in which most students did not draw free-body diagrams. The second group, in which

most of the students drew free-body diagrams for systems and objects but both were incomplete. The third group, in which most of the students drew free-body diagrams, both for systems and objects, but one of them was incomplete. The fourth group, only a small part of the students, drew complete and correct free-body diagrams for both systems and objects.

**Table 2.** The composition of students' ability to draw free-body diagrams.

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
Both the system and each object of free-body diagrams were drawn	35	8	6	7	6
Minor incompleteness in both the system and objects of free-body diagrams existed	30	13	13	13	15
Each object of the free-body diagram was drawn, but the system of the free-body diagram was not	25	0	1	0	0
The system of the free-body diagram was drawn, but objects of free-body diagram were not	15	0	0	0	0
Major incompleteness in both the system and objects of free-body diagrams existed	10	25	19	24	38
Objects of free-body diagrams were incomplete, and the system of the free-body diagram was missing	5	1	0	0	0
The system of the free-body diagram was incomplete, and objects of free-body diagrams were missing	3	0	0	0	0
No work done	0	58	66	61	46

For most of the students who did not draw free-body diagrams, students answered physics problems directly using a mathematical formulation. The incompleteness of the components of free-body diagrams, both in systems and objects, was represented by drawings that used only a few forces, particularly friction forces and components of the force in the vertical and horizontal directions. In general, students only drew familiar forces. For objects that were on the incline, i.e., on the problem no. 1 and no. 2, most students only drew gravity and tension. For objects that were in the horizontal plane, i.e., on the problem no. 3 and no. 4, most students only drew gravity, normal force, and tension. The force that was often not drawn were frictional forces, pairs of action and reaction forces, and components of forces that applied to objects in the incline. For a complete free-

body diagram, students drew all the forces that worked correctly on both the system and the object, including the suitability of the force with the coordinate axes, the direction and magnitude of the force, and symbols of force.

### Students Ability in Representation of Forces

The proportion of students in representing the forces when solving the problem on Newton's law of motion is shown in Table 3. It appears that the student's ability to represent the forces was unsatisfactory. Most of the students did not represent the forces. Most of the other students represented the direction and magnitude of forces in the system but were incomplete. Only several students were able to represent the direction and magnitude of force in the system correctly and completely.

**Table 3.** The composition of students' ability to represent forces.

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
Directions and magnitudes of the forces on the system were drawn completely and correctly	20	2	2	5	4
Directions and magnitudes of the forces on the system were drawn incompletely	15	42	35	36	42
Directions and magnitudes of some forces on the system were drawn mistakenly	10	3	2	1	19
Directions and magnitudes of the forces on the system were drawn mistakenly	5	0	0	1	0
No work done	0	58	66	62	40

Most of the students correctly wrote the direction and magnitude of the force on some objects whereas the force acting on other objects was not written. Some of the direction and magnitude of the force that was often not written completely or written but incorrectly was a frictional force. Some students wrote gravity for objects in the incline, but gravity did not lead to the center of the earth. In addition, students often did not write components of forces for objects in the incline. Based on the data, it appears that most students did not write down the direction and magnitude of the force, they tended to use the mathematical formulation directly and determined the appropriate solution. For several students who answered correctly, the direction and magnitude of force were written completely and correctly. The forces in each object were correctly drawn, including the components of the forces for the objects in the incline. The components of the force in the direction of the x-axis and the y-axis were identified and drawn correctly.

### Students' Ability in Determining The Type and Direction of Motion

The proportion of students in determining the type and direction of motion when solving the problems is shown in Table 4. It appears that most of the students did not write the resultant force so that they could not identify the direction of motion. Most of the other students were able to determine the resultant force but only on one component, the notation or the direction of motion. In addition, most of the students were wrong in determining the resultant of forces with notation and/or direction of motion. On the problem no. 4, there were 15 students who were able to determine the resultant of forces and write the notation and direction of motion correctly. Three objects in horizontal plane connected by a rope allowed students to easily identify the forces and their resultant. It was also relatively easier for the students to determine the direction of motion and writing symbols because there were only gravity, tension, and normal force.

**Table 4.** The composition of students' ability to determine the type and direction of motion.

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
The resultant force was found correctly with a correct notation of type and direction of motion	20	2	0	3	15
The resultant force was found correctly with a correct notation of type or direction of motion	15	19	15	18	22
The resultant force was found mistakenly with a correct notation of type and/or direction of motion	10	22	21	19	20
The resultant force was found mistakenly with an incorrect notation of type and direction of motion	5	22	3	4	10
No work done	0	40	66	61	38

**Students Ability in Writing Solutions for Equations**

The proportion of students in writing mathematical equations and solutions when solving the problems on Newton's law of motion is shown in Table 5. It appears that most of the students were able to correctly write the equations for unknown variables. Likewise, with the writing of solutions, most of the students

were able to solve them. Only a small number of students who answered incorrectly, they generally wrote the equation correctly, but it was difficult to finish up to get the solution. Some common mistakes were when moving variables from one to the other, and incorrectly calculating the division operation.

**Table 5.** The composition of students' ability to write solutions for equations.

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
Equations for unknown variables were written, and a correct result was obtained	5	100	88	67	97
Equations for unknown variables were written, but an incorrect result was obtained	4	3	17	38	8
Equations for all unknown variables were not written, but a correct result was obtained	2	0	0	0	0
Written equations and the result were incorrect	1	2	0	0	0
No work done	0	0	0	0	0

**Students Ability in Writing the System of Units**

The proportion of students in writing all of the units of physics quantities when solving the problems on Newton's law of motion is shown in Table 6. It appears that most of the students could write units for all appropriate quantities of physics. The

units of force, acceleration, and mass were written completely and correctly. Some of the other students wrote the unit correctly, but the writing of the symbol was wrong. For this group of students, some symbols that were often wrong in writing were forces symbols, especially frictional forces.

**Table 6.** The composition of students' ability to write the system of units.

Description	Max Score	Number of Students			
		Problem No. 1	Problem No. 2	Problem No. 3	Problem No. 4
Each term was used in the same and its own system of unit	5	70	72	97	85
Some terms were used in the same and their own system of unit	4	29	30	7	16
Terms were used in the different but their own system of unit	3	1	0	0	0
Some terms were used in the correct system of the unit but shown with incorrect symbols	2	5	3	1	4
No work done	0	0	0	0	0

The results of the study illustrated that students' ability in identifying coordinate axes, drawing free-body diagrams, representing forces, determining direction of motion based on the resultant forces, writing equations and solutions, and writing units when solving physics problems on Newton's law of motion could

be said to be unsatisfactory, especially on the aspects of identifying coordinate axes, drawing free-body diagrams, representing forces, and determining direction of motion based on the resultant forces. Based on the data in Table 1 to Table 6, it could be said that the proportion of the number of students on aspects with

unsatisfactory ability tended to be consistent. Students who were unable to identify the coordinate axes had a tendency not to be able to draw free-body diagrams. Likewise, students who were unable to identify the coordinate axes and draw free-body diagrams had a tendency not to be able to represent forces and determine the direction of motion based on the resultant of forces. Some students solved the problems by directly using mathematical formulations and calculating the appropriate solutions.

### Discussion

The results of this study indicated that students' ability in identifying coordinate axes was not satisfactory. The students were not able to determine the coordinate axes, especially for objects in the incline. Students had difficulties in determining x-axis and y-axis. Students' orientation to the coordinate axes remained in vertical and horizontal coordinate system. For a dynamic system consisting of two objects connected to the pulley, one object was in the incline, and another was hanging, most students were able to determine the coordinate system for the hanging object, but the student found it difficult to determine the coordinate system of objects that were in the incline. Students preferred to determine the magnitude of the force components directly rather than determine the axes and direction of the force components because they had to do many steps. In addition to determining the coordinate axes, students also had to determine the magnitude and direction of the force components and summarize the directional force components. This result is consistent with the research of (Flores-García, Alfaro-Avena, Chávez-Pierce, Luna-González, & González-Quezada, 2010) which states that students tend to directly use mathematical formulations rather than describing forces and their components geometrically.

Determining the coordinate systems is one of the strategies to be taken when solving the problems of force and motion (Science, 2005; Serway & Jewett, 2014). Students have learned about straight-motion kinematics thus strengthening their orientation of x and y coordinates systems in the horizontal and vertical directions. They have difficulties in changing the orientation of the coordinate system for objects in the incline. Thus, teachers should instill students' understanding of the coordinate system, especially for systems or objects that are on the incline. One way, as suggested by (Mazur, 2015), is to choose a coordinate system in such a way that one of the coordinate axes is in the acceleration direction of the object.

The results of this study indicated that students' ability in drawing free-body diagrams and representing forces was unsatisfactory. Free-body diagrams are sketches of objects and arrows that represent the forces acting on objects. The forces are represented by arrows and labeled according to the direction and forces type. The representation of free-body diagrams is a standard procedure for solving the problems on Newton's law of motion (Cutnell & W, 2012; Halliday, Resnick, & Walker, 2014). In this study, students only drew representations of particular forces, especially forces in vertical or horizontal direction. If forces were not in vertical or horizontal direction, students found it difficult to represent the forces in free-body diagrams. The day-to-day experience of vertically (e.g., free falling objects) and horizontally moving objects (e.g., car motion) caused students to be easier in representing forces in vertical or horizontal directions yet caused them difficulties in representing forces in other directions.

Students had difficulties in drawing free-body diagrams. The results of this study are similar to (Lee, 2017) and he proposes five steps in describing free-body diagrams, including a) sketching the



system of objects, b) selecting objects and performing isolation, c) defining forces and giving special marks, d) identifying forces and giving labels, and e) drawing the forces. In addition, (Heckler, 2010) suggests that teachers should implement collaborative problem-solving learning. Collaborative learning helps students learn to draw free-body diagrams and learn to solve problems based on correct procedures. By collaborative learning, students can learn to solve tasks partially and discuss to solve problems in an integrated manner.

Students' ability to determine the direction of motion of objects was also unsatisfactory. Students had difficulties in representing the direction of the force acting on the object. Students also found it difficult to represent vectors and operations mathematically to produce resultant vectors. Students rarely gave qualitative explanations of vectors and the relationship between a vector and its component vectors. Students had difficulties in determining the components of the force causing the students difficulty in determining the resultant of forces. The majority of the students had no functional understanding of Newton's second law as a relationship between vectors. The results of this study are consistent with the results of previous studies which suggest that most students have difficulty regarding vectors (Sari, Suyanto, & Suana, 2017) and their application in solving the problem of Newton's law of motion (Flores et al., 2004). To overcome such difficulties, (Flores et al., 2004) suggest that the content and sequence, of course, topics should be adapted to the target, i.e., the development of students' skills in understanding vectors and their application in mechanical systems.

The results showed that the students' ability in determining the solution of the problems on Newton's law of motion belongs to the satisfactory category. Students' ability in writing the system of

the unit for each quantity of physics showed similar results. Students tended to use mathematical formulas or shortcuts, commonly called *smart solutions*. Although they obtained a correct solution, it did not necessarily describe the ability of students in solving problems. Students who only determine the solution without the correct problem-solving procedures cannot be categorized as an expert. Rosengrant suggests that expert students in problem-solving have the ability to categorize problems in several types according to the physics principles used to solve problems, have a lot of procedural knowledge, and have a lot of interrelated and shared knowledge (Rosengrant et al., 2009). Students in expert categories have a lot of knowledge and know how to use their knowledge, begin with making good analysis and plan before solving the problem. The analysis was done by giving qualitative descriptions based on the principles of physics correctly without too many uses of mathematical calculations.

The results of this study indicated that the ability of students in solving problems based on procedures and physics rules was unsatisfactory. Thus, students must learn to use procedures and rules in accordance with the principles of physics. Determining the coordinate system, free-body diagram, forces representation, direction of movement, solution, and unit of physics quantity are important components that need to be given to students in order to possess the problem-solving ability. The use of multiple representations can assist the students in learning and building concepts and solve problems (Irwandani, 2014). Collaborative learning becomes an alternative strategy. In collaborative learning, students are taught to be responsible for the tasks assigned to each individual, before finally being integrated with solutions produced by other students. In collaborative work, students with better ability can help others who need learning assistance. Students

also need to be taught procedural thinking because the completion of physics problems is basically a sequential procedure until a solution is obtained.

### CONCLUSIONS AND SUGGESTIONS

The students' ability to solve the physics problems on Newton's law of motion was unsatisfactory. Although most of the students were able to provide solutions and write the units well, the ability to identify the coordinate axes, draw free-body diagrams, represent forces, and determine the direction of motion based on the resultant of forces was not satisfactory. It takes a lot of effort to help students to learn, especially by teachers to keep improving the learning process by implementing innovative learning strategies that stimulate students to be more active. Collaborative learning and procedural thinking exercises become alternative learning that can be applied so that the students are able to solve physics problems. Moreover, teachers can teach the use of various representations in solving physics problems so that the students have a good mastery of Newton's law so that it can be used to study the next material of physics.

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