Using physics representation worksheet to enhance students’ understanding and performance about force

H Hamdani*, S Mursyid and J Sirait
Program Studi Pendidikan Fisika, Universitas Tanjungpura, Pontianak, Indonesia

*hamdani052185@gmail.com

Abstract. The aim of this study is to investigate students’ abilities to understand and solve physics problems by teaching them how to develop representations using physics representation worksheets. The particular curriculum component studied here relates to the concept of force (the application of Newton’s laws). The first-year students were involved in this study to find out the extent to which the worksheet can support students’ understandings and capacity for problem-solving. An experimental approach was applied for this study. For data collection, before and after instruction, students were asked to solve 11 items from the force concept inventory-FCI (a standardized force concept test) which is a multiple-choice test. Two open questions were solved by students to measure students’ performance at the end of the instruction. Based on the analysis of the results, students’ score of the eight FCI items increased while score for the two open-ended items decreased; score for one item did not change. Students’ performance in solving inclined plane, above 50% students were able to correctly draw all forces exerted on an object. Furthermore, in the horizontal surface problem, 5 out of 23 students could perfectly solve the problem; they drew all forces precisely and executed the final answer.

1. Introduction
Physics concepts can be visualised in different forms including words, pictures or sketches, graphs, diagrams, mathematical equations, etc. Therefore, the ability to create, use, and translate these representations are important in helping students to understand physics as well as to solve physics problems [1,2]. There are several reasons why representations play an important role in students’ learning. First, during the problem-solving process, representations can be used as a tool to depict the problem [3]. Second, students who are taught by using representations consistently achieved higher scores than students who did not [4]. Third, representations can help problem-solvers to select the appropriate mathematical equation to answer a problem [5].

Studies about enhancing students’ understanding of forces (Newton’s laws) by encouraging them to create or draw diagrams have been conducted by physics education researchers. By teaching students how to draw correct free body diagrams (FBDs), this could increase students’ outcomes in introductory physics courses [6]. These researchers focused on encouraging students to draw FBDs through several steps. The results show that students who are taught by drawing force diagrams in introductory physics courses achieved higher scores than those who did not. Moreover, students who could correctly depict FBDs obtained higher scores than those who could not.

A group of physics education research from Finland [7] also carried out research by introducing interaction diagrams. The diagrams aim to identify all forces exerted on an object before drawing free body diagrams. By teaching and motivating high school students to draw interaction diagrams, the
researchers intended to help students successfully draw free body diagrams. They found that students who could correctly depict all forces in interaction diagrams did not automatically draw FBDs precisely.

The FBDs suggested by Rosengrant et al. [6] are placed on the XY axis to clearly identify the direction of forces without including a force component. Second, labelling forces are very important to show the interaction between two objects. Meanwhile, an approach introduced by Savinainen et al. [7] is to draw the interaction of all objects and the object of interest and then draw all the forces on the object of interest. This approach might affect students' identification of forces while selecting an appropriate equation to solve a problem. The differences between FBDs by Rosengrant et al. [6] and Savinainen et al. [7] are exhibited in figure 1; an example of the situation is a book placed on the table.

![Figure 1. The different forms of representations, (a) picture; (b) FBDs by Savinainen et al. [7] and (c) FBDs by Rosengrant et al. [6].](image)

Our previous study [8] was about students’ ability to choose diagrams for an object placed on a horizontal and inclined plane in three different situations (an object is at rest, is moving with constant speed, and is moving with constant acceleration) and students’ difficulties in drawing the diagrams. The results of the study indicate that students could not successfully draw the direction of normal force or friction and also, they struggled to determine the component of the weight force. Moreover, our students usually draw diagrams (forces exerted on the object) in the object. Consequently, students have struggled to determine the component of a force and to find out the net force. Therefore, we developed a physics representation worksheet that is a combination of the work by Rosengrant et al. [6] and Savinainen et al. [7].

The difference between our worksheet and their approach is that our physics representation worksheets distinguish between force diagrams and FBDs and focus on the labelling of forces. In some physics textbooks, force diagrams and FBDs have the same meaning and use. In this work, however, students are asked to draw all forces on the object of interest to help them understand the concept of each force exerted on the object of interest while drawing a force diagram. Meanwhile, in the process of drawing a free body diagram, all forces are drawn on the XY axis and the object of interest is represented by a dot. Students then draw the component of forces parallel to either the X- or Y-axis; this will help students to determine the net force. A more detailed physics representation worksheet (PRW) is shown in figure 2.

By differentiating between force diagrams and FBDs, we developed PRW as a means of assisting students to identify all forces, components, and the net force so that students can understand the force concept and solve the force problems. The research questions are, 1) do PRW assist students to grasp force concepts, and 2) do PRW help students to solve force problems?
### 2. Method

#### 2.1. Participants
This study involved 23 first-year students (pre-service physics teachers) at a department of physics education at Tanjungpura University (UNTAN). The participants included 18 female students and 5 male students (aged 18 and 19). Students who are accepted to this department have been selected through a University exam entrance. This department is one of the institutions in Kalimantan Barat that produces physics teachers. After completing their study, they will teach science and physics courses at junior high schools and or senior high schools.

#### 2.2. PRW
The PRW aims to help students by depicting students’ understanding in different forms: verbal, picture, concepts, force diagrams, FBDs, and mathematical equations. The contexts addressed in this worksheet are the horizontal surface, inclined plane, and pulley. The goal of this worksheet is to help students identify all forces exerted on the object, to draw the direction of the forces correctly, to determine the net force, and to formulate the appropriate equations.

In the PRW, we distinguished the use of a force diagram and free body diagram. It was supposed to give students the opportunity to identify and draw all the forces exerted on an object in the force diagram stage. Moreover, in the free body diagram stage, students could draw force vectors in XY axis and this

\[
\sum F = ma; \ a = 0 \\
\vec{N}_F on B + \vec{F}_H on B \sin \theta - \vec{F}_E on B = 0 \\
\sum F_x = ma \\
\vec{F}_H on B \cos \theta - \vec{F}_F on B = ma
\]
activity helps students to check the length of the vector and the position before determining the force component.

2.3. Data collection
To measure students’ understanding of forces, we administered a force concept inventory (FCI) as an international standard test [9]. The FCI addresses Newton’s laws and its application. We selected just 11 questions (identify forces and directions in various contexts and determine the magnitude of the force on an object) of the FCI because these items are appropriate for the goals of this study. Furthermore, to obtained data about students’ performance to solve force problems and we asked students to solve two open questions. The questions were about the objects that were placed on a horizontal and inclined surface. The two questions were taken from a teaching introductory physics textbook [10].

2.4. Data analysis
Students’ answers to the FCI both pre- and post-test were analysed by giving a score of 1 for a correct answer and 0 for an incorrect answer. Then, the students’ score for each question was exhibited in a graph to easily grasp the difference between the students’ scores before and after instruction. Regarding the students’ performance in solving problems, we focused on the correctness of all forces presented in their answers including the labelling of the forces, the direction of the forces, force component, mathematical equations, and the final answer. Students’ answers were categorised into three categories: correct, incorrect, and not provided.

3. Result and discussion
Before the instruction began, students were divided into six groups consisting of 3/4 students in each group, facilitated with a mini whiteboard. This whiteboard was a tool for students during discussion before doing the PRW. At the end of the instruction, each group presented their work so that other groups could comment on it or ask questions. This helped students to evaluate or rethink their work.

To obtain the effect of the PRW on students’ learning, a force test (FCI) was given before and after instruction. Students’ score is shown in figure 3. The mean scores for 11 selected problems in the pre- and post-test are 3 and 5 respectively. Based on a statistical analysis (t-test), there is a significant difference (p < 0.05) between students’ scores before and after learning Newton’s laws. Furthermore, eight questions of the FCI (Q5, Q15, Q16, Q17, Q25, Q26, Q28, Q29) increased, two questions (Q18 and Q30) decreased, and one question (Q27) did not change.

![Figure 3. Students’ score of FCI.](image)

Q5 and Q28 have the highest increase in score among the items; Q5 increased the most. Students were asked to identify the force exerted on a ball moving in a circular track as well as to find its direction. In the post-test, about 80% of students could successfully answer this question. Furthermore, the scores for Q16 and Q29 also increased. Q16 is about identifying the magnitude of the force and Q29 is about identifying the force and direction of the wheelchair while at rest. This kind of learning using
representation worksheet activities let students practice listing the interactions between the object of interest and other objects. By giving students a chance to identify the interactions between objects while learning Newton’s laws, they were successful in finding the magnitude of the force [7].

On Q18 and Q30, students’ scores decreased. Students were not able to find the direction of the force on a boy swinging on a rope. Most students think that the direction of the force is from the rope to the boy. They did not realize that the object of interest is the boy. The same thing happened for Q30 (identifying the direction of the force on a tennis ball). Students did not include forces exerted by the air on the ball. Consequently, their answers were incorrect. The obstacles to students determining the direction of forces might be affected by their knowledge of vectors. Sirait et al [10] found that students who lacked knowledge of vectors are not able to find the correct diagram in the horizontal and inclined contexts.

For the open question 2, students were asked to determine the magnitude of the coefficient kinetic friction between the box and the surface of the inclined plane while the box sliding down with constant acceleration. We analysed representations drawn by students in their answers including normal force, friction force, weight force (also the component in the X and Y-axis), and mathematical equation (presented in figure 4). Each representation was analysed according to the correct, incorrect, and not provided category. Based on the analysis, over 50% of students could correctly identify normal, friction, and weight forces (including the component of the weight force). However, about 50% of students were not able to select the appropriate mathematical representation, consequently, they could not find out the final answer (the coefficient kinetic friction). Figure 6 displays the students’ performance solving Q2. Based on the students’ answers, some students just drew force diagrams without FBDs; this might affect the ability of students to connect the diagrams and the appropriate mathematical representations. In fact, students who could correctly draw FBDs tended to provide the appropriate mathematical equations and determine the correct answer [6].

Students’ errors in mathematical equations include the sign of friction force. Students were not aware of the direction of the resultant forces parallel to the direction of acceleration of the box. Only a few students provided incorrect components of weight force (the use of sin and cos), so while executing the equation, they obtained the incorrect coefficient of friction. Furthermore, students who could successfully solve this problem drew all the forces exerted on the box. They then drew the force component in a different diagram. From the diagram, students continued to write down equations of the results of the forces in the X and Y-axis: \( \sum F_x = 0 \); \( N - W \cos 30^\circ = 0 \); \( \sum F_x = ma \); \( W \sin 30^\circ - f_{g \text{kinetic}} = ma \); \( W \sin 30^\circ - \mu_k = ma \).

This indicates that force diagrams and FBDs facilitate students’ ability to select the appropriate equation to determine the magnitude of the coefficient of kinetic friction (\( \mu_k \)).

The purpose of Q1 is to determine the magnitude of force exerted by hand (F) so that a block remains at rest on the wall (just about to start moving downward or upward). The students’ performance was...
assessed by several components such as normal force, weight force, F component, the net force in the X-axis, friction force, equation, and the magnitude of F. Students' answers for each component were categorised as correct, incorrect, and not provided. The answer was correct if the forces (the position and direction) are precise and the mathematical equations were correct. More detail about the students’ work (number of students) is shown in Table 1.

About 20% of students could successfully solve this problem; students could correctly draw all forces, mathematical equations, and find out the magnitude of the force. Students did not face difficulties while identifying and drawing normal force and weight force; it seems that 17 out of 23 students (about 70%) could identify and draw these forces. Students who successfully solved this complex problem drew both the correct force diagrams and FBDs. This indicates that separating these diagrams will help students to find the correct mathematical equations. The transparency of representations will guide students to use representations in solving problems [11].

However, most students were unable to determine the component of the F force in the XY axis or the net force in the X-axis. This indicates that students need practice in finding the component of a vector. The students’ skills in manipulating vectors affect students’ ability to identify the correct FBDs while solving problems regarding Newton’s laws [12].

| Students’ answers | \( \bar{N}_{\text{Won} \#} \) | \( \bar{F}_{\text{Won} \#} \) | \( \bar{F}_x \) | \( \bar{F}_y \) | \( \bar{F}_{\text{net} (x)} \) | Almost moving downward | Almost moving upward |
|------------------|-----------------|-----------------|-------------|-------------|----------------|-------------------|-------------------|
| correct          | 18              | 18              | 6           | 7           | 6              | 14                | 6                 |
| incorrect        | 2               | 3               | 1           | 2           | 2              | 1                 | 16                |
| not provided     | 3               | 2               | 16          | 14          | 15             | 8                 | 1                 |

4. Conclusion
Students can learn Newton’s laws by using PRW to help them identify the correct force (position, direction, and magnitude) exerted on an object. However, students should have enough knowledge of vectors and also have enough practice in using the PRW so that students become more familiar with force diagrams and FBDs to help them connect the diagrams and mathematical equations and finally help them to find the correct answers.

Acknowledgments
This work has been supported by a grant from Direktorat Riset dan Pengabdian Masyarakat, Direktorat Jenderal Penguatan Riset dan Pengembangan, The Ministry of Research, Technology and Higher Education (Kemenristekdikti) in 2017-2018. We thank to freshmen students of department of physics education, Tanjungpura University who participated in this study.

References
[1] Disessa A A and Sherin B L 2000 J. Math Behav. 19 385
[2] McPadden D and Brewe E 2017 Phys. Rev. Phys. Educ. Res. 13 020129
[3] Mason A and Singh C 2011 Phys. Rev. ST Phys. Educ. Res. 7 020110
[4] Huffman D 1997 J. Res. Sci. Teach. 34 551
[5] Van Heuvelen A 1991 Am. J. Phys. 59 898
[6] Rosengrant D, Van Heuvelen A and Etkina E 2009 Phys. Rev. ST Phys. Educ. Res. 5 010108
[7] Savinainen A, Makynen A, Nieminen P and Viiri J 2013 Phys. Rev. ST Phys. Educ. Res. 9 010104
[8] Sirait J, Hamdani and Mursyid S 2018 J. Phys. Conf. Ser. 997 012030
[9] Hestenes D, Wells M and Swackhamer G 1992 Phys. Teach. 30 141
[10] Arons A B 1997 Teaching introductory physics (United States: John Wiley & Sons, Inc)
[11] Ainley J 2000 J. Math Behav. 19 365
[12] Sirait J, Hamdani and Oktavianty E 2017 J. Turkish. Sci. Edu. 14 82