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THE PROBLEM OF PRE-SERVICE SCIENCE TEACHERS ON NEWTON'S LAWS TOPIC: A CASE STUDY

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Abstract

Newton's Laws is one of the topics in Physics that must be mastered by pre-service science teachers in Indonesia. This study aims to investigate the problems encountered by pre-service science teachers on Newton's Law topic, especially in drawing a free-body diagram. The method used in this research is a descriptive method. Samples were taken from three universities in Java, Indonesia. The total number of samples used was 230 pre-service science teachers consisted of 35 male (15.22%) and 195 female (84.48%) students. Data were collected based on written tests and interviews. The results showed that most pre-service science teachers still have difficulties in drawing a free-body diagram Newton's Law topic. Pre-service science teachers think that physics is a difficult subject with too many formulas, and they still find it difficult to understand the concept of physics while studying in high schools. These findings can be used as a reference or as an initial description of the problems of pre-service science teachers on Newton's Law topic so that lecturers can determine the appropriate learning strategies when teaching in class. The suggestion from this study is that lecturers who teach pre-service science teachers are expected to provide a re-explanation of the basics of physics such as how to draw free-body diagrams before they learn the concepts of physics at the next level.

Keywords: Draw a free-body diagram, Newton's laws, Pre-service science teachers.

1. Introduction

Newton's Laws is one of the topics in Physics that explains the process of identifying forces acting on the object of change of the object motion [1]. Newton's Laws of Motion consists of three laws. The Newton's first law describes the concept of inertia ($\sum \vec{\boldsymbol{F}} = 0$). The Newton's second law explains that the acceleration produced by a net force on an object is directly proportional to the net force and acceleration is inversely proportional to the mass of the object ($\sum \vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$). Then, the Newton's third law explains that action and reaction forces have the same magnitude and opposite direction ($\vec{\boldsymbol{F}}_{12} = -\vec{\boldsymbol{F}}_{21}$) [2, 3].

Previous studies related to Newton's Laws have been carried out in various countries. Physics research relating to Newton's first law [4], Newton's second law [5, 6], Newton's third law [7-10], and Newton's law of gravitation [11, 12] have been widely reported and documented. Other theoretical physics research related to the derivation of Newton's laws explains the derivation of Newton's third law formula from Newton's second law [2] and it also explains the derivation of Newton's laws from Kepler's laws of planetary motion [13]. Advanced physics research on Newton's laws is associated with brane worlds and the gravitational quantum as well [14].

In addition, studies related to Newton's laws have also been done in the field of education. In learning, Newton's laws are one of the topics taught in schools and colleges. Therefore, in order to teach the topic of Newton's Laws, many teachers or lecturers use various methods and approaches, one of which is by using the concept of cartoon-embedded worksheets [15], using image modelling with the ollie trick [16], mental models [6], demonstration [17], conceptual and laboratory exercise [18], and using student reasoning through representations [19]. Although there have been many studies relating to Newton's Laws, a case study that investigates problems faced by pre-service science teachers on the topic of Newton's law is yet to be performed. The gap between this study and previous reports is the main objective. If the previous reports aim to investigate the factors influencing the development of teaching strategies of lecturers in Newton's law [20] and evaluate Newton's first law students' representation [21], the present study aims to investigate pre-service science teachers' problems in drawing a free-body diagram in Newton's Law. In addition to using the written test method for pre-service science teachers, interviews are also undertaken to explore what problems related to drawing free-body diagrams in Newton's laws are faced.

A free-body diagram is a diagram that shows schematically all the forces acting on an object or system [22]. One of the basic concepts when studying the concepts of Newton's Laws is drawing a free-body diagram. The ability to draw a free-body diagram is very important for everyone who studies Newton's laws concepts such as students, pre-service teachers, teachers, lecturers, and others. This is because if one is unable to draw a free-body diagram, students will have difficulties in understanding the concepts of Newton's law or difficulties in solving problems related to Newton's laws. Newton's Laws is a basic concept of physics relating to subsequent physics concepts. Thus, if students cannot understand the concept of Newton's law, the student will find it difficult when they learn the concept of projectile motion [23].

Based on preliminary studies, pre-service science teachers experienced problems while learning the topic of Newton's laws. The results of exam scores from pre-service science teachers on the topic of Newton's laws are relatively low when compared to other topics in physics. This is because Newton's laws concept does not only require the learners to memorize the formula but also to understand it. Pre-service science teachers after graduating from college one day will be required to teach the topic of Newton's law to middle school students. The results of exam scores from pre-service teachers that are less than expected were suspected due to problems in drawing a free-body diagram. Problems in Newton's laws do not only occur in Indonesia, but it also occurs in several countries such as Malaysia and Australia [5, 24]. Based on this fact, research is needed to investigate the causes of problems encountered by pre-service science teachers in Newton's laws, so that by knowing what the core problem, a solution can be found to improve the conceptual understanding of pre-service science teachers of Newton's law. This study aims to investigate the problems encountered by pre-service science teachers on Newton's law topic, especially in drawing a free-body diagram.

2. Method

The method used in this research is a descriptive method. Data collection used two methods: written tests and interviews. The research samples are pre-service science teachers from three national universities in Java, Indonesia. The three universities come from 3 different provinces, namely: (1) University "X" in the city of Bandung, West Java, Indonesia; (2) University "Y" in Yogyakarta, Central Java, Indonesia; and University of "Z" in Ponorogo, East Java, Indonesia. The selection of these samples was chosen based on the credibility of the university. It is proven that the accreditation of both University "X" and University "Y" are, respectively, A (very good) and the accreditation of the University "Z" is B (Good), in which this was similar to literature [25]. Map of the sampling location can be seen in Fig. 1.

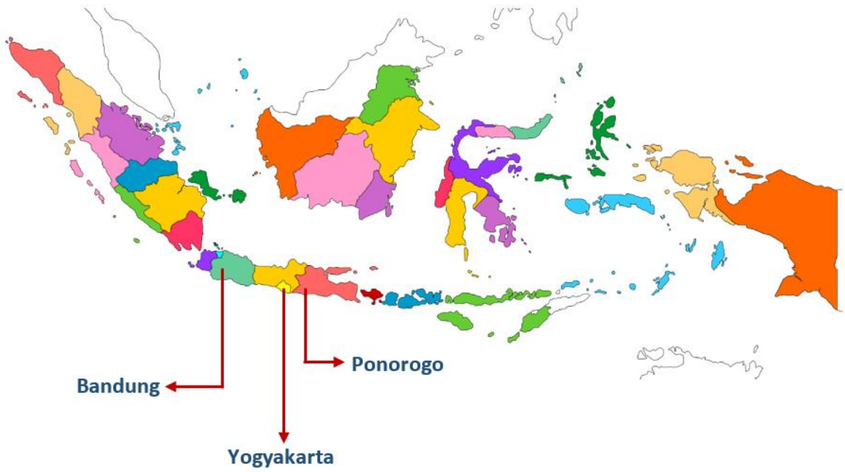


Fig. 1. Map of the sampling location.

The total number of samples is this study are 230 pre-service science teachers consisted of 35 male (15.22%) and 195 female (84.48%) students. The average age of the sample taken is 17-21 years. The sample comprised pre-service science teachers who are still in their first semester. The data were collected when pre-service science teachers had not taken Mechanics and Fluid courses so that the sample was considered to never receive a lecture in drawing a free-body diagram. This aims to see the initial abilities of pre-service science teachers on the topic of Newton's Laws, especially abilities in drawing a free-body diagram. The data collection was carried out for 3 years: in 2016, 2017, and 2018. The data of the sample in this study are shown in in Table 1.

Table 1. Data of the sample.

	University X	University Y	University Z	Total	Percentage
Female	68	32	95	195	84.48%
Male	8	10	17	35	15.22%
Total	76	42	112	230	100%

The instrument consists of 5 questions in the form of pictures of objects that have different shapes. The sample was given a test to drawing a free-body diagram of the object for ± 25 minutes. A close book system was carried out so that they were not allowed to open books or search for some literature on the internet. The answers from the pre-service science teachers were analyzed by researchers. The results of these answers were analyzed to investigate which answer is correct and which answer is incorrect or incomplete. Furthermore, the sample was interviewed by researchers to investigate the problems encountered by pre-service science teachers relating to the test. The selection of samples interviewed was conducted randomly from the three universities. The results of the interview were summarized to find out the problems faced by pre-service science teachers in Newton's Laws especially when it comes to drawing a free-body diagram.

3. Results and Discussion

This study aims to investigate problems faced by pre-service science teachers in Newton's Laws. There were five questions given. The results of the analysis of the pre-service science teachers' answers can be seen in Figs. 2 - 6. Evidence that most pre-service science teachers have difficulty in drawing free-body diagrams in question number 1 can be seen in Fig. 2.

Figure 2 shows an example of the answer to question number 1 from the pre-service science teachers. The image consists of 2 columns: the left column stating the example answers from the pre-service science teachers and the right column stating the solution for the correct answer. Based on the data analysis on problem number 1, most of the answers given by the pre-service science teachers were incorrect, including: (1) Not giving an arrow to express the tension of the string (T); (2) Giving only 1 arrow to indicate the tension of the string (T); (3) Giving 2 arrows to indicate the tension of the string (T), but the direction of the arrow is reversed; (4) Not drawing the gravitational force (w); (5) Drawing the normal force (N) on objects, whereas in matter of number 1 there is no normal force (N) that must be drawn; (6) Writing down the errors of magnitude symbols, for example: the symbol of the gravitational force is (w) but the symbol is written in the gravitational acceleration (g) and the symbol should be represented by the tension of the string (T) but the symbol is written frictional force (f). The evidence shows that most pre-service science teachers have difficulty in drawing free-body diagrams in question number 2 can be seen in Fig. 3.

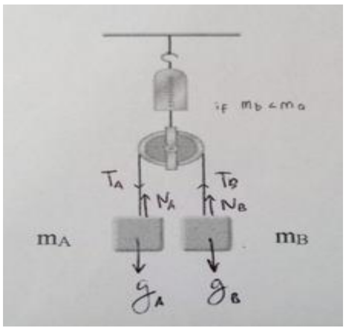
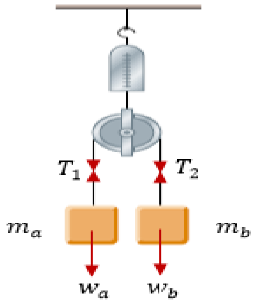
No.	Example of the answer by pre-service science teachers	Correct answer
1.		

Fig. 2. Data from question number 1.

Figure 3 shows an example of the answer to question number 2 given by the pre-service science teachers. The image consists of 2 columns: the left column stating the example answers from the pre-service science teachers and the right column stating the solution for the correct answer. Based on the data analysis on problem number 2, most of the answers given by the pre-service science teachers were incorrect, including:

(1) Not drawing the normal force (*N*) on objects;

(2) Not drawing the gravitational force (*w*) on objects;

(3) Not providing an arrow to indicate the tension of the string (*T*);

(4) Giving only 1 arrow to indicate the tension of the string (*T*);

(5) Writing down symbolic errors, for example: the symbol of the gravitational force (*w*) should be described but the gravitational acceleration (*g*) is written.

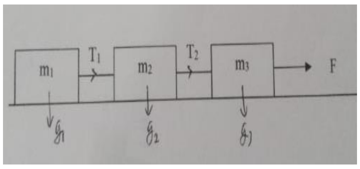
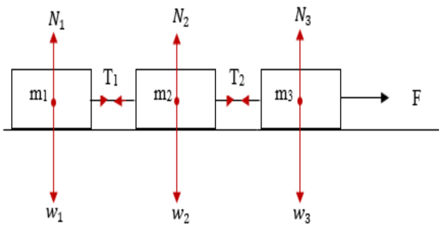
No.	Example of the answer by pre-service science teachers	Correct answer
2.		

Fig. 3. Data from question number 2.

Evidence that pre-service science teachers have difficulty in drawing free-body diagrams in question number 3 can be seen in Fig. 4. Figure 4 shows an example of the answer to question number 3 from the pre-service science teachers. The image consists of 2 columns: the left column stating the example answers from the pre-service science teachers and the right column stating the solution for the correct answer. Based on data analysis of question number 3, most of the answers given by the pre-service science teachers were incorrect, including:

(1) Not drawing the normal force (N) on objects;
(2) Not drawing the gravitational force (w) on objects;
(3) Error in drawing a projection of force towards the x-axis and y-axis.

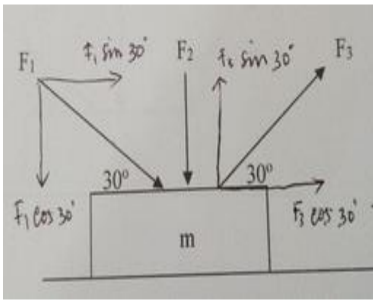
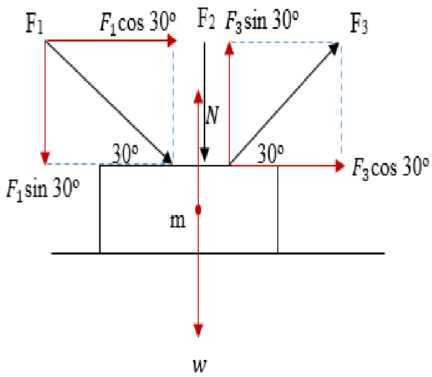
<table>
<tr><th>No.</th><th>Example of the answer by pre-service science teachers</th><th>Correct answer</th></tr>
<tr><td>3.</td><td>
</td><td>
</td></tr>
</table>

Fig. 4. Data from question number 3.

Pre-service science teachers still have difficulty differentiating in drawing vector projections between downward force (F1) and upward force (F3) on an object; (4) The difficulty in determining the vector F1 cos 30º, F1 sin 30º, F3 cos 30o, and F3 sin 30º. Evidence that pre-service science teachers have difficulty drawing free-body diagrams in question number 4 can be seen in Fig. 5.

Figure 5 showed an example of answer number 4 from the pre-service science teachers. There are 2 columns: the left column stating the example answers from the pre-service science teachers and the right column stating the solution for the correct answer. Based on the data analysis about number 4, most of the answers given by the pre-service science teachers were incorrect, including:

(1) Not drawing the normal force (N) and the gravitational force (w) on objects;

(2) Not providing an arrow to indicate the tension of the string (T); Giving only 1 arrow to indicate the tension of the string (T);

(3) the image has been given 2 arrow marks stating the tension of the string (T), but the direction is reversed;

(4) Error in determining w2 cos θ and w2 sin θ vectors;

(5) Errors in drawing the gravitational force (w).

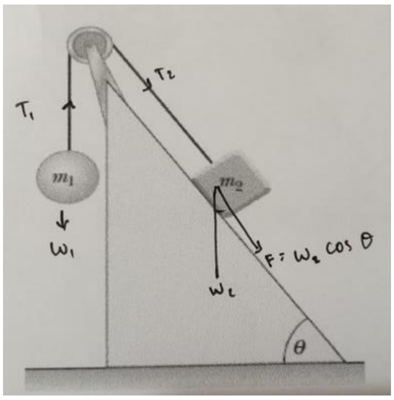
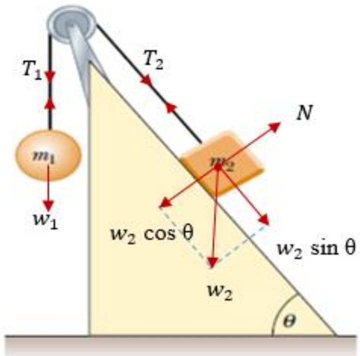
No.	Example of the answer by pre-service science teachers	Correct answer
4.		

Fig. 5. Data from question number 4.

Most pre-service science teachers have difficulties in drawing the gravitational force (w) in a plane inclined. They describe the gravitational force (w) not straight down. Evidence that pre-service science teachers have difficulties in drawing free-body diagrams in problem number 5 can be seen in Fig. 6.

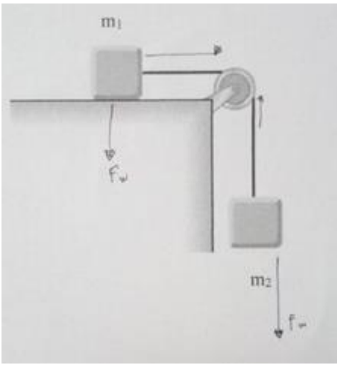
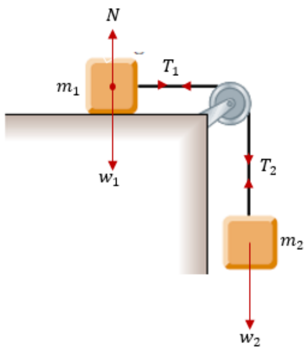
No.	Example of the answer by pre-service science teachers	Correct answer
5.		

Fig. 6. Data from question number 5.

Figure 6 shows an example of answer number 5 from the pre-service science teachers. There are 2 columns: the left column stating the example answers from the pre-service science teachers and the right column stating the solution for the correct answer. Based on the data analysis about number 4, most of the answers given by the pre-service science teachers were incorrect, including:

(1) Not drawing the normal force (N) and the gravitational force (w) on objects;
(2) Not providing an arrow to indicate the tension of the string (T); Giving only 1 arrow to indicate the tension of the string (T);

(3) the drawing has 2 arrows to indicate the tension of the string (T), but the direction is reversed.

Based on Figs. 2 to 6, pre-service science teachers still have experiences and some of them have difficulties in drawing free-body diagrams. A summary of the number of pre-service science teachers who answered correctly and who answered incorrectly or incompletely can be seen in Table 2.

Table 2. Summary Analysis of answers in drawing a free body diagram.

Questions	Correct answer		Wrong answers/ answers are incomplete		Total	
	Number of Pre-service science teachers	Percentage (%)	Number of Pre-service science teachers	Percentage (%)	Number of Pre-service science teachers	Percentage (%)
Number 1	31	13.48	199	86.52	230	100
Number 2	11	4.78	219	95.22	230	100
Number 3	11	04.78	219	95.22	230	100
Number 4	8	03.48	222	96.52	230	100
Number 5	13	05.65	217	94.35	230	100

Table 2 shows that in question number 1 which can answer correctly there are 31 pre-service science teachers (13.48%) and those who answer wrong or incomplete are 199 pre-service science teachers (86.52%). In question number 2 that can answer correctly there are 11 pre-service science teachers (04.78%) and those who answer wrong or incomplete are 219 pre-service science teachers (95.22%). In question number 3 that can answer correctly there are only 11 pre-service science teachers (04.78%) and those who answer wrong or incomplete are 219 pre-service science teachers (95.22%). In question number 4 that can answer correctly there are 8 pre-service science teachers (03.48%) and those who answer wrong or incomplete are 222 pre-service science teachers (96.52%). In question number 5 that can answer correctly there are only 13 pre-service science teachers (05.65%) and those who answer wrong or incomplete are 217 pre-service science teachers (94.35%).

Based on the results of data analysis from Figs. 2 - 6 and Table 2 show that pre-service science teachers have difficulties in drawing free-body object diagrams on the topic of Newton's law. Difficulties in pre-service science teachers in Physics especially Newton's law are in line with previous research which states that students find it very difficult when studying Newton's law [26]. In addition, students also experience misconceptions on the topic of Newton's law [27]. Students also do not know the stages in working on Newton's law [5]. Students think that the arrow style which is a vector analysis does not have any meaning. Some students also do not know how to solve vector components x and components y. This condition makes it difficult for students to solve the problem of Newton's law, especially in the inclined plane and pulley. This situation shows that students do not apply the mathematical concepts they learned into Newton's law [24]. To investigate what causes pre-service science teachers to experience difficulties in free-body drawing, the interview method is used. The results of the interview show that they have difficulties including

(1) Pre-service science teachers consider physics to be a difficult subject;

(2) Physics is a subject that calculates too much and many formulas;

(3) Pre-service science teachers cannot understand the physics concept well when they were still studying in high school.

According to the perception of pre-service science teachers, most physics teachers in their high schools did not understand well when explaining specific materials on the topic of Newton's law. This is because most learning methods used by the teacher are lectures, using PowerPoint media, and emphasis on the material is only theory (memorization of formulas) alone without any learning through experiments.

Based on interviews with physics lecturers who taught science education departments, the problems on Newton's law topics were caused by the basic concept of physics pre-service science teachers when studying in high school was not capable enough. When students enter the university level in the field of science education, they have a lot of difficulties when attending physics classes, especially for working on Newton's Law questions in the form of pictures. If the problem is in the form of an image, students must draw a free-body diagram first before working on the problem. However, it is proven that there are many pre-service science teachers who are still having difficulties in drawing free-body diagrams of the objects. This is due to the learning of physics in schools focusing on solving questions for national exam preparation or preparation for selection into state universities.

Most students also attend tutoring, so there are indications that students are accustomed to working on problems using a formula quickly and without drawing free-body diagrams first. Thus, students see physics as a subject of memorizing formulas only, not understanding concepts. Problems from pre-service science teachers experiencing difficulties in Newton's law are a result of lack of understanding in drawing free-body diagrams of objects. Strategies so that pre-service science teachers can understand the concepts of Newton's law are before lectures relating to Newton's law are given special training for drawing a free-body diagram. After all the pre-service science teachers have understood, then they are included in the material of Newton's laws. In addition, in teaching Newton's laws media or experiments are needed to help understand the pre-service science teachers. This strategy is in line with previous reports using media and experiments can provide positive responses to students [27-30].

When teaching the topic of Newton's Law many teachers or lecturers have used various methods or approaches by using the concept of cartoon-embedded worksheets [15], using image modeling with the ollie trick [16], mental models [6], demonstration [17], conceptual and laboratory exercise [18], and using student reasoning through representations [19]. Based on this, educators are expected to use the right choice of strategies so that students can understand concepts of Newton’s Law well.

4. Conclusion

The case study found that pre-service science teachers still experience difficulties in the topic of Newton's Law. One cause is their ability in drawing a free-body diagram; their drawing is still not as expected. The basic vector concept of pre-service science teachers is still weak. Pre-service science teachers think that physics is a difficult subject, with too many formulas, and they still find it difficult to understand the concept of physics while studying in high school. This finding can be used as a reference or an initial description of the problems of science teacher candidates on Newton's Law topics so that the lecturers can determine the appropriate learning strategies when teaching in class. The suggestion from this study is that lecturers who teach pre-service science teachers are expected to provide a re-explanation of the basics of physics such as how to draw free-body diagrams before they learn the concepts of physics at the next level.

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