JPII 12 (2) (2023) 178-186

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

THE PATTERN OF PHYSICS EDUCATION STUDENTS' DIAGRAMS AND ANSWERS IN SOLVING FORCE PROBLEMS

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DOI: 10.15294/jpii.v12i2.43020

Accepted: March 1st, 2023. Approved: June 09th, 2023. Published: June 10th, 2023

ABSTRACT

Force diagrams or some say free body diagrams (FBDs), as physics representations, are usually employed to teach and learn physics concepts such as force. Physics education studies indicate that the use of FBDs can support or hinder students' performance in solving physics problems. This study aims to investigate the type of representations drawn by students and the patterns of students' answers while solving force problems. By involving 230 preservice physics teachers, questions about the application of Newton's laws were administered to students to elicit the patterns of students' diagrams and answers. Results were analysed into three categories: complete, incomplete, and inappropriate force diagrams. In addition, some students did not draw diagrams in solving the problems. Based on students' answers, the percentage of students drawing incomplete diagrams (54% for horizontal problems and 42% for inclined problems) is higher than drawing complete diagrams (18% for horizontal problems and 35% for inclined problems). The percentage of students who drew inappropriate diagrams in solving horizontal and inclined problems is 20% and 10%, respectively. A few students (8% and 13%) did not draw diagrams for both questions. Students who drew complete diagrams tended to obtain the correct final answer. Some students who drew incomplete diagrams were not able to find the correct answers and even finish the problem. However, some students who drew incomplete diagrams could successfully solve the problem. The group of students who drew diagrams in the inappropriate category tended to demonstrate incorrect and unfinished answers. This study suggests that instructors should not only focus on the correctness of the diagrams but also focus on the completeness of diagrams drawn by students while solving the problems.

Keywords: force; force diagrams; physics problem solving; representations

INTRODUCTION

One of the basic concepts in physics is force. Therefore, this concept is commonly introduced in primary school before students learn more advanced concepts in senior high school and university. This concept is very important because it is used to learn physics topics such as mechanics, electricity, and magnetism (Nie et al., 2019). Generally, force is defined as an interaction between two objects (Etkina et al., 2019). For example, an object is placed on the table; there is an interaction between the object and table, the interaction between the object and earth (Sirait et al., 2023). Newton's Laws are usually applied to simply grasp the force concept (Balta & Asikainen, 2019).

Students' understanding of force has been widely explored by researchers. The force concept inventory (FCI) which has 30 items is a well-known test for measuring students' understanding of force and this test is often used as a diagnostic test at the high school and university level (Hestenes et al., 1992). Moreover, a counterintuitive

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dynamics test is developed to assess students' understanding of force (Balta & Eryılmaz, 2017). Besides developing the test, fostering students' understanding of force with various approaches has been done (Savinainen et al., 2013; Aviani et al., 2015; Robertson et al., 2021). Those studies focus on students' understanding of force whereas the forms of diagrams drawn by students have been not explored yet.

Force diagrams or free body diagrams (FBDs) are graphical representations that depict an object of interest and the forces exerted on this object by other objects with arrows of different lengths and directions (Rosengrant et al., 2009). Force diagrams as one of the physics representations are represented with arrows (Maries & Singh, 2018). It can be harnessed by teachers to teach the concepts and can be used by students to solve problems. Experts and students generally use force diagrams to visualise what objects interact with the other object of interest and in what direction those forces are exerted on the object of interest (Tay & Yeo, 2018).

Research on force diagrams has been widely conducted by experts to facilitate teachers in teaching physics concepts and to help students learn the concepts. The themes of the studies include teaching force diagrams, the forms of force diagrams, and the effect of force diagrams (Sirait, 2020). Teaching students how to draw diagrams with various approaches is the most common. Students' performances are investigated while solving physics problems. The impact of providing or not providing diagrams on problems is also investigated. However, the types of diagrams generated by students need to be explored.

Rosengrant et al. (2009) introduce six steps in drawing force diagrams including sketching the situation, circling an object of interest, modelling the system, looking for objects outside the system, drawing force arrows, and labelling the forces. They focus on drawing forces diagrams on the dot (the representation of an object of interest or the system) rather than drawing in the object. They find that university students who draw diagrams correctly are significantly more successful in obtaining the correct answer. Meanwhile, Savinainen et al. (2013) suggest drawing interaction diagrams – interaction between the object of interest or the target object and other objects – before drawing force diagrams. Their diagrams are drawn on the object. They find that only about fifty percent of high school students who correctly draw interaction diagrams create force diagrams correctly. The researchers also claim that the ability to identify the interaction of objects is not enough to draw force diagrams. They suggest the concepts of Newton's laws should be included in the process of creating diagrams. Figure 1 shows the difference between diagrams produced by Savinainen et al. (2013) and Rosengrant et al. (2009); the context is a box that is placed on the table.

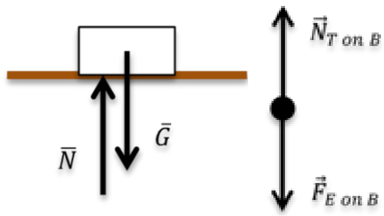


Figure 1. Examples of Force Diagrams

Furthermore, force components are usually determined first in finding the net force or the resultant forces in the x and y-axis. A study promotes the superposition approach which follows the vector addition rule (tail-to-tip rule) (Aviani et al., 2015). The study compares university students' performance taught by the superposition approach and the decomposition approach (a common approach in physics courses) and finds that students' achievement in the superposition class outperforms than decomposition class. In addition, the group of students taught by decomposition strategy tends to reveal misconceptions in force. In their study, students are asked to choose the appropriate diagrams using a multiple-choice test so the performance of students in drawing diagrams needs to be investigated in more detail.

The different formats of force diagrams also affect students' performance in solving force problems. High school students' performance is investigated by administering two different formats of problems: numerical problems and symbolic problems (Hung & Wu, 2018). They find that students' performance who solves numerical problems is higher than students who solve symbolic problems. Students' comments about the diagrams show that the symbolic format is more difficult, solving numeric problems takes less time than the symbolic format, and the numeric problem is more familiar.

The use of representations, particularly free body diagrams (FBD), does not always improve students' ability in solving problems. Heckler (2010) investigates the impact of prompting students to construct force diagrams while solving problems and finds that students who are prompted to draw diagrams are less successful in finding the correct answer than those students who are not. Students who do not receive the prompt to draw a diagram utilize intuitive solutions instead of formal strategies. Furthermore, Hekler's study is continued by Kuo et al. (2017) to investigate students' problem-solving performance by categorising two different approaches: standard procedure and shortcut approach. The standard approach consists of general steps of the problem-solving while the shortcut approach eliminates some procedures that focus on comprehending physics concepts instead of mathematical calculations. They find that students who get cues to draw diagrams tend to apply standard procedures. Moreover, the percentage of students with correct answers that apply the shortcut approach is higher than the standard approach. A study also is conducted to probe the impact of presenting diagrams on questions (Chen et al., 2017). The results show that low and medium-skilled students who receive questions with a diagram obtain a little higher score than students who do not use diagrams. Meanwhile, there is no statistical difference in students' performance for high-skilled students.

Recently, studies about physics representations focus on the effect of drawing representation while solving problems. Meanwhile, research about the forms or types of representations particularly force diagrams is limited. Tippet (2016) suggests that learning with representations is more meaningful than learning from representations. Drawing representations can be used to reason and learn concepts in science and math (Selling, 2016; Sunyono & Meristin, 2018; Yaman, 2020; Yeo & Gilbert, 2022; Tang, 2023). Thus, the purpose of this study is to investigate the force diagrams drawn by students while analysing students' answers in solving force problems. First, what are the patterns of students' diagrams in solving force problems?. The types of force diagrams will be coded into different categories by analysing all forces exerted on the object, the direction of the forces, and the correctness of forces. Second, how do students perform in solving force problems based on the type of diagrams?. Students' answers are analysed to categorise the correctness of the answers.

METHODS

A survey design aims to describe the aspects or characteristics of the population including knowledge, abilities, attitudes, opinions, and beliefs (Creswell & Creswell, 2018). Surveys can be exploratory, confirmatory, and descriptive (Cohen et al., 2018). In this study, a descriptive survey was used to explore students' abilities to solve force problems focusing on force diagrams drawn by students and the correctness of the solutions.

Table 1. Features in Grouping Students' Diagrams in Horizontal Problem

Complete	Incomplete	Inappropriate	No Diagram
Drawing all forces: F exerted by John, F exerted by Bill, Weight force (W), Normal force (N), Static friction force (f_s)	Forces exerted on the box are not completely drawn such as not providing weight force, normal force, static friction force, etc.	Drawing 2 friction forces or Drawing 2 boxes or Drawing F John and F Bill in the same direction	No diagrams provided

This study involved 230 preservice physics teachers that consist of 63 males and 167 females of the Department of Physics Education, Teacher Training and Education Faculty, Tanjungpura University – Indonesia. Students who are studying in this department were selected by either the university selection process through students' portfolios or the test after they have completed their studies from high school. Students usually take science compulsory courses such as math, physics, biology, and chemistry in high school. These students are prepared to become physics teachers either at junior or high school after completing a four-year program. Therefore, besides students learning content knowledge (physics content), they also take pedagogy content knowledge such as assessment, curriculum, and teaching physics (Schiering et al., 2022).

The survey problems used in this study were open-ended formats that cover force concepts, especially Newton's Laws. Two questions are in two different contexts: horizontal surface and inclined plane; both contexts are familiar to students from physics textbooks and exams. These two questions were adapted from previous studies. The first question (horizontals surface) was adapted from Heckler's study (2010). The original question asked students to draw diagrams meanwhile this study did not put this request in the problem sheet so that students have the flexibility to choose whether they were drawing diagrams. The second question is if an object on an inclined plane was adapted from Lin's and Singh's research (Lin & Singh, 2015). The initial question provided a sketch that was not included in this study to avoid students' decisions in drawing diagrams.

Q1. John is pushing a box with a force of 480 N in one direction and Bill is pushing the box with a force of 340 N in the opposite direction. The box is not moving. There is friction between the box and the floor and the coefficient of static friction is μ_s = 0.4 and the coefficient of kinetic friction is μ_k = 0.25. What is the minimum mass that the box can be in order for it to remain motionless?

Q2. A box that has 15,000 N weight is at rest on a 30° inclined plane. The coefficient of static friction between the box and the surface is 0.9 and the coefficient of kinetic friction is 0.8. Find the magnitude of friction force on the box._[Sin 30° = 0,5; Cos 30° = 0,86; Tan 30° = 0,57; gravitational acceleration = 10 m/s^2].

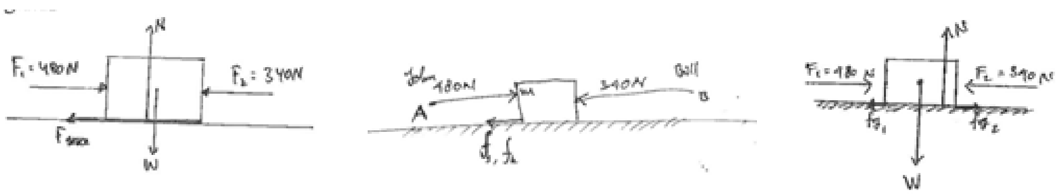
Open-ended force questions were administered to investigate the types of representations drawn by students to solve the problems. All students had learned Newton's Laws in the Basic Physics course, so they were familiar with this topic. The students were given 30 minutes for completing the problems. Students' answers were then analysed (content analysis) including the type of students' diagrams and the correctness of students' answers (Creswell & Poth, 2018; Liu et al., 2022; Wei et al., 2022). Students' diagrams were grouped into four categories: complete, incomplete, inappropriate, and no diagrams. Complete diagrams are those where all forces were drawn and correct, whereas in incomplete diagrams the forces drawn by students were correct, but students did not draw all the forces. If students drew complete or incomplete diagrams but those are incorrect (or partially correct), those diagrams were categorised as inappropriate. The rubrics for categorizing students' diagrams for questions 1 and 2 are shown in Table 1 and Table 2. The percentage of students' diagrams was calculated. The student's answer is correct if s(he) was able to present the accurate concepts, mathematical equations, and final answers. If one of these criteria is not correct, a student's answer was categorized as an incorrect answer. If students are not able to completely solve the problems, students' answers are categorised as unfinished answers. Then the percentage of students' answers for these three categories was calculated.

Table 2. Features in Grouping Students' Diagrams in the Inclined Plane Problem

Complete	Incomplete	Inappropriate	No Diagram
Drawing all forces: Weight force (W) W_x W_y Normal force (N) Friction force (f_s)	Forces exerted on the box are not completely drawn, such as not providing weight force and its component, normal force, static friction force, etc	Drawing two friction forces or The direction of W is incorrect or The direction of the force component is incorrect or The direction of the friction force is incorrect	No diagrams provided

RESULTS AND DISCUSSION

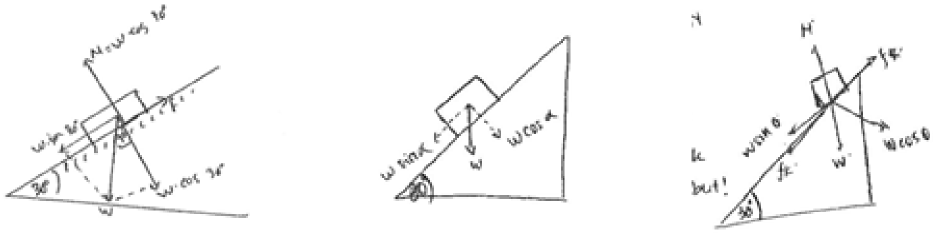
The problem is not accompanied by pictures and diagrams so that students have opportunities to freely draw their diagrams. Based on data analysis of students' answers while solving two problems given in a survey (horizontal and inclined plane problems), students' diagrams are classified into four different categories: complete, incomplete, inappropriate, and no diagrams. The percentage of students who draw complete diagrams in solving horizontal and inclined surface problems is 18% and 35%, respectively. Meanwhile, about half of the students draw incomplete diagrams for both questions (54% for horizontal problems and 42% for inclined problems). Then, 20% and 10% of students draw inappropriate diagrams in solving horizontal and inclined surface problems. The examples of students' diagrams are shown in Figure 2 and Figure 3. In summary, about 90% of students draw force diagrams in solving both questions although they are not asked to draw diagrams. This is a higher percentage than in a previous study done by Rosengrant et al. (2009); they find that an average of 58% of students draw force diagrams in their exams.



Complete Incomplete Inappropriate

Figure 2. Type of Force Diagrams Drawn by Students in Solving the Horizontal Problem (Q1)

The category of complete diagrams means that all forces exerted on the object are drawn with correct positions and directions. As can be seen in Figure 2 and Figure 3, students draw weight force, normal force, and friction force. In the category of incomplete diagrams, students do not draw either normal force or weight force. Then students who draw complete diagrams but incorrect directions are categorized as inappropriate diagrams. The percentage of students' answers in solving problem 1 is displayed in Figure 4. Students who draw complete diagrams tend to obtain the correct answers (28 out of 42 or 67%) while solving the horizontal plane problem (Q1). A correct answer implies that the concepts involved and mathematical equations are used correctly to solve the problem. These students draw representations (diagrams) to illustrate the problems and self-checking as a means of finding the correct solution (Ainsworth et al., 2011; Tytler et al., 2020). This finding seems to align with the result of a previous study conducted by Lucas and Lewis (2019) that students who draw diagrams are more likely to successfully solve physics problems in both mechanics. It means that students can interpret and integrate the meaning of representations (Nielsen et al., 2022; Prain & Tytler, 2022).



Complete Incomplete Inappropriate

Figure 3. Type of Force Diagrams Drawn by Students in Solving the Inclined Plane Problem (Q2)

This study uses different terms in categorising students' diagrams. Three categories of students' diagrams are used in this study: complete, incomplete, and inappropriate diagrams. Meanwhile, a study conducted by Rosengrant et al. (2009) just distinguishes the correct and incorrect force diagrams. They categorize incomplete and inappropriate diagrams as incorrect diagrams. The incomplete diagrams in this study are not grouped as incorrect diagrams, because although they do not depict all forces, these diagrams are otherwise drawn correctly and some of the students who draw incomplete diagrams can find the correct solutions.

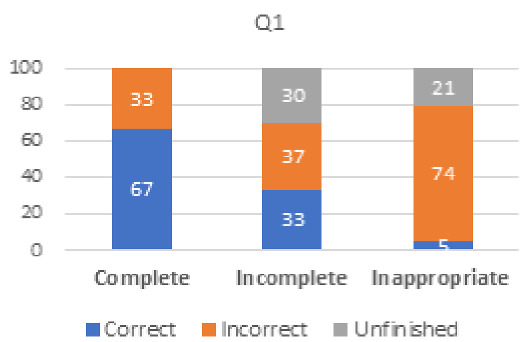


Figure 4. The Percentage of Students' Answers based on the Type of Diagrams in Solving Q1

It suggests that students have different ways to construct their knowledge and represent their understanding (Rau, 2017; Svensson & Campos, 2022). The constructivist point of view states that knowledge is built in the mind of the learner through personal experience (Bodner, 1986). The process of constructing new knowledge is when students try to organize, structure, and restructure their experience. In the context of constructing representations, students come to the classroom with an understanding of representation (DiSessa, 2004; Park et al., 2020). In other words, students deploy their prior knowledge and previous experiences to create representations.

However, in the inclined problem (Q2), the trend is different, only 28% (22/78) of students who draw complete diagrams can solve the problem correctly. The percentage of students' answers is shown in Figure 5.

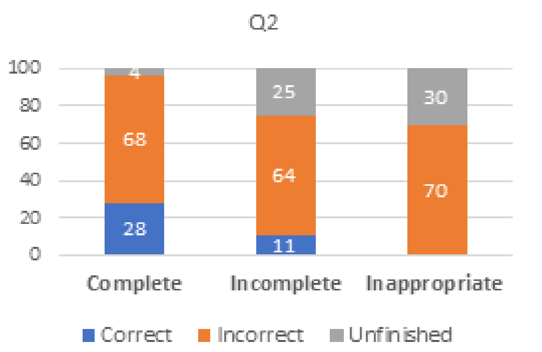


Figure 5. The Percentage of Students' Answers based on the Type of Diagrams in Solving Q2

This result aligns with the previous study that students have difficulties in identifying force diagrams while an object is placed on an inclined plane (Sirait et al., 2018). For some problems, the presence of diagrams did not help students to choose the correct answers and for other problems, students who draw diagrams are still unable to select the correct answers (Vignal & Wilcox, 2022). Some students do not really use complete diagrams to produce the correct mathematical equations in finding the magnitude of the static friction force. Some students draw complete diagrams but do not notice that their diagrams can be used to write down the mathematical equation (the net force $\sum F=0=f_s - mg \sin \theta$). Instead, they write the friction force equation ($f_s \max = \mu_s N$). In other words, some students do not demonstrate representational competence (Gebre & Polman, 2016; Chang, 2018; Scheid et al., 2019) to translate from diagram form to mathematical equations. Redish and Kuo (2015) state that math is a language of physics that can be used to represent physics concepts. Transforming one form of representation to another form of representation is difficult for students (Ivanjek et al., 2016; Ceuppens et al., 2019; Van den Eynde et al., 2019). Ertikanto et al. (2018) find that mathematical representation skills affect students' learning outcomes of science.

The answers of students who draw incomplete diagrams are categorised into three groups: correct, incorrect, and unfinished. The number of students who draw incomplete diagrams and obtain incorrect answers is higher than students who obtain the correct answers. Two-thirds of students who draw incomplete diagrams obtain incorrect answers when solving the problem 2. These students focus on friction force equations instead of the net force in the x-direction. However, the results show an interesting finding that some students can solve the problems correctly even though their diagrams are incomplete. A previous study finds that, for some students, adding information such as drawing force diagrams is useful because it can reduce working memory, whereas some more knowledgeable students can solve the problem without adding information or drawing force diagrams (Kalyuga & Singh, 2016; Kuo et al., 2017). Some students may not need to draw all forces exerted on the object because they already know how to solve the problem or they have been familiar with the problem. In other words, students know when and why they draw representations (Sirait, 2019; Kohnle et al., 2020). For example, in problem 1, students are familiar with the horizontal context, so they may have known the magnitude of the weight force is the same as the magnitude of the normal force, and thus their directions. Then, in problem 2, students may not have drawn the component of weight force because they are familiar with the context that the component of weight in the x-direction is using sin θ and using cos θ for the y-direction.

Students who draw inappropriate diagrams tend to obtain incorrect answers and some can not completely solve the problems. Based on students' answers, students who draw this kind of diagram draw incorrect diagrams such as the incorrect direction of forces. In addition, some students also write incorrect mathematical equations. Students should have conceptual knowledge in drawing representations besides mathematics knowledge (Sirait et al., 2017; Hamdani et al., 2019). Students who draw inappropriate force diagrams seem to have a partial understanding of physics concepts such as friction force. For example, while students solve problem 1, some students draw both friction forces (static and kinetic) in the same direction and the different direction; in other words, students may be unsure when static friction force and kinetic friction forces are exerted on an object. These students may have conceptions that 'the direction of the static friction force is always opposite to the external force'. The friction force is one of the abstract concepts in learning force. Consequently, they draw two friction forces because two external forces 'force John and force Bill' are exerted on the box. However, this conception is appropriate if only one external force is exerted on an object. Based on Newton's Laws, 'the direction of the friction force is opposite to the direction of the net force or the acceleration of the object (Etkina et al., 2019).

CONCLUSION

Students have different ways of drawing force diagrams when solving force problems: complete diagrams, incomplete diagrams, and inappropriate diagrams. Students who draw complete diagrams indicate that they have enough concepts and find the correct answers. Meanwhile, there seems to be a lack of knowledge for students who draw inappropriate diagrams. Then surprisingly, some students who draw incomplete diagrams can nevertheless solve the problems correctly. Thus, this finding suggests that instructors should pay attention to grading students' problem-solving by not only focusing on complete diagrams but also focusing on incomplete diagrams. Their drawing incomplete diagrams do not mean that their diagrams are incorrect. For some students, drawing force diagrams is not easy; it might be caused by the abstractness of force diagrams. For example, to solve the problems in this study, students needed to draw sketches, force diagrams, force components, and generate equations. In addition, force concepts are also abstract whereas students need physics concepts for drawing diagrams. At the same time, students draw diagrams to understand physics concepts. Consequently, some students may draw inappropriate diagrams. Therefore, instructors should be careful in teaching force concepts, which include diagrams. Teachers should make sure that students have enough knowledge of how to draw diagrams before the diagrams can be used to learn other concepts.

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