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PHYSICS EDUCATION STUDENTS' VIEWS ABOUT FORCE DIAGRAMS WHILE SOLVING PHYSICS PROBLEMS

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ABSTRACT

Force is one of the most fundamental concepts in physics, used to describe and explain a wide range of phenomena. Students can use force diagrams to learn about fundamental force concepts and solve problems related to forces. However, a limited study has focused on students' views in drawing force diagrams. This study aims to explore students' views about force diagrams while solving physics problems. A qualitative study was conducted to explore students' views on drawing and using force diagrams when solving force problems, involving 18 physics education students. Before the semi-structured interviews were conducted, the students were given two force problems to solve. All interviews were recorded, transcribed, and coded for analysis. Data from the interview was analyzed using NVivo software. This study identified five themes related to students' views on force diagrams: purposes, conventions, physics concepts, mathematical concepts, and incomplete diagrams. The most frequently mentioned theme by students was the purpose of drawing force diagrams. Students' knowledge about force concepts and trigonometry also affected their diagrams. Students had different ways to draw diagrams, either on the dot or on the object, and had reasons for drawing the incomplete force diagrams. These findings suggest that students should possess sufficient knowledge of physics and mathematics to draw force diagrams effectively. Students should also understand when force diagrams are applicable and recognize the advantages of drawing them. This study suggests that to support students' effective understanding of force diagrams, educators should employ appropriate strategies and equip students with the skills to create and utilize force diagrams while learning about force concepts and solving problems.

Keywords: force; force diagrams; physics problems; representations; views

INTRODUCTION

Representations in physics include verbal descriptions, pictures or sketches, tables, graphs, diagrams, and mathematical equations (Klein et al., 2017; McPadden & Brewe, 2017; Scheid et al., 2019). Experts typically employ these representations to comprehend phenomena, visualize situations, evaluate ideas, and clarify their findings (Kohnle et al., 2020). For example, sketches are commonly used to illustrate complex situations in a simple form. Diagrams, such as force diagrams, can be used to visualize all forces acting on an object and to determine whether an object is moving with constant speed or acceleration (Etkina et al., 2019). For students, one of the important skills in physics problem-solving is the ability to shift between different forms of representation (Bollen et al., 2017). For example, students can transform data on a table into a graph and vice versa. Then, using representations can foster students' understanding of physical and mathematical concepts (Hamdani et al., 2019). In addition, the ability to construct and interpret representations can enhance students' understanding of science concepts (Tippett, 2016).

Force is a crucial concept in physics, as it is applied in various topics, including mechanics,

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electrostatics, and magnetism (Nie et al., 2019). The concept of force is typically used to understand the interactions between charges and the interaction between objects and the Earth. Generally, force is defined as an interaction between two objects (Etkina et al., 2019). For example, to understand how a book on the table remains at rest, the interactions between other objects and the book should be identified. Then, all interactions can be visualised by using force diagrams. The net force acting on the book can be determined from force diagrams, and these diagrams can then be converted into mathematical equations. Force is always related into motion when learning mechanics topics (Giambattista et al., 2004). The net force acting on an object can predict the motion of an object; likewise, the motion of an object can predict the forces acting on it. Newton's Second Law ($\Sigma F=ma$) is applied to comprehend the relationship between force and motion (Giancoli, 2014).

Based on the literature, students' thinking about forces is categorized into two main types of ideas: misconceptions and resources. Misconception refers to students' pre-instructional cognitive structures, which differ from those of experts (Nie et al., 2019). In contrast, a resource is a piece of knowledge that gets activated in real-time and in context-sensitive ways (Robertson et al., 2021). Students' thinking about forces has been summarized based on both misconceptions and resource paradigms. First, a moving object ($v\neq 0$) keeps moving because there is a force ($F\neq 0$) inside the object. In other words, a moving object carries a force to keep it moving. Second, an object not in motion must have no any forces acting on it. Third, velocity is proportional to applied force; students believe that motion and force are directly proportional without thinking about acceleration. Lastly, the net force determines motion; this means that if the net force is not zero then an object is moving, but if the net force is zero then an object is stopped or slowing down.

Research about students' understanding of forces is one of the main foci in physics education. Several instruments have been developed to delve into students' ideas in comprehending forces such as Force Concept Inventory (FCI) (Hestenes et al., 1992), Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998), Counterintuitive Dynamics Test (CIDT) (Balta & Eryılmaz, 2017). Teachers or instructors, as well as researchers, typically use multiple-choice tests to assess students' comprehension of force, where students are asked to select the appropriate answers. Moreover, a body of research has also grown in measuring students' understanding of force by involving multiple representations, such as the Representational variant of the Force Concept Inventory (R-FCI) (Nieminen et al., 2010), Free Body Diagram Test (FBDT) (Aviani et al., 2015), Force Representational Competence Test (FRCT) (Sirait et al., 2023), and Force Diagrams Representation Test (FRDT) (Sirait et al., 2023). These tests generally investigate students' conceptual knowledge about force by examining the consistency of students' answers in different formats of representation. However, the literature is limited regarding students' understanding of representations, particularly force diagrams, their motivations for drawing representations, and their views on drawing representations while solving physics problems.

Force diagrams, or free-body diagrams, 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 (Etkina et al., 2019). The longer an arrow, the greater the force exerted on an object; the shorter an arrow, the smaller the force exerted on an object. The way of drawing force diagrams can be either on the object or on the dot (Lee, 2017; Sirait, 2020). Drawing force diagrams can be useful for visualizing the components of a force and determining the resultant force (the sum of the forces) exerted on an object.

Research on force diagrams has been conducted extensively by experts to support teachers in teaching physics concepts and to aid students in learning these concepts. Researchers suggested steps and approaches to assist students in drawing force diagrams as a means of understanding the physics concepts and problems. Six steps are proposed by Rosengrant et al. (2009) for drawing force diagrams, including sketching the situation, circling an object of interest, modeling the system, identifying objects outside the system, drawing force arrows, and labeling the forces. Savinainen et al. (2013) introduced interaction diagrams to identify interactions between the objects of interest and other objects before drawing force diagrams. Aviani et al. (2015) suggested two different approaches to drawing free-body diagrams: superposition and decomposition. The decomposition method is a common approach that refers to determining a vector's components, followed by finding the resultant of the vector. By contrast, the superposition method refers to adding vectors, where the tail of one vector is placed at the end of the previous vector. The different formats of representations in solving force problems have also been explored. Chen et al. (2017) explored the performance of students who solve force and motion problems, providing representations, and those who do not. Hung and Wu (2018) examined the performance of high school students in solving two different formats of force problems: numerical and symbolic problems.

Studies about force diagrams have been summarized by Sirait (2020). Firstly, some studies have focused on teaching students to draw force diagrams using approaches as a means of facilitating their learning of concepts and solving problems. Those studies aimed to investigate the impact of drawing and using force diagrams on students' performance when solving problems. However, few studies reported the reasons why students draw representations. Secondly, some studies examined the presence of force diagrams in problems and how giving hints to draw force diagrams also affected students' performance. Those studies indicated that providing diagrams in problems did not have a positive effect on students' performance in solving problems. Thirdly, survey studies also examined students' representational competencies – the ability to construct, use, and translate representations by designing representational tests with different forms. Studies have revealed that students struggle to transform one form of representation into another. Studies on force diagrams have generally focused on students' cognition in drawing force diagrams and have been conducted quantitatively. A qualitative study is needed to explore students' perceptions about force diagrams, which has not been done in quantitative studies.

A body of research has grown in affective domains, including views, motivation, attitudes, beliefs, identity, and self-efficacy in science education (Kaur & Zhao, 2017; Woitkowski & Wurmbach, 2019; Stadermann & Goedhart, 2020; Sirait, 2023). Views commonly refer to opinions, perspectives, beliefs, interests, and thoughts, as well as reasons regarding objects, situations, and concepts (Blue, 2018; Gyllenpalm et al., 2022). The primary focus of this study is force diagrams, which are based on the concept of force.

Thus, to gain a deeper understanding of students' views on force diagrams, it is essential to conduct a study investigating what they think and reason when drawing force diagrams while solving force problems. The purpose of this study is to elicit students' views on force diagrams in the context of physics problem-solving.

METHODS

This study employed a qualitative approach to explore students' thoughts and views about force diagrams. Patton (2014) explains that the major source of qualitative data is obtained from what people say, whether verbally through an interview or in written form through document analysis or survey responses. The main goal of using qualitative methods is to find out the meaning of a phenomenon from the views of participants (individual perspectives) by using observations and interviews to collect data (Creswell & Creswell, 2018). Obtaining detailed information and identifying subjective understanding and motivation are characteristics of qualitative research methods. In addition, Merriam and Tisdell (2015) state that understanding the meaning of what people think and how they perceive their world through their experiences is the characteristic of a qualitative study.

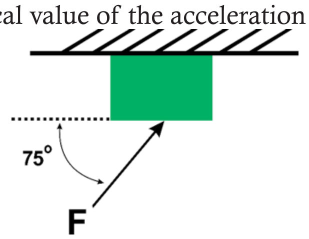
The participants in this study were 18 physics education students from various cohorts (first- to fourth-year students) enrolled at a public university in West Kalimantan, Indonesia. Physics education students at this university are preparing to be either science teachers at junior high schools or physics teachers at senior high schools. They must take compulsory courses, such as basic physics, mechanics, waves and optics, electricity and magnetism, and modern physics, which are considered content knowledge (Etkina et al., 2018; Phelps et al., 2020). Additionally, students acquire knowledge and skills in teaching physics content, known as pedagogical content knowledge (Schiering et al., 2022), through various mandatory courses, including teaching physics strategies, planning for physics teaching, and assessing physics learning. Students normally graduate from their study program in about four years.

Before interviews were conducted, students had to solve two problems, which covered horizontal and inclined plane contexts. All students have learnt the concept of force in basic physics and mechanics courses. The first question (Q1) was adopted from Arons (1997), which asked students to determine the normal force exerted on the block and to evaluate whether the block is moving with a constant acceleration. This question provided students with opportunities to draw representations, including force diagrams. The second question (Q2) asked students to determine the magnitude of tension (T) exerted on the car, which was adopted from Lin and Sing (2015). The process of solving the problem was recorded by Livescribe tools, which have a pen and a workbook. Students had the opportunity to write their answers in a workbook using a pen. The tools were connected to a smartphone via Bluetooth to enable recording the data. Students were given 30 minutes to solve both problems.

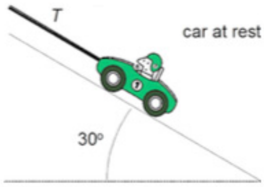
Q1. A block (mass 12.0 kg) is held against the ceiling by a force F = 160 N at an angle of 75° to the horizontal, as shown below. It is known that the block is in motion (sliding along the ceiling) and that the coefficient of kinetic friction is 0.2. [sin 75^o = 0.96; cos 75^o = 0.25; tan 75^o = 3.73; and g = 10 m/s^2].

a.Determine the normal force exerted by the ceiling on the block

b. Determine whether the block is accelerating along the ceiling, and, if it is, calculate the numerical value of the acceleration



Q2. A car weighing 15,000 N is at rest on a frictionless 30° incline, as shown. The car is held in place by a light, strong cable (T) parallel to the incline. Determine the magnitude of T. [sin 30^o = 0.5; cos 30^o = 0.86; tan 30^o = 0.57; and g = 10 m/s^2].



After students solved both problems, they were invited for interviews. Patton (2014) asserts that conducting interviews is appropriate when exploring the feelings, thoughts, intentions, and other aspects of interviewees. The purpose of the interviews in this study is to gain insight into the students' thoughts and perspectives. Semi-structured interviews (Merriam & Tisdell, 2015) were adopted to gather information about students' views. The interviews were intended to gain an in-depth understanding of the reasons, thoughts, and perceptions behind drawing force diagrams. The interviews were recorded on video and audio, and lasted 30 minutes.

The students' responses from the interviews were transcribed and coded. Coding is used to categorize students' responses, enabling the identification of specific categories for data analysis (Cohen et al., 2018). The process of coding in this study used several steps suggested by Creswell & Creswell (2018): reading transcripts, noting initial ideas; picking one transcript, thinking about the meanings and write the meanings in 2-3 word phrases; begin coding by identifying segments of the text relating to a particular code; make a list of all codes and group them; go back to the data and try to code using this scheme, refining and removing codes whenever necessary. After coding, thematic analysis was employed to identify the reasons and motivations behind students' use of diagrams in problem-solving. Thematic analysis is used to identify and analyse the patterns or themes of the data (Miles et al., 2019).

All interviews were transcribed into text form in Indonesian and then analyzed using computer software (NVivo). The aim in analyzing verbal data using this software is to help identify patterns in students' responses and ultimately to extract themes from students' views for drawing diagrams. Students' responses were coded to identify patterns, including similarities and differences (Saldana, 2015). For the credibility of data analysis (Tay & Yeo, 2018), two physics education lecturers did the same coding for one participant's transcript. Both of them then discussed the similarities and differences in their codes. After they reached an agreement, they continued to code the remaining transcripts. After obtaining the fixed codes, all codes and students' responses relating to all codes were translated into English. Finally, all codes were grouped into several themes.

RESULTS AND DISCUSSION

Each participant was first asked to solve two force problems (Q1 and Q2) and then continued with the interviews. All interviews were transcribed, analyzed, coded, and themes were generated. Table 1 lists the five themes and 12 sub-themes of students' views about force diagrams, along with descriptions. Students' views were identified in terms of purposes, conventions, physics concepts, mathematical concepts, and incomplete diagrams. The following subsection describes and illustrates students' views about force diagrams, with excerpts derived from semi-structured interviews and examples of students' answers while solving force problems. The students' names in the excerpts are pseudonyms.

Table 1. Themes of Students' Views about Drawing ForceDiagrams

Themes	Sub-themes	Description
Purposes	To identify forces To find the direction and sign of forces To determine the component of forces To support in selecting mathematical equations	This theme was generated from students' perceptions about the reasons why they drew diagrams while solving the problems. Students mentioned the function of force diagrams and the advantages of drawing diagrams.
Conventions	The label of forces Drawing the object Drawing on the dot Drawing a dotted line	Students were concerned about forces, such as accepted ways of drawing diagrams, how to symbolize forces, and the effect of drawing forces on the object or in the x-y coordinate plane.
Physics concepts	Forces Newton's Laws	Concepts that include the concept of forces and Newton's laws are mentioned by students as aspects of drawing force diagrams.
Mathematical concepts	Vector Trigonometry	Besides physics concepts, mathematical concepts are also important in drawing force diagrams.
Incomplete diagrams	-	Students drew incomplete diagrams for several reasons.

The first theme of the students' views about drawing diagrams was categorised as 'purposes'. One of the sub-themes of the purpose is to identify forces. Almost all students mentioned that drawing force diagrams helped them to identify forces exerted on an object. Sirait et al. (2023) found three different categories of force diagrams drawn by students: complete, incomplete, and inappropriate force diagrams. One of the students, Zack (a first-year student), said:

"*The first diagrams aim to draw all forces exerted on the block, and drawing the second diagrams is to know what forces are exerted in the x and y axes*".

When he solved the first question (Q1), he drew all forces on the block first, and then drew forces in both vertical and horizontal directions (Figure 1). His complete diagrams show that he drew all forces exerted on the block including weight force (W), normal force (N), friction force (f_k), F, the component of F in *x* direction (F cos 75°), and the component of F in *y* direction (F sin 75°). Zack knew that the normal force is in the *y*-axis, so he focused on the diagrams in the vertical direction, including the normal force, the weight force, and the component of F. He then continued to write an equation (Newton's First Law) and included the three forces in the equation. He also did the same steps to determine the magnitude of the block's acceleration. Zack recognised that the direction of the block's acceleration is along the *x*-axis and focused on all forces in the *x*-axis: the component of F and the kinetic friction force. Subsequently, he redrew the diagrams on the *x*-axis by drawing the two forces. He then wrote an equation (Newton's Second Law) including the two forces. At the end of his work, he successfully determined the magnitude of the normal force and the magnitude of the block's acceleration. His work indicated that he drew force diagrams to guide him in examining all forces exerted on the object and identifying which forces were in the *x*-axis or *y*-axis. The work of this student aligns with Lucas and Lewis (2019), who found that students who draw diagrams are more likely to solve physics problems successfully.

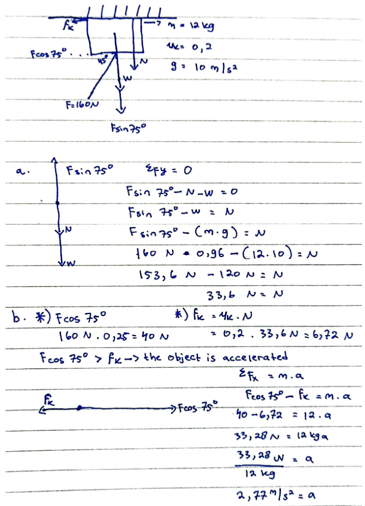


Figure 1. Zack's Work Solving Q1

By drawing forces on the block in solving Q1, Amy, a third-year student, recognised that she had made a mistake at the beginning, and then revised the direction of forces. For her, diagrams are useful for reminding her to examine all forces exerted on the block in more detail. This indicates that drawing representations (force diagrams) is helpful for illustrations (Tytler et al., 2020). Amy drew all forces, but one of the forces (normal forces) was in the incorrect direction; her diagrams are categorized as inappropriate diagrams. Some students tend to draw the normal force in an upward direction because they often solve force problems where an object is placed on a surface, rather than below the ceiling or on a wall (Sirait, 2020). Consequently, she wrote an incorrect mathematical equation. Even though she could not determine the correct answer, she thought that drawing diagrams had enabled her to see all the forces exerted on the block.

Amy: "At the beginning, I thought the direction of N was similar to the direction of W, but after drawing the diagrams, it seems another force is similar to the direction of N."

Additionally, a third-year student, Steve, drew incomplete force diagrams when solving Q1. He mentioned during the individual interview that drawing diagrams helped him to recall forces exerted on the object. Below is a part of a conversation during the interview.

Researcher: "So, what is your purpose in drawing these kinds of diagrams?"

Steve: "To help me in analysing forces exerted on the block, even though my diagrams are not complete."

Researcher: "What does analyzing mean here?"

Steve: "To know all forces."

Researcher: "How about if you do not draw force diagrams?"

Steve: "If I do not draw, actually, I could, but the diagrams help me to analyse and recall forces."

Another purpose for drawing diagrams is to find the direction and sign of forces. Most students perceived that one of the purposes of drawing diagrams was also to find out the direction and sign of forces. The views of some students on this idea are presented below.

Mike: "It is obvious that if I am not drawing, it is difficult to imagine where the direction of force is. Then I drew diagrams to avoid the mistakes of drawing the direction of forces because it also affects the calculation."

Amy: "At the beginning, I thought the direction of normal force (N) is the same as the direction of weight force (W), but after drawing the diagrams, it seems the direction of N is the same as the direction of F sin alpha."

Harry: "I usually draw diagrams to decide which forces are positive or negative."

Drawing diagrams enabled Harry (a first-year student) to determine the sign of forces as shown in Figure 2. This aligns with the recommendation of a study that drawing force diagrams helps students determine the direction and sign of the forces exerted on an object (Mattson, 2004).

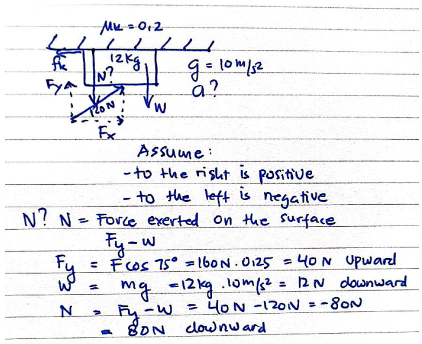


Figure 2. Harry's Work Solving Q1

The signs of forces are useful for him, either for determining the net force or for manipulating equations. Harry wrote down, "I assume the right and upwards are positive." His work pointed out that the weight force (W) was 120 N going down (*ke bawah*), Fy, which has a magnitude of 40 N, is going up (ke atas), and the normal force (N = 80 N) is going down (*ke bawah*).

Besides identifying forces and determining the direction of forces, one of the purposes of drawing diagrams, as described by students, was to determine the component of forces. While a force is exerted on the object which is not parallel with the vertical or horizontal direction (shaping an angle) as shown in questions Q1 and Q2, the component of the forces is needed to know the resultant of the force in the *x*- and *y*-axis. Particularly in an inclined context, the component of weight force is determined in order to see the direction and the magnitude of weight force in the *x*- and *y*-directions. Generally, the components of forces are depicted with dotted lines. This is even harder to imagine without drawing. The forces are invisible, but we can relate them to physical things – the engine of the car, or someone pushing the block along the ceiling. Components of the forces are 'imaginary' at another level (Sirait, 2020). The purposes of students in drawing diagrams, especially those related to the component of forces, are shown below.

Ana: "This problem provided F and angle, then I added forces here, what is the name? Yes, the

component of force in the x and y direction."
Vera: "The purpose is so that I know what forces are in the x- and y-axis. If we talked about an inclined plane, there are forces in the x-axis and y-axis."
Chris: "Here we know the object is on the inclined plane, so to determine the direction, we projected the weight force (W) in x- and y-axis (W_x and W_y), then wrote a mathematical equation."

When Josh (a third-year student) solved Q1 (Figure 3), he drew the components of F to obtain the components of F_x and F_y before moving to writing the mathematical equations. To determine the component of F, he projected F onto the x-axis (Fx = F cos 75°) and the y-axis (Fy = F sin 75°), applying concepts from trigonometry.

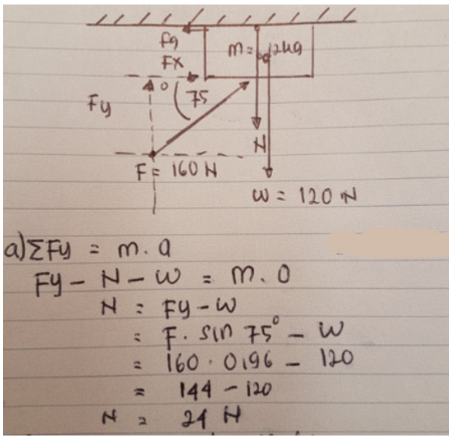


Figure 3. Josh's Work Solving Q1

Knowing the component of F guided him to determine the net force in the vertical direction. He included the component of F in the *y* direction in the equation. Overall, his mathematical equations are correct, as they include F_y, N, and W forces. A small mistake occurred when calculating the magnitude of F *sin* 75°; he obtained the value F_y as 144, but it should have been 153.6.

Determining the component of forces is one of the difficulties in drawing force diagrams correctly. For example, if an object is placed on an inclined plane, students should draw the components of the weight force to find the net force in the *x* and *y* axes. Some students mentioned that they had challenges finding out the components of forces as shown below:
Ana: "The difficulty is to determine the component of forces because if one of the forces is wrong, it will affect all forces."
Maria: "While solving the problem, I am confused about the direction of the force component."
Evan: "I think that it is more difficult in the context of an inclined plane than a horizontal surface because it has many forces, and I have to find the component of forces in the x and y axes."

Some students struggle to draw the component of a force for several reasons (Sirait et al., 2019). First, students should master the trigonometry concepts, including the application of sine and cosine functions. Second, the component of force is more abstract than the force itself because the component of force is not an applied force exerted on an object.

To obtain the final answer, mathematical equations are typically required to solve the problems. In the context of force problems, students mentioned that diagrams are useful for deciding on the appropriate equations. This is referred to as representational competence, which involves transforming from one representation to another (Küchemann et al., 2021)graphs, and mathematical equations, and relating these to one another as well as to observations and experimental outcomes. In this study, we present the initial validation of a newly developed cross-contextual assessment of students' competence in representing vector-field plots and field lines, the most common visualization of the concept of vector fields. The Representational Competence of Fields Inventory (RCFI. Students' comments relating to the advantage of drawing diagrams in selecting mathematical equations are shown below:
Leo: "I think that diagrams are needed for solving complex problems that involve many forces. It will help me in applying mathematical equations."
Vera: "It is easier to write mathematical equations while looking at the diagrams because sometimes I forget the formula."
Zack: "I got the equations from the diagrams drawn. Personally, by drawing diagrams, we can determine mathematical equations that will be used because mathematical equations can be changed depending on the context."

From the students' statements above, they obtained the benefit of drawing diagrams that connect to mathematical equations, because physics contains many formulas that they might not be able to memorize completely. Thus, diagrams can be helpful in guiding students to write down the equations used to solve the problem, as equations can be altered depending on the context, as Zack mentioned. Amy also recognised that drawing diagrams was crucial for her. She said that "for me it is crucial because my mathematical equations depended on these diagrams. I drew the incorrect normal force; consequently, all my calculations are incorrect".

As Daniel (a second-year student) said, the diagrams assisted him in selecting which forces would be included in an equation. His work in solving Q2 is presented in Figure 4.

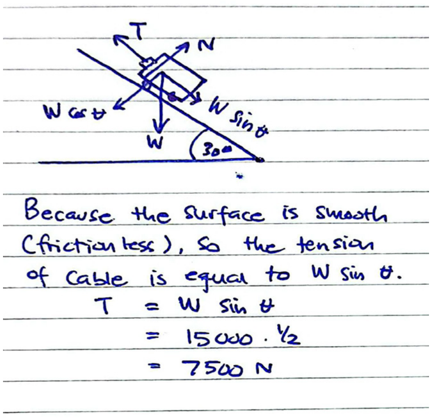
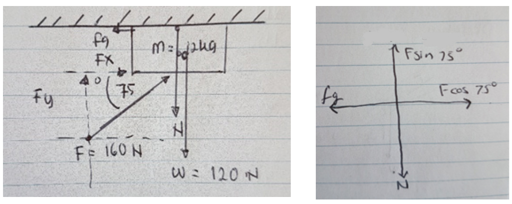


Figure 4. Daniel's Work on Q2

He just needed two forces (T = cable force and W *sin* θ = the component of W in the x-axis) to solve the problem in Q2 to determine the magnitude of T. This indicates that drawing force diagrams guides students to generate the correct mathematical equation. Redish (2021) argues that the meaning of physical concepts can be transformed into mathematical concepts. In this context, the magnitude of T and W *sin* θ is the same, so it is converted into equation form.

How students drew their force diagrams is categorised as the 'conventions' theme, including labelling of forces, drawing diagrams either in the object or on the dot, and drawing dotted lines to represent a specific force. These themes primarily focus on the features of force diagrams. Labelling forces is about how students name forces (Etkina et al., 2019). Moreover, some students may be more comfortable drawing forces on a real object rather than on a dot that represents one, as shown in Figure 5. Rosengrant et al. (2009) suggested drawing force diagrams on the dot as the representation of an object of interest. Meanwhile, Savinainen et al. (2013) focused on drawing force diagrams of real objects.



(a) (b)

Figure 5. Drawing Forces in (a) Real Object; (b) in dot

There are many characteristics or features of force diagrams drawn by students while solving problems. First, students have different opinions about the labelling of forces. To symbolize a force, some students were more comfortable using a symbol with a letter rather than two letters that represent the interaction of two objects. For example, while students drew the force of the Earth on the box in Q1, they symbolised it with W instead of . A student (Joyce) said that "personally, it is easier with one symbol, such as W, than force of the Earth on box." In addition, familiarity with the symbol is one reason to use a single letter. Moreover, some students said that "a symbol of force with two letters that shows the interaction between two objects should be explained for beginner learners". Students' responses indicate that they represent a force by the simplicity and familiarity of the symbols (Wendel, 2011). Besides weight and normal force, students were also concerned with the symbols of friction force. Generally, the symbol of friction force is instead of . Then, friction force is symbolised with as static friction force and as kinetic friction force. Students' comments from interviews about the symbol of friction force are shown below.

Frank: "In my view, friction force is usually symbolised with f or f_g."

Dayana: "Based on my experience learning from the physics course, the symbol of friction force is f, not F."

Some physics textbooks define force as a push or pull. Consequently, these two definitions influence the naming of forces. For example, a person is pushing a box on the floor. To name the push force on the box, students label it as F rather than $F_{\text{person on box}}$ ($F_{\text{P on B}}$). In fact, force is defined as an interaction between two objects (Maloney, 1990).

When students drew diagrams, some of them tended to draw all the forces on the object. This might have helped students identify the forces exerted on the object, such as the weight force, normal force, and friction force. However, for a complex problem that involves many forces exerted on the object, students may need to draw all forces in the x-y direction to see the direction of forces and their components clearly. Below are students' responses about drawing forces on the object.

Frank: "It is much easier for me to draw the diagrams in the box (or on the real object) because I know the position of the forces, and it also saves my time."

Joyce: "Drawing in the box makes it easier to identify forces."

Steve: "Because I already understood the problem while drawing in the box, so I do not need to draw on the dot."

For some students, drawing all forces on the object instead of just on the dot is helpful in recalling other forces. For example, after drawing the weight force, students can draw the normal force. However, if multiple forces act on the object, such as the force of the inclined plane, it becomes more complex. So, drawing on the dot will be one of the solutions for students (Sirait, 2021).

Some students have opinions about drawing diagrams on a dot (in the *x-y* axis) as displayed in Figure 5(b). They argued that drawing diagrams on a dot would be easier to determine the direction of forces, either on the x-axis or y-axis, and the resultant of forces. Here are some comments from students.

Ana: "Drawing on the dot will simply distinguish which forces are in the x-axis and y-axis and which forces are positive and negative."

Maria: "It is easier to determine the direction of forces and the resultant of forces."

Jane: "If only drawing the object, it is not clear yet which forces are in the x-axis and y-axis."

In addition, a student stated that drawing diagrams in the dot would be helpful, but it would require more time. This might be one of the reasons why students drew on the object to save their time while solving the problems. Moreover, some students said that drawing diagrams of the object was enough if they already understood the problems. This view suggests that drawing force diagrams, whether for real objects or on a dot, relies on the complexity of the problem at hand. Students draw diagrams to understand the problems (Vignal & Wilcox, 2022).

Students' knowledge about physics concepts may also affect how they draw diagrams. In this study, force concepts, including normal force, weight force, and friction force, are necessary when drawing force diagrams. To draw forces correctly, students must understand the concepts behind each force. For example, the normal force is perpendicular to the plane; the direction of the friction force is always opposite to the direction of the net force exerted on an object. The students' conceptions about the normal force are shown below.

Ana: "We must know the concepts of forces. For example, the normal force is always perpendicular to the surface."

Amy: "The normal force is not always in the same direction as the weight force."

Eva: "The normal force is always directed upward and originates from the center of the object."

Steve: "For this question, why is the normal force going down, not going up, because the direction of the normal force is keeping away from the horizontal surface. For example, if the object is placed on the table, the normal force is going up, while if the object is placed below the table, the normal force is going down."

From the students' comments above, Ana and Steve demonstrate their understanding of the normal force, which is that it is always perpendicular to the surface. Steve even explained the direction of the normal force in more detail, which is not always going up, as Eva had said it always does. Meanwhile, Mike focused on using an equation (calculating the friction force) to determine the magnitude of the normal force.

Students perceived that understanding the concepts also contributed to their successful problem-solving. After identifying all forces exerted on an object, students then focused on how each force was drawn, including its position, direction, and connection with other forces. For example, the direction of the normal force and the weight force is the same in Q1. Students stated that concepts of forces included in the problems or diagrams are important to consider. To solve the problems in this study, the physics concepts include normal force, weight force, friction force, and Newton's laws.

First, the normal force is the interaction between the object and its surroundings. Generally, the normal force is drawn starting from the base of the object, and it is perpendicular to the surface (Etkina et al., 2019). While an object is placed on the horizontal surface, the direction of the normal force is up or in the opposite direction of the weight force, but the direction of the normal force is different from when an object is placed on the inclined plane. In Q1, the box is placed below the ceiling, so both the normal force and the weight force have the same direction, pointing downward.

Second, the friction force is related to the normal force. The friction force and the normal force form an angle of 90^o. Mathematically, the magnitude of the friction force is proportional to the coefficient of friction times the magnitude of the normal force () (Giancoli, 2014). There are two types of friction forces: the static friction force acts when the object is at rest or nearly at rest, and the kinetic friction force acts while the object is moving, either with constant velocity or constant acceleration. Thus, the concept of friction force is connected to the normal force and the motion of the object.

Furthermore, understanding the concepts of forces, including friction forces, is also a challenge for students, which affects their performance in drawing force diagrams. Many students reported confusion in distinguishing between static and kinetic friction forces. Consequently, they were unable to draw the direction of friction forces correctly, and even drew both friction forces in a single situation. This is in line with Balta and Asikaninen (2019), who suggest that some students may struggle to find the correct net force when considering the friction force. The difficulties students experience in drawing diagrams related to the friction force are illustrated below.

Mike: "The difficulty is in the concept. I was always taught that we need to determine the components of forces along the x and y axes, and then we can find the normal force. In fact, the magnitude of the normal force (N) is not always the same as the magnitude of the weight force (W), so this makes me confused."

Ana: "There are two friction forces – static and kinetic. Whether the object is moving or not depends on the friction force. Which force is used? I am confused."

Frank: "The question made me confused because it asked the magnitude of the friction force while the coefficient of friction has been provided. Then the magnitude of the friction force can be determined without using an equation. ."

Mike thought the magnitude of the friction force was equal to the magnitude of the weight force. His assumption can be correct while the object is at rest on a horizontal surface. However, while other forces are exerted on the object and while an object is placed on an inclined plane, his conception is not applicable. In fact, the friction force relates to the normal force (the relation is perpendicular). The magnitude of the friction force can be determined by using an equation (is the friction force; is the coefficient of friction, and it can be static or kinetic; is the normal force). For some students, the concepts of static and kinetic friction forces are interchangeable.

Furthermore, the use of the friction force equation must be done carefully because it depends on the object's motion. For example, while the object is at rest or almost moving, the magnitude of the static friction is the same as the magnitude of the net force exerted on the object. Subsequently, while the object is in motion, the equation of the friction force can be determined to calculate the magnitude of the kinetic friction.

The concepts of Newton's Laws are also needed in drawing force diagrams. These are beneficial for checking whether an object is at rest, moving with constant velocity, or moving with constant acceleration (Alonzo & Steedle, 2009; Nie et al., 2019). For example, the car is at rest in Q2, so the net force along the x-axis is zero; this means that the magnitude of the cable force (T) is equal (but in the opposite direction) to the magnitude of the weight force component (Wx), as shown in Figure 6.

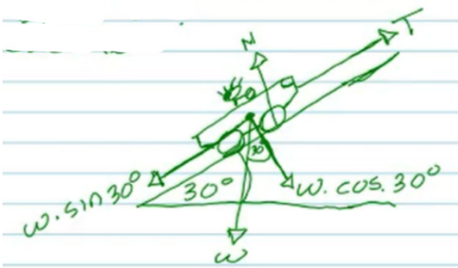


Figure 6. A Student's Work ($T = W_x$) Solving Q2

Many students mentioned Newton's Laws while understanding the problems and drawing the diagrams. Students' comments about Newton's laws while drawing force diagrams are shown below.

Evan: "The problem mentions that the block is moving, so I thought . The block is moving on the x-axis, so I wrote . Meanwhile, the block is not moving in the y-axis, so the total force is zero."

Harry: "Does the object move? Let us prove with . First, we assume the object is not moving so we use f_s to symbolise static friction force. If W_x is bigger than f_s, the object is moving. However, I found that , meaning that f_s is bigger than W_x. It means that the weight force (x component) is not able to make the object move."

Steve: "I thought that the block moving in the y-axis is impossible, so Newton's 1st law: was applied. Then, the block is moving to the right or x-axis, so Newton's 2nd law law was applied."

Tina: "I solved it directly on the y-axis because I thought the block falling was impossible, so ."

The concept of Newton's Laws corresponds to the forces exerted on the object and the acceleration of the object. For example, the net force is in the same direction as the motion of the object. It can be concluded that the acceleration of the object might be more than zero or zero, so the velocity of the object is either increasing or constant. Thus, based on the students' views above, understanding the concept of Newton's Laws helped them connect all forces exerted on the object and determine whether the object is at rest or in motion (Nie et al., 2019).

Besides physics concepts, mathematical concepts such as vector and trigonometry were mentioned by students when they drew diagrams. A force is represented by a vector depicted with a straight arrow (Etkina et al., 2019). To determine the net force or the resultant of forces, students should add and subtract force vectors (Heckler & Scaife, 2015)but in almost all cases the questions posed were in the vector arrow representation. In a series of experiments involving over 1000 students and several semesters, we investigated student understanding of vector addition and subtraction in both the arrow and algebraic notation (using i, j, k. Moreover, when a force vector is not precisely either in a vertical or horizontal direction, students should find the component of the force by using trigonometry. A vector, which is a fundamental concept in mathematics, consists of an arrow, direction, and magnitude. One of the students (Steve) mentioned that:

"I think that to draw the diagrams simply, we must understand the concept of vectors because force is a vector that has a magnitude and a direction. So, it is important to understand the vector."

This student thought that to be able to draw diagrams correctly, one had to have enough knowledge about vectors. That is very important because forces are represented by arrows, which consist of both direction and magnitude. In other words, having a good understanding of vectors will help students visualise a force, determine the components of forces, and find the net force (Barniol & Zavala, 2014; Sirait et al., 2018). Another student (Harry) added the idea that "because force is a vector, we do not only write the magnitude but also the direction." This means that a complete understanding of force requires knowledge of both its magnitude and direction. For instance, to determine the net force exerted on the object, one should know the magnitude as well as the direction of all forces.

Another student, Eva, said that drawing diagrams was related to vectors. The length of an arrow represents the magnitude of a force.

Researcher: "Do you think that the length of these arrows is important?"

Eva: "Yes, it is important because these arrows represent the magnitude of the forces."

Trigonometry is also one of mathematical skills that affects students in the process of drawing force diagrams. Trigonometrical ability is generally employed to determine the component of a force in *x*- and *y*-directions (Giambattista et al., 2004). Having ample trigonometry knowledge will enable students to find the force components as well as the net force, particularly in the inclined plane context. Below are students' comments about trigonometry while drawing force diagrams.

Joyce: "I have to know trigonometry to find out the component of forces."

Steve: "I made a triangle to simplify finding sin, cos, and tan using Pythagoras. For example, sin theta = 3/5."

Zack: "The concept of trigonometry is important because force problems are not only on a horizontal surface but also on an inclined plane."

Rose: "Actually, it is more difficult to solve a problem that is the context in an inclined plane than a horizontal surface because we have to analyse force components at different angles."

In this study, students applied trigonometry concepts to solve problems. In Q1, a force (F) is exerted on a box to keep its position below the floor and prevent it from falling. The position of the force is not really in the x- and y-directions, but it is angled 75 ° to the horizontal axis. Therefore, in order to determine the net force in both the x-axis and y-axis, students should find out the components of the force by applying trigonometry concepts (*sin* and *cos*). Furthermore, a car is at rest on the inclined plane in Q2, and students should apply trigonometry concepts to determine the components of the weight force in the x- and y-directions before determining the net force in the *x*- and y-axes. This suggests that math concepts are very essential in learning physics (Burkholder et al., 2021; Turşucu et al., 2017).

Some students seem to need to draw complete diagrams, while others might not have shown such a need. Students who drew incomplete diagrams provided reasons for not completing the diagrams. For example, in the context of the inclined plane problem (Q2), students were asked to determine the magnitude of the cable force (T) pulling the car. In a complete diagram, students should draw the normal force and weight force, and then find the components of W in the x- and y-axes. Due to the force T being parallel to Wx in the x-axis, students determined the net force, or the resultant of forces, along the axis and then applied Newton's First Law in mathematical equations. Students' comments are presented below.

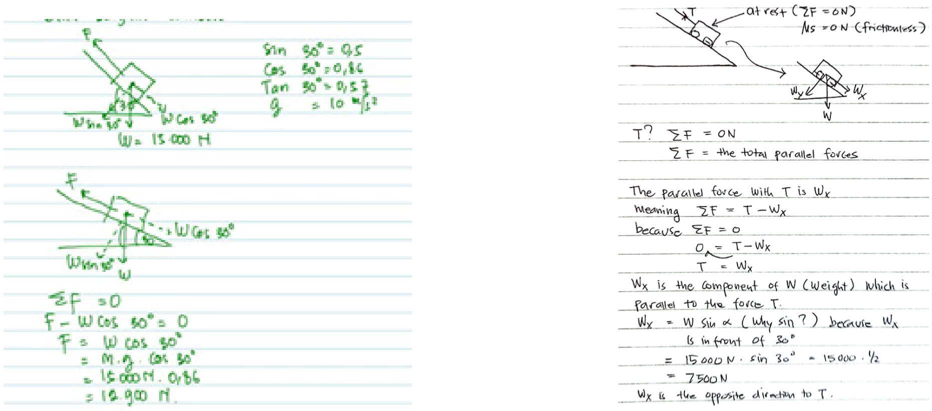
Joyce: "To identify forces exerted on the car. There are three forces: the pull force (T), the weight force, and the normal force. I did not draw normally because I think it is not used in calculations, but I know it in my head.

Harry: "I should draw the normal force so that I know the component. I did not draw because I do not think it is necessary."

Tina: "Before analyzing, there are three forces: weight force, T force, and normal force. I did not draw because there is no question asking about the normal force. Actually, it is not good, I should have drawn, but I was in a hurry."

Rob: "Because in y direction is going up and down, so it is impossible that the car is jumping up and down. We calculate in the x direction. Actually, there is a normal force, but we did not determine the normal force, so we must not have drawn."

Joyce (a fourth-year student) and Harry (a first-year student) drew incomplete diagrams (neither of them drew the normal force) while solving Q2, as shown in Figure 7, which asked for the magnitude of T to make the car remain at rest. Joyce used F to represent T and drew the weight force along with its components. However, she made a mistake in using the formula to determine the component, although she wrote a correct equation to determine the magnitude T; consequently, she obtained an incorrect final answer. Moreover, Harry drew the T force and weight force along with the correct components. He also added the explanation that W_x is parallel to T in the x direction. He then wrote a correct mathematical equation and found a correct final answer.



(a) (b)

Figure 7. Joyce's Work (a) and Harry's Work (b)

Some students did not draw the normal force for several reasons. First, they said that the normal force did not need to be drawn because it would not be needed in the calculation to determine the value of T. Second, due to the surface being frictionless, the normal force was not exerted on the car, as Evan said:

"I think if the surface is frictionless, then there is no normal force."

Another reason is that the normal force could be obtained from the friction force equation, so some students did not draw the normal force.

Researcher: "Why didn't you draw all the forces?"

Mike: "I think it is not needed. We can determine the normal force by using the friction force equation. The friction force is equal to the normal force times the coefficient of friction."

Some students also mentioned that if they had understood the problem, they would not have needed to draw the complete diagrams.

Steve: "Maybe because I memorised that in inclined plane, x axis, we used sin, not cos, so no need to draw, I have understood."

Leo: "Actually, as long as we understand the problem, we do not need to draw."

Leo, a third-year student, did not draw the normal force exerted on the car (displayed in Figure 8); instead, he focused on all forces in the x-direction, which are T and mg sin 30°. He then wrote a correct formula to determine the magnitude of T.

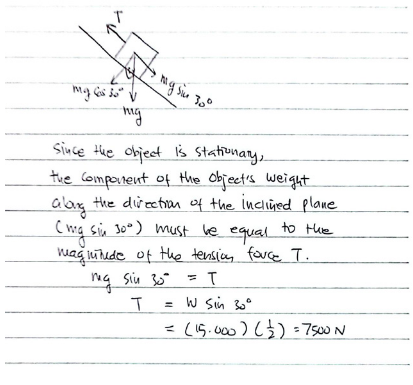


Figure 8. Leo's Work in Solving Q2

Based on students' responses, the data indicate that students have different ways of representing their knowledge (Svensson & Campos, 2022). Studies have found that drawing representations, such as force diagrams, is beneficial because it can lessen working memory; meanwhile, some more knowledgeable students can solve the problem without drawing force diagrams (Kalyuga & Singh, 2016; Kuo et al., 2017) it is assumed that the acquisition of domain-specific knowledge structures (or schemas. Furthermore, for students who know how to solve the problem and are familiar with it, some students might not draw force diagrams. This finding aligns with previous studies, which suggest that students recognize when they draw representations (Kohnle et al., 2020; Sirait, 2021).

CONCLUSION

Students have several views about drawing force diagrams while solving problems, including purposes, conventions, physics concepts, mathematical concepts, and drawing incomplete diagrams. Students consider that by drawing force diagrams, they can obtain several benefits: identifying forces, determining the direction of forces, finding the component of forces, and assisting in generating mathematical equations. Furthermore, students also mentioned that both physics and mathematical concepts are important to draw force diagrams successfully. Knowing the force concepts is helpful in identifying and drawing forces. Then, mastering vectors and trigonometry is essential in determining the components of forces and the resultant of forces. The way students draw diagrams, such as complete and incomplete diagrams, is also a matter of personal preference for students. Moreover, the labeling of forces, the forms of arrows used for applied forces, and the components of forces are important. Additionally, whether the forces are depicted within the object or on the dot is also important. This study suggests that students should be taught the advantages of drawing force diagrams, how to draw them, and the skills they should possess while doing so.

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