Students' understanding of forces: Force diagrams on horizontal and inclined plane

J Sirait¹, Hamdani¹ and S Mursyid¹

¹Department of Physics Education, Tanjungpura University, Pontianak, Indonesia

E-mail: judyantosirait@gmail.com

Abstract. This study aims to analyse students’ difficulties in understanding force diagrams on horizontal surfaces and inclined planes. Physics education students (pre-service physics teachers) of Tanjungpura University, who had completed a Basic Physics course, took a Force concept test which has six questions covering three concepts: an object at rest, an object moving at constant speed, and an object moving at constant acceleration both on a horizontal surface and on an inclined plane. The test is in a multiple-choice format. It examines the ability of students to select appropriate force diagrams depending on the context. The results show that 44% of students have difficulties in solving the test (these students only could solve one or two items out of six items). About 50% of students faced difficulties finding the correct diagram of an object when it has constant speed and acceleration in both contexts. In general, students could only correctly identify 48% of the force diagrams on the test. The most difficult task for the students in terms was identifying the force diagram representing forces exerted on an object on an inclined plane.

1. Introduction

Force is one of the most fundamental concepts in physics. It is used to describe and explain a variety of phenomena in mechanics and electromagnetism. Therefore, many physics education researchers conducted studies concerning conceptual understanding of forces involving students from high school to university students [1-3]. The findings show that many students still have alternative conceptions of forces and some students cannot not clearly explain the meaning of the term force. These difficulties might affect students’ understanding of how to apply the force concept in other contexts.

One of the tools to help students understand force concepts is a force diagram (otherwise called a free body diagram-FBDs) – a representation that depicts an object of interest and the forces exerted on this object by other objects [4]. One can delineate a problem with different representations such as sketch or picture and diagrams. For example, a car is at rest on inclined plane. Students might visualize this verbal description using a sketch and draw a force diagram as shown in figure 1. In this diagram, the object of interest (the system, in this case, the car) is represented as a dot and forces exerted by other objects are shown with the vector arrows labelled with two subscripts. The first subscript signifies the system and the second-the object that exerts the force on the system.

A group of researchers in the United States carried out both quantitative and qualitative approaches to investigate whether university students who use force diagrams consistently during their course spontaneously utilize the diagrams on multiple choice tests to solve problems without getting credit for the solution [4]. They also compared performance of the students’ who used forced diagrams to those who did not and the quality of students’ representations. Rosengrant et al. found that students
who learned free body diagrams tended to draw a diagram while solving problems on multiple-choice tests and obtained higher scores than students who did not. Also, they found that high achieving students harnessed FBD to understand the problem and evaluate the answer.

![Diagram](image)

**Figure 1.** Different types of representations: (a) sketch or picture and (b) force diagram.

In helping students to identify correctly forces and to draw correctly free body diagram, Savinainen et al. suggested to draw interaction diagram (ID) before constructing free body diagram (FBD) [5]. The purpose of ID is to identify all objects that interact with an object of interest and ID is depicted verbally (words). The researchers conducted a study of the impact of using ID by involving high school students in Finland. They divided students into those who were taught interaction diagrams and those who were not. Students were asked to solve eight questions which cover Newton’s Law concepts by constructing both ID and FBD for each question. Their findings show that while there is a positive correlation between constructing ID and identifying forces, they still had students who correctly constructed interaction diagrams, but did not always correctly identify forces and did not always correctly draw FBD. This shows that using an interaction diagram is not sufficient to support students in drawing a free body diagram.

The use of free body diagrams (FBDs) does not always contribute positively on students’ performance while solving physics problems. A study analysed the effect of encouraging students to draw force diagrams while solving problems [6]. The quantitative study involved university students in United States who were taking a calculus-based introductory physics course with two different classes: traditional, or regular class, and honours class. Students in the regular class learned with using force diagrams during the problem-solving exercise (common problem solving strategy) while the teaching strategy in the honours class focused on an explicit problem solving approach which did not follow common problem solving procedures, but in which students also practised constructing force diagrams. Students were asked to solve four open problems concerning Newton’s laws. Within each class students received two distinct formats of the problems: some were asked to draw a diagram and some had no prompting for a diagram in the problems. Heckler found that students who were prompted to draw diagrams were less successful in determining the correct solution than those students who were not. Students who did not receive the prompt to draw a diagram employed intuitive solutions instead of formal strategies. However, students have different style in approaching physics problems; it depends on the type of questions. Students, for example, might have different strategies in solving Newton’s laws problems in horizontal and inclined context. It means that intuitive knowledge is not always appropriate to all problems.

The goal of this study is to investigate students’ difficulties in understanding force diagrams for horizontal surfaces and inclined planes which addresses three concepts: an object is at rest, at constant speed, and at constant acceleration.
2. Methodology
To acquire detailed information about students’ ability to understand force concepts, a survey was applied by involving 212 pre-service physics teachers (freshmen, sophomore, junior students) who had taken a basic physics course at the Teacher Training and Education Faculty, Tanjungpura University. The participants in this study are dominantly by female students (153 females and 59 males). These students will become physics teachers in junior and senior high schools after completing four-year study in the department of physics education.

We adapted an existing test from Aviani et al. [7] as an instrument to measure students’ understanding about forces in terms of force diagram. The translators who work at the science education department translated all items from English into Indonesian. We then chose items based on our needs for this study and designed a number of other items to complete the test. Afterwards, five faculty members of the physics department validated the items to measure (face validity) how well the test items addressed physics content. The test, which is multiple-choice, consists of six items which covers three situations: an object is at rest, at constant velocity and at constant acceleration. The purpose of this test is to examine students’ ability to choose the appropriate force diagrams in different contexts-horizontal surface and inclined plane. An open question which covers inclined plane context, was also given to 60 first year students (freshmen students) to obtain more detail how students approach the question. Students were given 40 minutes to solve all questions. Before analysing statistically, students’ works were firstly tabulated.

3. Result and Discussion
The percentage of students successfully answered more than or equal to three to six items (≥ 50%) is 56%. Based on the analysis, students faced difficulties to solve inclined problems (whether an object is at rest or is moving). Students were only able to answer inclined plane questions less than 50%. Furthermore, in the context of horizontal surface students correctly solved the problems more than a half of the items. Students’ answers for each item are displayed in Table 1.

| Context          | Item | A | B | C | D | E |
|------------------|------|---|---|---|---|---|
| Horizontal Surface | 1    | 12| 2 | 83| 2 | 1 |
|                  | 2    | 11| 6 | 27| 15| 40|
|                  | 3    | 52| 16| 10| 13| 9 |
| Inclined Plane   | 4    | 4 | 40| 18| 7 | 31|
|                  | 5    | 16| 42| 23| 10| 8 |
|                  | 6    | 55| 15| 10| 7 | 13|

Overall, the average percentage of problems that can be successfully solved by students is 48% (about three items). More than 80% of students successfully answered question #1: a block rests on a horizontal surface; students were asked to choose the correct free body diagrams. They chose correctly force diagrams. Students were able to identify all forces exerted on the block such as earth force on the block (weight force) and table force on the block (normal force). Only few students (about 20%) conceived that only a weight force is exerted on the object.

Furthermore, more than 50% of students seemed to lack the ability to identify force diagrams, while an object moves with constant speed and constant acceleration (#2 and #3). For a block on constant speed, students did not completely identify all forces acting on the object. Besides, they couldn’t successfully apply their conceptual knowledge (Newton’s laws) to this situation to determine the resultant force (the net force is zero when an object moves at constant speed). Question #3 which shows that a block is accelerating on a horizontal surface, is presented in figure 1. The students’ difficulty is they are not aware of friction force, weight force, and normal force.
On an inclined plane, on the other hand, the students were not aware of the situation of the object (whether the block is at rest or moving). Moreover, they just selected the free body diagram consisting of real forces without considering about the components of the forces. Also, the students could not successfully apply their conceptual understanding on the horizontal surface to an inclined plane. Palmer [8] stated that students are inconsistent in applying the same concept in different situations.

About 70% of students were not able to provide the correct answers when an object acts at rest. Figure 2 shows question #4 which represents force diagram of a block at rest on an inclined plane. Students only noticed the real forces on an object without thinking about vector components (why the object does not move on an inclined plane). Moreover, when an object moves with constant speed and constant acceleration, about 50% of students were not able to correctly distinguish free body diagrams for every situation.

Furthermore, for an object at constant speed, many students were not able to identify the correct force diagram. Some students did not fully identify all of the forces exerted on the object, and did not successfully apply trigonometry concepts in determining the resultant of the forces. Students also lack the ability to apply Newton’s First Law in this situation in order to determine that the resultant force is zero when an object moves at constant speed. This indicates that the students could not completely represent all of the forces exerted on the block with diagrams by considering the law of inertia. Therefore, students should be encouraged to check the consistency of their understanding [9]. In this occasion, students should evaluate whether the concept of Newton’s first law is consistent with the net force (force diagram).
Some of the students (about 50%) did not include the normal force or the component of weight force on the object while the block is accelerating along an inclined plane. In this context, they applied the concept of Newton’s Second Law, but the lack understanding of force components. This suggests that a teacher should be careful in prompting students to use force diagram while solving physics problems [10,11]. In addition to utilize force diagrams, students’ views about representations including force diagrams has a positive correlation with students’ grade on basic physics course [12].

Besides multiple-choice questions, an open-ended question (inclined context) was given to 60 students (first year students) to seek how students approach the problem. The question is “a car which has 15000 N weight is at rest on a 30° inclined plane. The coefficient of static friction between box and the surface is 0.9 and the coefficient of kinetic friction is 0.8. Find the magnitude of friction force on the car (note: sin 30° = 0.5; cos 30° = 0.86; gravitational acceleration in earth = 10 m/s²).” The physics concept of this problem is similar to question number 4 on multiple-choice problem.

Table 2. The list of students’ difficulties.

| Students’ difficulties                  | N and percentage |
|----------------------------------------|------------------|
| To draw sketch/picture                 | 3 (5%)           |
| To identify forces acting on the car   | 45 (75%)         |
| To draw correctly the direction of the forces | 35 (58%) |
| To select correctly the appropriate equations | 58 (96%) |

Table 2 shows the list of students’ difficulties in solving the inclined plane problem. Even though the question is not provided a sketch (visualisation), almost students (95%) drew correctly pictorial representation to represent the situation; only 3 students did not provide a picture and drew an incorrect sketch.

Identifying forces exerted on the car is one of students’ difficulties. They had lack ability to identify completely forces such as force of earth on car (weight force), force of surface on the car (normal force), force of surface on the car (static friction force), and force component of weight force.
Furthermore, 58% of students struggled to draw correctly the direction of the forces. Mostly students provided incorrect direction of the component of weight force. An example of incorrect answer is shown in figure 3. Due to drawing the incorrect directions of forces and not drawing free body diagrams, students did not select correctly the appropriate equation to solve the problem. Students jump directly to an equation \( f_s = \mu_s N = \mu_s mg \cos \theta \). They did not notice that the car is at rest, so the static friction force is equal (but opposite direction to) the component of weight direction with x-axis.

A correct answer is presented in figure 4. The student starts by drawing sketch or picture then drawing free body diagram, and making label for each of force. The students completely identify all forces exerted on the car and also correctly draw the direction of forces. Furthermore, the student also draws a diagram to visualize all forces and component before choosing the appropriate equation to solve the problem. This diagram is very helpful to determine the net force in terms of Newton’s Laws. Sirait et al. [13] found that most students agreed that using representations such as force diagrams help them in solving physics problems.

![Diagram](image)

**Figure 5.** A correct student’s answer.

4. **Conclusion**

In summary, the most difficult task for students in terms of the force concepts is identifying the force diagrams while an object is placed on an inclined plane whether it is at rest, moving with constant speed and constant acceleration. Students should be facilitated with mathematical tool such as vector and trigonometry. Thus force diagrams should be taught clearly and students are given opportunity to create or draw their own representations.

**Acknowledgement**

This study was supported by The Ministry of Research, Technology, and Higher Education – Indonesia grant No: 107/SP2H/LT/DRPM/IV/2017. We thank to lectures and students at department of physics education – Tanjungpura University who participated in this study.

**References**

[1] Hestenes D, Wells M and Swackhamer G 1992 *Phys. Teach.* **30** 141  
[2] Savinainen A 2002 *Phys. Edu.* **37** 45
[3] Thornton R K and Sokoloff D R 1998 *Am. J. Phys.* **66** 338  
[4] Rosengrant D, Van Heuvelen A and Etkina E 2009 *Phys. Rev. ST Phys. Educ. Res.* **5** 010108  
[5] Savinainen A, Makynen A, Nieminen P and Viiri J 2013 *Phys. Rev. ST Phys. Educ. Res.* **9** 010104  
[6] Heckler A F 2010 *Int. J. Sci. Educ.* **32** 1829  
[7] Aviani I, Erceg N and Mešić V 2015 *Phys. Rev. ST Phys. Educ. Res.* **11** 020137  
[8] Palmer D 1997 *Int. J. Sci. Educ.* **19** 681  
[9] Low D J and Wilson K F 2017 *Am. J. Phys.* **85** 54  
[10] Lin S and Singh C 2015 *Phys. Rev. ST Phys. Educ. Res.* **11** 020105  
[11] Sirait J, Hamdani and Oktavianty E 2017 *J. Turkish. Sci. Educ.* **14** 82  
[12] Hamdani, Mursyid S, Sirait J and Etkina E 2017 *Jur. Penel. Pengem. Pend. Fis.* **3** 151  
[13] Sirait J, Sutrisno L, Balta N and Mason A 2017 *Jur. Pend. Fis. Indo.* **13** 79