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STUDENTS' USE OF REPRESENTATIONS IN SOLVING PHYSICS PROBLEMS: COMPLETE AND INCOMPLETE FORCE DIAGRAMS

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Students' Use of Representations in Solving Physics Problems: Complete and Incomplete Force Diagrams

Abstract

Physics concepts can be represented in many different forms such as verbal descriptions, sketches or pictures, graphs, diagrams, and equations. Force diagrams, or some say free body diagrams (FBDs), as physics representations are usually employed to teach and learn force concepts. Recent studies, which mostly have used quantitative approaches, indicate that the use of force diagrams can support or hinder students' performance in solving physics problems. This study investigates students' use of force diagrams when solving force problems. An interpretivist approach was implemented to answer four research questions including students' views about physics problem solving, students' views about representations, how students draw force diagrams when solving force problems, and students' views about drawing force diagrams. For data collection, surveys and interviews were conducted involving university students. A problem solving survey and representations survey aimed to obtain students' perceptions. Along with both surveys, two force problems were given to see students' performance in solving problems including their diagrams. Some students were invited to participate in individual clinical interviews, and later in paired interviews to obtain students' views about drawing force diagrams. The results show that most students viewed that mathematical knowledge as the most important element in solving physics problems and students often used representations for helping them to understand the problem and find the correct answer. Based on students' solutions, diagrams were categorised as complete, incomplete, and inappropriate. Students who drew complete diagrams tended to gain the correct answers in contrast to students who drew inappropriate diagrams. An interesting finding is that some students could solve problems correctly with drawing incomplete diagrams. From interviews, students asserted some reasons for drawing diagrams including to find the sign and direction of forces and to support in selecting mathematical equations. They recognised that physics and mathematical concepts are important in drawing force diagrams.

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CHAPTER 1
INTRODUCTION

1.1 Focus of study

The Indonesian education system is managed by the ministry of education. It means that the curriculum of each level (from primary school to high school) is almost similar in every school. Students learn for six years in primary school or elementary school then they continue to junior high school for three years. After graduating from junior high school can continue their study either in senior high school or vocational high school for three years. Students learn general science during in primary and junior high school. Meanwhile, in high school, students learn science including physics, chemistry, and biology. The content of physics curriculum involves mechanics, electricity and magnetism, wave and optics, and thermodynamics. After graduating from high school, students can continue to university level with facing selection process. The first process is called invitation process. Students who have good performance have chances to apply university based on their performance including grades and other achievement during their study in high school. The university examine students' portfolio. The second process is through university entrance exam.

The physics education department at universities in Indonesia play a role in generating physics teacher candidates. Students who are studying in this department are preparing to become physics teachers in either junior or senior high schools after completing their studies. Before coming to this department, they have passed the university test after graduating from senior high school. The teacher preparation program in Indonesia is a bit different from that of Western countries, such as the UK and USA. In Western countries, for example, a student generally has a bachelor's degree before entering a teacher preparation program at a university school of education. By contrast, in Indonesia, a student who wants to be a teacher can apply directly to a teacher training and education faculty after graduating from senior high school.

The basic physics course, as one of the fundamental courses and a compulsory course in physics education departments, is taught in the first academic year. This course covers physics concepts such as Newton's Laws, momentum & impulse, work & energy, fluids, and basic electricity and magnetism. These are fundamental concepts for students to master before taking advanced courses such as optics and waves, thermodynamics, and quantum physics. For physics education students, physics courses (basic physics I and II) have eight credits in total which are taken by students at the first semester and the second semester. The course consists of lecture in the classroom and experiment in the laboratory. Students' grades are derived based on assessment including written exams and students' performance in lab.

Physics concepts can be represented in many different forms, such as verbal descriptions, sketches or pictures, diagrams, graphs; these are called *representations*. A study by Bollen *et al*. (2017) suggested that an important skill in physics problem solving is an ability to shift between different types of representations. They stated that using representations can improve students' understanding of mathematical and physical concepts. Tippett (2016) analysed literature on science representations and found that an ability to construct and interpret representations can enhance students' understanding of science concepts.

Force is a very important concept in physics because it is used in other topics besides mechanics, such as electrostatics and electromagnetism. For instance, the concept of force is usually used to understand the interaction of charges. Most students assume that problem solving in physics, for example, with problems involving forces, is similar to mathematics because most problems use equations (Bryan and Fennell, 2009). They often move directly to a mathematical equation while solving several problems without considering concepts, principles, representations, or strategies that would be helpful to find the best solution. Based on my experience in teaching physics, many university students proceed directly to equations without thinking about strategies to understand the problem. For example, when students solve a problem relating to motion and forces, they might first identify known variables, and then write an unknown variable. Based on unknown variables, they might write an equation such as Newton's Law ($\sum F = 0\,; \sum F = ma$) where F is force, m is mass, and a is acceleration. From the acceleration, they connect to motion variables such as velocity (v) and time (t). Consequently, students who rely on equation might not be successful at finding the best solution. It might be affected by their experiences studying in high school, which focus on presenting known and unknown variables and writing mathematical equations relating to unknown variables.

A common representation in physics is a force diagram used to represent forces exerted on an object. Research about force diagrams has been widely conducted by experts to facilitate teachers in teaching physics concepts and to help students learn the concepts. There are steps and approaches suggested to assist students in drawing diagrams as a means of understanding the concepts and solving the physics problems (Rosengrant, Van Heuvelen and Etkina, 2009). Savinainen *et al*. (2013)suggested drawing interaction diagrams – an interaction between the object of interest or the target object and other objects – before drawing force diagrams.

However, the use of representations, particularly free body diagrams (FBD), does not always improve students' ability to solve problems. Heckler (2010) investigated the impact of prompting students to construct force diagrams while solving problems and found that students who were prompted to draw diagrams were less successful in finding the correct answer than those students who were not. Students who did not receive the prompt to draw a diagram utilised intuitive solutions instead of formal strategies. A study conducted by Chen *et al.* (2017) to probe the impact of presenting diagrams in questions found that low-and-medium-skilled students who received questions with a diagram obtained a slightly higher score than students who did not use diagrams. Meanwhile, there is no statistical difference on students' performance for high achieving students.

To date, there remains no consensus about the role of representations in physics problem solving because some studies have found that using representations could foster students' performance, while others have claimed that there is no difference between the performance of students who drew representations and students who did not, particularly in drawing force diagrams. In terms of problem solving, the existing literature suggests several approaches or steps that might be followed by students, including drawing representations, identifying concepts, and selecting mathematical equations. These three ideas: concepts, diagrams, and equations (CDE) were used as a conceptual framework in this study. In this case, force concepts include normal force, friction force, weight force, and external force (applied force). In terms of drawing representations, previous studies suggest several methods for drawing diagrams. In this study, vector concepts and force concepts are needed in drawing force diagrams. A force exerted on an object is represented by an arrow, which shows the magnitude and the direction of the force (force vector). Thus, this study, by involving university students, deeply focuses on the use of representations in solving force problems, including drawing diagrams and the reasons behind doing so.

1.2 Significance of Study

Research about representations, including the use of force diagrams, has been widely done by physics education researchers. Most of them have used quantitative studies by involving large numbers of students to generalise their findings, such as the effective approach to teach force concepts by using force diagrams and the effect of providing diagrams in problems. Meanwhile, few studies have focused on what students think about their diagrams. Therefore, my study focuses on students' diagrams and reasons for drawing diagrams when solving force problems by implementing a qualitative approach. Previous studies have suggested that drawing diagrams could improve students' performance in problem solving. However, some students might not need to draw complete diagrams in solving problems. Hence, the reasons why students draw diagrams needed to be explored.

Using a qualitative approach yielded an opportunity to analyse deeply students' solutions in solving problems by looking at students' diagrams and interpreting students' motivation in drawing diagrams from interviews. At the beginning, 230 students were given surveys about problem solving and the use of representations to obtain students' responses generally. Along with two surveys (problem solving and representation surveys), students were asked to solve two problems in order to find the forms of diagrams drawn by students and how these related to students' solutions. After the students' work was analysed, 28 of them were invited to participate in individual clinical interviews based on their solutions to two further problems. Then, some students who participated in individual interviews were invited to participate in paired interviews to analyse other students' work from the survey problems. Students' responses from both interviews (individual and paired interviews) were analysed to obtain students' reasons for drawing diagrams while solving problems. Analysing students' solutions during problem solving generated new understanding, including the different ways students had to draw diagrams. They also had different motivations for drawing diagrams.

1.3 Background of the Author

I taught a physics course in senior high school before I became a lecturer at the Department of Physics Education, Teacher Training and Education Faculty at Universitas Tanjungpura in Indonesia. Some of the participants in my study know me as a member of academic staff at department of physics education. So, during conducting the study, some of them may think that they are being assessed. However, I informed the students that I am not recently a physics teacher so their response and performance will not affect students' grades. Therefore, they were comfortable during data collection.

At university level, the content of physics is more advanced than high school level. Based on my teaching experiences for several years, I have found that most students are more focused on mathematical equations, and they argue that many equations should be memorised in learning physics. For example, students should retain several equations while solving translational, circular, and rotational motion, and when those motions relate to forces, more equations should be memorised. The previous studies (literature) suggest that representation can be one of the tools in helping students learn physics concepts and solve physics problems.

My interest is students' problem-solving performance. In 2015, I conducted a survey study involving first year physics education students in Indonesia to investigate how they selected the correct diagrams based on problems given. Students were asked to solve six multiple choice questions about force concepts, including when an object is at rest, moving with constant speed, and moving with constant acceleration in different contexts: horizontal surface and inclined plane. The results showed that about half of the students were able to solve one or two questions. This indicated that students might have difficulties in understanding the diagrams given, or students might have their own diagrams to represent forces exerted on an object. Thus, I am interested in exploring students' problem solving, particularly drawing force diagrams and the reasons for drawing and not drawing diagrams. In addition, students' views about problem solving and representations were also investigated.

1.4 Outline of the thesis

The aim of this study is to investigate students' use of representations in solving physics problems. Accordingly, students' views about problem solving and representations were explored. Qualitative study was implemented to collect data by involving undergraduate students at one of the universities in Indonesia. Both surveys, problem solving and representations, were administered to students to gather their responses. These surveys gave an overview of the role of mathematical concepts in physics problem solving, how students approach problems, and the role of representations during solving the problems. In order to obtain data on whether students would draw representations and what kind of diagrams they might draw, survey problems based on horizontal and inclined surfaces were given to students. The relationship of students' diagrams to the correctness of their final answers was also analysed. Students' views about drawing diagrams were analysed from individual and paired interviews, and generated several themes, such as students' motivations, conventions, physics and mathematics concepts.

This thesis has seven chapters in total. Chapter 1 outlines the introduction addressing the background for doing this study. Chapter 2 discusses the literature review, which has several sub-sections, including the theory of knowledge construction. Next, studies about physics problem solving and representations are explained in the latter sub-sections. The conceptual framework and research questions are described in the last sub-sections. Chapter 3 discusses the methodological study, including research approaches, instruments, the pilot study, data collection, and data analysis. Findings of quantitative study are presented in Chapter 4, whereas Chapter 5 displays qualitative data. Chapter 6 concentrates on the discussion of findings, which are linked to the previous studies and theories. Lastly, Chapter 7 is the conclusion chapter, which provides the key findings of research, the limitations of this study, and the implications for teaching and research.

CHAPTER 2
LITERATURE REVIEW

This chapter is a review of research related to the use of representations and problem solving, which includes theoretical perspectives. Constructivism (2.1) and cognitive theory (2.2) are used as foundation theories for how students construct knowledge and the process of students' thinking. Research concerning students' strategies in solving problems, the difference between experts and novices in solving problems, students' views about problem solving, and the types of problems are discussed in the problem-solving section (2.3). The force concepts and the types of representations are presented in sections 2.4 and 2.5. Then section 2.6 discusses studies on using force diagrams including the effect of teaching force diagrams, the effect of force diagrams in problems, and representational competencies. The conceptual framework of the study is constructing diagrams and the use of concepts, diagrams, and equations described in section 2.7. Lastly, the research questions are discussed in section 2.8.

2.1 The Theory of Constructivism

The constructivists contend that "knowledge is constructed in the mind of the learner" (Bodner, 1986). This statement is described in more detail as follows:

> …learners construct understanding. They do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world even in the absence of full or complete information. (p. 874).

The statement indicates that students actively build their knowledge from their experiences, whether from prior knowledge or existing knowledge. Knowledge construction occurs as students try to organise, structure, and restructure their experiences. As students learn concepts, they connect their previous experiences (prior knowledge) to the new experience to generate knowledge (Cook, 2006). Elby (2000) asserts that "learners do not walk into the classroom as blank slates ready to be filled with knowledge. Instead, as students construct a new understanding, their prior knowledge plays a crucial role" (p.482). An implication of this view in terms of teaching and learning is that teachers can facilitate students to activate their learning by connecting prior knowledge with existing knowledge (the knowledge that students have before building the new knowledge) while learning a new concept as a means of achieving meaningful learning.

The field of cognition in learning physics addresses how people learn and understand a phenomenon (Carey, 1986; Larkin, 1981; Redish, Edward F., 1994; Sabella and Redish, 2007). A physics teacher is expected to help students learn physics concepts, especially students who face difficulties. Furthermore, the benefit of understanding students' learning is that a teacher can guide students in organising their knowledge (Redish, 1994). Therefore, teachers need to focus not only on physics content but also on how students interact with the content. Interaction with the content means how students organise their knowledge in understanding the concept and even in solving the problem (Sabella and Redish, 2007). The ability to combine knowledge organisation and create representations can be one of the approaches to help students learn physics concepts and problem solving.

Drawing representations can be used to learn concepts (Ainsworth, Prain and Tytler, 2011; Heijnes, van Joolingen and Leenaars, 2018; Kamphorst *et al*, 2019; Selling, 2016; Tytler *et al*, 2019). For example, constructing force diagrams can be one of the alternative approaches for learning force concepts (Larkin, 1981; Rosengrant, Van Heuvelen and Etkina, 2009; Savinainen *et al*, 2015). The purpose of teaching students to draw force diagrams and use diagrams is to support them in understanding forces. For example, students can take advantage from drawing diagrams to determine the net force or the total force by applying the concept of Newton's laws. Besides learning concepts, force diagrams can also be used in problem solving.

Constructivism will be a theoretical framework used in this study to investigate students' performance while solving the problems related to representations such as free body diagrams. The process of constructing and using representations while solving physics problems is the focus of this study. Whether students understand the problems then draw representations or need representations as a tool to help them understand the problems will also be explored. Based on the theory of constructivism, to build new knowledge, they connect their prior knowledge to the new knowledge by using representations. In this study, students might use representations or create new representations to understand physics problems. Representations constructed by students, including force diagrams, will be analysed.

2.2 Cognitive Theory

The constructivism paradigm discusses how learners construct their knowledge, and then how knowledge is processed in the mind can be understood with cognitive theory. According to cognitive learning theory, that information is processed through cognitive structure then stored in long term memory, and it can be recalled once needed to build new knowledge. Cook (2006) states that:

> working memory has two components, a visuo-spatial sketchpad and a phonological loop, that initially process visual and verbal information independently. Two largely independent working memory processing systems mean information load that might be overwhelm one of these processing systems can be managed when divided across two of the systems. (p. 1076).

Similarly, Mayer and Moreno (2003) reveal that the human information-processing system consists of two channels: an auditory/verbal channel for processing auditory input and verbal representations and a visual/pictorial channel for processing visual input and pictorial representations. However, each channel has limited capacity. They make assumptions that "only a limited amount of cognitive processing can take place in the verbal channel at any time, and only a limited amount of cognitive processing can take place in the visual channel at any one time." (p. 44).

That theory suggests that combining pictures and words to learn concepts might be more effective than concepts depicted only in word form. In one example, when students are learning about fractions, the activities consisting of text and visual representations are better in building students' knowledge than activities presented as text only (Rau, 2017). As another example, integrating words and pictures while learning concepts can reduce cognitive load (Kalyuga *et al*, 2003). This indicates that adding representations in instruction can support students to build their knowledge. In terms of problem solving, students might obtain benefits from drawing representations such as sketches and diagrams to visualise the problems.

Studies recommend that to successfully solve a problem, students should have ample conceptual knowledge. They should be able to understand the problem, apply the relevant concepts, draw representations, and interpret the solutions (Sabella and Redish, 2007). Students should notice when and how to use that knowledge. For example, while solving the mechanics problems, students should be able to combine the force concept and the energy concept. Students need to organise their knowledge in order to help them successfully solve physics problems. In addition, based on cognitive theory, creating force diagrams can help students to produce knowledge. In the context of force, for instance, by viewing or creating force diagrams, students might be able to select what concepts will be applied and the equation needed to find the solution.

2.3 Problem Solving in Physics

Problem solving is one of the most important skills in a basic course, especially in mathematics and science courses (Frederiksen, 1984; Sweller, 1988). Students are commonly asked to solve physics problems while doing exercises and homework and taking exams. There is an alternative view that students will develop such skills in the process of solving problems and teachers can support this by highlighting what they are doing rather than needing to explicitly teach them. For example, diSessa *et al.* (1991) designed learning activities to help young students in solving graph problems. Students had chances to create and modify their own representations based on their observations until students and teachers compared with conventional representations.

Studies about physics problems suggest that in order to become fluent physics problem solvers, students should have a deep conceptual understanding of physics and applying some strategies or procedures (Larkin *et al*, 1980). In addition, students' attitudes, expectations, and beliefs are also the possible factors that affect their problem-solving performance (Mason and Singh, 2010; Redish, Edward F., Saul and Steinberg, 1998). Moreover, involving representations such as force diagrams can also affect students' performance.

2.3.1 Problem-Solving Approaches

Problem solving is defined as activities following procedures or steps to find the goal (Pólya, 1957). In terms of physics, problem solving is a task of looking for the solution from given information by applying strategies (Dhillon, 1998; Larkin and Reif, 1979). Based on this definition, a student should have strategies or an approach in order to reach the solution for a problem. Physics education researchers have developed some strategies to help students in problem solving. Heller *et al*. (1992) designed five steps: visualizing the problem, describing the problem in physics terms, planning a solution, executing the plan, and evaluating the answer. Huffman (1997) promoted procedures called explicit problem solving to solve problems: focusing on the problem, describing the physics, planning the solution, executing the plan, and evaluating the solution.

Docktor *et al.* (2015) introduced a conceptual problem solving approach comprising three parts: principle, justification, and plan. Writing the principle or concept that is appropriate to the problem is the first step, then subsequently to justify the problem by explaining why the concept or principle is relevant to the problem. The 'plan' part encompasses three steps: drawing the representations, writing the equation, and solving the problem.

Table 2. 1 Problem solving steps in physics

No	Heller et al	Huffman	Docktor et al
1	Visualise the problem	Focus on the problem	Principle: Write principle and concept appropriate to the problem
2	Describe the problem	Describe the physics	Justification: Explain why principles and concepts are appropriate
3	Plan the solution	Plan the solution	Plan: Draw representations Write equation Solve the equation
4	Execute the plan	Execute the plan	
5	Evaluate the solution	Evaluate the solution	

Overall, two approaches (Heller et al and Huffman) presented above are almost similar in the procedures: describing, planning, executing, and evaluating. Meanwhile, Docktor et al approach suggests presenting concepts and principles first, and then planning the solution. The similarities of those approaches are asking problem solvers to include concepts needed and drawing representations to find the solution. In my study, the ideas suggested by experts will be used to explore how students employ concepts, diagrams, and equations while solving a problem.

2.3.2 Types of Problems

In terms of complexity, problems can be placed into different categories: qualitative or quantitative and well-defined or ill-defined (Maloney, 2011). Qualitative problems focus on applying concepts and principles in solving problems. Students are examined on their ability to write down concepts and principles and explain why they are appropriate to the problems. Meanwhile, finding the solution mathematically is the concern of quantitative problems. One consequence of Maloney's categorisation is that these kinds of problems should be introduced or taught so that students are familiar with them and can solve different types of problems successfully.

Furthermore, a well-structured problem has three aspects such as the initial state (the given values), the final state (the quantity to be found), and the procedures to be used; whereas an ill-structured problem has more than one or two aspects and does not explicitly provide procedures for finding the solution (Frederiksen, 1984). The differences between these kinds of problems are summarised in table 2.2.

Table 2. 2 The differences between well-structured and ill-structured problems (Frederiksen, 1984)

Well-structured Problems	Ill-structured Problems
Generally found at the end of textbook chapters	The problems are typically emergent and not well-defined.
Require the application of a finite number of concepts, rules, and principles	The solutions are not predictable or convergent.
Consist of a well-defined initial state, a known goal state, constrained set of logical operators	The problem elements are unknown or not known with any degree of confidence.
Present all elements of the problem to the learner	There is uncertainty about which concepts, rules, and principles are necessary for the solution.
Require the application of a limited number of regular and well-structured rules and principles	Have multiple solutions and solution paths
Have knowable and comprehensive solutions	Have multiple criteria for evaluating solutions

Well-structured problems will be used in this study for several reasons. First, the problems which have values enable problem solvers to find the exact number in the final solution. This kind of problem will be used in my study because it is more familiar to students. Second, the solution of problems should be comprehensive, including the concepts, representations, and equations used by students. Drawing representations is one of the foci of this study. Third, considering the limitation of time in solving the problems, less time is needed to solve well-structured problems than ill-structured problems.

Jonassen (2003) stated that there are two main factors that affect students' success in solving problems. First, students learn well-structured problems at school, whereas students come by many problems called ill-structured in their daily experiences. Second, students often face difficulties in transferring problem-solving skills learned at school to novel problems in different contexts.

2.3.4 Expert and Novice Problem Solvers

The previous section has discussed several approaches to solving physics problems as well as the different types of problems. How researchers have defined 'expert' and novice' have been studied (Balta and Asikainen, 2019; Chi, Feltovich and Glaser, 1981; Dhillon, 1998; Kohl and Finkelstein, 2008; Kuo *et al*, 2013) and will be discussed in this section. In terms of organising knowledge (Sweller, 1988), experts organise their knowledge systematically and they are able to connect among concepts. In contrast, novices struggle to organise their knowledge and they perceive that physics is a collection of disconnected facts and equations. Moreover, a study carried out by Chi *et al* (1981) involved graduate students as experts and undergraduate students as novices to categorise 24 physics problems regarding mechanics based on the similarity of the solutions. Experts tended to group problems based on the similarity of concepts or principles (deep structures) whereas novices relied on the surface structures (Chi, Feltovich and Glaser, 1981). In terms of using representations, experts use representations more flexibly and efficiently than novices (Kohl and Finkelstein, 2008). The differences between experts and novices in solving physics problems are shown in more detail in table 2.3 adapted from Rosengrant *et al* (2009).

The categorisation of students as experts and novices explained above is based on the degree level of students. For example, undergraduate students are categorised as novices, whereas graduate students and lecturers are grouped as experts. In my study, the term of expert and novice is utilised to distinguish between students' level of study (semester). The first and the second-year students are categorised as less experienced (novices) in solving physics problems. Meanwhile, students who are in the third and fourth year of their study and have more experience in learning physics (and of course, in solving physics problems) are classified as experts.

Table 2. 3 The differences between expert and novice problem solving

Expert	Novice
Conceptual knowledge affects problem solving.	Problem solving largely independent of concepts.
Often performs qualitative analysis, especially when stuck.	Usually manipulates equations.
Uses forward-looking, concepts-based strategies.	Uses backward looking means-end techniques.
Has a variety of methods for getting unstuck.	Cannot usually get unstuck without outside help.
Is able to think about problem solving while problem solving.	Problem solving uses all available mental resources.
Is able to check answer using an alternative method.	Often has only one way of solving a problem.

2.3.5 Attitudes toward or Views about Problem Solving

Science education researchers and educators believe that students' attitudes towards science can affect students' performance in learning science subjects and solving problems. Therefore, a number of instruments have been designed and developed to measure students' perception about science such as the Behaviours Related Attitudes and Intensions toward Science (BRAINS) (Summers and Abd-El-Khalick, 2018), the My Attitudes Toward Science (MATS) (Hillman *et al*, 2016), and the Views about Science Survey (VASS) (Halloun and Hestenes, 1998). Researchers have also investigated students' views in others subjects such as mathematics, chemistry, physics, and geoscience (Angell *et al*, 2004; Mujtaba *et al*, 2018; Panaoura *et al*, 2009; Young and Shepardson, 2018). Studies also investigated the relation between students' views about a subject and students' achievement in that subject. General findings indicate that students who have more interest in learning a certain subject tend to achieve higher performance.

Surveys for assessing students' views about physics learning have been developed, including the Colorado Learning Attitude Science Survey (CLASS) (Adams *et al*, 2006) and the Maryland Physics Expectation Survey (MPEX) (Redish, Saul and Steinberg, 1998). Both surveys address some indicators, including personal interest, personal confidence, conceptual understanding, the role of math, and problem solving. Madsen *et al* (2015) conducted a meta-analysis study of the use of surveys in physics classes. They found that there is a small positive correlation between students' perception about physics and their conceptual understanding. The relation of specific aspects, such as problem solving and performance, needs to be investigated.

The physics problem solving survey was developed in various languages such as English (Mason and Singh, 2010), Turkish (Balta, Mason and Singh, 2016), Indonesian (Sirait *et al*, 2017), and Thai (Rakkapao, S. and Prasitpong, 2018). The survey addresses the role of concepts, equations, and representations in problem solving, the use of strategies, and problem-solving confidence. The main purpose of these quantitative studies was to explore the views of participants about physics problem solving based on different levels of experience in learning physics – from high school students to graduate students. These quantitative findings have not explored the reasons why students agree or disagree with each statement. Thus, conducting a qualitative study involving interviews might yield more detailed data about students' views of problem solving.

2.4 Force Concepts

One of the very important concepts in an introductory physics course is force, because it is discussed in mechanics and even in electrostatics topics (Nie *et al*, 2019). Previous studies highlighted researchers' concerns in investigating students' understanding of force (McDermott and Redish, 1999). Force concepts are used to investigate the motion of objects. Newton's laws are the fundamental laws employed to comprehend force concepts experimentally and mathematically.

Force is defined as a push or pull on an object, resulting in a change in the object's motion. Classical mechanics defines Newton's First Law with reference to an inertial system or inertial reference frame. The first law is defined "in an inertial system, every free particle has constant velocity. A particle is said to be free if the total force on it vanishes". Mathematically, the first law is

$$\sum \vec{F} = 0$$

Newton's Second Law states that the acceleration that the object experiences is directly proportional to the net force acting on the object, and inversely proportional to its mass. The Second Law can be written in mathematical form as:

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

Here, a is the acceleration, F is the force, and m is the mass. This expression can also be separated into x and y components so that the motion along each of these directions can be analysed separately

$$\vec{a}_x = \frac{\sum \vec{F_x}}{m}$$

$$\vec{a}_y = \frac{\sum \vec{F_y}}{m}$$

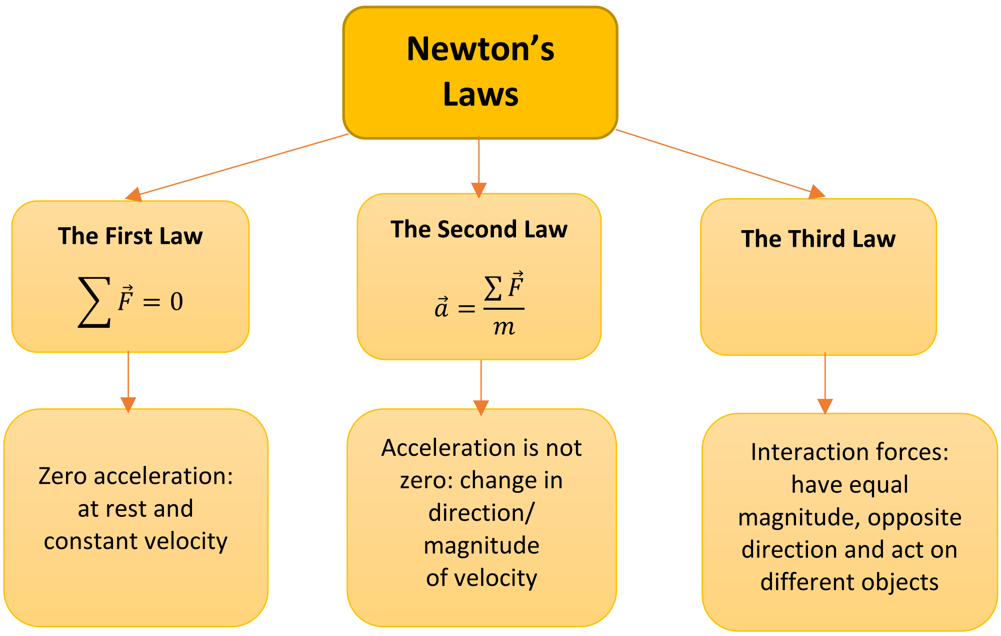


Figure 2. 1 The concept of Newton's Laws

Newton's third law is defined as "to the force $\overrightarrow{F_{12}}$ exerted by any other object on a particle there corresponds an equal and opposite force $\overrightarrow{F_{21}}$ exerted by the particle on that object". For two interacting particles, the third law can be written

$$\overrightarrow{F_{12}} = - \overrightarrow{F_{21}}$$

Newton's laws are used to analyse the interaction between objects mechanically and electrically. In mechanics, the motion of an object is influenced by mechanical forces such as the normal force, weight force, and friction force. Meanwhile, electrical force is the interaction between two electric charges.

Different types of force are discussed in this study. Gravitational force is always going down to the Earth. Meanwhile, a force which is always perpendicular to the surface is called the normal force. Friction forces are exerted on an object in the opposite direction to that of the net force exerted on the object. Static friction force is exerted when the object is at rest or almost moving. Whereas, when the object is moving, kinetic friction force is exerted on the object.

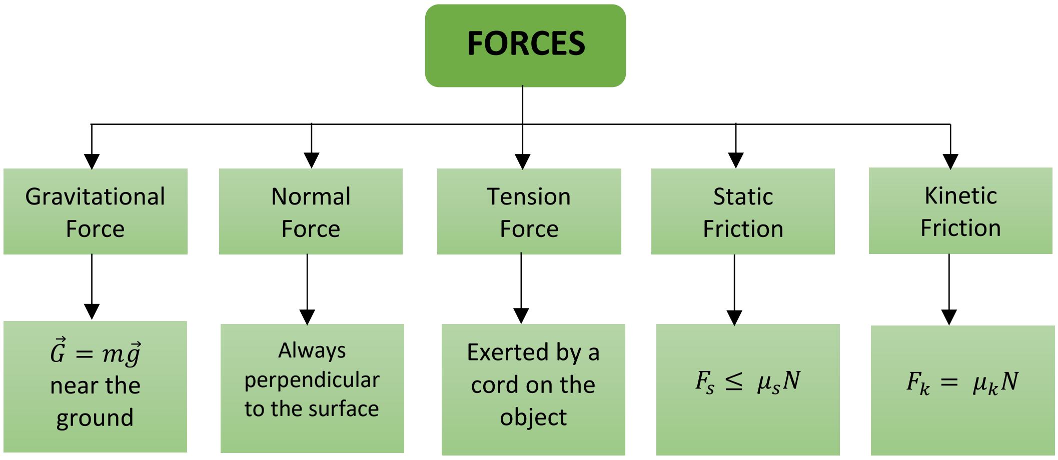


Figure 2. 2 Types of force

2.5 Representations

2.5.1 Types of Representation

Science concepts, including physics, chemistry, and biology that consist of phenomena and abstract and even complex concepts need to be depicted in more concrete forms. For example, the interaction among organisms in a certain environment might be presented in sketch or schematic form to simplify the interaction; the velocity of a car can be visualised in a graph to easily see the change of the velocity; the interaction between molecules in a substance can be depicted as molecular structure diagrams to help in visualising the abstract interaction. Besides science concepts, mathematics concepts such as fractions can be represented in different formats such as verbal, part-whole diagram, ratio, calculation, decimal, percentage, etc. These are called representations. Thus, the definition of a representation is something that symbolises or stands for objects and/or processes (Van Heuvelen, 1991b).

The classifications of representations in mathematics and science and even in terms of cognitive psychology are varied. In chemistry, for example, there are three categories of representations: macroscopic, sub-microscopic, and symbolic (Kozma and Russell, 1997; Treagust, David, Chittleborough and Mamiala, 2003). Macroscopic representations refer to observing chemical phenomena and conducting experiments in a laboratory. Sub-microscopic level includes molecules, atoms, electrons, etc. that are commonly used to explain the phenomena in the microscopic level. In order to visualise and explain the macro and micro phenomena, symbolic representations such as pictures, graphs, reaction mechanisms, and chemical equations are used. Furthermore, multiple representations in biological science are classified into three dimensions (Treagust, David F. and Tsui, 2013). The first dimension is known as modes of representations, to include real objects, photographs, natural drawings, graphs, tables, equations, etc. The second dimension is level of representations – symbolic, macro, and sub-micro – which is similar to chemical representations. The domain knowledge of biology that consists of evolution, homeostasis, energy, continuity, development, and ecology, is the third dimension of biological representations. All of these dimensions are connected to each other in order to fully visualise the concepts of biology. In the physics domain, a concept or problem can be visualised from the real object to abstract representation (Van Heuvelen and Zou, 2001). For example, an object at rest on a table can be presented in verbal form, sketch, force diagrams, force components, and mathematical equations.

How information is processed in the mind has been discussed in the cognitive theory section. The process of producing and interpreting those representations (math and science representations) can be understood with cognitive theory. Based on a cognitive psychology perspective, representations are classified into two main types of representations: internal and external representations (Eysenck and Keane, 2010) (displayed in figure 2.3).

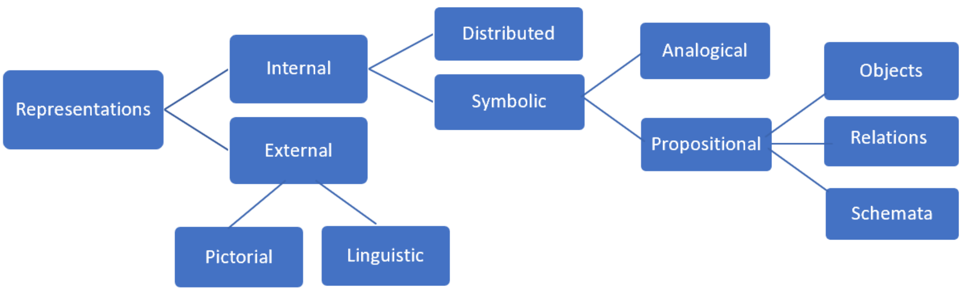


Figure 2. 3 Different Types of Representations

External representations can be verbal forms (words in written or spoken language) and visual forms (pictures and diagrams, etc). The visual or graphical representations such as pictorial forms and diagrams are almost similar to the real object because both have the same structure. Meanwhile, internal representations or mental representations are all external representations that are organised and cognitively processed in the mind. Rau (2017) stated that 'internal representations are building blocks of mental models, which constitute students' content knowledge of a particular topic or domain'. Moreover, Zhang (1997) also defines internal representations as the knowledge and structure in memory, as propositions, productions, schemas, neural networks, or other forms.

The forms of math and physics representations are almost similar due to the characteristics of both subjects being the same, such as using calculation processes to determine the solution. The visual representations used in physics are tables, graphs, charts, diagrams, etc. (De Cock, 2012; Van Heuvelen and Zou, 2001). Equations are the most often used in math, as well as in physics, and this kind of representation is often used to calculate the solutions.

2.5.2 Physics Representations

2.5.2.1 Vector Representations

Vector representations are usually used by physicists to represent physics concepts including gravitational force, friction force, electrostatic force, electrostatic field, etc. Therefore, experts and physics educators recognise that vector representations should be taught to students in order to help them grasp those concepts. One physics representation is a vector represented with an arrow which shows the direction and the magnitude (Arons, 1997). Physics concepts such as forces are usually displayed with vectors. For example, in figure 2.4 John pushes a box on the floor with 300 N to the right. The force exerted by John on the box is represented with an arrow. The notation of the vector is commonly represented with $\vec{F}$ and **F** (the letter in bold) and the magnitude of the vector $\vec{F}$ is generally represented with explicit notation $|\vec{F}|$ (Knight, 2004).

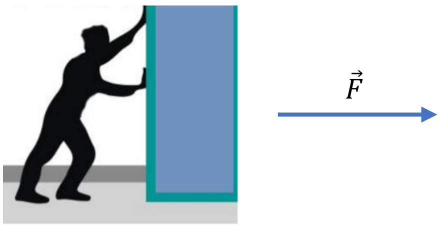


Figure 2. 4 An illustration and a force vector

A vector is employed in understanding an object's motion in kinematics, such as constructing motion diagrams and force diagrams (Etkina, Gentile and Van Heuvelen, 2014). In electricity and magnetism concepts, a vector field is also utilised to illustrate electric force and electric field (Campos *et al*, 2019; Cao and Brizuela, 2016; Klein *et al*, 2018; Pocoví, 2007). In other words, the vector has very important role in learning physics concepts as shown in the previous examples; vectors are employed to depict the motion of an object as motion diagrams and to depict forces as force diagrams.

Students' abilities to add and subtract vectors are essential for students to solve physics problems relating to vectors. Moreover, the ability to find out a vector's components is also prominent in determining the net force, or the resultant of forces. Barniol and Zavala (2014) conducted research about vectors (vector tests), by comparing the understanding of university students who solved problems with mathematical contexts, with those who solved problems with physical contexts. In the context of force, they found that there is no significant difference in finding the correct answers for both contexts. This suggests that the presence of contexts might not produce a positive impact on solving vector problems. Furthermore, a study focusing on the notion of vectors, by employing a vector test designed by Barniol and Zavala, has been done by other researchers (Rakkapao, Suttida, Prasitpong and Arayathanitkul, 2016). The results showed that most students were not able to differentiate between adding and subtracting two vectors. Once two vectors are presented in an opposite direction, students tend to add them directly, even if being asked to subtract them. This indicates that students' difficulties in understanding vectors may affect their ability to learn physics concepts such as forces.

2.5.2.2 Diagram Representations

Diagrams as visual representations, including force diagrams, are generally used in physics to represent the concepts and solve problems. Table 2.4 shows different types of diagram representations based on physics topics (Wong *et al*, 2011). Motion and force diagrams are commonly used by physics teachers to teach force and motion concepts in physics courses. A motion diagram represents a moving object with a series of dots. The position of the dots represents the location of the object at equal time intervals. The direction of the object's motion and the magnitude of its velocity are represented by the direction and the length of the arrows. The change in velocity (acceleration) is represented with a Δv arrow (Van Heuvelen, 1991a).

Table 2. 4 Types of diagrams

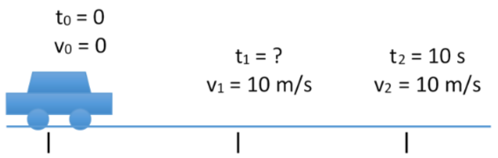
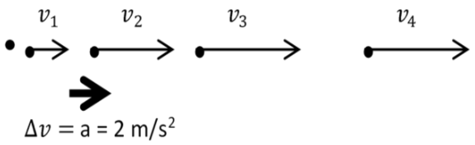
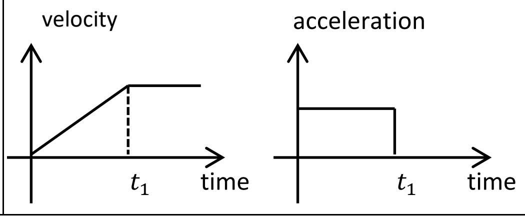
Physics Topics	Visual Representations
Kinematics	Motion diagrams
Forces and dynamics	Force diagrams
Energy	Energy bar charts
Fields	Field line/vector diagrams
Electricity	Electrical circuit diagrams
Geometrical optics	Ray diagrams
Wave	Wave front diagrams
Quantum Physics	Energy level diagrams

Force diagrams are graphical representations in which an object of interest is represented with a dot and the forces exerted on it by other objects are shown with arrows of different lengths and directions. These diagrams help students and experts visualize what objects interact with the object of interest, and in what direction those forces are exerted on the object of interest. A force diagram can also be used in connection with other representations. Physicists, for example, have the option to use pictures, motion diagrams and mathematical representation with force diagrams to understand different concepts. To solve a mechanics and electrostatics problem, physicists may first draw a picture of the scenario, then use this picture to help construct a force diagram. To evaluate their force diagram, they might then construct another representation such as a motion diagram.

Rosengrant, Van Heuvlen and Etkina (2009) suggest six steps on how to draw force diagrams:

> (1) sketch the situation described in the problem, (2) circle an object (objects) of interest in the system, (3) model the system as a particle, (4) look for objects outside the system (external objects) that interact with the system, (5) draw force arrows that represent the external interactions that effect the behaviour of the system object, and (6) label the forces in the diagram with two subscripts identifying two interaction objects. (p. 3-4).

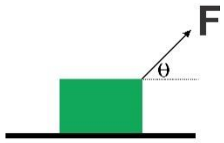
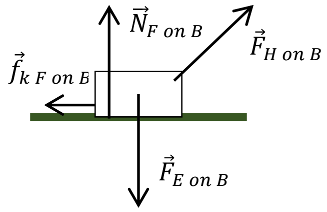
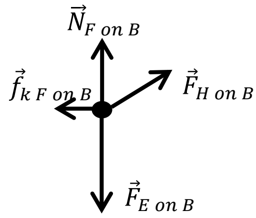
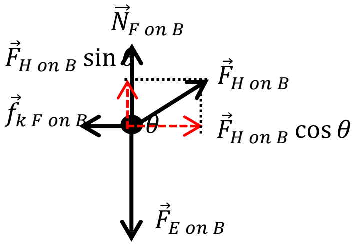
An example of a physics problem (in a kinematics topic) is presented verbally (shown in figure 2.5). Then, sketches or pictorial representations, diagrams, and graphs are employed to visualise the problem and the concepts. Mathematical equations, as the most frequently used in physics problem solving, are used to find out the solution.

<table>
<tr><td>Verbal
A car at a stop sign initially at rest starts to move forward with an acceleration of 2 m/s^2. After the car reaches a speed of 10 m/s, it continues to move with constant velocity. Determine the total distance reached by the car for 10s.</td><td>Sketch

</td></tr>
<tr><td>Motion Diagrams

</td><td>Graphs

</td></tr>
<tr><td colspan="2">Mathematical Equation
$x = vt$; $v_t = v_0 + at$; $x = v_0t + \frac{1}{2}at^2$; because v_0 =0,
so 10 m/s =0 + 2 m/s^2 (t)= 5 s, therefore $t = \frac{10\ m/s}{2\ m/s^2} = 5\ s$
Then $x = v_0t + \frac{1}{2}at^2$; $x = 0 + \frac{1}{2}(\frac{2m}{s^2})(5s^2)$
$x = 25m$
Due to the car moves with constant velocity from t_1 to t_2, so $x = vt$
$x = \left(\frac{10m}{s}\right)(5s) = 50\ m$
The total distance reached by the car is 25 m + 50 m = 75 m</td></tr>
</table>

Notes: t = time; v = velocity; a = acceleration; and s = distance

Figure 2. 5 Examples of Physics Representations

An example of physics representations, such as force problems, is displayed in figure 2.6. The force problem is usually presented in verbal representations, and then depicted in sketch or picture forms; these forms can be assumed to be real objects. Forces exerted on the block are drawn in force diagrams or free body diagrams; this is a quite abstract representation, then a force component as the more abstract is commonly used to determine the net force. Lastly, mathematical representations involving Newton's laws are another level of the abstraction of representations.

Verbal A box on the floor is pulled by hand (F) then the box is moving with constant acceleration	*Picture/sketch* 
Force Diagram 	*Free Body Diagram* 
Force Component 	*Mathematical Equation* $\sum \vec{F_y} = m\vec{a}; a = 0$ $\vec{N}_{F\ on\ B} + \vec{F}_{H\ on\ B}\sin\theta - \vec{F}_{E\ on\ B} = 0$ $\sum \vec{F_x} = m\vec{a}$ $\vec{F}_{H\ on\ B}\cos\theta - \vec{f}_{k\ F\ on\ B} = m\vec{a}$

Notes: $N_{F\ on\ B}$ = the force of floor on block (normal force); $F_{H\ on\ B}$ = the force of hand on block; $F_{E\ on\ B}$ = the force of earth on block; and $f_{k\ F\ on\ B}$ = the friction force on block

Figure 2. 6 Different forms of representations to visualise a force problem

2.5.2.3 Mathematical Equations

A mathematical equation is a quantitative representation that is usually used in the planned solution in problem solving strategies (Redish, Edward and Kuo, 2015). After representing or visualizing the problem using representations such as sketches, diagrams, graphs, and bar charts, students can obtain a quantitative answer to the problem using mathematical representations (Van Heuvelen and Zou, 2001). For instance, after students represent the situation using force diagrams, they may find it easier to select the equation to determine the sum of the forces exerted on the object. Moreover, students who have been successful in drawing bar charts of work-energy concepts tend to formulate them more easily in mathematical form (Van Heuvelen and Zou, 2001).

However, students usually are confused to see many equations while learning a concept; consequently, they are not interested in learning. In one possible way of formulating mathematical equations, a teacher can ask student to model the equation from other representations, such as graphs and force diagrams. A teacher also can assign students to describe an equation in a different format to avoid students' boredom in mathematical equations.

2.6 Research on Using Force Diagrams

Studies about representations in learning physics and problem solving have been widely explored by researchers in order to help students' learning. The topic of representation in physics education research is still an interesting topic for investigation because representation can be applied to various topics and concepts such as mechanics, electrostatics, magnetism, and quantum physics. For example, one of the studies has promoted force diagrams – or, some say, free body diagrams (FBD), a representation that depicts some objects of interest and the forces exerted on them by other objects – to help students understand force concepts, as well as to solve force problems (Rosengrant, Van Heuvelen and Etkina, 2009).

Research about force diagrams has been widely conducted by experts and physics teachers to facilitate teachers in teaching physics concepts and to help students learn the concepts and solve the problems. In order to generate an overview of the research that has been done about the use of force diagrams, I conducted thematic review. The ERIC database was used to find the relevant articles, published in international journals by using the queries: "force diagrams" OR "free body diagrams". This search resulted in 204 papers. Then a filter "physics" was used to obtain 60 papers and "papers published since 2004" was used to yield 30 papers. The reason for using publications since 2004 is to obtain papers that can be categorised as the latest research. The abstracts of all papers were read to obtain an overview of the studies. Two journals in which some papers were published were excluded because both journals present only short reviews of studies. Finally, 16 articles were analysed to find the trends in research on force diagrams. Each paper was analysed comprehensively by focusing on research question, methodology, and findings. The parts of methodology included participants, design, instruments, topics, data collection, and analysis. The results of the analysis were coded into three main themes as displayed in table 2.5. The descriptions of all papers are presented in Appendix 1.

Table 2. 5 The research focus on force diagrams

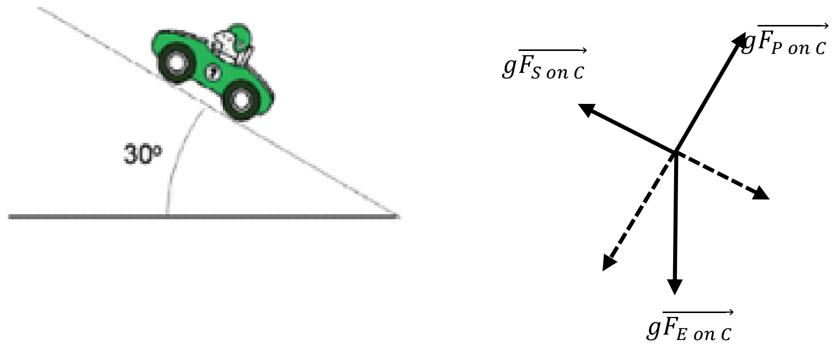
No	Themes	Description
1	The effect of teaching force diagrams	Teaching students with a focus on drawing diagrams with various approaches
2	The effect of force diagrams in problems	Investigating the impact of providing or not providing diagrams in problems and prompting students to draw diagrams
3	Representational competencies (consistency or fluency) and format of force diagrams	Investigating students' abilities to translate between representations, including force diagrams

Teaching students how to draw diagrams is the most common (eight studies). Then, analysing the impact on students' performance by drawing force diagrams is also interesting for researchers. Furthermore, the effect of presenting diagrams in problems and the effect of prompting students to draw diagrams on students' performance are examined. In addition, the different effects of different formats of force diagrams on students' performance in solving problems was explored. The competence of students, including the ability to translate between representations, is also one of the interesting topics. Each theme will be discussed comprehensively in the following sections.

2.6.1 The Effect of Teaching Force Diagrams

Rosengrant *et al.* (2009) conducted both quantitative and qualitative studies in the United States to investigate whether university students who were taught free body diagrams (FBD) during their course would utilise the diagrams during tests (mid-terms and final exams). They also examined the performance of students that use free body diagrams compared to those who do not and the quality of students' representations. Their study involved both one group of students who were encouraged to use representations during lectures and recitation classes and another group of students whose instructors did not reinforce the use of representations during their physics course. Rosengrant et al. found that students in the first group who learned free body diagrams tended to draw a diagram while solving multiple choice tests and obtained higher scores than students who did not. Also, they found that a high-achieving student utilised FBD to understand the problem and evaluate the answer while a low-achieving student did not use the diagrams. Their study suggests that teaching students to use free body diagrams can help them to become effective problem solvers. However, why some students do not use representations during problem solving needs to be explored further.

Before drawing free body diagrams, students are usually introduced to drawing interaction diagrams (ID) as a means of helping them to correctly identify and construct free body diagrams (Savinainen *et al*, 2013). Interaction diagrams represent the interaction between an object of interest and other objects, which is presented verbally while FBD is depicted in a vector. For example, *a car is at rest on an inclined plane*. Students might visualise this verbal question into sketch (figure 2.7a) representation then identify forces exerted on the car by drawing interaction diagrams (figure 2.8), and then finally drawing free body diagrams (figure 2.7b).



(a) (b)

Figure 2. 7 Different types of representations: (a) sketch or picture and (b) free body diagram (FBD)

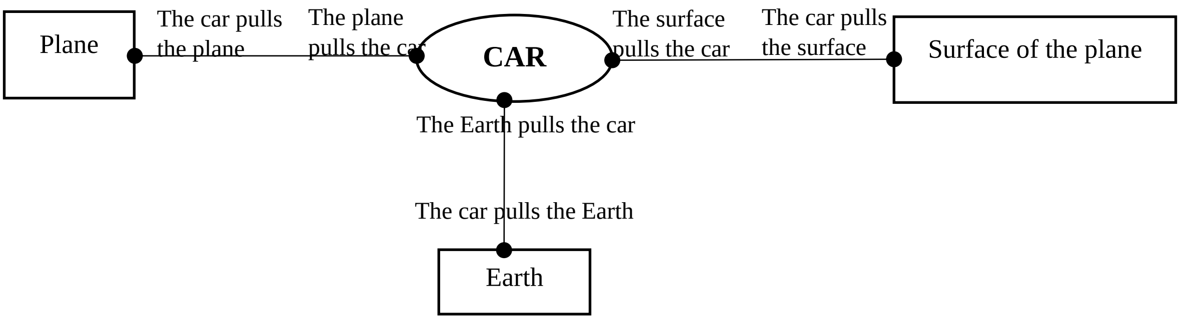


Figure 2. 8 Interaction Diagram (ID)

The researchers (Savinainen *et al*, 2013) undertook a study of the effect of using ID involving high school students in Finland. They divided students into those who were taught interaction diagrams and those who were not. To gather data, ID group students solved eight test questions which covered Newton's Law concepts by constructing ID and FBD. Meanwhile, students who were not taught ID solved two questions by constructing FBD. Their findings show that there is a positive correlation between constructing ID and identifying forces. Students who correctly constructed interaction diagrams, however, did not always correctly identify forces and did not always correctly draw FBD. This indicates that using an interaction diagram is not sufficient to support students in drawing a free body diagram. One of the possible factors that influences students' performance in drawing ID and FBD is the mathematical aspect. I suggest that mathematical skills such as vectors and trigonometry may be needed by students to construct and interpret diagrams. Whether interaction diagrams and free body diagrams are sufficiently easy and clear for students when used in problem solving has not been probed yet. Savinainen et al conducted a study quantitatively, so a qualitative approach is needed to investigate students' thoughts in understanding of diagrams while solving the problems.

A difference between the approaches of Rosengrant et al and Savinainen et al is focusing on drawing force diagrams on the dot (the representation of an object of interest or the system) used by Rosengrant *et al*, rather than drawing on the object done by Savinainen at al. Moreover, Savinainen et al suggested drawing interaction diagrams before drawing force diagrams. Figure 2.9 shows an example of both diagrams (force diagrams on the object and on the dot); the context is *a box is placed on the table*. Drawing force diagrams on the object might be more concrete for some students, rather than drawing force diagrams on the dot because the presence of an object can help students to identify forces exerted and the direction of the forces. Meanwhile, drawing force diagrams on the dot looks more abstract because students should know all forces exerted on the object and the direction of all forces.

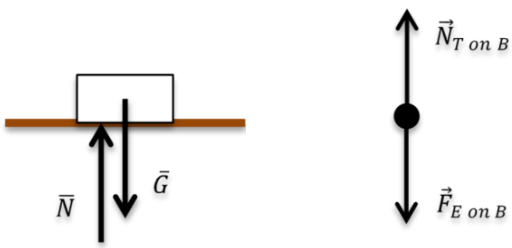


Figure 2. 9 Examples of force diagrams

A strategy in helping students to understand force concepts was designed by Mualem and Eylon (2010) by including visual representations such as force diagrams. The study concentrated on a 'system': focusing on an object of interest and identifying other objects interacting with an object of interest, which is almost similar to a study conducted by Rosengrant *et al*. (2009). The difference is drawing arrows as representing forces in real objects and in a dot. An example of the strategy implemented in students' learning is shown in Figure 2.10. In this activity, students also were asked to determine the sign of the forces, which is helpful in determining the resultant of the forces.

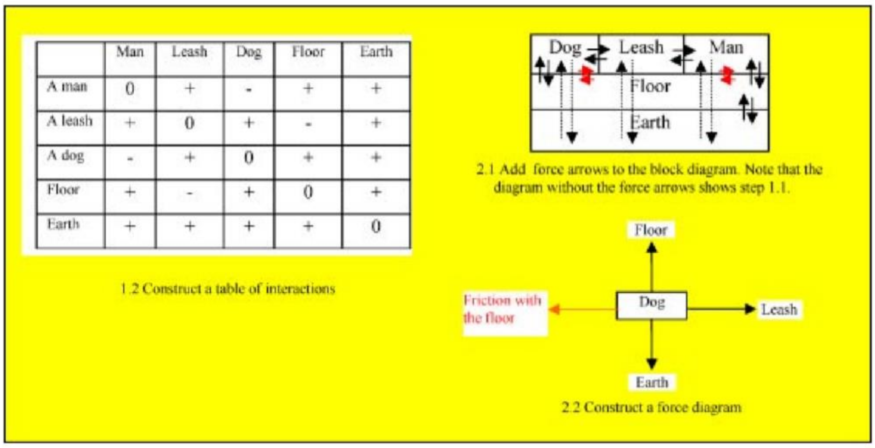
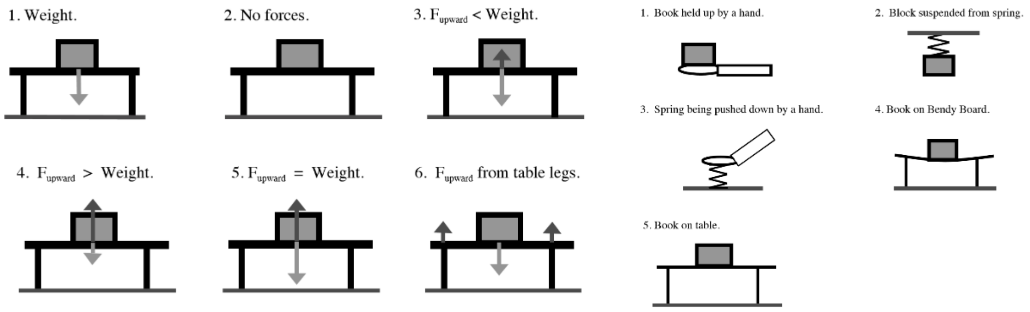


Figure 2. 10 An example of a force diagram

For the purpose of data collection in examining the effectiveness of the strategy, five classes (n = 106) of 9th grade of students in a high school in Israel were involved as an experimental group receiving this approach while learning the force concepts. Other students with the same grade and different grades were categorised as control groups. They found that students who learned with the approach had significantly higher scores than students who did not in solving conceptual force problems. The interviews were also conducted to obtain students' understanding of forces in more detail, such as the terminology used by students to explain force concepts. However, students' response to the strategy was not explored and students' force diagrams while solving the conceptual force problems were not presented.

Analogy was used to assist students to understand force concepts, particularly Newton's Third Law, which is commonly known as 'action-reaction' force (Bryce and MacMillan, 2005). To collect data, 21 students (15-year-olds) in a secondary high school in the UK were asked to choose correct force diagrams of a phenomenon (a book is at rest on the table). Moreover, the semi-structured interviews, by giving several analogies regarding conceptual force, were conducted to elicit the conceptual change of the students. The force diagrams and analogies used in their study are shown in Figure 2.11.

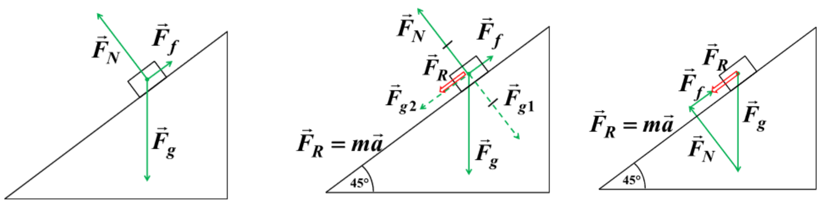


(a) (b)

Figure 2. 11 An example of force diagrams and analogies

The researcher found that many students were not able to choose the correct force diagrams. The first analogy 'book held up by a hand' was the most chosen by students to help them in explaining the context 'a book is at rest on the table'. However, the use of analogy did not guarantee helping students in choosing the correct answer for force diagrams and explaining the concept of Newton's Third Law. Some students changed their ideas to choose the force diagrams. Instead of giving students force diagrams of a phenomenon, my study will explore the form of students' diagrams while solving force problems and how they respond to their diagrams.

A study conducted by Aviani *et al.* (2015) used a quasi-experimental design by implementing two different approaches to drawing free body diagrams: superposition and decomposition. The decomposition method is a common approach which refers to the determination of a vector's components, followed by finding the resultant of the vector. By contrast, the superposition method refers to adding vectors, while placing the tail of a vector to the previous vector. The example of the two methods is presented in Figure 2.12. The context is *a box is sliding down on an inclined plane*.



(a) (b) (c)

Figure 2. 12 Different methods determining resultant force: (a) force diagrams, (b) decomposition method, and (c) superposition method

The researchers (Aviani et al) analysed the effect of these methods – looking at students' understanding of forces, as well as their ability to identify forces. In order to collect data, first year physics students from two different universities in Croatia were taught with the two approaches before solving 12 multiple choice questions. They found that there was a statistically significant difference between the performance of the superposition group and the decomposition group in identifying the real forces in the test. Their findings suggest that using the superposition approach is less likely to lead to forming misconceptions. However, this study did not assess students' ability to solve open questions to see the process of solving the problem. The process of drawing force diagrams might give teachers and researchers an understanding of what learners think about their diagrams.

Besides students as a focus of the studies on force diagrams, the existing literature also shows how teachers teach force concepts with encouraging students to draw and use diagrams. The pedagogical aspects of teaching force concepts with introducing force diagrams have been explored by Hubber, Tytler and Haslam (2010) by involving three secondary teachers in Australia. Their study explored the process of teachers while teaching force concepts in the classroom by analysing data from video-audio recorders and observation. They found that before teachers introduced the scientific meaning of force and force diagrams to students, they tried to help students to construct their understanding of force by connecting students with their own daily experiences. Then, teachers provided some simple experiments to bridge students' prior knowledge and scientific convention. During the experiment, students were assisted to construct their own force diagrams. At the end of the session, students were introduced to the scientific convention of force diagrams, which consist of arrows representing the magnitude and the direction of forces. This study suggests the benefits of bridging students' diagrams and scientific diagrams. However, the motivation of students to draw force diagrams, especially during problem solving, will be important for teachers.

A study about pedagogical knowledge of a teacher was also conducted by Tay and Yeo (2018). The study applied an exploratory case study approach to collect data. They recorded a single lesson of 1.5 hours of a physics teacher in a senior high school (grade 11) in Singapore. They analysed data by coding the teacher's activity, including the interaction with students while discussing the force concepts, particularly the Newton's Third Law of motion. They found eight pedagogical actions done by the teacher, including clarification, evaluation, explanation, modification, exploration, etc. Clarification is the most frequently acted upon by the teacher while discussing the concepts based on students' diagrams. The teacher often clarified the meaning of diagrams. This study suggested that one of the benefits of pedagogical aspects done by teachers is knowing students' difficulties in understanding force concepts. This study needs to be explored by involving more teachers, longer lessons, and other concepts to gain further evidence. The difficulties faced by students in drawing force diagrams is also important to be investigated in helping teachers design a lesson plan.

The existing literature about teaching students to draw diagrams as explained above is not always successful in helping students to learn concepts and solve problems. It seems that the abstractness of the concepts and force diagrams might be one of the factors that did not support students' understanding. The other aspects of drawing force diagrams are important to be explored.

2.6.2 The Effect of Force Diagrams in Problems

The use of representations, particularly free body diagrams (FBD) does not always improve students' ability to solve problems. Heckler (2010) investigated the impact of prompting students to construct force diagrams while solving problems. The participants in this quantitative study were university students (n=891) who were taking a calculus-based introductory physics course with two different classes: traditional, or regular class, and honours class. Students in the traditional class were taught by using force diagrams in the problem-solving exercise (common problem-solving strategy) while the instruction in the honours class focused on an explicit problem-solving approach which did not follow common problem solving procedures, but in which students also practised constructing force diagrams. Students were administered a test to solve four open questions concerning Newton's laws. Within each class students received two different instructions for the problems: some were asked to draw a diagram, and some had no prompting for a diagram in the problems. The researchers found that students who were prompted to draw diagrams were less successful in finding the correct answer than those students who were not. Students who did not receive the prompt to draw a diagram utilised intuitive solutions instead of formal strategies. I argue that intuitive strategies are not always applicable to all problems because they sometimes can lead students to form incorrect solutions. For example, this problem was used in a study conducted by Sherin (2006): *two blocks, a heavier one and a lighter one, are given a shove and then they slide on the table, eventually coming to rest. The blocks are shoved* *in such a way that they start off with the same initial speed*. Students were asked which block travels farther. One example of intuitive knowledge stated by students is the heavier block should travel a greater distance because heavier things are "harder to stop". This intuitive knowledge guided students to focus on the magnitude of force to slow down the block and avoid the effect of friction force.

In addition, students may have different styles in solving the problems; it depends on the types of problems. For example, to solve a basic problem, a student just needs to identify known variables in the problem, write concepts and equations, and find the solution without providing representations such as sketches or diagrams. Furthermore, those questions used in Heckler's study only explored Newton's Laws in a horizontal context. Therefore, further investigation should be done in an inclined plane context and other concepts, such as electrostatics, in order to determine the effect of prompting students to draw diagrams because students might have different strategies in solving different contexts of problems.

A similar study to examine the effect of prompting students to construct diagrams in problem solving has also been done by Kuo, Hallinen and Conlin (2017). They started from the research findings of Heckler. This study focused on strategies used and the types of force diagrams drawn by students while solving problems. They examined 136 university students who solved two open questions which covered Newton's Law concepts. Students' answers were assessed by three criteria: the type of diagram, problem solving approach, and the correctness of the answers. The results showed that students who were prompted to draw a free body diagram tended to draw standard diagrams – drawing diagrams for each object - and to apply a procedural approach: step by step followed by students to solve the problems. However, even the students who were not asked to draw force diagrams tended to draw standard diagrams. Then, about half of the students drew incorrect or ambiguous diagrams. The term *standard diagram* means drawing all objects that are mentioned in a problem and drawing all forces exerted on the objects. Furthermore, students who applied "short cut" approaches – without following standard procedures - were more correct than those who followed a procedural approach for one question. The examples of the diagrams are shown in figure 2.13.

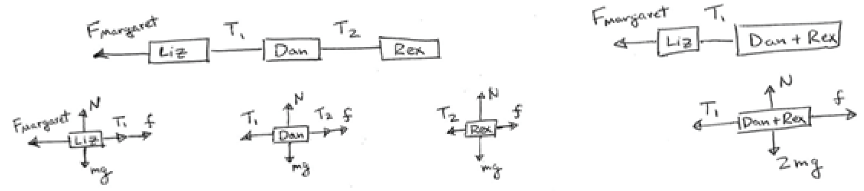


Figure 2. 13 Types of diagrams: separate boxes and combined boxes

The suggestion from Kuo et al is that short cut approaches may be helpful for specific problems but cannot be applied for complex problems because such approaches omit some steps that would be helpful to find the other variables in the problem. Moreover, this large-scale quantitative study did not explore students' reasons and motivation for drawing and not drawing force diagrams; these were not explored yet in their study.

A group of physics education researchers (Chen *et al,* 2017) also probed the impact of presenting diagrams on the questions of students' performance while solving physics problems: kinematics, Newton's Laws, circular motion, conservation of momentum, and conservation of energy. The researchers had hypothesised that prompting a diagram in a problem has small positive effects on students' performance. To test this hypothesis, university students were asked to solve 12 different questions (six items with diagrams and others without diagrams) through an online course. They found that low and medium attaining students who received questions with a diagram obtained about 5% higher score than students who did not use diagrams. Meanwhile, there was no statistical difference in students' performance for high attaining students. This finding indicates that the presence of diagrams in the problem had positive impact on some students' correct answers. However, representations provided in the questions are not all diagrams, but some of them are sketches or figures which did not show the relevant forces. Moreover, the types of diagrams drawn by students were not explored and the motivation of high attaining students to draw and not to draw diagrams remains to be probed. In my study, I will aim to explore students' motivation in drawing force diagrams.

Studies about the effect of diagrams in problems have been mostly conducted in mechanics topics. Maries and Singh (2018) carried out studies to investigate the impact of providing diagrams with focusing on students' performance in solving electrostatic problems. In their first study, they divided introductory physics students (university students, n=111) into three groups: prompted to draw diagram, provided with a diagram, no support. Then, students were asked to solve two problems about electric force and electric field. Moreover, in the second study, 23 students from the first study were interviewed to collect data about the process of solving the problems and to investigate the effect of providing diagrams in the problems. They found that students who worked problems with diagrams had lower scores in both problems than other groups. This indicates the presence of diagrams did not give positive effect for students' performance. However, the researchers found that half of the "provided with a diagram" group of students spent less time in conceptually analysing the problems. In other words, providing diagrams can be helpful for understanding the problem. In addition, students generally commented positively about the presence of diagrams. However, the motivation or reason of students in drawing diagrams should be investigated further.

Based on the description above, using force diagrams can be either a help or hindrance to students in successfully solving problems. In other words, there are several variables such as the types of problems, and the types of representations, as well as variations in the kinds of instructions, which make it difficult to see a clear pattern. However, when the representations can be helpful and the motivation of learners to use or draw these representations have not been explored qualitatively.

2.6.3 Representational Competence

Representations are usually employed by experts and students to learn concepts, solve problems, and communicate scientific ideas. Therefore, the ability to use, create, interpret, and translate from one form of representation to another form is very important; this is called representational competence, or as some people say, representational consistency, representational fluency or flexibility (Gebre and Polman, 2016; Kohl and Finkelstein, 2005; Kozma and Russell, 1997; Rau, 2017). diSessa and Sherin (2000) introduced a term 'meta representational competence (MRC)'.

> MRC includes the ability to select, produce, and productively use representations but also the abilities to critique and modify representations and even to design completely new representation' (p. 386).

The capabilities of selecting, using, and even creating the appropriate representations can support students to successfully solve a problem. For example, consider an electrostatic problem*: a point charge +q at a distance d from a point P, then a point charge +q is added to the left at distance d from the original charge. Determine* *the magnitude of the electric field before and after the charge is added*. To solve this problem, students might use pictorial representations to illustrate the problem with added verbal descriptions. Students have opportunities to draw electric field lines or vector fields to determine the magnitude of electric fields or use mathematical formulas. The ability to choose one of those should be supported by understanding the concepts.

According to cognitive theory, representational competencies are categorised into conceptual and perceptual representational competencies (Rau, 2017). Knowledge and skills to use representations and to choose a certain representation for solving problems are conceptual representational competencies. Meanwhile, perceptual representational competencies include the ability to recognise the meaning of representations to process information and to translate among representations. Peirce defined representational competence as a triadic meaning-making which is the ability to construct and interpret the relationships between a referent, its representation, and its meaning (Carolan, Prain and Waldrip, 2008; Scheid *et al*, 2019). The referent can be an object, process, and an experience. Then, the referent can be presented in representations such as verbal, visual, mathematical, etc. Generating meaning through interpretation can be a concept, idea, explanation, etc. In physics, for example, a box on the table is a real object (referent), straight arrows are used to represent forces (force diagrams representation), and the meaning is that there are forces exerted on the box by the earth and the table.

Research about representational competence has been explored in science education. Kozma and Russel (1997) described representational competence in chemistry as the ability to use chemical representations such as macro, sub-micro, and symbolic representations to think, reason, and communicate scientifically and translate between these representations. The idea of representational competence was used by Chang (2018) to investigate the aspect of representational competence while students were constructing and transforming chemistry concepts using a computer. The researcher found four aspects including using dynamic representations, visualisation strategies, multiple representations, and adequate science concepts. The result of the study also showed that there is a correlation between content knowledge and using representations. Students who have more content knowledge tend to use multiple representations. The study indicates that conceptual understanding is one of the factors that influence students' ability to construct and use representations.

Furthermore, in physics education studies, representational competence refers to students' ability to translate between representations such as text, graph, diagram, equation, etc. (Kohl and Finkelstein, 2005; Meltzer, 2005; Nieminen, Savinainen and Viiri, 2010). Graph representations are usually employed to learn the motion of an object in kinematics topics. The velocity and the acceleration of an object can be visualised into different forms including verbal, graphical, and equation. Therefore, students need the ability to transform among these representations to support them in learning the concepts and help them solve motion problems.

In the context of forces, students' competence to switch different representations: verbal, graphical, and diagrams in force contexts have been studied by Nieminen *et al.* (2010; 2012). They began by designing the representational force concept inventory (RFCI) and analysed the relationship between students' competence and conceptual understanding. They found that there is a correlation between students' consistency in interpreting force representations and students' learning of forces. Furthermore, Meltzer (2005) also conducted a study of students' performance in solving similar problems with different formats. The study reveals that students were more successful in solving Newton's Law problems in verbal form than diagrammatic form. Students had difficulties in solving diagrammatic problems in mechanics and electric circuits compared to other problem representations. Moreover, Ibrahim and Rebello (2012) also investigated students' competence while solving kinematics and work problems in different formats. Their study indicated that students tended to use mathematical representations to solve problems and employed mathematical representations while providing qualitative explanations. In addition, the formats of problems affected students' choice of representations to solve the problems. The findings of those studies suggest students' competencies are influenced by the type of problems, the form of representations, conceptual understanding, and mathematical abilities.

The different formats of force diagram may also affect students' performance in solving force problems. Hung and Wu (2018) investigated high school students' performance by administering two different formats of problems: numerical problems and symbolic problems. They found the performance of students who solved numerical problems was higher than that of students who solved symbolic problems. The example of these two formats are shown in Figure 2.14. Students' comments about the diagrams included saying the symbolic format is more difficult, solving numeric problems took less time than symbolic format, and numeric problems are more familiar.

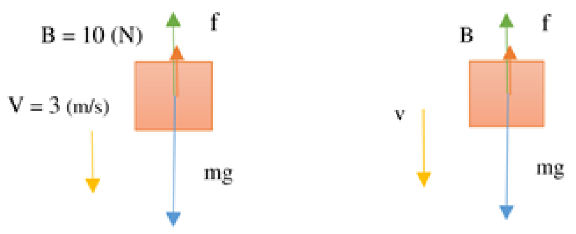


Figure 2. 14 Numerical and symbolic force diagrams

Besides students' competencies relating to force diagrams, studies about students' competencies of graph representations have been done by physics education researchers. Ivanjeck *et al*. (2016) conducted a study involving university students to investigate students' ability to interpret graphs in three domains: physics, mathematics, and other contexts. They found that students have difficulties in understanding the slope and the area under a graph. Moreover, in a similar study about understanding the graph done by Planinic *et al*. (2013) in physics and mathematics contexts, they concurred that students found graphs in physics contexts are more difficult than in mathematics contexts. This indicates that students have not been able to transform their understanding into different contexts. A recent study done by Van den Eynde *et al.* (2019) investigated students' consistency in translating physics concepts between graphs and equations. They found that it is easier for students to solve kinematics problems in a mathematics context than a physics context. Moreover, students were more successful when starting from a graph and then continuing with equations than moving from equations to graphs. The indication of these studies is that alongside conceptual understanding and mathematical concepts, the context or domain can affect students' ability to interpret representations.

2.6.4 Summary

In summary, the review of literature has discussed studies of representations including types of representations and force diagrams as one kind of physics representations in teaching and learning physics. They focused on different levels of students (from primary school to university students), methodology, and different physics topics. The literature review highlighted several key issues of studies on force diagrams. Firstly, some studies focused on teaching students to draw force diagrams with approaches as a means of facilitating students to learn concepts and solve problems. Those studies intended to examine the effect of drawing and using force diagrams on students' performance while 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 positively affect 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 revealed that students have difficulties transforming one form of representation to other forms.

Those studies generally focused on students' cognition in drawing force diagrams and were conducted quantitatively. A qualitative study is needed to explore students' perception about force diagrams, which has not been done in quantitative study. Thus, to have a deeper understanding of students' views about force diagrams, it is important to conduct a study investigating what diagrams are drawn by students and what they think and reason in drawing force diagrams while solving physics problems.

2.7 Conceptual Framework

Constructivism and cognitive theory that have been discussed in the previous section state that students construct their own knowledge and how knowledge produced in the mind is affected by the form of information and prior knowledge. In this study, these theories are used as a foundation to understand how students construct their own representations including force diagrams and what they think about drawing representations while solving force problems.

A force diagram is depicted in a vector, which consists of an arrow and label (name). To draw or construct a force diagram, students should have conceptual understanding of vectors and forces (mathematical and physics concepts) as shown in figure 2.15. Vector concepts as part of mathematical concepts involve adding, subtracting, and the components of vectors. Moreover, understanding Newton's Laws is the ability to comprehend force concepts. For example, from the statement *"when an object is placed on the inclined plane and the object is at rest"*, students are asked to determine the net force exerted on the object. To draw a force diagram on the object, students should know physics concepts include force concepts such as the interaction between an object and other objects and the concept of friction force. Furthermore, students need addition, subtraction, and the components of vectors to find out the net force exerted on the object. This study will investigate whether students construct and use this diagram while solving problems and how they use it in the problem-solving process.

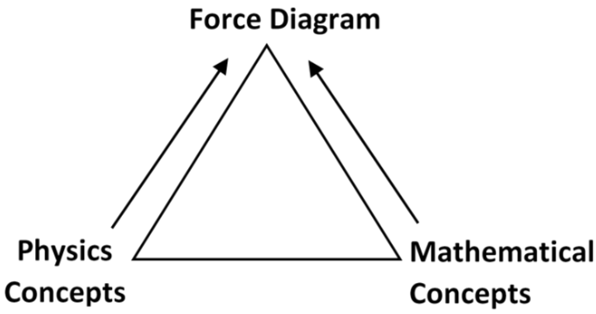


Figure 2. 15 Constructing diagrams

In terms of physics, problem solving is a task of looking for the solution from given information by applying strategies or approaches (Dhillon, 1998; Larkin and Reif, 1979). From the definition, a student should have strategies or approaches in order to reach the solution during problem solving. Therefore, experts have designed step-by-step procedures as a means of helping students to visualize a problem with representations, apply a relevant concept, select an appropriate mathematical equation, and evaluate the solution (Docktor *et al*, 2015; Heller, Keith and Anderson, 1992; Huffman, 1997; Van Heuvelen, 1991).

In order to analyze a problem, learners might need to construct or draw representations to visualize the problem in different forms. For example, if a problem is represented verbally, students need to draw pictures or sketches and diagrams to analyze the problem. At the same time, students must have conceptual understanding to construct the diagrams. From the diagrams, mathematical equations can be generated to compute the solution. From the problem-solving strategies or steps proposed by experts to solve a problem, there are three main aspects, including representations, concepts, and equations. In solving force problems, concepts, diagrams, and equations (CDE) are needed. Those aspects are connected to each other where students can freely move from one to another. The relationship among these aspects is shown in figure 2.16.

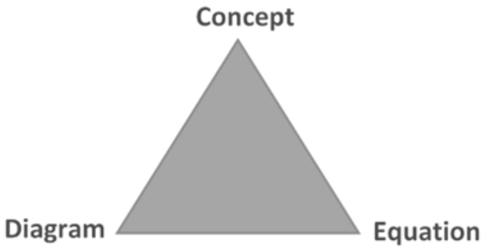


Figure 2. 16 The process solving a problem

To solve physics problems (in this study Newton’s laws), students may require force concepts, diagrams, and mathematical equations. A student might start by writing the concepts involved in the problem, and then drawing diagrams before deciding the appropriate mathematical representations to find the final solution. Furthermore, a student might not need diagrams, he/she just entails concepts and mathematical equations to solve the problem. This study will explore how students move between three ideas: concept, diagram, and equation (CDE) during solving force problems.

2.8 Research Questions

Studies about drawing and using representations in problem solving focused on students’ performance in solving problems. They taught students some approaches to drawing productive force diagrams. Some studies examined students’ performance to understand different formats of representations, including force diagrams. Besides cognitive factors, the use of representations in problem solving might be affected by affective factors. Based on the literature review, students (high school and university students) generally solve problems in doing homework and exams by involving concepts, diagrams, and equations. When students solve problems, students might face different types of problems and implement different approaches then students might draw representations in their solutions. Therefore, this study began with exploring the perception of student teachers about physics problems solving and representations. The student teachers may perceive problem solving and representations differently because besides the ability to solve problems, draw and use representations, they must think about how to teach. The group of students in the literature review might have different views and approaches from students in this study (student teachers) while solving physics problems. Thus, whether students draw and use representations in their solutions can be explored by giving students the opportunity to solve force problems and observing what they do. Students’ motivation and perception in drawing force diagrams needs to be explored. The research questions consist of sub-questions:

1. What are students’ views about solving physics problems?
2. What are students’ views about physics representations?
3. How do students’ production and use of force diagrams relate to their success in solving force problems?
4. In what ways do students think about, draw, and use force diagrams as they solve physics problems?

CHAPTER 3
METHODOLOGY

This chapter presents the research methodology used to investigate the diagrams students employ in solving force problems, and students' motivation for drawing force diagrams. Section 3.1 describes the interpretivist paradigm used in this study, and the rationale for a qualitative approach is explained in section 3.2. Instruments for data collection – including problem-solving and representation surveys, force problems, and interviews – are presented in section 3.3. Section 3.4 outlines the pilot study, including the process of data collection, findings, and reflection. Ethical issues are explained in section 3.5. The process of data collection for the main study is explained in more detail in section 3.6, and Section 3.7 discusses the analysis of quantitative and qualitative data.

3.1 Philosophical Perspective

Interpretivism is a philosophical discipline that seeks to understand the meaning of people's behaviour and the product of that behaviour (Fay, 1996). The main purpose of this philosophy is to reconstruct the self-understanding behind human behaviour. People may interpret something differently and interpretations can be accepted, as long as they are based on systematic treatment of the data. Generally speaking, interpretivism can be defined as understanding human behaviour, products, and relationships. From an interpretivist perspective, understanding humanity is different from understanding nature. Theories, laws, and measurements are required to build concepts in science; whereas in the human sciences, concepts are employed to explain and describe human activity through the study of social life (Fay, 1996).

There are different ways to interpret what people do and say (Pring, 2004). Firstly, intentions are embedded in action. In the case of this study, students intended to show their ability to solve a problem. In addition, students' ability to explain the process of solving the problem, and the use of a diagram, can become the purpose of acts. Secondly, students use words or language and representations as ways to communicate their views or understanding to the interviewer. In other words, I interpreted how students present their language in the problem-solving process and elucidated the meaning of students' explanations while solving the problem. Therefore, based on the arguments above, I chose interpretivism as the paradigm for this study.

Positivist philosophy is not quite relevant to this study for several reasons. First, the positivism paradigm extracts meaning from the research result by analysing data statistically, and based on that, provides generalisations to apply to other samples or populations, whereas interpretivist philosophy interprets students' views through text and language and extracts meaning from them (Cohen, Manion and Morrison, 2011). Second, factual knowledge, from a positivism perspective, can be obtained simply through measurement (Laudan, 1996). Interpretivism, on the other hand, posits that knowledge can be obtained through interpretation (Scott, 2010). Thirdly, the position of researchers in positivism is independent or objective (Cohen, Manion and Morrison, 2011), and this means that the interaction of researchers and participants must be minimised. However, interaction between researchers and participants is the main point of interpretivist study, in order to attain more detailed data, especially while conducting interviews and observations (Scott, 2006).

3.2 Research Approach

Studies regarding representations discussed in the literature review predominantly employ quantitative methods and a positivist approach to test a hypothesis through statistical analysis. In this research, I am aiming to interpret students' understanding of, and views about representation. Patton (1990) explains that the major source of qualitative data is obtained from what people say whether verbally thorough an interview or in written form through document analysis or survey response. The main goal of using qualitative methods is finding out the meaning of a phenomenon from the views of participants (individual perspective) by using observation and interview to collect data (Creswell, 2013). Obtaining detailed information and identifying subjective understanding and motivation are characteristics of qualitative research methods (Fraser and Tobin, 1998). In addition, Merriam (2009) says that understanding the meaning of what people think, and how they understand their world within their experiences, are the characteristics of qualitative study. She adds that focusing on the process and understanding are the key points of the qualitative approach.

Most previous studies focused on the effect of teaching representations, and on students' competence in choosing and using representations using quantitative methods. So, there is a lack of qualitative study in investigating students' use of representations. A qualitative approach was applied in this research to explore university students' thoughts and views about representations while solving physics problems. Data from problem-solving and representation surveys were employed to gain the background of views from a large group of students (n=230) about physics problem-solving and the use of physics representations. Two force problems were also given to the larger group of students and the analysis of their work including the form of force diagrams drawn by students helped to identify a small group of students to be selected for interviews (individual interviews, n=28; pairs interviews, n=16). Clinical interviews provided qualitative data which was analysed to interpret students' motivations in drawing force diagrams while solving force problems.

3.3 Instruments

Several instruments were used in this study including problem solving, representations, and force problem surveys. These surveys (one package) were given to all students (n=230) at the beginning to gather quantitative data and some more qualitative data in the students' solution. More detail about these surveys will be explained in the following subsection. Students were given about an hour to fill out the surveys and solve the survey problems. The survey problems were two questions which aimed to explore students' performance including their diagrams, and the results were used as the basis for selecting students to participate in individual interviews. Then the interview problems that differed from the survey problem were administered to students before individual interviews were conducted. Each student who participated in individual interviews (n=28) solved two questions individually, which formed the basis for clinical individual interviews. To gain students' motivations (qualitative data) in drawing diagrams, several questions were asked, based on students' answers about force problems, with interview guidelines, such as the purpose of drawing diagrams, the process of drawing diagrams, and the experience of using diagrams in physics problem solving. After several weeks, students from the individual interview were invited to participate in paired interviews (eight pairs, n = 16) to obtain students' views about force diagrams drawn by other students in response to the survey problems.

3.3.1 The Problem Solving Survey

This survey was intended to answer the research question: *What are students' views about solving physics problems?* The problem-solving statements were adapted from the Colorado Learning Attitude Science Survey (CLASS) (Adams *et al*, 2006) and the Attitude and Approaches to Problem Solving Survey (AAPS) (Mason and Singh, 2010). CLASS is a validated survey designed to measure students' beliefs about physics and about learning physics. This survey consists of 42 items in several categories including real world connection, personal interest, conceptual understanding, and problem-solving (the original survey is presented in Appendix 2). This survey was designed by researchers in the United States and has been used by many physics education researchers. Three items (8, 9, and 10) from CLASS were used in this study. The AAPS is a validated survey used to investigate students' attitudes specifically in physics problem-solving. This survey consists of 33 items addressing several ideas such as the use of representations, the role of mathematics, the role of concepts, checking the answers, using strategies, and interest in solving problems (the original survey is presented in appendix 3). Seven items were adapted from AAPS.

Therefore, the problem-solving survey in my study consists of 10 statements (Appendix 4) which explore students' views on strategies, approaches, difficulties, concepts, equations, and interest in solving physics problems. This survey uses rating scales with five options: *strongly agree, agree, don't know, disagree, and strongly disagree*. The rating scales are helpful tools in determining participants' answers, because they help researchers in grouping and analysing responses easily (Cohen, Manion and Morrison, 2011).

3.3.2 The Representation Survey

This survey aims to answer the research question: *What are students' views about physics representations?* Two representational items (2 and 8) were adapted from the Attitude and Approaches to Problem Solving Survey (AAPS) (Mason and Singh, 2010) and others were created specially. The items of the representations survey were created from literature such as different types of representations in physics, the advantage of drawing representations. The representation survey has not validated yet because the purpose is not to make generalisations through the use of inferential statistics, but rather to get an overview of the views of students about representations which could inform teaching. In addition, the number of items used in this survey is limited for a validated survey. So, to generate a validated survey, the number of items needs to be developed and it will take a long process.

The representation questionnaire comprises 10 statements (Appendix 5) that investigate students' beliefs about representations, covering for example types of representations, the use of representations, the benefits of representations, drawing or creating representations, the difficulties in using representations in physics problem-solving. This questionnaire also uses rating scales with five options: *strongly agree, agree, don't know, disagree, and strongly disagree*.

3.3.3 The Force Problem Survey

The survey problems are in an open-ended format that addresses force concepts, especially Newton's Law. The problems address the research question: *How do students' production and use of force diagrams relate to success in solving force problems?* Two questions investigate how students approach force problems and whether representations were used or created in supporting their answers. The physics concept covered by these questions is an object at rest or not moving in two different contexts: horizontal surface and inclined plane. Both contexts are familiar to students from physics textbooks and exams. The first question (horizontal context) is about two people pushing a box on a horizontal surface in different directions. Students were asked to find the minimum mass of the box for it remain at rest. Survey problem 1 was adapted from Heckler's study (2010). The original question asked students to draw diagrams. I did not include this request as one of the purposes of this study was to explore whether or not students would choose to draw representations. Survey problem 2 involves a box at rest placed on an inclined surface, and students were asked to determine the magnitude of the friction force. This question was taken from Lin's and Singh's study (2016). Neither question was attached to pictures or sketches, leaving students the choice of which representations they used to solve the problems.

The two questions used to explore the students' diagrams are shown below.

Survey problem 1: 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 a friction between the box and the floor and the coefficient of static friction is $\mu_s = 0.4$ and the coefficient of kinetic friction is $\mu_k = 0.25$. What is the minimum mass that the box can be in order for it to remain motionless?

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

Students' solutions were grouped into four categories: complete diagrams, incomplete diagrams, inappropriate diagrams, 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 more detail about categorisations can be seen in section 4.3.1 Table 4.3 and section 4.3.2 Table 4.6. Then students' diagrams were used to select participants for individual interview. Each category of diagram was represented among the students selected for individual interview.

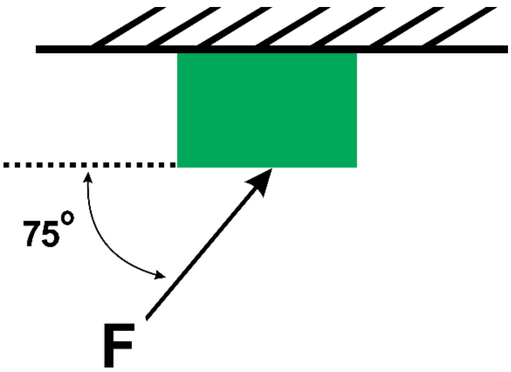
3.3.4 Interviews

Both individual and paired interviews were used to gather students' views or beliefs about drawing force diagrams and approaches implemented to execute the problems. Patton (1990) asserts that conducting interviews is appropriate when exploring the feelings, thoughts, intentions, etc, of interviewees. The purpose of interviews in this study is to find out what is in the students' minds. Semi-structured interviews (Merriam, 2009) were adopted to gather information about students' thinking.

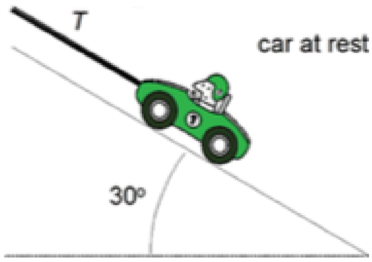
The individual interviews were intended to gain in-depth the reasons for drawing force diagrams. Before individual interviews were conducted, students had solved two interview problems (shown below), which cover horizontal and inclined plane contexts (the contexts are similar to those in the force problem surveys). The first interview problem was taken from an introductory physics textbook (Arons, 1997). This problem asked students to determine the magnitude of normal force exerted on a box which is below a ceiling and is held against the ceiling by a force, and the magnitude of the box's acceleration. Many problems (or standard problems in physics textbooks) are commonly presented on horizontal surfaces, so this problem allowed students to express their understanding or employ their diagram in solving a problem which is different from standard problems in a horizontal context. The second interview problem was taken from Lin's and Singh's study (2016) which asks for the magnitude of T force exerted on a car that is pulled upward. Both problems were presented with sketches or figures to avoid misunderstanding about the problems. Based on students' answers from the survey problems, a couple of respondents misinterpreted the problems, for example assuming there are two boxes when there is only one box (survey problem 1).

Interview problem 1: 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° = 0.96; cos 75° = 0.25; tan 75° = 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



Interview problem 2: A car which weighs 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° = 0.5; cos 30° = 0.86; tan 30° = 0.57; and g = 10 m/s^2].



The questions I asked students during individual interviews were based on students' answers for both force problems; this interview is called the clinical interview. The clinical interview is "an unstructured and open-ended method intended to give students the opportunity to display his natural inclination" (Ginsburg, 1981). The clinical interview gives participants opportunities to express their thoughts, to explain reasons in choosing strategies while solving the problem, drawing diagrams, and to reflect on their work. The themes of questions that were covered during interviews were the strategies applied in solving the problems, the difficulties in determining the solutions if there were any, the types of diagrams used, and the reasons for using or not using diagrams.

I also conducted paired interviews to obtain students' views about force diagrams drawn by other students in response to the survey problems. Students were given a couple of other students' works to evaluate and critique. Before the interview was conducted each student read and analysed other students' work. During the interviews, each student had the opportunity to deliver comments about students' work, particularly about force diagrams. The paired interviews allowed interviewees to compare their work, including the ways they solved problems, force diagrams, and final solutions.

3.4 Pilot Study

Before the main study is conducted, a pilot study has been carried out to evaluate the process of data collection. This pilot study is preliminary research on a small scale with the aim of assessing or examining the feasibility, time, and cost in order to try to predict an appropriate sample size and improve upon the study design prior to performance of a full-scale study (Oppenheim, 1992).

3.4.1 Data Collection

The participants involved in the pilot study were eight students in the post graduate certificate of education (PGCE) programme at the University of Leicester. These students come from different undergraduate disciplines, such as physics, mathematics, science, and engineering. After completing the programme, they receive a certificate to teach physics at secondary school. Students were asked to fill out two surveys: representation and problem-solving, and to solve the survey problem (shown below). After that, three volunteer students were available to conduct semi-structured interviews in order to more deeply assess students' views and their processes in solving problems.

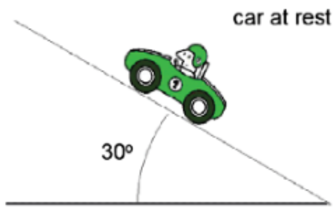
The representations survey consisted of eight statements with five options (*strongly agree, agree, don't know, disagree, and strongly disagree*) and this survey was aimed at obtaining students' views about their own experience in using representations in their studies. Moreover, the problem-solving questionnaire that has six items was used to see students' attitudes in solving physics problems. Both surveys were validated by my supervisors before being administered to the students.

The survey problem which covered Newton's Law concepts was administered to all students in order to observe their performance while solving the problems (the process of problem-solving, the use of representations such as diagrams and mathematical equations, and the correctness of the final answer). After that, data on students' responses to the surveys, and students' answers from the problems, were analysed to acquire students' patterns in solving problems and using representations.

The survey problem asked students to determine the magnitude of frictional force on a car at rest on an inclined plane. The interview problem was given before individual interviews; students were asked to determine the magnitude of the acceleration of the car without including a picture of the context. Both problems were adapted from Lin's and Singh's study (2016). The first problem was original, whereas the second problem was modified from the first problem.

Problem 1 (Survey)

A car which has 15,000 N weight is at rest on a 30º inclined plane shown below. The coefficient of static friction between the car's tires and the road is 0.90, and the coefficient of kinetic friction is 0.80. Find the magnitudes of frictional force on the car. Note: these trigonometric results might be useful (sin 30º = 0.5, cos 30º = 0.866).



Problem 2 (Interview)

A car which has 15,000 N weight is sliding down at constant acceleration on a 30º inclined plane from the top to the bottom. The coefficient of static friction between the car's tires and the road is 0.90, and the coefficient of kinetic friction is 0.50. Find the magnitudes of the acceleration of the car. Note: these trigonometric results might be useful (sin 30º = 0.5, cos 30º = 0.866). Gravitational acceleration on earth is 10 m/s^2.

Participants in the interview were volunteers who received email messages from the researcher asking if they were available to take part in interviews. Three students agreed to an interview. Before the interview began, students were asked to solve a problem (problem 2) which was similar to the previous question. Students were asked questions such as: “Did you have difficulties in solving this problem? Why did you draw this kind of diagram to solve this problem?”. The process of solving the problem was recorded using Livescribe software. A clinical interview of about 20-30 minutes was used to ask more questions about students’ responses on the surveys, and these conversations, including students’ answers on problem-solving, were recorded.

3.4.2 Pilot Study Findings

Students’ responses for both surveys are presented in Appendices 6a and 6b. The data showed that all students had learned representations in secondary school (item 1) and frequently used representations such as pictures, diagrams, or graphs while solving physics problems (item 2). Moreover, most students thought that using representations would help them understand physics concepts (item 5). Seven students agreed that representations helped them to understand problems more easily (item 3), and to find the correct answer in solving the problems (item 4). Interestingly, all students responded that they are good in representing information in multiple ways (item 6). Based on the survey, almost all of the students (7 out of 8) indicated that they always draw representations even though there is no extra credit (item 8).

More than half of the participants (5 out of 8) agreed that mastering mathematics is the most important element in the physics problem-solving process (item 1). However, three of the students disagreed with this statement. Item 2 is about identifying physics principles before looking for an appropriate equation; six students agreed, and two students did not know. Five students agreed that “matching a problem with the correct equations and then submitting the values to get a number is characteristic of problem-solving” (item 3) and two students did not. Almost all students agreed that if they applied two approaches and got different answers, they would think of it (item 4), and if they got an unreasonable answer they would think of it (item 5). Item 6 is about the format of a problem; three students agreed that solving a symbolic problem is more difficult than finding a numerical answer; meanwhile two did not disagree, while three were *don’t know*s.

All students solved the problems with various solutions and diagrams. They took between 10 and 15 minutes to solve the problems. All students drew force diagrams: one was a complete diagram, two of them were incomplete, and the others were inappropriate. An example of a student's solution for the first problem is presented below (Figure 3.1).

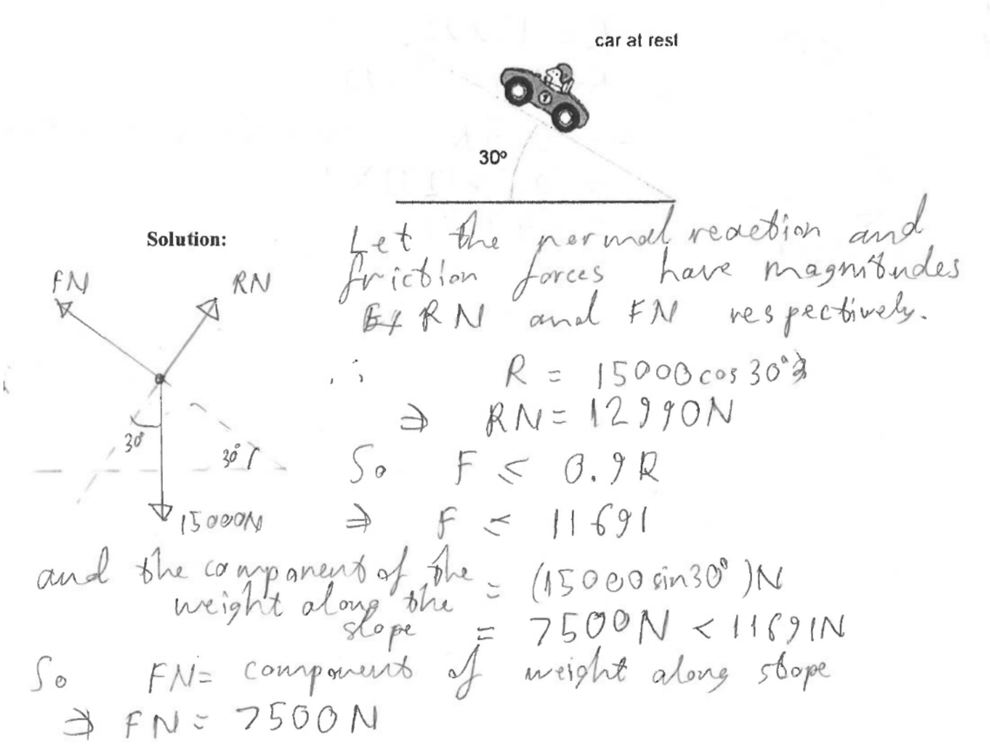


Figure 3. 1 An example of student's solution (survey problem)

The following is the conversation between the interviewer and a student during interview after solving a problem. A student's solution from the interview is shown in Figure 3.2. Based on the transcript, students communicated their purpose in drawing diagrams, such as finding the sign of forces. He also mentioned that drawing diagrams helped him to visualise the forces. From this interview, I got a sense of a student's answer to the questions I asked. This was helpful for me in conducting the main study.

Interviewer: *Why did you draw the diagram to solve this problem?*

Student: *I draw so I can see which forces can be balance. Then find the sign of forces. I got the information and present the equation.* [sic]

Interviewer: *How did you get the equation: acceleration = Res force/mass?*

Student: *I got from force = m a. But did not write down just in my head.* [sic]

Interviewer: *If you did not draw this diagram, do you think that you could solve this problem?*

Student: *I think that it depends on how well your mathematics in your head.* [sic] *I think I could. When I was a student, I drew a diagram to help me visualising the forces.*

Interviewer: *Why did you draw the longer arrow?*

Student:	*To visualise the bigger force because the car is accelerated to this direction.*
Interviewer:	*Do you think that force diagram will be helpful for high-, medium-, and low-skilled students?*
Student:	*I think that it might be helpful for all students. I will encourage them to do it. If they cannot demonstrate with math, it will help them to visualise the forces acting on the object and also to make sense.*
Interviewer:	*Do you think that there is a special skill for drawing diagrams or students should have enough physics concepts to draw the diagram?*
Student:	*I think it is not.* [sic] *As long as you get understanding acceleration and force. I don't think it is particular skill and you have to get practice to do it.*
Interviewer:	*I presented two different questions, one is with a picture and the other is not. Do you think that this picture will help you to solve the problem?*
Student:	*I always draw the diagram.*

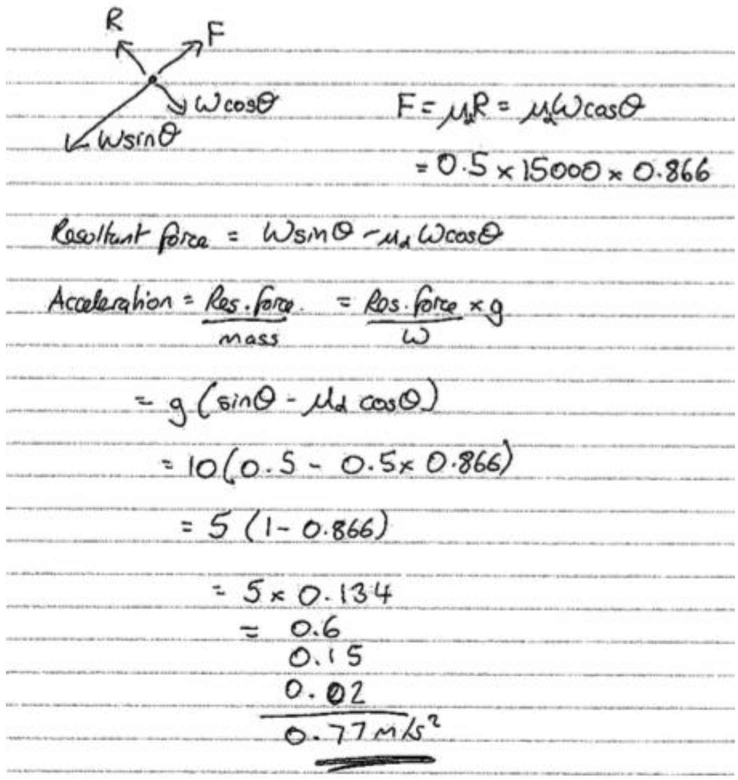


Figure 3. 2 An example of a student's solution (individual interview)

3.4.3 Reflection

After conducting the pilot study, I reflected before carrying out the main study. Problem-solving occupies six items in the pilot study. I added four items which addressed the role of approaches and equations in problem-solving, and the interest in solving physics problems. Therefore, the total is 10 items. In the pilot study, the representations survey had eight items. I added two items to address the difficulties of using representations and drawing students' own representations, so the total is 10 items.

Regarding the force problems, the context explored in the pilot study was only in an inclined context for both the force problem survey and interview. I realised that a horizontal surface problem should be added to see various students' diagrams in different contexts. Therefore, I added two horizontal problems, one for the force problem survey and the other for the interviews. I also changed the inclined plane interview problem to make it similar to the problem in the survey. So, in the main study two problems were used for each of the survey and the interview, covering horizontal surface and inclined planed contexts.

Reflecting on the timing for administering both surveys and test, I decided that questionnaires and survey problems would be administered to students at the same time to help the researcher to analyse the data having documented students' responses and problem-solving approaches. It takes time to analyse data before continuing to the interviews, so I should allow time for analysis because interview participants will be selected based on students' responses to the surveys and test. Furthermore, the duration of the interview should be flexible, based on students' answers.

3.5 Ethical Considerations

This study explored students' views about force diagrams while solving physics problems. To acquire data, I administered questionnaires and surveys. Also, interviews were conducted to obtain more detailed information relating to students' views and understanding. Accordingly, before carrying out the study, I had to arrange for documents such as consent forms and letters of permission to be reviewed by the university board. Thomas (2013) states that most social sciences studies interact with humans; therefore, researchers must consider the ethics of what they are doing. The privacy of respondents' answers, including personal background information, must be assured by researchers so that respondents feel comfortable in providing the information needed (Cohen, Manion and Morrison, 2011).

In order to gather data from students naturally, I as a researcher informed them that their work and responses would not affect their course grades. My role in this study is not as their lecturer or teacher; therefore, students could freely provide views and responses regarding the surveys and should will feel more comfortable in answering interview questions.

I obtained a letter of ethical approval from the University of Leicester for conducting a pilot study which involved post graduate certificate of education (PGCE) students (physics concentration) as participants, and for conducting the main study involving students at Tanjungpura University, Indonesia. The documents submitted to the university ethics board were the surveys, interview guide, participant information sheet, consent form, and letter of permission to undertake the pilot and main study. The documents can be seen in Appendices 7a,7b and Appendix 8.

3.6 Data Collection of the Main Study

3.6.1 Participants

The subjects of this study were 230 pre-service physics teachers (undergraduate students) of the Teacher Training and Education Faculty, Tanjungpura University, Indonesia.

More details of participants in this study are presented in Table 3.1.

Table 3. 1 The distribution of participants

Students' Year	Male	Female	Total
First Year	15	37	52
Second Year	12	43	55
Third Year	20	42	62
Fourth Year	16	45	61

Before coming to this faculty, they passed the university test after graduating from senior high school. During high school, the students took compulsory courses such as maths, physics, biology, and chemistry. In the university physics education department, in the first year, they must also take compulsory science courses, but the content is more advanced than in senior high school. Besides the physics content, students also complete education courses, such as educational psychology, and pedagogical content knowledge, such as assessment, teaching and learning. After graduating from this department, they expect to have both science content knowledge and pedagogical content knowledge. They will become physics teachers in junior and senior high schools after completing a four-year study in the physics education department.

3.6.2 Surveys and Interviews

All instruments were translated into the Indonesian language. The translations were validated by Indonesian faculty members of the department of physics education, Tanjungpura University. Before collecting data, I contacted the head of the department via email, attaching a letter of recommendation from school of education at the University of Leicester to inform them the purpose of the study, and I received permission to conduct the study. After arriving at Tanjungpura University, I approached the lecturers and arranged an appropriate schedule for students.

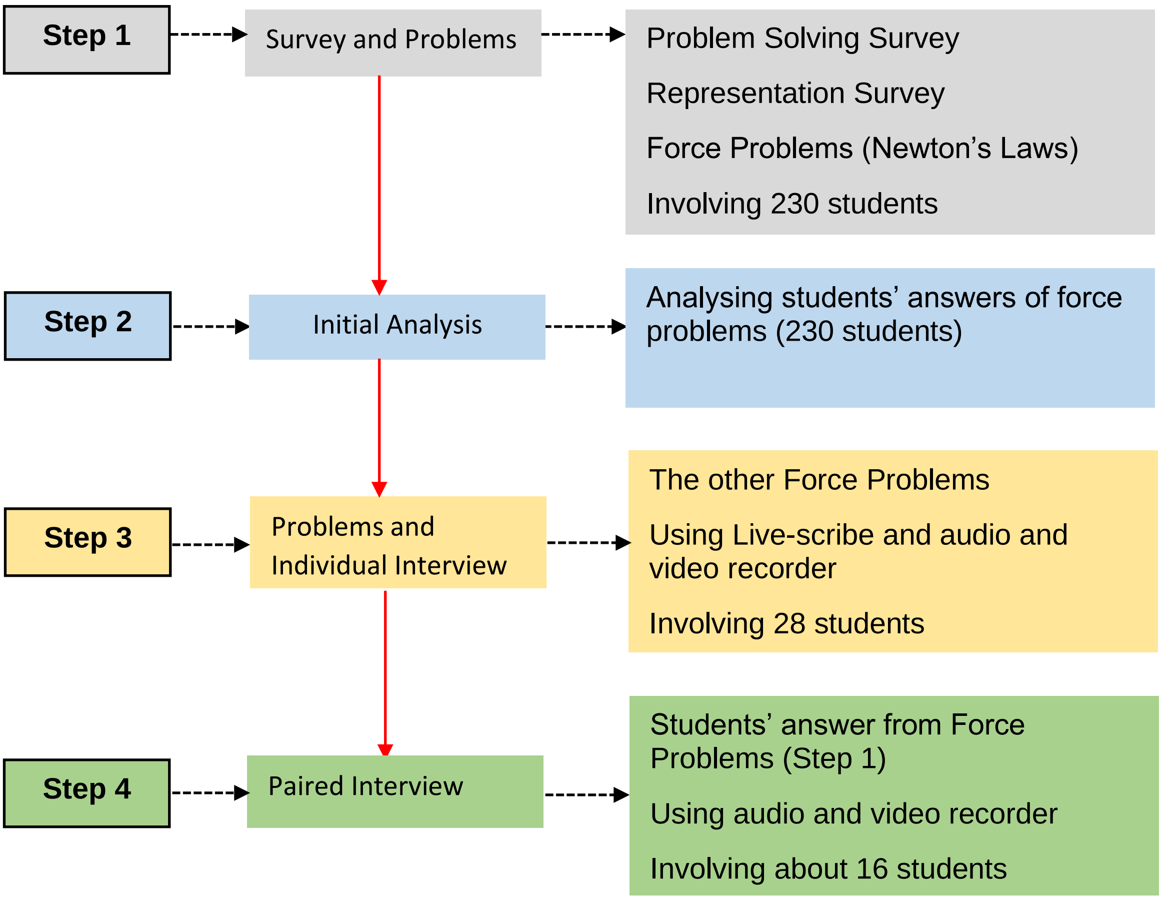


Figure 3. 3 The Flow Chart of Data Collection

The first step was explaining to students the purpose of the study and asking them to fill out both the information letter and the consent form. Then students were given personal data sheets, representation and problem-solving surveys, and force problems in one package. To fill out both personal data and surveys, students were given 25 minutes and about 30 minutes to solve the force problems. In the second step, I analysed students' answers involving diagrams, mathematical equations, and final answers, with a view to inviting them to individual interviews. The participants for individual interview comprised 28 students from different year groups. Before conducting the individual interview as the third step, students were given two force problems and they solved them using a Livescribe tool as means of recording the process of solving the problems. The tools consist of a pen and a workbook, and each of the students wrote their answer in the workbook using the pen. Then the pen was connected to smartphone via Bluetooth to enable recoding of the data. Students were given 30 minutes to solve two problems. During the individual interview, every student was asked questions based on student's answers. Individual interviews lasted between 30 and 40 minutes, and audio and video were recorded.

In the fourth step, 16 students (eight pairs) from the individual interview were involved in paired interviews. At the beginning of the interview students were given students' work (not their own) from the first step and were asked to evaluate and comment on it regarding diagrams presented and approaches implemented. Students responded verbally and commented in the students' answer sheets. During the paired interview, audio and video were recorded and sessions lasted about an hour.

Table 3. 2 Research questions, instruments, and participants

No	Research Questions	Instruments	Participants
1	What are students' views about solving physics problems?	Physics problem solving surveys	230 students
2	What are students' views about physics representations?	Representations surveys	230 students
3	How do students' production and use of force diagrams relate to the success in solving force problems?	Force problem surveys	230 students
4	In what ways do students think about, draw, and use force diagrams as they solve physics problems?	Individual interview and pairs interview	28 students and 16 students

3.7 Data Analysis of the Main Study

This study consists of quantitative and qualitative data. Data from the surveys – on problem-solving, representations, and force problems – were classed as quantitative data, whereas that from individual and paired interviews were categorised as qualitative data.

3.7.1 Data Analysis from the Surveys

Data collected from both surveys were utilised to answer research questions designated 1 and 2. The analysis of the survey data aimed to gain an overview of students' views about problem-solving and representations. Rather than undertaking detailed statistical analysis data from each statement of the problem-solving and representation survey was condensed into three categories: agree (strongly agree and agree), neutral/not known, and disagree (disagree and strongly disagree) and the percentage of students' responses for each item was obtained. Although this meant that some detail was lost, the use of the three categories helped me to identify general patterns in whether students gave positive, neutral, negative responses regarding physics problem solving and representations. In addition, the percentage of students from each different group (students' level of study) was also obtained.

Data from the force problem surveys answered research question 3. Students' work was assessed and analysed to evaluate their performance in areas such as strategies or approaches and representations. Students' solutions including force diagrams were categorised to determine the pattern of diagrams drawn by students. Students' written answers were grouped into four categories: complete diagrams, incomplete diagrams, inappropriate diagrams, and no diagrams. In this study, 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 (see section 4.3.1 Table 4.3 and section 4.3.2 Table 4.6). Then students' diagrams were used to select participants for individual interview. Each category of diagram was represented among the students selected for individual interview. Moreover, the patterns of mathematical equations written by students who drew incomplete and inappropriate diagrams and who did not provide diagrams were also obtained. The percentage of students who drew different categories of diagram in each different group of students was obtained. Lastly, the percentage of students' correctness in solving the problem, based on the category of their diagrams, was calculated (section 4.3.2 Figure 4.11 and section 4.3.2 Figure 4.14).

3.7.2 Data Analysis from Interviews

Students' responses (qualitative data) from the interviews addressed research question 4. Students' responses from both interviews (individual and paired interview) were transcribed and coded. Researchers have utilised coding to categorise participants' responses in order to identify certain categories for the purpose of data analysis (Cohen, Manion and Morrison, 2011). Creswell (2005) suggests several steps to code data: 1) read transcripts, noting initial ideas; 2) pick one transcript, think about the meanings and write the meanings in 2-3 word phrases; 3) begin coding by identifying segments of the text relating to a particular code; 4) make a list of all codes and group them together; 5) go back to the data and try to code using this scheme, refining and removing codes whenever necessary. After coding, thematic analysis was used to identify students' reasons and motivation in using diagrams in physics problem-solving. Thematic analysis is used to identify and analyse the patterns or themes of the data (Boyatzis, 1998).

All interviews (from individual and paired interviews) were transcribed into text form in Indonesian then analysed using computer software (NVivo). The aim in analysing verbal data using this software is to help in finding a pattern in students' responses, and finally to identify themes in students' reasons for drawing diagrams. Students' responses were coded to find patterns such as similarities and differences. For the reliability of data analysis, I and my colleague (a postgraduate researcher in science education) did the same coding for one participant's transcript. We then discussed the similarities and differences in our codes. After we reached agreement, I continued to code the rest of transcripts. After obtaining the fixed codes, I translated all codes and students' responses relating to all codes into English. Finally, all codes were grouped into several themes.

The following example demonstrates the coding process. This is a transcript of a conversation (individual interview) between researcher and student after solving force problems.

Researcher: Would you explain briefly the process of solving this problem?

Student: If I came across a problem like this, I usually draw forces exerted on the object. So, here I draw all forces, there are W which is always going down to Earth then drawing normal force which is always perpendicular to the plane. After that, there is also friction force which is opposite direction with the motion of the object. Here, there is also a force pushed the block with the angle is 75^o, so we must find the component of that force in x and y axis. Because the problem *asking the magnitude of the normal force exerted on the block, we focus the normal force on y axis. Thus, we can see all forces exerting in y axis: W, N, and F sin θ. Then, to find out the acceleration of the block, we focus all forces on x axis: F cos θ and friction force.*

Researcher: What is the purpose of drawing this kind of diagrams?

Student: Ya, to see easily the forces and distinguish what forces in x and y axis. It helped me to find out the component of forces and answer the question.

Researcher: How about if you did not draw this diagram?

Student: If I did not, I will be confused which forces in x and y axis.

Researcher: Did you face difficulties in drawing this diagram?

Student: A little bit difficult in using sin and cos while drawing force component.

Researcher: Why did you write $\sum F_y = 0$*?*

Student: If we see x and y axis, the box is not moving up and down in y direction. So $\sum F_y = 0$.

Table 3. 3 An example of the process of coding

Text Segments	Codes	Themes
I draw all forces, there are W which is always going down to Earth then drawing normal force which is always perpendicular to the plane. After that, there is also friction force which is opposite direction with the motion of the object. Here, there is also a force pushed the block with the angle is 75^o	Identifying forces	Purposes
We can see all forces exerting in y axis: W, N, and F sin θ. Then, to find out the acceleration of the block, we focus all forces on x axis: F cos θ and friction force	Finding the direction of forces	
to see easily the forces and distinguish what forces in x and y axis	Finding the direction of forces	
It helped me to find out the component of forces	Determining the component of forces	
if we see x and y axis, the box is not moving up and down in y direction. So $\sum F_y = 0$	Supporting in selecting mathematical equations	
a little bit difficult in using sin and cos while drawing force component	Trigonometry	Mathematical concepts

An example of the process of coding the extract is shown in Figure 3.3. Before the coding process, all the transcripts were read to get the sense of the whole conversation. Then the texts were divided into several segments and coded. After all texts were coded then the text was re-read to make sure a text segment is appropriate to a code; if not, the coding was revised. After all codes were confirmed, they were grouped to generate themes.

3.8 Summary

This methodology chapter has discussed several ideas including the philosophical perspective in conducting qualitative research, the instruments used to collect data, conducting a pilot study before conducting the main research, the process of data collection, and data analysis. Data from surveys, including students' views about problem-solving and representations, and students' diagrams, will be presented in Chapter 4 to address research questions 1,2, and 3. The qualitative data, including students' views about drawing force diagrams obtained from both individual and paired interviews, will be explained in Chapter 5 to address research question 4.

CHAPTER 4
PROBLEM SOLVING AND REPRESENTATION SURVEY

This chapter presents quantitative data from surveys about students' views on problem solving and representations, as well as surveys about students' use of diagrams. Students' perceptions about physics problem solving are discussed in more detail in section 4.1, followed by students' perceptions about representations in section 4.2. Students' performance in solving force problems (both in horizontal and inclined plane contexts), including force diagrams drawn by students, mathematical equations used by students, and the correctness of solutions formulated by students, are discussed in section 4.3. The participants in this part of the study were 230 students who will be physics teachers either in junior high schools or senior high schools.

4.1 Physics Problem Solving Survey

This survey aims to solicit students' views about solving physics problems. The items in the survey were adapted from existing surveys such as the Attitudes and Approaches to Problem Solving Survey (AAPS) (Mason & Singh, 2010) and the Colorado Learning Attitudes about Science Survey (CLASS) (Adams et al., 2006). The survey consists of 10 items which address strategies or approaches, difficulties, and interest in solving problems. In addition, the survey covers the role of concepts and equations in the process of solving problems. It uses rating scales offering five options: *strongly agree, agree, don't know or neutral, disagree, and strongly disagree*. The students' responses were reduced to three views: strongly agree/agree, neutral/not known, and disagree/strongly disagree, in order to make students' responses easier to analyse.

Table 4.1 shows the percentage of students' responses to solving physics problems. Almost all of the students believe that mastering mathematics is the most important skill in being able to solve physics problems (item 1). In fact, physics consists of concepts, and needs mathematics as a language for analysing those concepts. Therefore, students may think that they always require equations to solve problems while facing homework and exams; consequently, they perceive that manipulating mathematical equations requires more effort than understanding physics concepts.

Table 4. 1 The percentage of students' responses (n=230)

Item	Statement	Students' Response (%)			Note
		Agree	Neutral	Disagree	
1	In solving problems in physics, being able to handle the mathematics is the most important part of the process	98	1	1	
2	In solving problems in physics, I always identify the physics principles involved in the problem first before looking for corresponding equations	93	7	0	
3	Problem solving in physics basically means matching problems with the correct equations and then substituting values to get a number	48	13	38	1 no answer
4	If I used two different approaches to solving a physics problem and they produced different results, I would spend considerable time thinking about which approach is more reasonable	82	17	2	
5	If I obtain an answer to a physics problem that does not seem reasonable, I spend considerable time thinking about what may be wrong with the problem situation	93	6	0	
6	It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer	65	24	11	
7	There is usually only one correct approach to solving a physics problem	5	14	80	3 no answer
8	If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works	92	8	0	1 no answer
9	If I do not remember a particular equation needed to solve a problem in an exam, there is nothing much I can do to come up with it	18	24	58	
10	I enjoy solving physics problems	56	38	5	2 no answer

In solving physics problems, most students (93%) said that they always identify physics concepts or principles involved in the problem before deciding the appropriate equations to use (item 2). One possible reason why students do this is because it will help them to remember which equation is matched to a particular concept. They may think that they will obtain extra credit from an instructor or teacher once they provide a correct concept, even though they cannot successfully find the final solution.

About half of the respondents agreed that solving a problem involved matching the problem to the correct equations and substituting values to obtain the number (item 3). Some students may have agreed to this statement because they have much experience in solving quantitative problems, where the final answer is a number. Moreover, students possibly think that physics and mathematics are similar. Therefore, students may take their mathematics approach and apply it to physics. The percentage of students agreeing and disagreeing with this statement is not significantly different, so the data from each level of students should be looked at in more detail. Students' responses to item 3 for each year group are displayed in figure 4.1. The first year bar does not add up to 100% because one student did not respond.

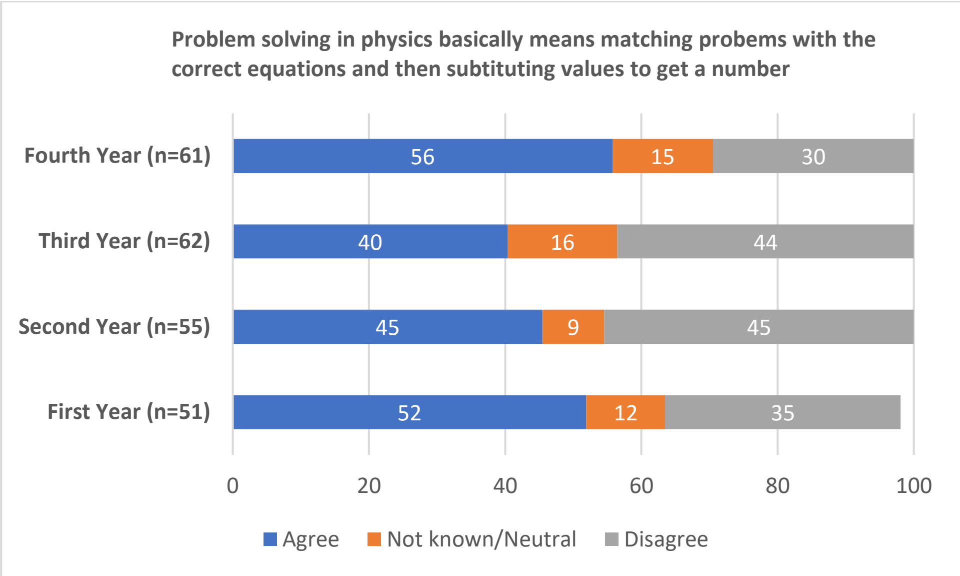


Figure 4. 1 The graph of the percentage of students' responses to item 3

The graph presents the percentage of students' responses for each group in order to explore whether students' level or experience in learning physics affects their response to the process of solving problems. From the graph, surprisingly, the fourth-year students, categorised as more experienced students, showed a higher percentage compared to the novice problem solvers in their first year. This finding suggests that during their study, the fourth-year students may often have solved quantitative problems – in either homework or exams – which require as the final answer a number or equation, rather than qualitative answers or concepts.

A physics problem might be solved using more than one approach. For example, problems involving the velocity and acceleration of an object can be solved using either Newton's laws or work-energy. The result of the survey shows that 80% of the students agreed that once they solve a problem using two different approaches, and they obtain different answers, they will think of the most reasonable answer (item 4). Students may apply more than one strategy or approach to prove that they have obtained the right answer. Moreover, almost all students also look carefully at the problem when getting an unreasonable answer (item 5). This is a productive activity to make sure a problem solution is complete and correct. Furthermore, many students (80%) disagree with the statement "there is usually only one correct approach to solving a physics problem" (item 7). This might be relevant to item 4, that students often recheck their answers if they solve a problem using two different approaches and obtain two different answers. The percentage of each student group's responses to item 7 is shown in figure 4.2.

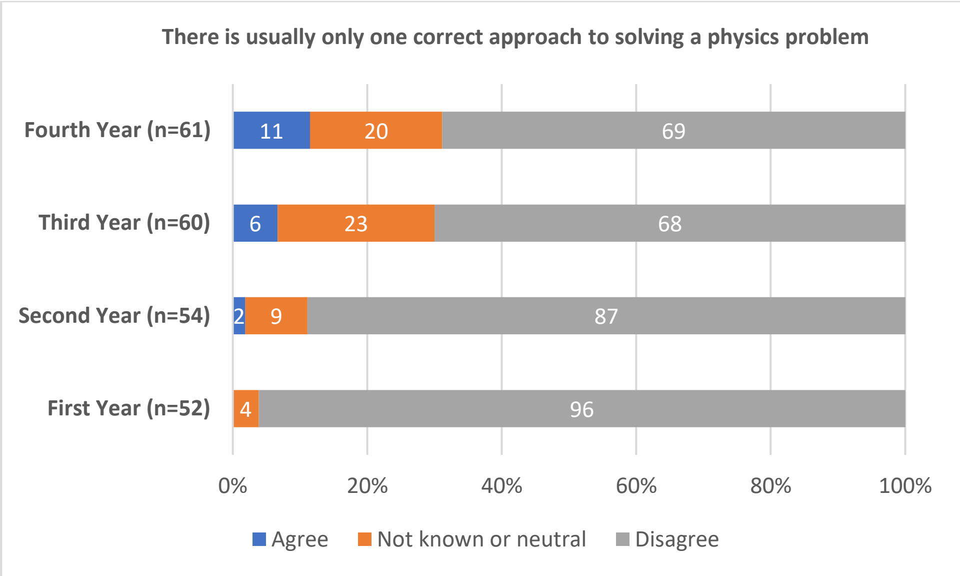


Figure 4. 2 The graph of the percentage of students' responses to item 7

Displaying students' percentage responses by year group is aimed at showing the pattern because only less than 10% of students agreed with this statement. The graph indicates that first- and second-year students have a higher percentage than third- and fourth-year students, who disagree with that statement. These responses suggest that when students are more experienced in solving physics problems, they feel that some problems can be solved by only one approach, and some might be solved by more than one; therefore the number of the third- and fourth-year students choosing to stay neutral is higher than among first- and second-years.

The form of physics problems can employ either symbols or numbers, and 65% of students agreed that they face difficulties in solving symbol problems rather than numbers problems (item 6). This indicates that students may be more comfortable with manipulating equations containing numbers because they can visualise the situation easily. For example, "a 10kg box is pulled by a force 50 N", rather than "a box which has M mass is pulled by a force F". However, 24% of students feel that both types of problem are similar. They may argue that both problems can be either easy or difficult, and they might not struggle in finding the correct answer as long as they know the concepts involved in the problem. Moreover, students in different year groups have different perceptions of different types of physics problems (provided in Figure 4.3). A higher percentage of first-year students view a symbolic problem as more difficult than a numerical problem. This group of students may have had that kind of view because they might have less experience in solving various problems compared to second-, third-, and fourth-year students.

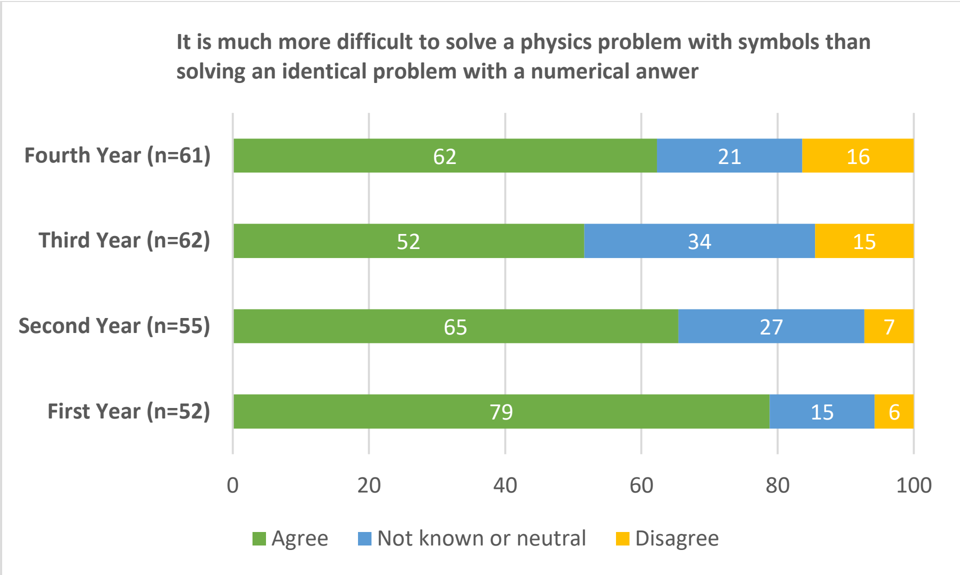


Figure 4. 3 The graph of the percentage of students' responses to item 6

When students were asked whether they enjoy solving physics problems (item 10), only 56% said that they like to solve physics problems, and 38% were "not known" or neutral. Students might be neutral because they are not interested in solving all physics problems; the responses might be affected by factors such as the type of problems, as discussed previously, and the level of difficulty of problems (simple or complex). Moreover, the fourth-year students showed more enjoyment than other groups of students in solving physics problems. The possible reason might be that students who have learned many topics of physics, and students experienced in teaching physics, might be more confident of solving physics problems. The percentage scores of each group of students responding to item 10 is shown in Figure 4.4.

The results of the physics problem-solving survey can be summarised as all students consider the role of mathematics in physics to be more dominant than purely physics concepts, because they often manipulate mathematical equations in determining the best solution. Some students recognise that different strategies or approaches can be implemented to solve a problem. Another factor that might affects students' views of solving physics problems is the form they take (symbolic or numerical).

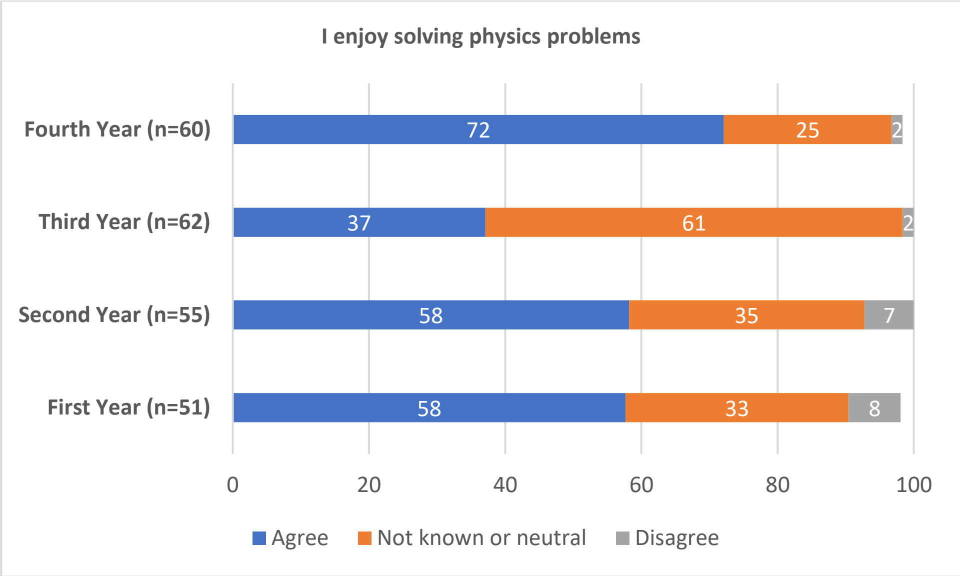


Figure 4. 4 The graph of the percentage of students' responses to item 10

4.2 Physics Representation Survey

The representation survey comprises 10 statements that investigate students' beliefs about the types of representation, the use of representations, the benefits of representations, drawing or creating representations, the difficulties of using representations in physics problem solving. Some items were adapted from the Attitudes and Approaches to Problem Solving Survey (AAPS) (Mason & Singh, 2010) and some items were newly devised. This questionnaire uses rating scales offering five options: *strongly agree, agree, don't know, disagree, and strongly disagree*. The data collected from the representation survey were grouped based on students' responses (agree, neutral/not known, and disagree) and their levels of study. The participants were the same as those in the problem solving survey. Details of students' responses to each statement of the survey are shown in Table 4.2.

The result of the physics representation survey shows that 83% of students have learned representations such as diagrams, graphs, and mathematical equations during their studies in high school and at university, and they were taught how to draw and use them (item 1). It is likely that the students have been familiar with different forms of physics representations. A small percentage of the participants (6%), however, disagree with the statement; these students might have not learnt representations at school.

Table 4. 2 The percentage of students' response (n=230)

Item	Statement	Students' Response (%)			Note
		Agree	Neutral	Disagree	
1	I learned representations (picture, diagrams, graphs, equations, etc) while studying at high school or university	83	11	6	
2	I often use representations (pictures, diagrams, graphs, etc) while solving physics problems	71	22	6	1 no answer
3	I use representations while doing physics problems to make a problem easier to understand	80	18	1	1 no answer
4	I use representations to help me find the correct answer	76	19	4	1 no answer
5	I think that representations will help me understand the physics concepts	86	13	1	
6	I am good at representing information in multiple ways (words, equations, pictures, graphs, tables, diagrams, etc)	12	59	30	
7	When I am drawing representations such as force diagrams and equations, I check or evaluate my answer to make sure the diagram and equation match well	79	17	3	
8	I usually draw pictures and/or diagrams even if there is no partial credit for drawing them	64	29	7	
9	I have difficulties in using representations presented in textbooks	36	43	21	2 no answer
10	I often create my own representations (different from those taught in the classroom and in the textbooks) while solving physics problems	33	47	20	1 no answer

Furthermore, 71% of students stated that they often use representations while solving physics problems (item 2). However, 22% of the respondents remained neutral; these students may not draw representations for all types of problems – they might provide representations only for complex or difficult problems, not for simple ones. Relating to this statement, item 8 asked students whether they draw representations such as pictures and diagrams even though no extra score is given by teachers or lecturers; 64% of students agreed with this statement, a little lower than the agreement with item 2. This indicates that the impact of prompting students to draw representations might be one reason for students deciding to provide diagrams in solving problems. Moreover, the first-year students with less experience in learning physics and representations show less motivation to draw representations (the graph can be seen in Figure 4.5). The graph shows that half of the first-year students agreed to this statement, compared to 75% among the fourth-year group.

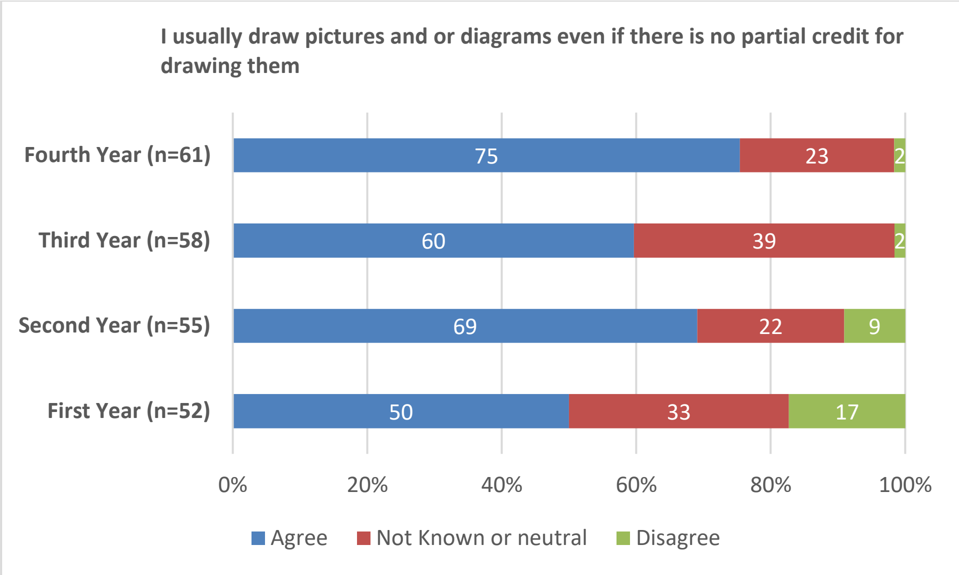


Figure 4. 5 The graph of students' percentage responses to item 8 by year-group

The physics representation survey asked about the purpose of using representations. Item 3 is about using representations to understand a problem more easily. Item 4 is about the use of representations to find out correct answers. Using representations to help students to understand physics concepts is the subject of item 5. The results of the survey show that more students think that representations help in grasping concepts, rather than understanding problems and finding correct answers. Some students may consider that when concepts are represented in different forms, such as diagrams and equations as presented in textbooks, it will help them to understand concepts. One possible reason why students think drawing representations will help in understanding problems is that they regard drawing a sketch, for example, as helpful in visualising a problem, even when they are not able to successfully solve it.

The responses of students for item 3 for each year group is shown in Figure 4.6. From the graph, it can be seen that the first-year students have the lowest percentage of agreement with statement 3, compared to other groups of students. The lack of opportunities to learn physics, and lack of experience in drawing representations, might be possible reasons for this response. Later year-groups return more positive responses because they have already used different kinds of representation and know the benefits of using this approach.

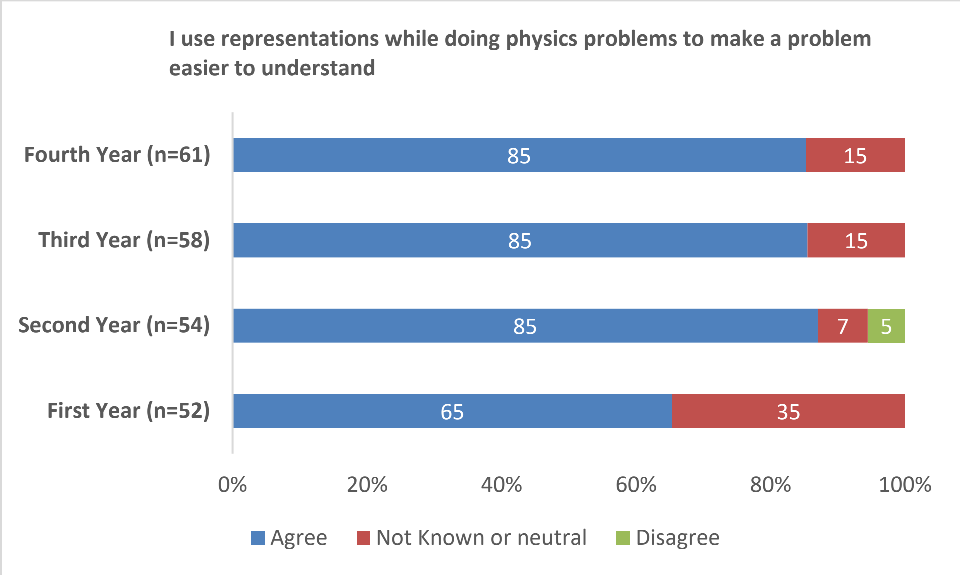


Figure 4. 6 The graph of students' percentage responses to item 3 by year-group

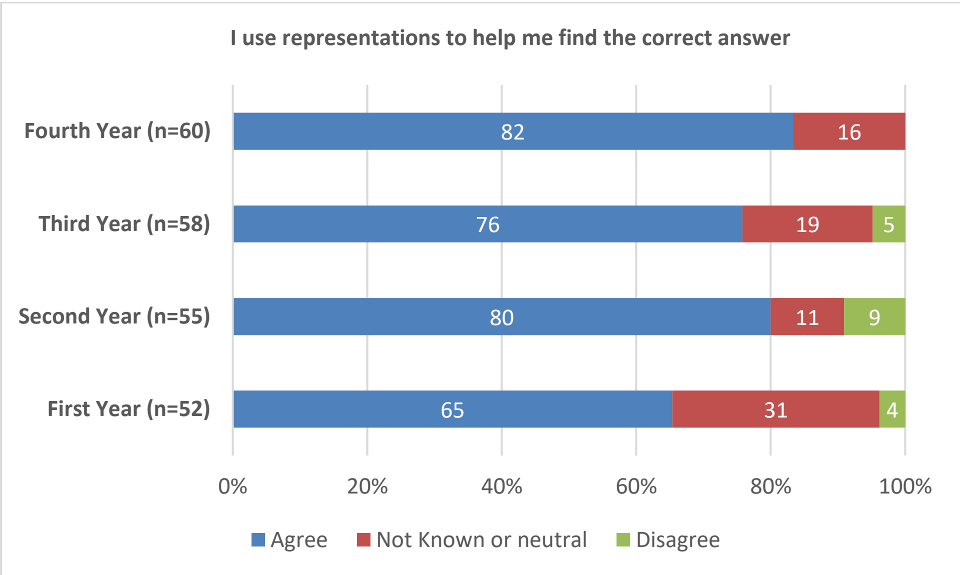


Figure 4. 7 The graph of students' percentage responses to item 4 by year-group

Furthermore, the proportions of student responses to using representations to find correct answers (item 4) are displayed in Figure 4.7. The first-year students again show the lowest percentage in responding to the use of representations for determining the correct answer. These students may have less knowledge of connecting sketches, diagrams and equations employed to solve a problem. As can be seen in the graph, the upper group of students (second-, third-, and fourth-years) who have more experience in learning representations, and have practised solving homework and even exam problems, has a higher affirmative percentage than the first-year students.

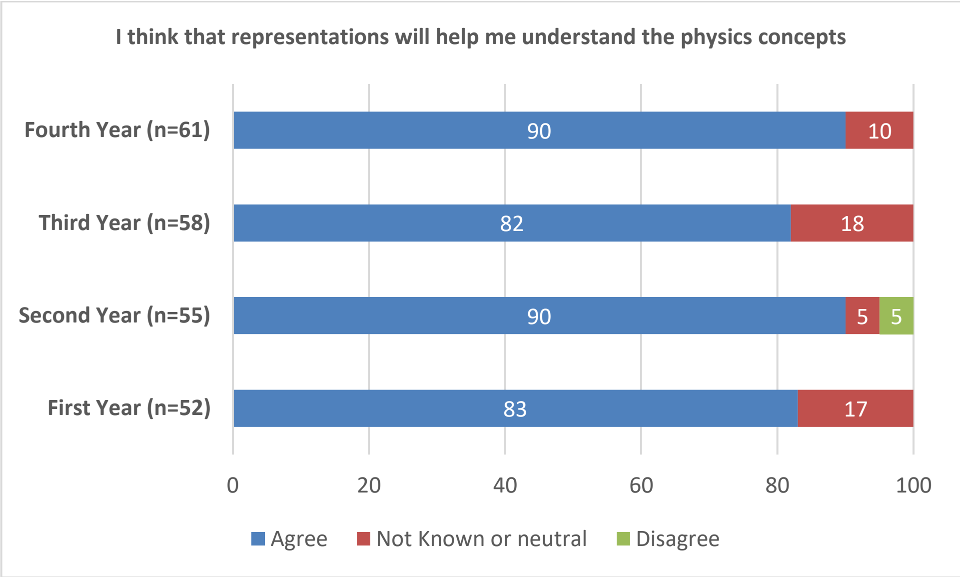


Figure 4. 8 The graph of students' percentage responses to item 5 by year-group

The percentage of student-groups' responses to item 5 is displayed in Figure 4.8. This graph shows that more than 80% of each group agreed to this statement "representations will help me to understand physics concepts". Surprisingly, no group of students disagreed with this statement, except a small percentage of the second-year group (5%). Between 5% and 18% of students had neutral views.

For item 7, about 80% of students agreed that they checked their answers while solving problems; for example, students checked the consistency of force diagrams and equations. This indicates that they were aware of their competency in transforming between representations. However, about 60% of students chose to be neutral about, or not know, whether they are good in representing physics concepts (item 6). But 30% of students were brave enough to say that they are not good at visualising information or concepts in different forms. Only 12% of students felt that they can represent concepts in multiple ways.

Regarding the use of representations presented in textbooks (item 9), 36% of students agreed that this was difficult, whereas 43% said neutral or not known, suggesting that some students might not find all representations challenging. A small percentage of students (20%) had no problem with representations presented in class and textbooks. Moreover, some students might not draw their own representations because a third of them reported struggling to understand representations while learning the course and reading textbooks (item 10). Meanwhile, 20% of students simply copied or followed instructions on how to draw representations from their teachers or textbooks.

4.3 Students' Diagrams

4.3.1 Horizontal Problem

Along with administering the problem solving survey and representation survey, force problems were given to students to explore the types of diagrams they draw. The first problem was about a box placed on a horizontal surface and students were asked to determine the mass of the box. The problem is shown below:

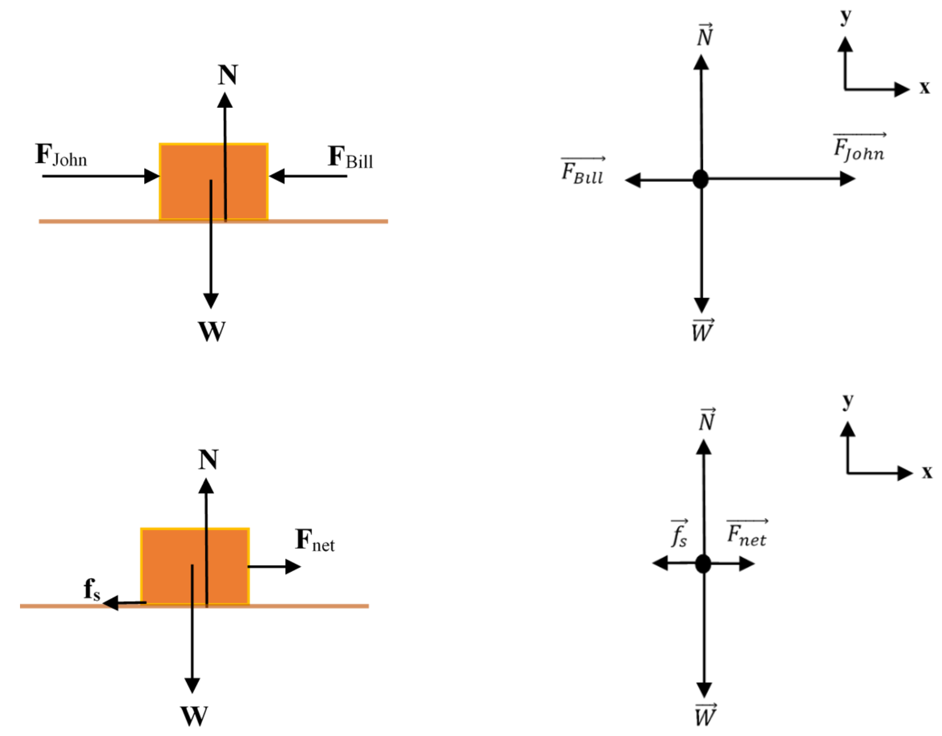
> John is pushing a box with a force of 480 N in one direction and Bill is pushing the box with a force of 340 N in the opposite direction. The box is not moving. There is a friction between the box and the floor and the coefficient of static friction is μ_s = 0.4 and the coefficient of kinetic friction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

The problem was not accompanied by pictures or diagrams, so students had the opportunity to freely draw their diagrams. The force diagrams drawn by students were coded into four different categories, shown in Table 4.3.

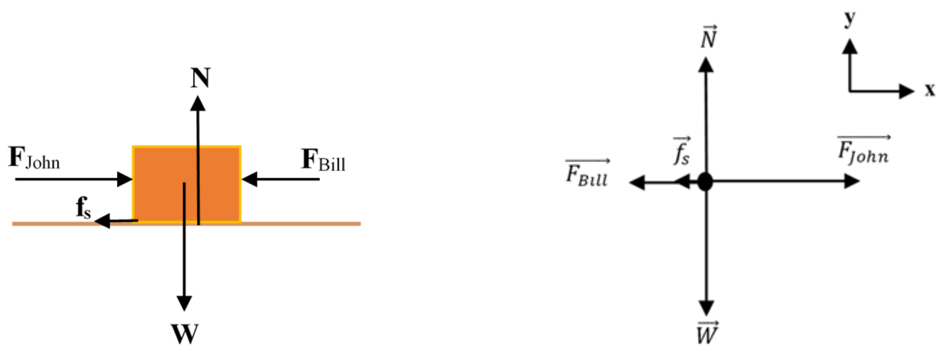
Table 4. 3 Features in grouping students' diagrams in horizontal problem

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

The ideal force diagrams that could be used to solve the horizontal problem are shown in Figure 4.9. These diagrams ideally help students to identify all forces exerted on the box, to see the direction of forces, and to determine vectorially the net force in the x-y axis. Tutors teaching this kind of representation intend to make this step easier. Due to the box not moving in the y direction, the net force is equal to zero; it means the magnitude of weight force is equal to the normal force. Moreover, the box is not also accelerating in the x direction so the total force is equal to zero. The forces exerted by John and Bill are known, so the magnitude of static friction can be determined. As the box remains at rest, it means that the static friction exerted on the object is equal to the coefficient of static friction times the normal force. Due to the normal force being already known from the magnitude of weight force, the mass of the box can be calculated.



Or



sketch and forces force diagrams

Figure 4. 9 Physics representations of the horizontal plane problem; W = force of Earth on box, N = force of surface on box (normal force), F_{John} = force of John on box, F_{Bill} = force of Bill on box, and f_s = frictional force of surface on box (static friction force)

Mathematical equation can be generated from the force diagrams above. Firstly, the net force is determined.

$$F_{net} = F_{John} - F_{Bill}$$
$$= 480N - 340N = 140N$$

The total forces exerted in the box (y direction) is determined by using Newton's First Law because the box is not moving in y direction

$$\sum F_y = N - W = 0$$

$$N = W$$

Then the total forces exerted in the box (x direction) is determined by using Newton's First Law because the box is at rest.

$$\sum F_x = F_{net} - f_s = 0$$

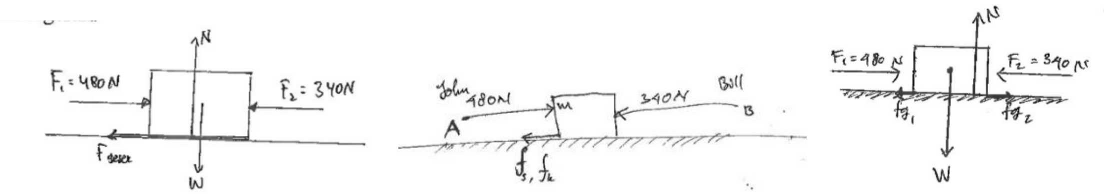
$$140N = \mu_s N$$

$$140N = \mu_s mg$$

$$140N = (0.4)(m)(10\frac{m}{s^2})$$

$$m = 35kg$$

The complete diagrams drawn by students show all forces exerted on the box, including the forces exerted by John and Bill, force of earth on box, force of surface on box (normal force and static friction force). If students did not draw one of the forces, this was categorised as an incomplete diagram. Other diagrams were categorised as inappropriate diagrams, for example where students drew two friction forces – either static or kinetic friction force – or drew forces for John and Bill in the same direction. Examples of different categories of force diagrams drawn by students are displayed in figure 4.10.



complete incomplete inappropriate

Figure 4. 10 Type of force diagrams drawn by students in solving survey problem 1

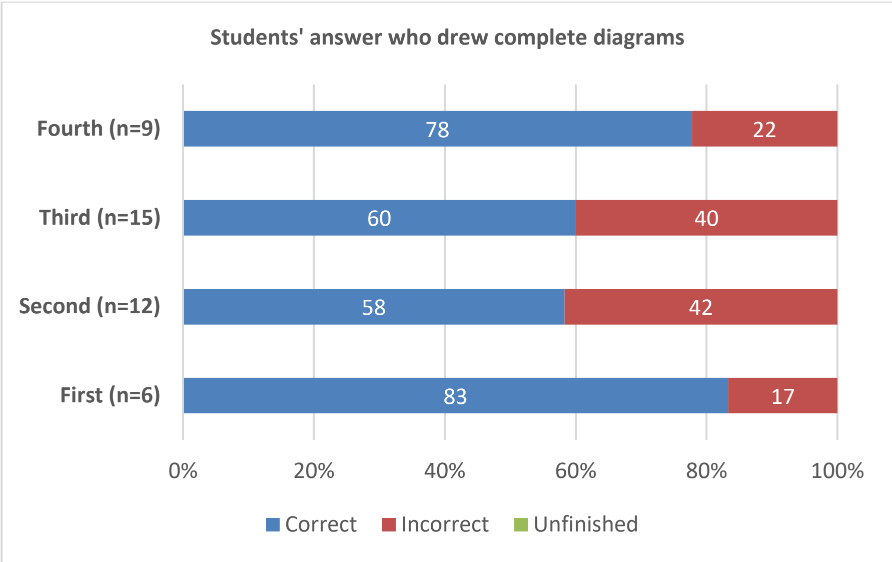
Table 4.4 displays the percentage of students who drew different categories of force diagrams while solving a force problem in the horizontal context.

Table 4. 4 The percentage of students drawing force diagrams for the horizontal problem, based on student levels

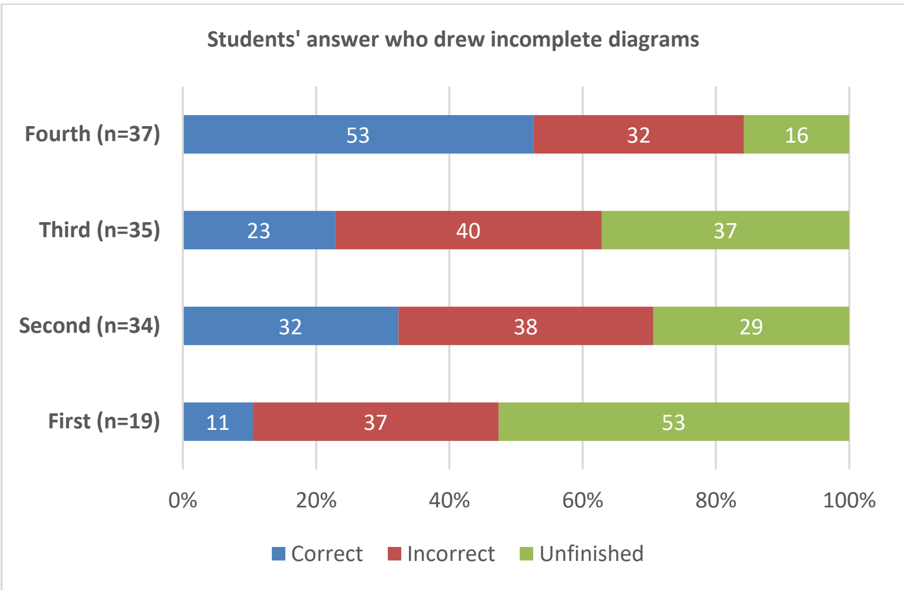
Students' Level	Type of Force Diagrams			
	Complete	Incomplete	Inappropriate	No Diagram
	%	%	%	%
Fourth Year (n = 60)	15	63	19	3
Third Year (n = 61)	23	57	13	7
Second Year (n = 55)	22	62	16	0
First Year (n = 51)	12	37	29	22

The table shows that less than a quarter of students drew complete diagrams in solving the horizontal problems. It also shows that about half of the second-, third-, and fourth-years drew incomplete diagrams. This might indicate that students with more experience in drawing diagrams and solving various problems may not need to draw complete diagrams to solve some problems; it might depend on the type of problem. Meanwhile, the number of first-year and fourth-year students drawing inappropriate diagrams – or even not providing diagrams – is higher than the number drawing complete diagrams. These students may lack practice in drawing diagrams properly, and consequently were not confident in drawing diagrams, or were reluctant to draw diagrams.

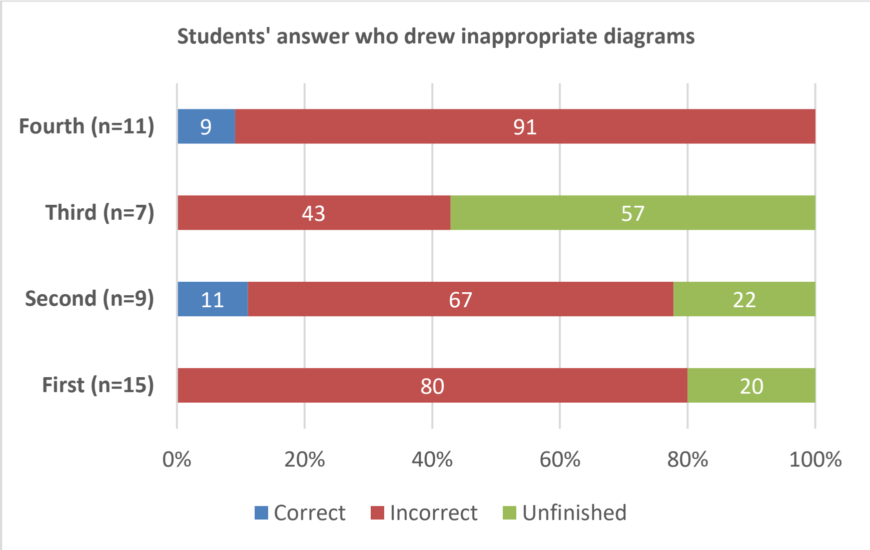
Students' answers for the horizontal plane problem were analysed based on their diagrams; the percentages of students' answer are shown in Figure 4.11. Diagram 4.11a shows that students who drew complete diagrams tended to successfully solve the problem. This indicates that drawing complete force diagrams could help students to reach correct answers. Furthermore, a higher percentage of first-year students who drew complete diagrams found the correct answer, compared to other year-groups. This group of students might take advantage of drawing diagrams – or students have actually clearly understood the problem.


Students' answer who drew complete diagrams
Fourth (n=9)
Third (n=15)
Second (n=12)
First (n=6)
78
22
60
40
58
42
83
17
0%
20%
40%
60%
80%
100%
Correct
Incorrect
Unfinished

(a)


Students' answer who drew incomplete diagrams
Fourth (n=37)
Third (n=35)
Second (n=34)
First (n=19)
53
32
16
23
40
37
32
38
29
11
37
53
0%
20%
40%
60%
80%
100%
Correct
Incorrect
Unfinished

(b)



(c)

Figure 4. 11 The percentage of students'correct, incorrect or unfinished answers who drew (a) complete diagrams, (b) incomplete diagrams, and (c) inappropriate diagrams in solving horizontal problems

An example of the work of a student who drew a complete diagram when solving survey problem 1 is shown in Figure 4.12. First, the student drew all forces exerted in the box including F push by John and F push by Bill (F_1 and F_2), normal force (N), weight force (W), and static friction force (f_s). Then s(he) determined the net force ($F_1 - F_2 = 480N – 340N = 140N$) for which is the value and direction (to the right) are correct. Then s(he) drew the second diagram in the dot to show the net force is to the right, static friction force is to the left, normal force is going up, and weight force is going down. This student used Newton First Law mathematically ($\sum F = 0$) to show that the box remains at rest and s(he) obtained the magnitude of the static friction force as equal to the magnitude of the net force ($f_s = \sum F\ (F_{net})$), and the magnitude of the normal force is equal to the magnitude of the weight force ($N = W = mg$). Then all known variables were included to the equation and the answer obtained that the magnitude of mass is 35kg. This student's solution indicates that s(he) was able to identify all forces exerted in the box and drew them correctly which seems to demonstrate and understanding of the force concepts. Then this student showed that s(he) found the net force first in order to determine the direction of static friction force. S(he) also employed Newton's Laws correctly. It seems that the second diagram helped this student to depict the net force and the static friction force.

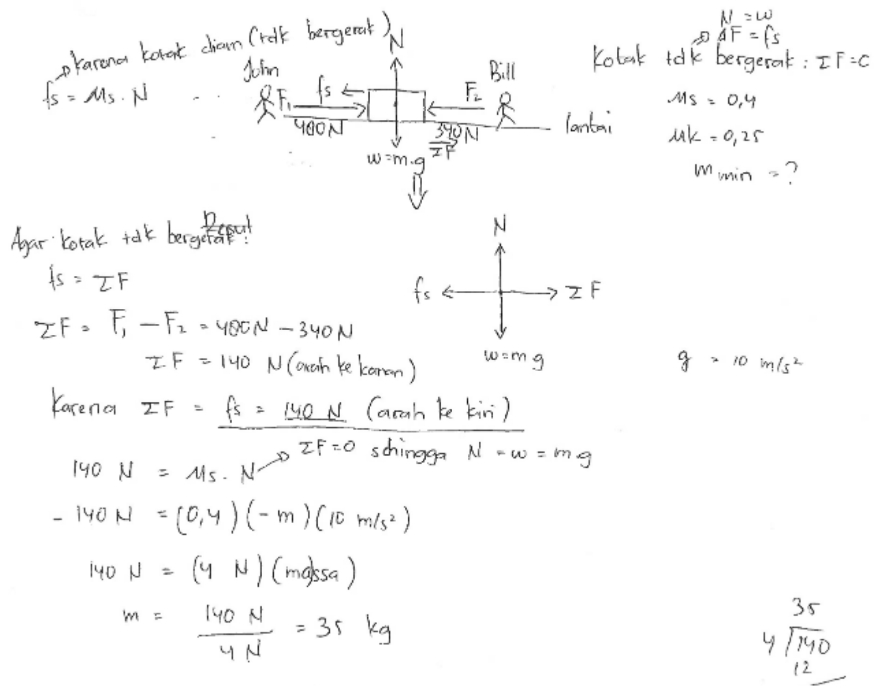
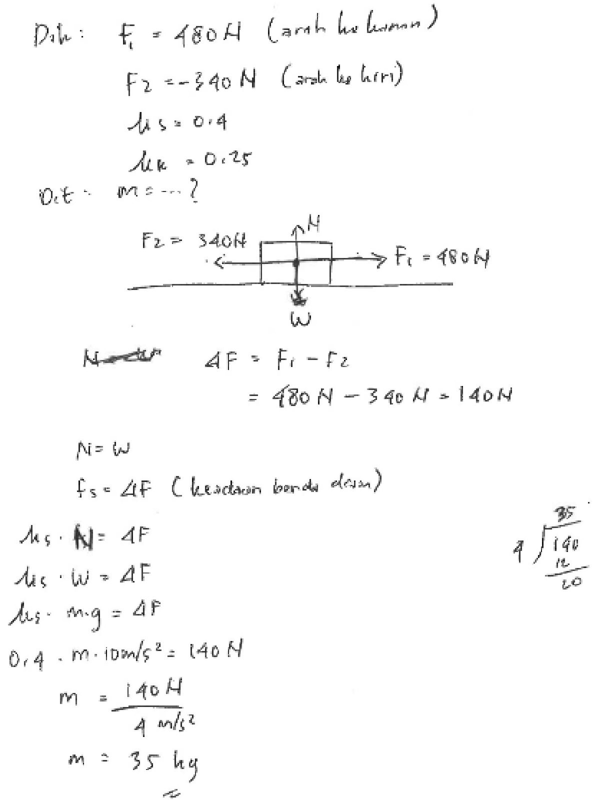


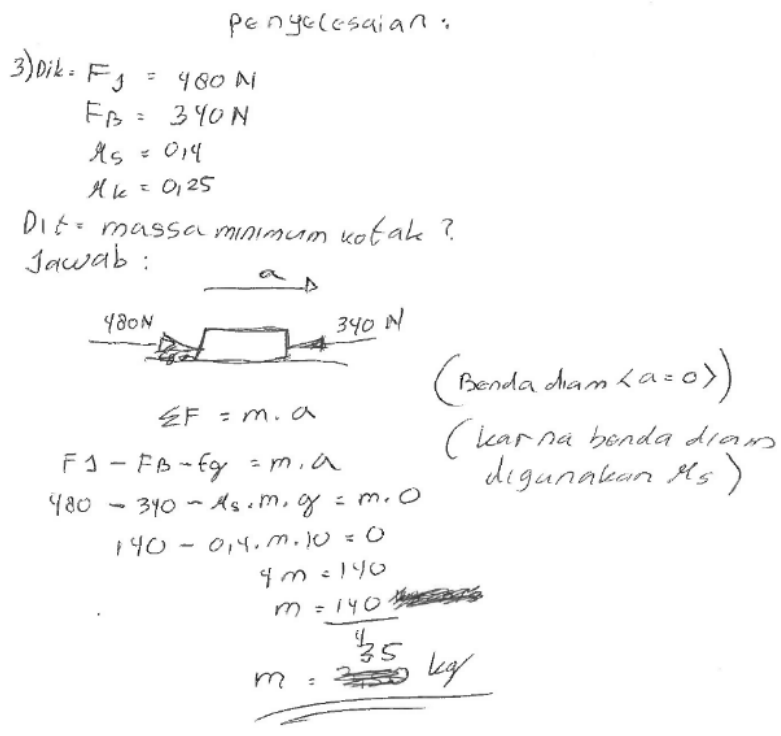
Figure 4. 12 An example of student's answer drawing complete diagrams in solving survey problem 1

When students drew incomplete diagrams, many were not able to determine the correct solution, and were unable to solve the problem. The fourth-year students who drew this kind of diagram were more successful than other groups of students in finding the correct answer. This might be because they are more experienced in solving various physics problems.

However, some students could obtain the correct solution with drawing incomplete diagrams. Two examples of students' answers who drew incomplete diagrams are shown in figure 4.13. Figure 4.13a shows a work of a student who did not draw the friction force but s(he) drew other forces exerted on the box: weight force (W), normal force (N), F push by John (F_1), and F push by Bill (F_2). After drawing diagrams, the student determined the net force ($\Delta F = F_1 - F_2$). Then s(he) wrote an equation N =W to show that the magnitude of weight force equals to the magnitude of normal force. Lastly, the student wrote $f_s = \Delta F$ to show that the box is at rest (*keadaan benda diam*) and put numbers into the equation to find out the magnitude of the mass of the box. This student's answer indicated that s(he) knew the direction of friction force is opposite to the direction of net force. The students were able to determine the net force and the friction force mathematically but s(he) visualised it in his/her mind.



(a)

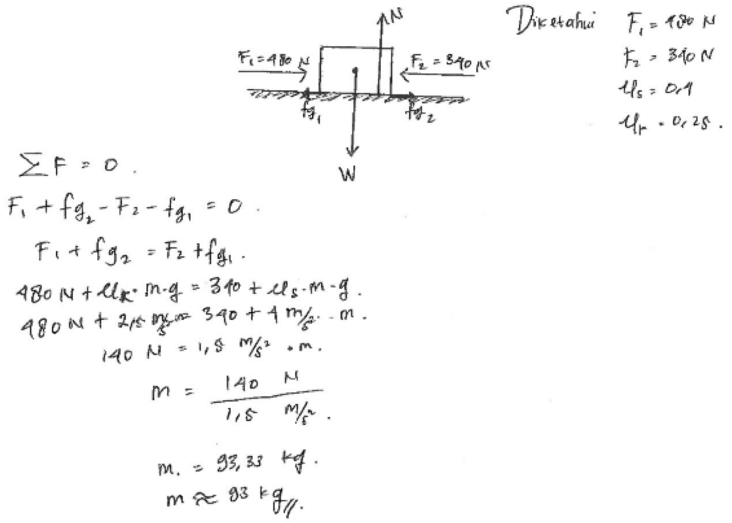


(b)

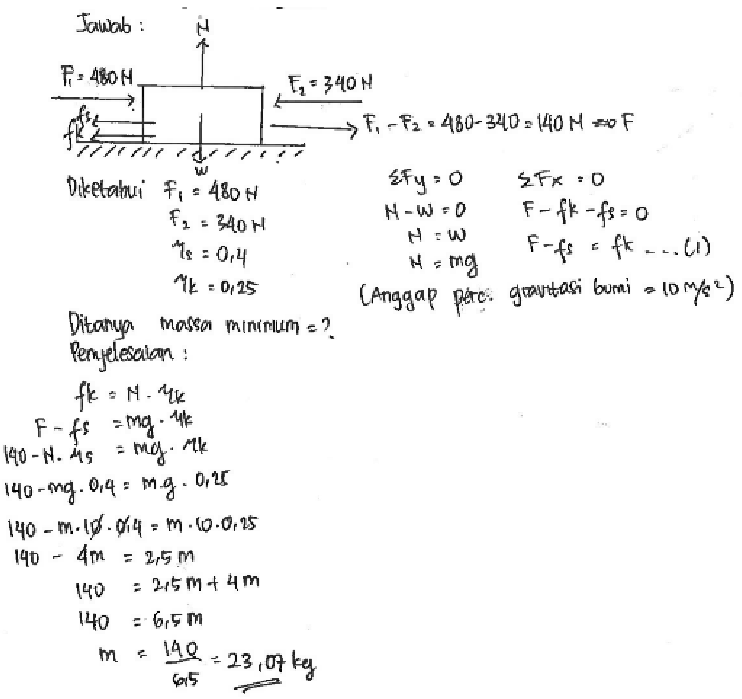
Figures 4. 13 Examples of students' answer drawing incomplete diagrams in solving survey problem 1

The student's work displayed by Figure 4.13b shows that s(he) did not draw the normal force and the weight force. This student might think that the normal force and the weight force are not needed in the calculation or the direction of these two forces exerted on an object in horizontal surface were visualised in his/her mind without displaying in diagrams. S(he) just drew three forces including F_{John} (F_J), F_{Bill} (F_B), and friction force (f_g). This student wrote a note that 'because the box is not moving so a = 0, and the coefficient static friction force (μ_s) is used. This indicates that this student knew the concepts used to solve the problem. Then s(he) wrote an equation $F_J - F_B - f_g = ma = 0$. Finally, the student put the numbers to equations to determine mass and obtained the correct answer (m = 35kg).

Inappropriate diagrams appeared not to help students to successfully solve the horizontal problem. Most of these students' answers were incorrect, and this might be caused by the diagrams leading students to use incorrect mathematical equations. It might also be that they did not understand or partially understand the physics concepts, and so could neither draw appropriate diagrams, nor solve the problem. Two examples of students' work containing diagrams that were categorised as inappropriate are displayed in Figure 4.14. The first example (Figure 14.4a) shows that this student drew forces exerted on the box including F_1 represents F_{John}, F_2 represents F_{Bill}, normal force (N), weight force (W), and two static friction forces which are different directions (f_{g1} and f_{g2}). This student indicates that s(he) has not put together the concept of net force and the friction force; the friction force exerted on the box should be only one. This student might consider that the friction force is opposite to the external forces (F_{John} and F_{Bill}). In terms of physics concept, the friction force is opposite to the net force. Even though s(he) was able to generate mathematical equation ($\sum F = 0;\ F_1 + f_{g2} - F_2 - f_{g1} = 0$) from the diagrams but according to physics concepts, the diagrams and equations were partial correct. In other words, the process was correct but the answer was incorrect.



(a)



(b)

Figure 4. 14 Examples of students' answer drawing inappropriate diagrams in solving survey problem 1

In the second example displayed in Figure 14.4b the student drew forces including F_1, F_2, W, N, and two different friction forces with the same direction – static (f_s) and kinetic (f_k). In addition, s(he) also drew the net force ($F_1 – F_2 = F$). Regarding the friction force, this student included the kinetic friction force, which was not appropriate; it should be only static friction force exerted on the box that is considered as the box is not moving. This indicates that this student partially understood the concept of friction force. Further, s(he) determined the net force in y direction ($\sum F_y = 0; N - W = 0; N = W$) and in x direction ($\sum F_x = 0; F - f_k - f_s = 0; F - f_k = f_s$). From this equation, the student put numbers to determine the magnitude of mass (m). Based on the student's answers including diagrams, concepts, and equations used in the solution, s(he) was able to translate from diagrams to equations; however, due to the inclusion of kinetic friction, the final solution was incorrect.

The types of student diagram and the mathematical equations they used were also compared, and results are displayed in Table 4.5.

Table 4. 5 The description of students' diagrams and equations

Type of diagrams	Description of diagrams	Description of equations
Incomplete	Not drawing static friction	Using static friction $f_s = \mu_s N$
		Using kinetic friction $f_k = \mu_k N$
		$\sum F = ma = F_1 - F_2 = ma$
	Not drawing normal force and weight force	$F_1 - F_2 - f_k = 0$
		$F_{John} - F_{Bill} = ma$
	Not drawing normal force, weight force and static friction force	$f_s = \mu_s N$ and $f_k = \mu_k N$
		$F_1 - F_2(\mu_s \mu_k) = mg$
		$F_1 - F_2 - f_s = \mu_s$
		$F_1 - F_2 - f_k = 0$
		Determining two masses
		$-f_k + F_{John} - F_{Bill} = ma \text{ and } -f_s + F_{John} - F_{Bill} = ma$
Inappropriate	Drawing two friction forces in the same direction	$F - f_k - f_s = 0$
	Drawing two friction forces in different direction	$\sum F = 0 = F_{John} - F_{Bill} + f_k - f_s$
	Drawing two boxes separately	Determining two masses using $f = \mu_s N$
		$F_1 - f_s = 0 \text{ and } f_s - F_2 = 0$
		$F_1 = m_1 g \text{ and } F_2 = m_2 g$
No Diagram		Using two friction force in an equation $F_1 - F_2 - W - f_k - f_s = 0$
		$F_1 - f_s = ma \text{ and } F_2 - f_k = ma$
		$\sum F = ma$
		$f = \frac{Q_1 Q_2}{\mu_s \mu_k}$

Students wrote various equations to solve the horizontal problem. Equations used by students who drew complete diagrams are not presented because most of these students successfully solved the problem. Some students who drew incomplete diagrams (not including static friction) tended to write static friction or kinetic friction equations. One possible reason for this is that students did not include friction force in their diagrams. In addition, they might memorise friction force equations to solve this problem; consequently, some of them even determined both static and friction force equations to find the mass of the box. Moreover, some students also included in their equations both static and kinetic friction coefficients at the same time.

Some students who drew inappropriate diagrams provided two friction forces (static and kinetic) in an equation because they drew two friction forces in the same direction or in different diagrams. Consequently, they came up with two different magnitudes of box mass. Some students who did not draw diagrams to solve the problem also included two friction forces in their equations, and some used static and kinetic friction equations separately. In addition, students also applied electrostatic equations to solve the problem.

4.3.2 Inclined Plane Problem

The second problem involved a box placed on an inclined plane and students were asked to determine the friction force on the box. The problem is shown below:

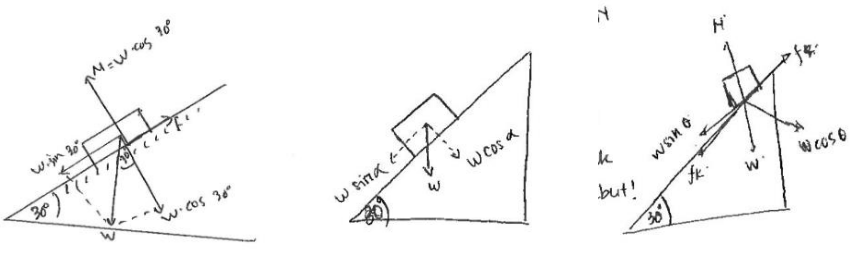
> A box which has 15000 N weight is at rest on a 30º inclined plane. The coefficient of static friction between box and the surface is 0.9 and the coefficient of kinetic friction is 0.8. Find the magnitude of friction force on the box. [Sin 30º = 0,5; Cos 30º = 0,86; Tan 30º = 0,57; gravitational acceleration = 10 m/s^2]

Students' diagrams in solving the inclined plane problem were grouped into four categories: complete, incomplete, inappropriate, and no diagram. The characteristics of each type of diagram are shown in Table 4.6.

Table 4. 6 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 force component is incorrect or - The direction of friction force is incorrect	No diagrams provided

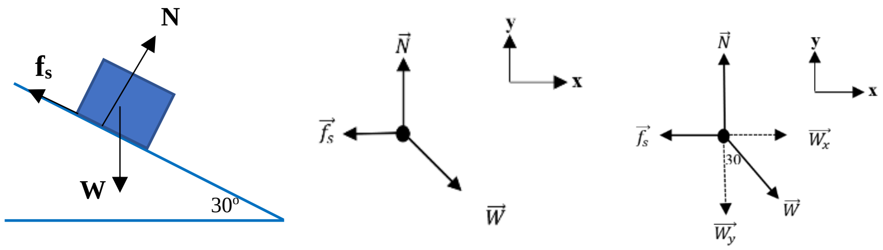
The complete diagrams include weight force, normal force, friction force, and the force component of weight force. If students did not draw one of those forces, their diagrams were classified as incomplete diagrams. However, when students drew two friction forces, and the directions of friction force, force component, and weight force were incorrect, the diagrams were categorised as inappropriate diagrams. The examples of diagrams provided by students to solve the inclined plane problem are displayed in Figure 4.15.



Complete Incomplete Inappropriate

Figure 4. 15 Type of force diagrams drawn by students in solving survey problem 2

The ideal force diagrams utilised to solve the incline problem are shown in Figure 4.16. As the problem was not initially presented with a picture or sketch, students could draw a sketch to visualise the problem and identify all forces exerting in the box. The next step is drawing all forces, including weight force, normal force, and static friction force. Due to the box being on an inclined plane, students need to draw the weight force components as a means of helping to find the net force in the x-y axis. The problem stated that the box is at rest; students focus on the x-axis because the static friction is on that axis.



sketch and forces force diagrams force component

Figure 4. 16 Physics representations of the inclined plane problem

By implementing Newton’s first law, students can determine the magnitude of static friction. Due to the box not moving in the y-axis, the net force is equal to zero. Therefore, the magnitude of normal force is equal to the magnitude of the component of weight force in the y-axis. The component of weight force in the x and y axes can be determined by implementing trigonometry concepts. Subsequently, by focusing on the box remaining at rest and on all forces in the x-axis, the magnitude of weight force in the x-axis is equal to the magnitude of static friction. From the force component

$$\sum F_x = 0$$
$$f_s - W_x = 0$$
$$f_s = W_x$$
$$f_s = m\ g\ sin\ 30^0$$
$$f_s = (15000\ N)(0.5)$$
$$f_s = 7500\ N$$

The number of students drawing force diagrams while solving the incline problem is exhibited in Table 4.7. It can be seen from the table that most students (first- and fourth-years) drew incomplete rather than complete or inappropriate diagrams. However, these groups have a higher percentage who did not draw diagrams at all, especially the first-year students. Some of the fourth-year students may think that they do not need to draw complete diagrams – or even draw diagrams at all – to solve this kind of problem because it is sufficiently familiar to them. As for the first-year students, some may lack the knowledge to draw diagrams, so they drew incomplete diagrams, or none at all.

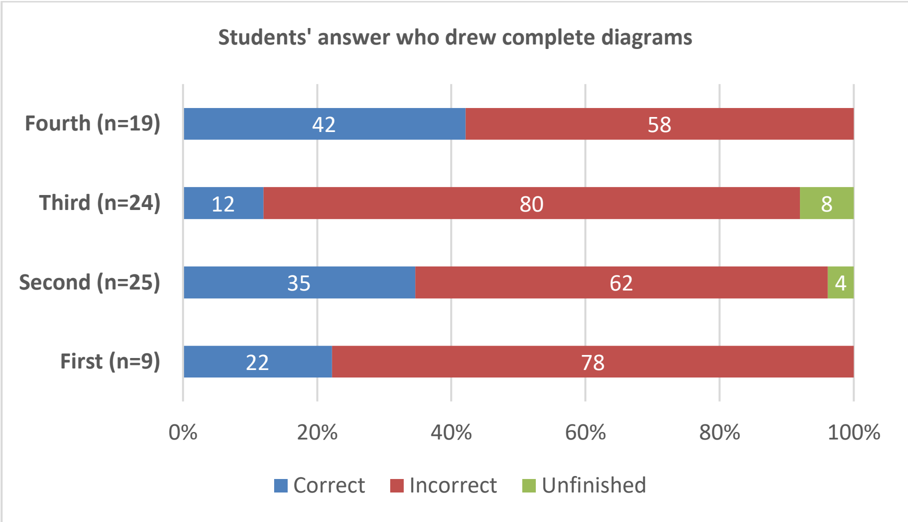
Table 4. 7 Types of force diagrams, based on students' levels, for the inclined plane problem

Students' Level	Type of Force Diagrams			
	Complete	Incomplete	Inappropriate	No Diagram
	%	%	%	%
Fourth Year (n = 60)	31	48	8	13
Third Year (n = 59)	41	32	15	12
Second Year (n = 55)	47	36	13	4
First Year (n = 52)	19	54	6	23

More students drew complete diagrams for the incline problem than for the horizontal problem. This might be because students needed to determine the component of weight force to solve the incline problem, and therefore required complete diagrams.

The percentage of first-year students drawing complete diagrams is the lowest for both problems, compared to other groups of students.

Figure 4.17 shows the relationship between the type of students' diagram and students' final answers for the inclined plane problem. From the diagrams, it can be seen that students who drew complete diagrams, have more correct answers than do students who drew incomplete diagrams. Students who drew inappropriate diagrams could not successfully find the correct answers, and they could not completely solve the problem.



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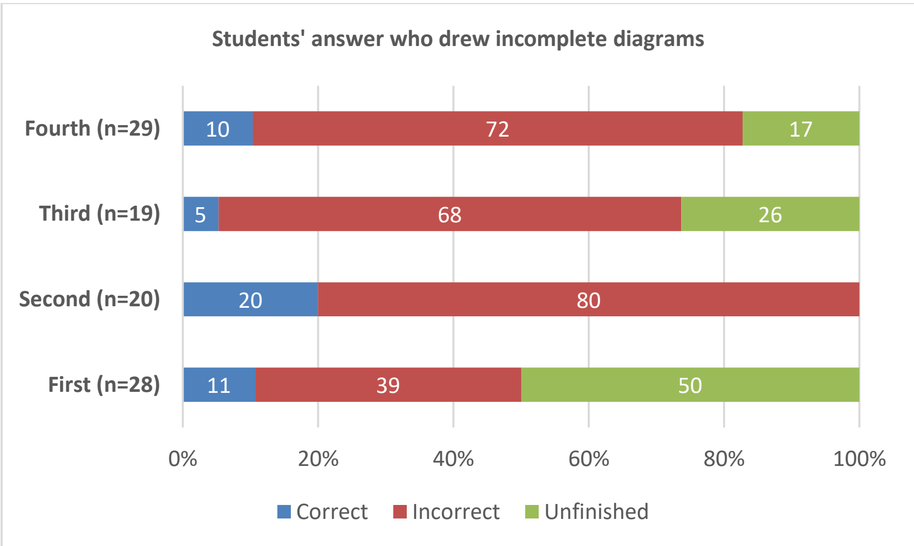

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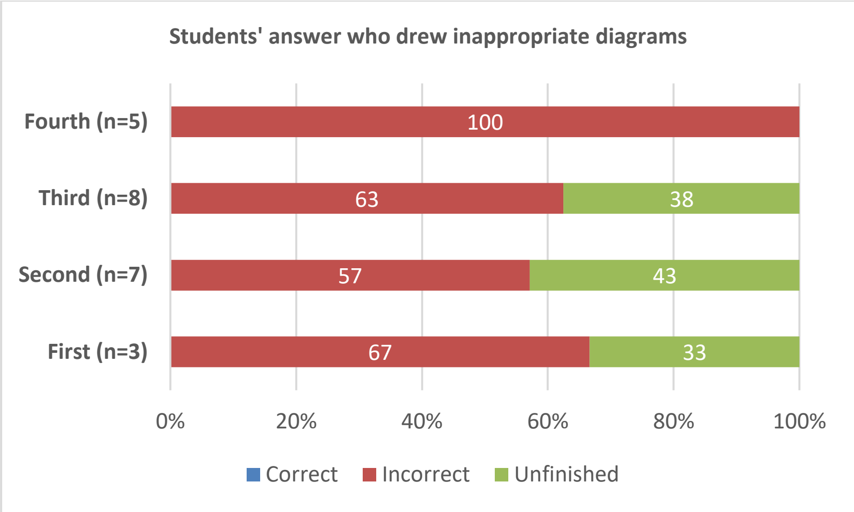
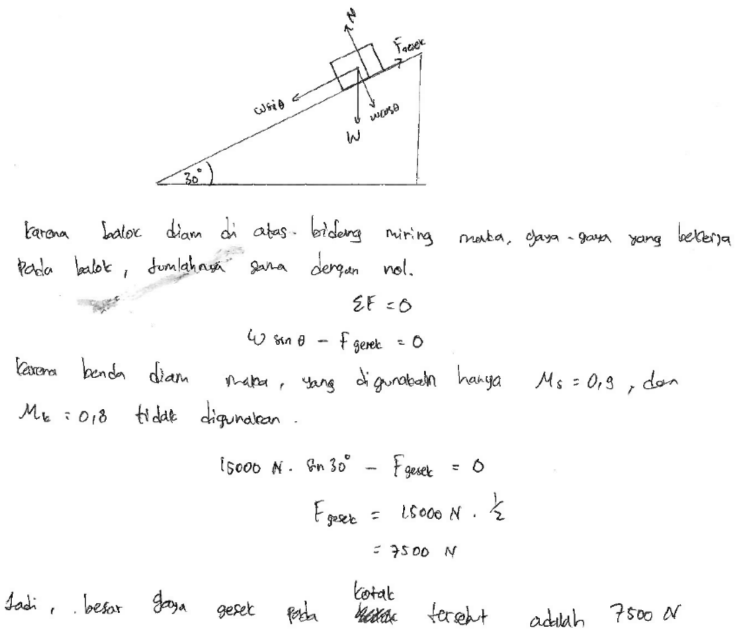


(c)

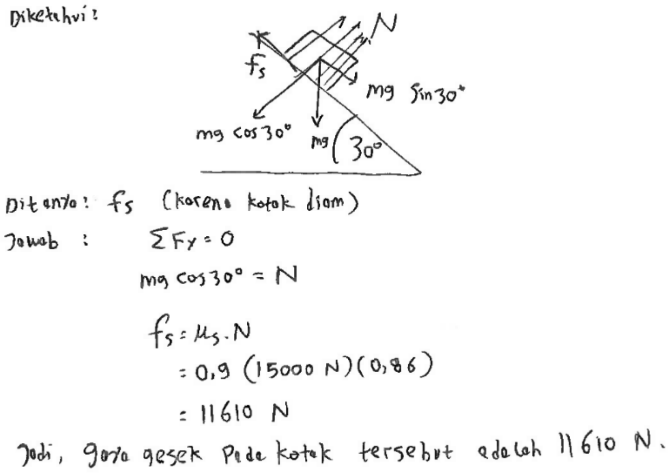
Figure 4. 17 The percentage of students' correct, incorrect or unfinished answers who drew (a) complete diagrams, (b) incomplete diagrams, and (c) inappropriate diagrams in solving inclined planed problems

Two examples of students' work who drew complete diagrams when solving survey problem 2 (inclined plane context) are shown in Figure 4.18. In Figure 4.18a, a student drew all forces including N, W, and friction force; s(he) also drew the component of W in x direction (W sin θ) and in y direction (W cos θ). All forces are correct in terms of position and direction. After that, the student expressed his/her understanding about the problem by writing "the box is at rest, so the total force exerted in the object is equal to zero". S(he) wrote mathematically $\sum F = 0; W \sin\theta - f_{ges} = 0$) ($f_{ges}$ is static friction force). Then the student recognised the friction force used in this problem, s(he) wrote that "as the box is not moving, so the coefficient of static friction force is used ($\mu_s = 0.9$). Finally, s(he) wrote down the previous equation and put numbers into it and determined the magnitude of static friction force (f_s) is 7500N. From this student's answer, it can be seen the student had enough understanding about force concepts and knew when Newton's Laws were used. Then a mathematical equation was generated from the diagrams.

Meanwhile, in the second example (Figure 4.18b), a student drew all forces correctly including the component of weight force (mg sin 30^o and mg cos 30^o). After drawing diagrams, s(he) wrote down two equations. the first is $\sum F_y = 0; mg\cos 30^0 = N$; this equation was generated from the diagram and described that the magnitude of normal force is equal to the magnitude of the component of weight force is y direction. The second equation is $f_s = \mu N$; this equation was not derived from diagrams but s(he) might be familiar with this equation about friction force and memorised it. In fact, this equation will be appropriate, if an object is almost moving. In this case, the student might think that the equation written is applied for all situation: an object is at rest and it is almost moving. This student seemed more focus on the equation instead of relating to the diagram.



(a)



(b)

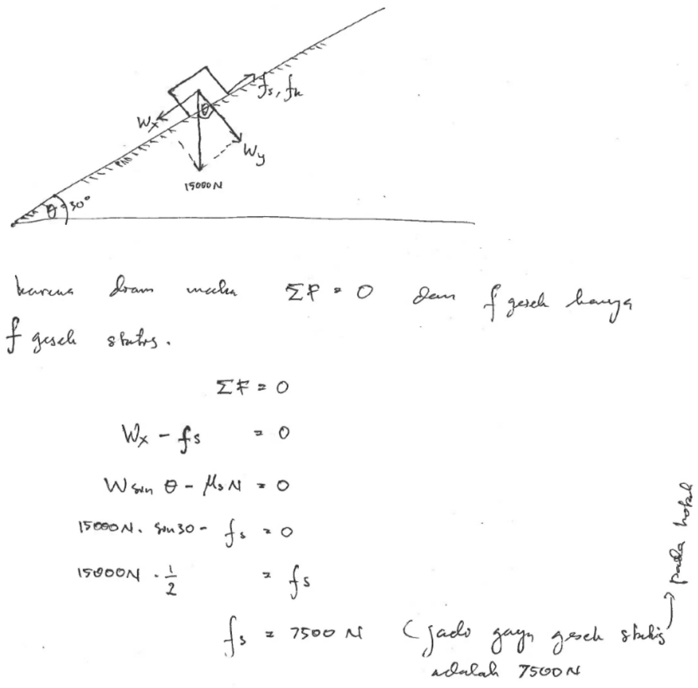
Figure 4. 18 Examples of student answer drawing complete diagrams in solving survey problem 2

Figure 4.19 shows two examples of students' solution in solving survey problem 2 who drew incomplete diagrams but obtained different final answers. In the first example (figure 4.19(a)), the student did not draw the normal force but depicted the weight force, including its component, and the friction force. This student wrote a statement "because the box is at rest so $\sum F = 0$ and static friction force is exerted on the box". This student indicates that s(he) knew the concept and Newton's Laws used to solve this problem. Then s(he) was able to write down Newton's First Law mathematically

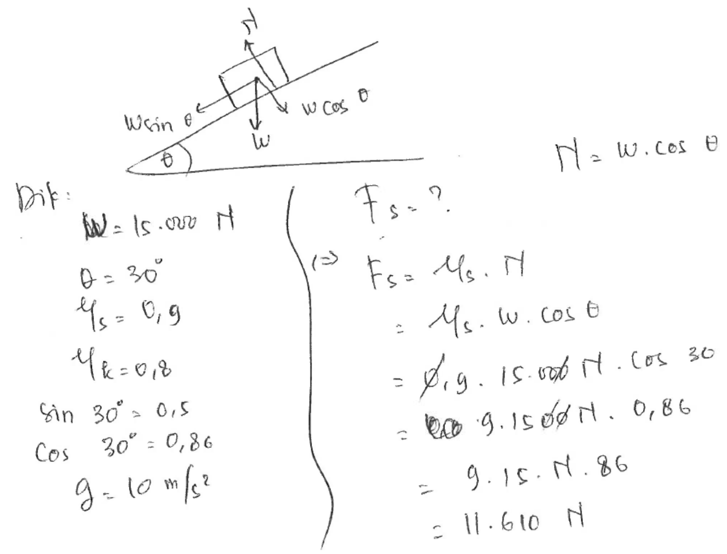
$$\sum F = 0$$
$$W_x - f_s = 0$$
$$W \sin\theta - \mu_s N = 0$$
$$15000 \sin 30 - f_s = 0$$
$$f_s = 7500N$$

According to equations above, the student wrote $\mu_s N$ then went back to f_s. This shows that the student fully understood the purpose of question. Moreover, based on his/her diagrams, this student did not draw normal force because s(he) might know that it was not used in the equation or might know the direction of the normal force without depicting it in diagram.

However, in the second example (Figure 4.19(b)), the student did not draw the friction force but included the normal force (N), the weight force (W) with its component (W sin θ and W cos θ). Based on the student' work, s(he) wrote the static friction force equation ($F_s = \mu_s N$) after drawing diagrams and identifying known variables. This indicates that this student used her diagrams to show the normal force (N) is equal to the component of weight force in y direction (mathematically: N = W cos θ). But s(he) did not employ the diagrams to produce an equation of total force in x direction which is static friction force exerted on the box. Instead, this student wrote directly a common equation of friction force ($f_s = \mu_s N$) which is not appropriate in this problem.



(a)



(b)

Figure 4. 19 Examples of students' answers drawing incomplete diagrams in solving survey problem 2

Two examples of students' work (Figure 4.20) who drew inappropriate diagrams while solving survey problem 2 show that the solutions are incorrect and one of those is unfinished. The first example (Figure 4.20a) shows that the student first drew forces including normal force (N), weight force (W) and its component (W cos 30^o and W sin

30°), and two friction forces: static friction force (f_s) and kinetic friction force (f_k). Then s(he) drew the direction of acceleration (a) of the box. The student seems to misunderstand the problem or lack of knowledge about the friction force that is why they have drawing two friction forces. S(he) drew two friction forces: static and kinetic friction force (f_s and f_k). In addition, drawing the direction of a (acceleration) means that the box would be moving which the problem states that it is not. Further, s(he) produced an equation from his/her diagram to determine the total force in y direction ($\sum F_y = 0; N - W \cos 30^0 = 0$); this equation is correct and matched to the diagrams. Then s(he) wrote an equation to determine the total force in x direction:

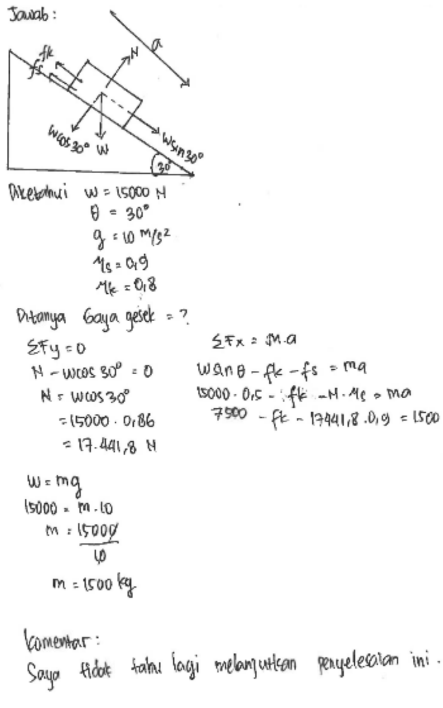
$$\sum F_x = m\,a$$

$$W \sin\theta - f_s - f_k = m\,a$$

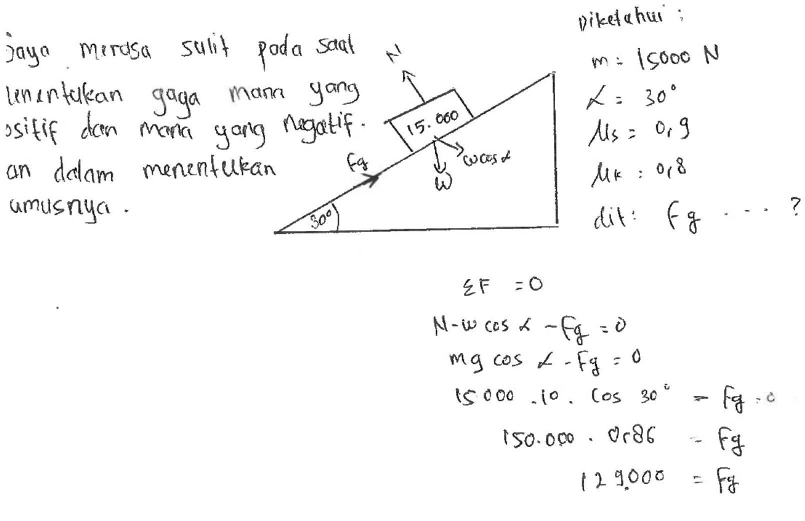
Mathematically, these equations are matched to the diagrams but in terms of physics those are incorrect because of drawing two friction forces in the box. At the end of his/her work, there is a note "I don't know how to proceed this". This student seems struggling while solving this problem.

In the second example (Figure 4.20b), the student seems to lack knowledge in drawing diagrams because s(he) drew forces with incorrect directions. For example, the position of the friction force (f_g) is not in the box and the direction of W cos α is incorrect. To find the solution, s(he) wrote equations: $\sum F = 0; N - W \cos\alpha - f_g = 0$.

This student mixed all variables in one equation without considering the position of forces whether in x- or y-axis. This student seems to be facing difficulties in solving this problem. This is supported by his/her note on the left "I feel difficulties to determine which forces are positive or negative and to select the formula". From this statement, this student had not fully understood the concept of friction force and how to manipulate vectors.



(a)



(b)

Figure 4. 20 Examples of students' answers drawing inappropriate diagrams in solving survey problem 2

The equations used by students to solve the inclined plane problem were varied. Some who drew incomplete diagrams used either static friction force equations or kinetic friction force equations, or even used both equations. These students were not able to distinguish between static friction and kinetic friction. Students might lack knowledge about the concept of friction forces; therefore, they directly wrote friction force equations based on their understanding. Moreover, students who did not draw friction force in their diagrams, tended to write static or kinetic friction force equations.

The inappropriate diagrams drawn by students may affect their equations. For example, students who drew two different friction forces included static and kinetic friction force in one equation. Then students also determined the magnitude of each friction force. This indicates that students did not completely understand when to use static and kinetic friction forces. Furthermore, without drawing diagrams in solving the inclined plane problem, students seemed to lack the ability to solve the problem successfully. It can be seen from Table 4.8 that students wrote irrelevant equations such as including all forces in the x- and y-axes in one equation.

Table 4. 8 The description of students' diagrams and equations

Type of diagrams	Description of diagrams	Description of equations
Incomplete	Not drawing static friction force	$f_s = \mu_s N = \mu_s\, mg \cos 30^o$
		$f_s = \mu_s N = \mu_s\, mg \cos 30^o$ and $f_k = \mu_k N = \mu_k\, mg \cos 30^o$
	Not drawing normal force	$f(\mu_s + \mu_k) = mg \sin 30^o$
		$f_s = \mu_s\, mg$
	Not drawing the component of weight force	$W - f\ Sin\ 30^o = 0$
		$f_k = \mu_k N + W \sin 30^o - N$
		$f_s = \mu_s N = mg \cos 30^o$
Inappropriate	Drawing two friction forces in the same direction	$W \sin\theta - f_k - f_s = ma$
	Drawing two friction forces in the different direction	$f_s = \mu_s N = \mu_s\, mg \cos 30^o$ and $f_k = \mu_k N = \mu_k\, mg \cos 30^o$
	Drawing incorrect weight force component	$N + \sin\theta - W = ma$
No Diagram		$F - W \cos\theta - f_s - f_k = 0$
		$W\ f = ma$
		$\sum F_x = ma = F - W \sin 30^0$
		$W \cos\theta\ f_s = ma$
		$f_s = \mu_s N = \mu_s\, mg \cos 30^o$

4.4 Summary

Students' responses from the problem solving and representation survey and students' diagrams from survey problems have been described in this chapter. Based on the problem solving survey, a half of students responded that they enjoy solving physics problems. Then most students agreed that mathematical knowledge is the most important thing in the physics problem solving. Students' responses from representation survey indicated that many students often used representations such as pictures, diagrams, graphs, etc., while solving problems and they use it to make problems are easier and to help them finding the correct answers. Students' diagrams while solving survey problems were grouped into three categories: complete, incomplete, and inappropriate diagrams. Students' who drew complete diagrams tended to obtain the correct answers. Even though students drew incomplete diagrams, some of them could solve the problems correctly. Meanwhile, students who drew inappropriate diagrams indicated that they were facing difficulties and tended to get incorrect answers; it might be because lack of physics knowledge or having partial understanding about physics concepts.

CHAPTER 5
QUALITATIVE FINDINGS (STUDENTS' VIEWS ABOUT FORCE DIAGRAMS)

The previous chapter has discussed students' views about representations and problem solving based on quantitative survey data and the types of representations drawn by students while solving two force problems. In this chapter, students' views about force diagrams obtained from individual and paired interviews are explored in more detail.

5.1 General Overview of Students' Views

The semi-structured interviews were conducted to explore in detail students' reason and motivation for drawing force diagrams while working on problems. The purpose of the interviews was to answer the research question *in what ways do students think about, draw and use force diagrams as they solve physics problems?*

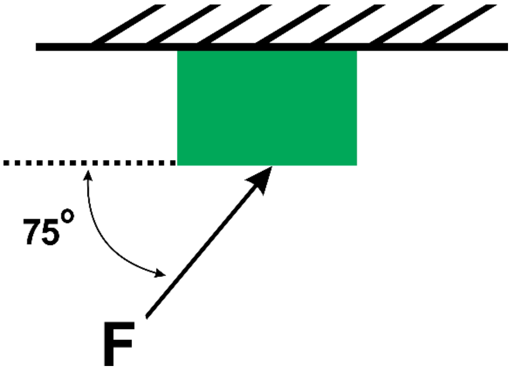
The individual interviews involving 28 students were conducted first and took about one hour each. I asked questions during interviews based on students' performance in solving the problems. Before the interviews began, students were asked to solve force problems individually, which were different from the previous problems in the survey questions but using the same context of horizontal and inclined surfaces. Those problems were intended to allow me to observe the process of solving the problems, including how students drew force diagrams. The activities of solving the problems were recorded by using tools - Livescribe. The tools consist of a pen and a workbook where each of the students wrote their answers in the workbook by using the pen. The tools were connected to smartphone via Bluetooth to enable recording the data.

Later, paired interviews, involving 16 students (eight pairs) from the group of students in the individual interviews, were carried out to elicit students' comments about force diagrams drawn by other students. This interview gave students the chance to compare their diagrams with others and to evaluate students' work. In addition, this interview also gave opportunities for students to express their understanding of the problems, the concepts, and the way they solved the problems. Each pair of students interviewed was given various students' work obtained from the survey questions (described in Chapter 4). The average length of each paired interview was also about one hour.

These two force problems were given during individual interviews. The first question examined students' understanding about the forces exerted on an object placed below a horizontal surface and its motion. Meanwhile, assessing students' understanding about forces exerted on a car placed an inclined surface was asked in the second question.

Q1. A block (mass 12.0 kg) is held against the ceiling by a force F = 160 N at an angle of 75^o 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].

c. Determine the normal force exerted by the ceiling on the block
d. Determine whether the block is accelerating along the ceiling, and, if it is, calculate the numerical value of the acceleration



Q2. A car which weighs 15,000 N is at rest on a frictionless 30^o incline as shown. The car is held in place by a light strong cable (T) parallel to 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].

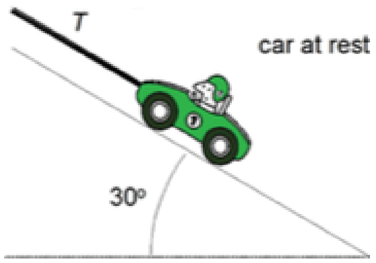


Figure 5. 1 Questions during individual interviews

All interviews were transcribed then analysed by computer software (NVivo). The reason for using this software is to help in analysing verbal data and finding the pattern of students' responses as a means of identifying themes of students' views. The process of coding has several steps to find all themes. First, each individual interview or paired interview (students' responses) was transcribed into written form in the Indonesian version. Students' diagrams were also included in the process of coding. Second, the data then were coded to find the patterns such as the similarities and differences of students' comments. I and my colleague (postgraduate researcher in science education) did the same coding for one of participants' responses as a means of conducting the reliability of the data analysis process. We then discussed the similarities and differences in our codes. After reaching an agreement, I continued to code the rest of the transcripts. Third, after obtaining the final codes, I translated all codes into English. Then students' responses relating to all codes were also translated into English. Finally, all codes were grouped to determine several themes.

The summary of students' perceptions or views about drawing force diagrams is displayed in Table 5.1. The order of the themes presented in the table shows the most frequent said by students. Students' purposes for drawing force diagrams is the most common.

Table 5. 1 Themes of students' views about drawing force diagrams

Themes	Sub-themes	Description
Purposes	To identify forces To determine the component of forces To find the direction and sign 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.
External Reasons	Learning in high school Obtaining credit from instructor	There are some factors that influenced students to draw force diagrams not directly related to their work on the problem.
Conventions	The label of forces Drawing in the object Drawing in the dot Drawing dotted line	Students were concerned about the forces such as accepted ways of drawing the diagrams, how to symbolise the forces and the effect of drawing forces in the object or in the coordinate *x-y*.
Physics Concepts	Forces Newton's Laws	Concepts which include the concept of forces and Newton's laws are mentioned by students as the aspects of drawing force diagrams.
Mathematical Concepts	Vector Trigonometry	Besides physics concepts, mathematical concepts are also important in drawing force diagrams
Using incomplete diagrams	-	Students drew incomplete diagrams for several reasons

5.2 Purposes

5.2.1 Identifying Forces

The first theme of the students' views about drawing diagrams was categorised as 'purposes'. One of the sub-themes of the purposes is to identify forces. Almost all students mentioned that drawing complete, incomplete, or inappropriate force diagrams helped them to identify forces exerted on an object. One of the interviewees, Maria (a third-year student) said,

> *"I have drawn all forces then I looked at the variable that will be determined. So, I checked the position of the normal force whether in x- or y-axis. As that is in the y-axis, I looked for forces in y-axis. Moreover, to find out the magnitude of acceleration, due to the same direction with x-axis, I searched all forces in x-axis."*

Based on her statement, her force diagrams helped her to identify forces in *x*- and *y*-directions. Knowing the position of normal force might be easier for her to determine its magnitude.

Zack, as a first-year student, mentioned his purpose to draw force diagrams.

> *Zack: the aim of the first diagrams is to draw all forces exerted on the block and drawing the second diagrams is to know what forces exerting in x and y axis.* (this statement came from individual interview).

When he solved the first question (Q1), he drew all forces first on the block, and then drew forces in vertical and horizontal directions (Figure 5.2). 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^o), and the component of F in *y* direction (F sin 75^o). Zack knew that the normal force is in the *y*-axis, so he focused on the diagrams in vertical direction including normal force, 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 in *x*-axis and focused on all forces in *x*-axis: the component of F and the kinetic friction force. Subsequently, he redrew the diagrams in *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 found the magnitude of the normal force and the magnitude of the acceleration of the block. His work indicated that he drew force diagrams to guide him to look at all forces exerted on the object and identify what forces are in *x*- or *y*-axis.

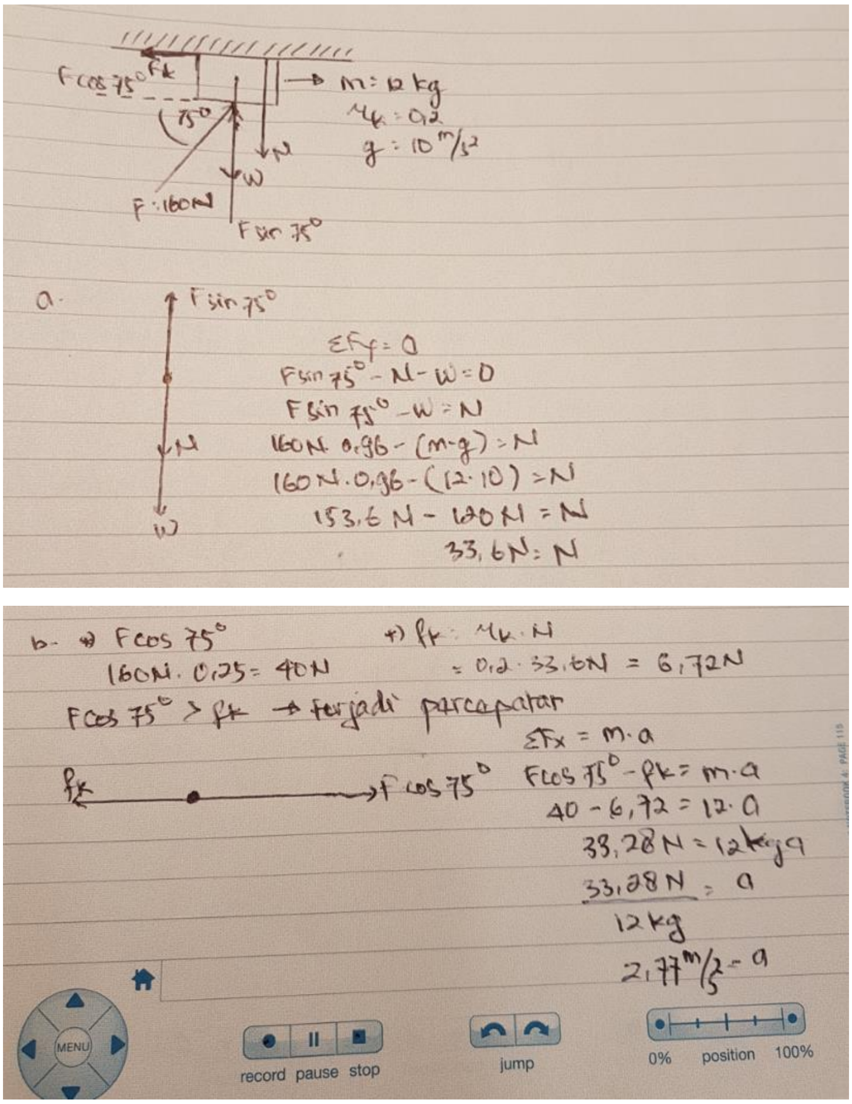


Figure 5. 2 Zack's work solving interview problem 1

Another student (Jane is a first-year student) mentioned the following:

Jane: the reason drawing force diagrams is to see easily and distinguish what forces exerted in x- and y-axis then it is helpful to determine the component of forces

This statement is similar to Zack's reason. Jane added, "If I did not draw all forces, it made me difficulties to see what forces in *x*- and *y*-xis." Her steps in drawing forces solving Q1 could be seen from Livescribe application and depicted in Figure 5.3. She began by drawing weight force (W), and then followed by normal force (N). Then, Jane drew the components of F in *x* and *y* directions. Finally, she drew the friction force exerted on the block by symbolising it with f_g.

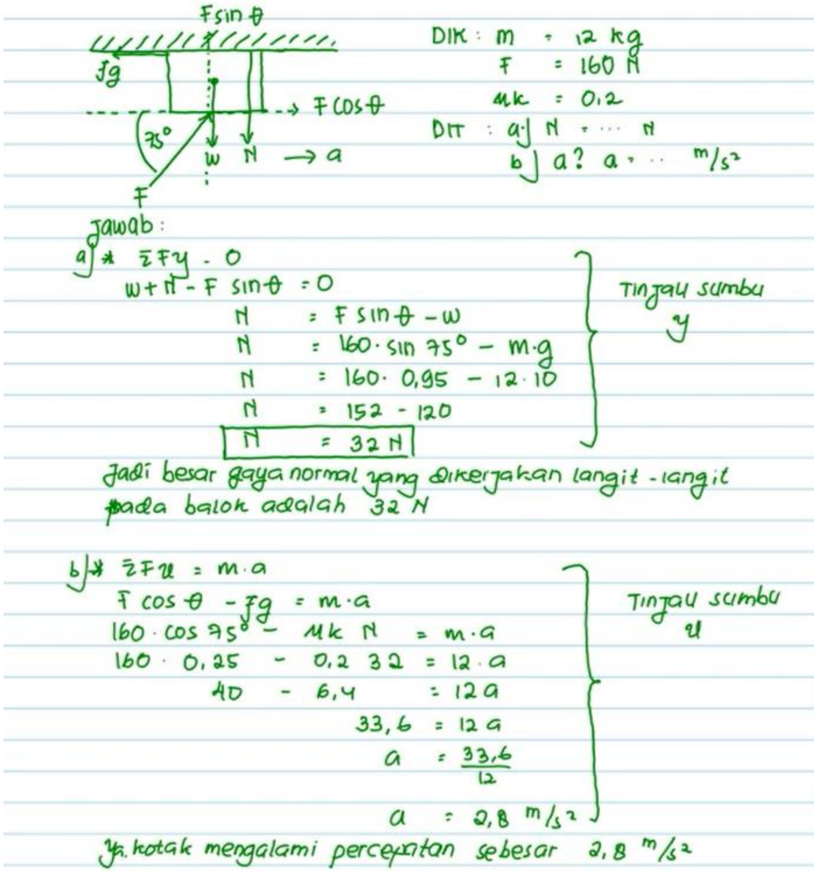


Figure 5. 3 Jane's work solving interview problem 1

Jane's work indicated that she was confident while drawing all forces (complete diagrams) and writing equations. When I asked her to clarify her procedures in solving the first problem, she felt more confident. Jane explained the process of solving Q1 as shown below.

> *Researcher: Would you explain briefly the process of solving this problem?*
> *Jane: If I came across a problem like this, I usually draw forces exerted on the object. So, here I draw all forces, there are W which is always going down to Earth then drawing normal force which is always perpendicular to the plane. After that, there is also friction force which is opposite direction with the motion of the object. Here, there is also a force pushed the block with the angle is 75°, so we must find the component of that force in x- and y-axis. Because the problem asking the magnitude of the normal force exerted on the block, we focus the normal force on y axis. Thus, we can see all forces exerting in y axis: W, N, and F sin θ. Then, to find out the acceleration of the block, we focus all forces on x axis: F cos θ and friction force.*

From her statement and diagrams above, her motivation to draw force diagrams was to help her identify all forces exerted on the object before analysing the components of forces and finding the solution.

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 to remind her to look in more detail at all forces exerted on the block. Amy drew all forces, but one of the forces (normal forces) was in an incorrect direction; her diagrams are categorised as inappropriate diagrams. 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 forces exerted on the block.

Amy: at the beginning, I thought the direction of N is similar to the direction of W but after drawing the diagrams it seems there is another force which is similar to direction with N.

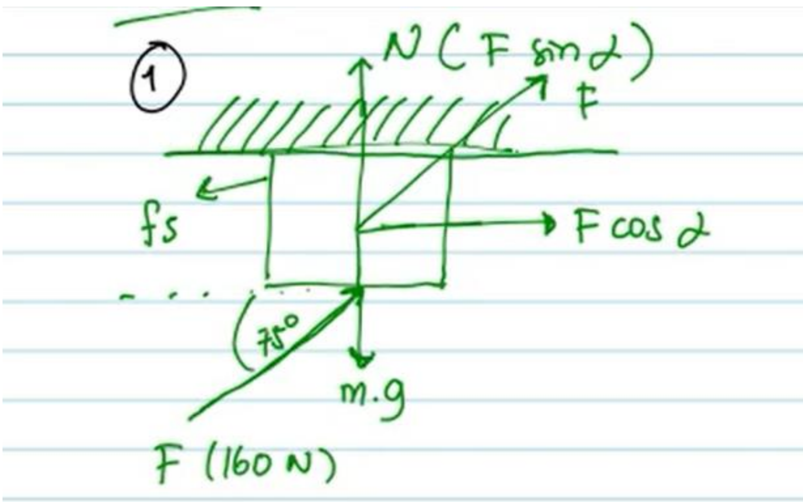


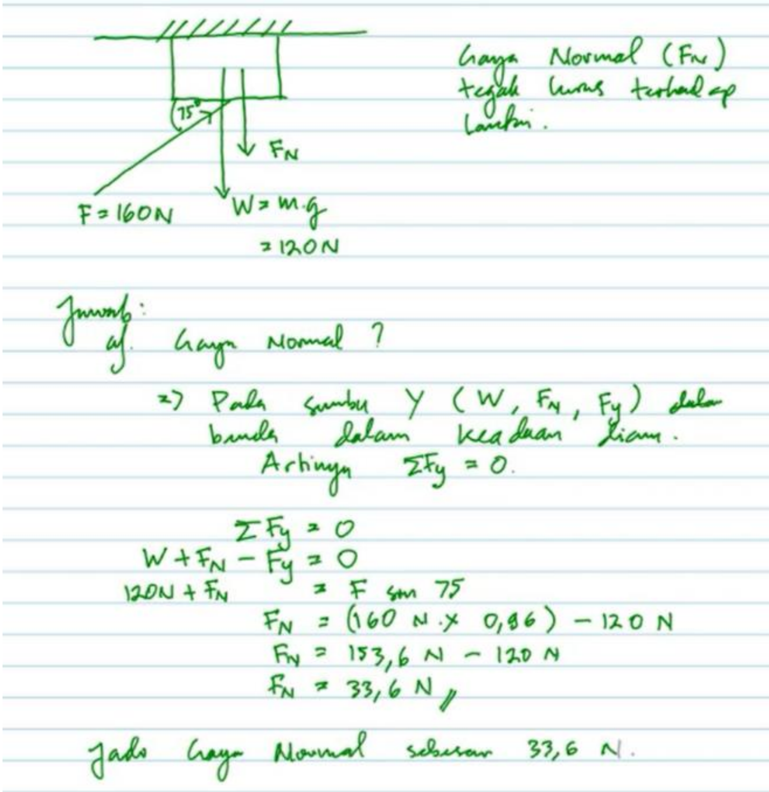
Figure 5. 4 Amy’s work solving interview problem 1

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

Researcher: So, what is your purpose in drawing this kind of diagrams?
Steve: To help me analysing forces exert on the block even though my diagrams are not complete.
Researcher: What does analysing mean here?
Steve: To know all forces

Researcher: How about if you don't draw force diagrams?
Steve: If I don't draw, actually, I could, but the diagrams help me to analyse and recall forces.

Based on the conversation and his diagrams, Steve recognised that drawing diagrams enabled him to know all forces being exerted on the block and analyse all forces. His work in solving Q1 is presented in Figure 5.5.



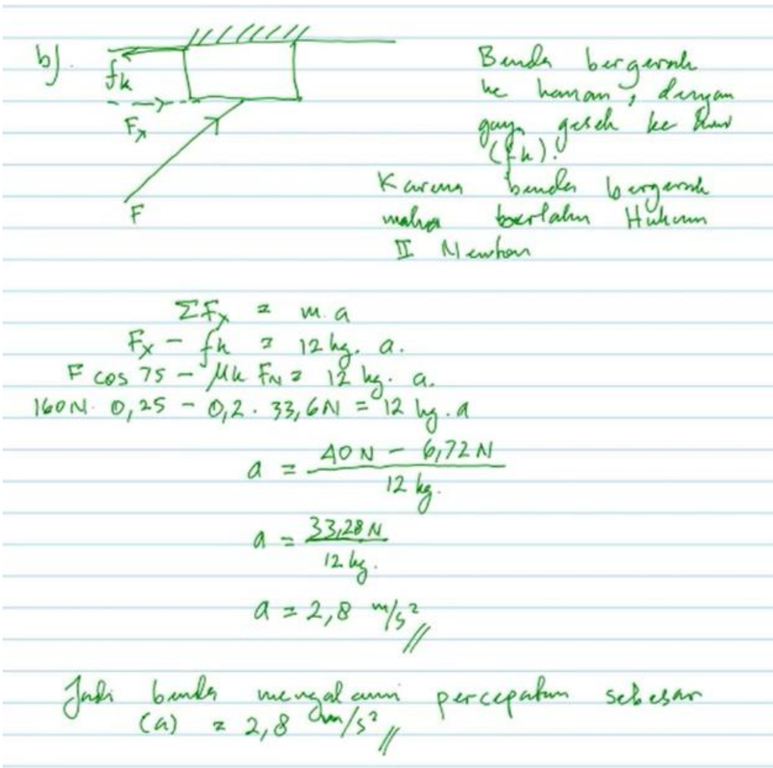


Figure 5. 5 Steve's work solving interview problem 1

In the first diagram, he drew F force (F =160N), normal force (F_N), and weight force (W) correctly. He then drew the second diagram showing kinetic friction force (f_k), F force, and the component of F in x direction (F_x). Even though Steve did not draw the component of F force in *y*-axis, he was able to write the component of F forces mathematically (F sin 75). From his work, he was successful in determining the magnitude of normal force and the magnitude of block's acceleration.

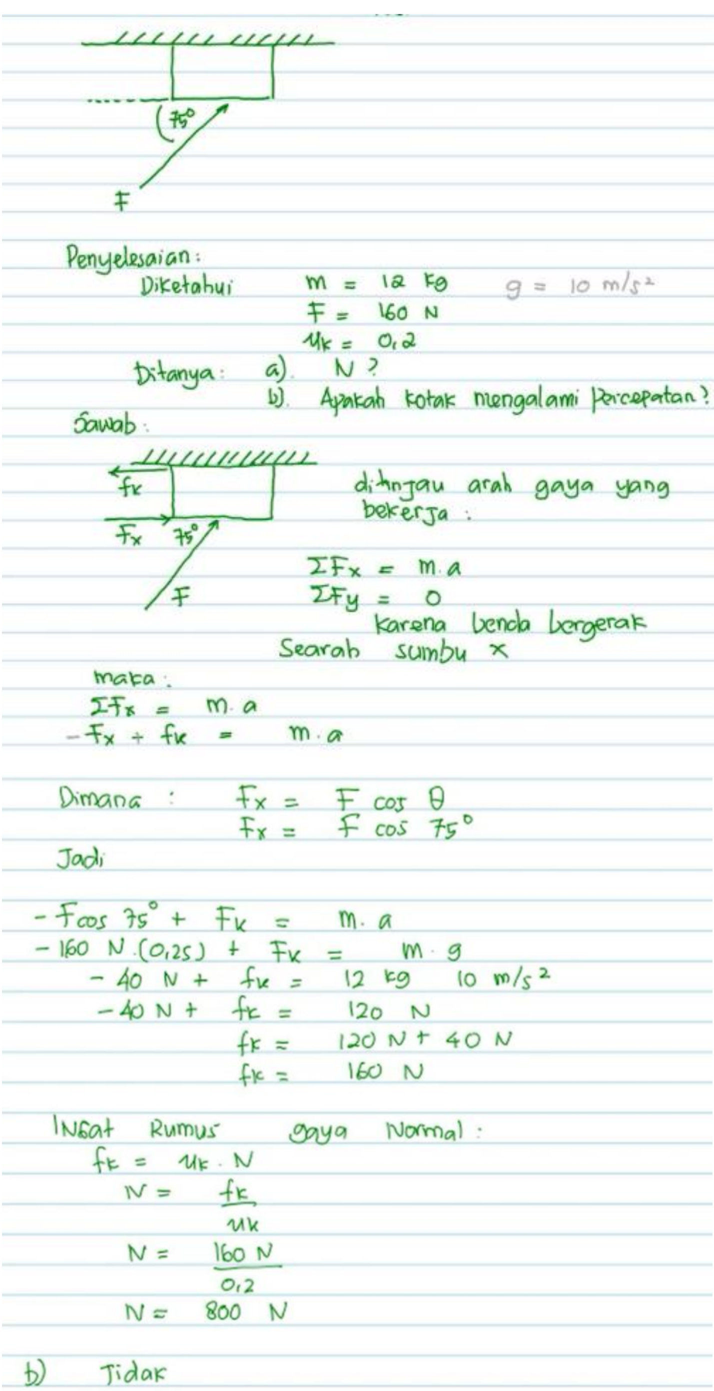


Figure 5. 6 Evan's work solving interview problem 1

During individual interview, Evan (a third-year student) stated his aim to draw diagrams "first sketching the diagrams, what forces exerted in the block. From diagrams we can identify known variables and unknown variables. I think I need to draw diagrams because the problem does not depict friction force". In fact, Evan drew incomplete diagrams (shown in Figure 5.6) because he did not include normal force, weight force, and the component of F force in *y* axis. He just drew kinetic friction force (fk), F_x (the component of F), and F force. He then wrote a mathematical equation ($-F\cos 75^0 + f_k = m\,a$) to determine the magnitude of kinetic friction force (f_k) and determine the magnitude of normal force (N) from an equation ($f_k = \mu_k\,N$).

Eva, a fourth-year student, said that she needs to draw force diagrams because Q1 just presented only one force (F) exerted on the block. This indicated that by drawing diagrams, she would able to identify forces exerted on the block. However, she missed the friction force and the component of F, and she drew the normal force with incorrect direction (N is going up); therefore, her diagrams were categorised as inappropriate diagrams. Below is part of the conversation with Eva.

Researcher: What is the purpose of your diagrams?
Eva: To easily solve the problems
Researcher: Is there another purpose?
Eva: To know forces exerted on the block because the problem just displayed only F force.
Researcher: How about if you did not draw the force diagrams?
Eva: I might be not able to solve it because there are many forces.

Her work is displayed in Figure 5.7. Based on the diagrams, Eva drew inappropriate diagrams that were missing friction force and the component of F. In addition, she drew an incorrect normal force, which is the direction of N (normal force) should be going down (the same direction with W). Then, the component of F_y was also incorrect; she wrote F *cos* θ instead of F *sin* θ. Consequently, her mathematical equation (F+N-W) is incorrect. Moreover, the value of the normal force is used to determine the magnitude of the acceleration of the block (*a*). Automatically, the value of *a* is incorrect.

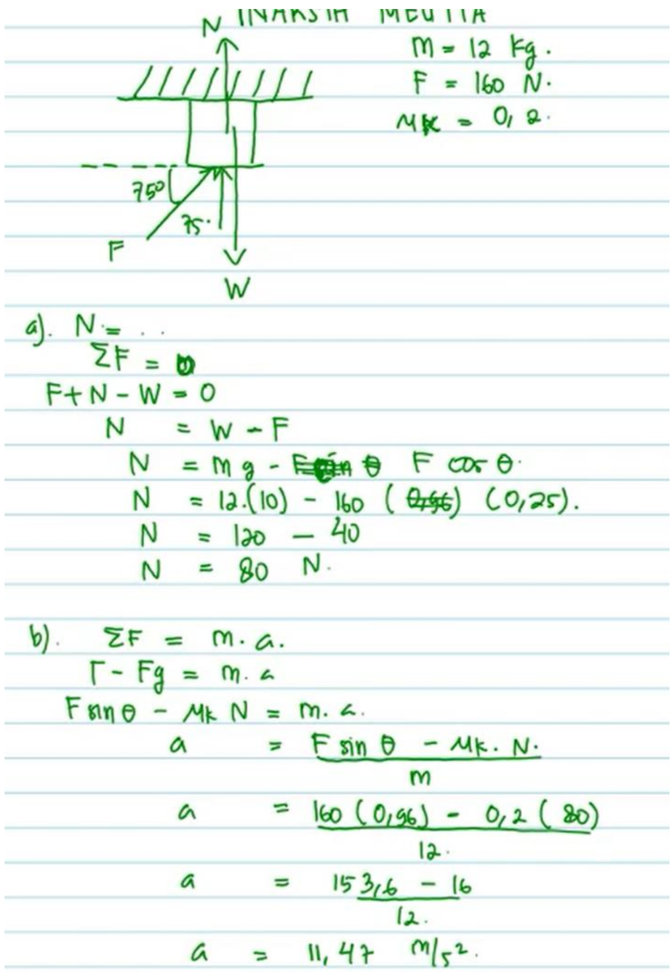


Figure 5. 7 Eva's work solving interview problem 1

Jane and Zack drew all the forces (complete diagrams) including the normal force, weight force, friction force, and the component of F exerting on the block (Q1) and identified forces which were drawn in the vertical and horizontal direction. They were able to write down equations correctly and determine the correct answers – the magnitude of the normal force and acceleration. Meanwhile, Steve and Evan drew incomplete diagrams but they have different solutions; Steve could find the correct answer whereas Evan could not. Moreover, Amy and Eva, who drew inappropriate diagrams, were not able to find the correct solution.

5.2.2 Finding the Direction and Sign of Forces

Another purpose for drawing diagrams is finding the direction and the 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. Some students' views about this idea are shown 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 in 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.

Evan (third-year student) mentioned specifically that his aim in drawing diagrams (Figure 5.6) was to know the sign of the friction force. He knew the direction of push force opposite to the direction of friction force, so he was able to find the direction of friction force because in the problem, the push force was drawn.

Evan: I think I need to draw diagrams because the problem does not depict the friction force, the direction of friction force is not provided in the equation. So, I drew the diagrams. I think the direction of friction force is opposite to the direction of push force. If the push force is to the right, the direction of friction force is to the left.

Drawing diagrams enabled Harry (first-year student) to determine the sign of forces. The signs of forces are useful for him, either for determining the net force or for manipulating equations. He wrote down "I assume the right and upwards are positive". His work pointed out that he wrote the weight force (W) was 120 N going down (*ke bawah*), F_y which the magnitude is 40N is going up (*ke atas*), and the normal force (N = 80N) is going down (*ke bawah*).

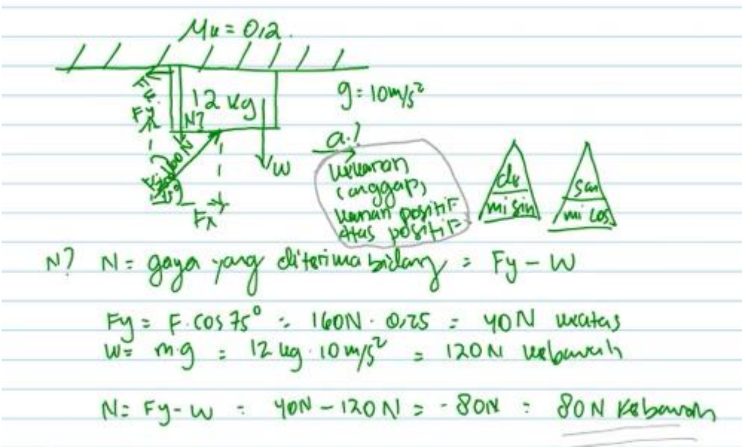


Figure 5. 8 Harry's work solving interview problem 1

Her knowing the direction and the sign of forces indicated that Vera (a third-year student) was more comfortable in determining the resultant of forces. She said, "If we talked about the direction of force, we will talk about adding and subtracting. So, we must know the direction of forces." This seems to show that it enabled her to see which forces were the same or the opposite direction, and then she could easily do the adding or subtracting process.

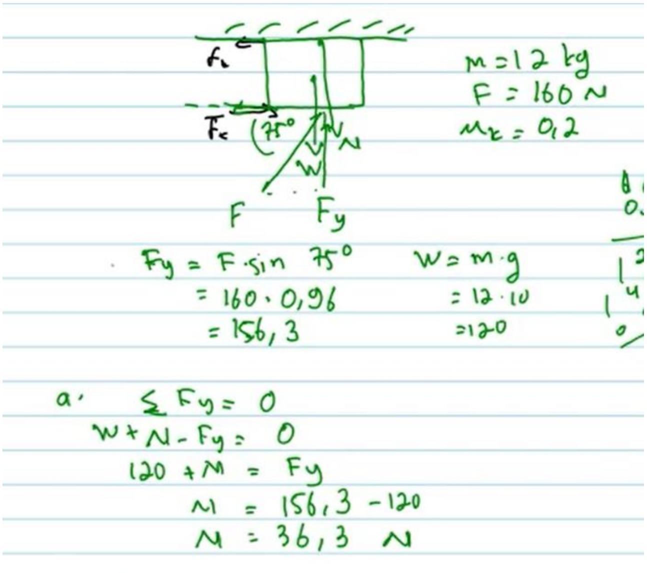


Figure 5. 9 Mona's work solving interview problem 1

Another student, Mona (a first-year student) explained in more detail her diagrams relating to signs and direction of forces exerting on *y*-axis: "Ya, in vertical direction, there are normal force and weight force which are going down, meanwhile the component of F indexed F_y which I found before is going up. So, I gave the sign of forces which are going down is positive whereas going up is negative". Based on her work, she was able to write down the mathematical equation with the correct signs including all forces in *y*-axis. Finally, she could determine the magnitude of normal force correctly.

From paired interviews, students also gave comments about other students' work relating to the sign of forces. Ana, a second-year student, gave a comment about a student's diagram, shown in Figure 5.10, relating to the direction of forces and the sign of forces in mathematical equations:

Ana: I think the forces are complete but there is incorrect sign if we see in x axis. The force F_A is to the right, so the sign is positive. Then F_B is to the left and it is opposite to F_A and the sign is negative. The friction force f_{sA} is to the left and here the sign is negative, correct. However, friction force f_{sB} which is the sign going to the right, the sign should be positive. If one of the signs of the forces is incorrect, it can affect the final result.

She noticed that the direction of friction force f_{sb} is to the right, so the sign of that force should be positive in the equation. Ana indicated that drawing diagrams could be helpful for finding the direction of forces and checking the sign of forces in mathematical equations.

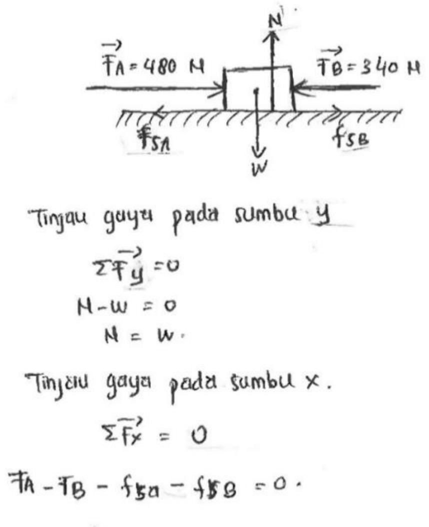


Figure 5. 10 A student's work solving survey problem 1

5.2.3 Determining the Component of Forces

Besides identifying forces, one of the purposes for drawing diagrams described by students was determining the component of forces. While a force is exerted on the object which is not parallel with vertical or horizontal direction (shaping an angle) as shown in questions Q1 and Q2, the component of forces is needed to know the total 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 *x*- and *y*-directions. 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. Students' purposes for drawing diagrams, especially the component of forces, are shown below:

> *Ana: this problem provided F and angle then I added forces here, what the name is? yes, the component of force in x and y direction.*
> *Vera: the purpose is so that I know what forces in x- and y-axis. if we talked about inclined plane, there are forces in x- and y-axis.*
> *Jane: for this kind of problem, we usually determine what forces exerting on the object and the component of forces in x- and y-axis.*

Chris: here we know the object is on the inclined plane so to determine the direction, we projected weight force (W) in x- and y-axis (W_x and W_y) then writing mathematical equation.

When Josh (a third-year student) solved the Q1, he drew the components of F to obtain the component of F_x and F_y before moving to writing the mathematical equations. To determine the component of F, he projected F in x ($F_x = F \cos 75^o$) and y ($F_y \sin 75^o$) axis, implementing trigonometry concepts. Knowing the component of F guided him to determine the net force in the vertical direction. He included the component of F in *y* direction in the equation. Overall, his mathematical equations are correct by including F_y, N, W forces. A small mistake occurred when calculating the magnitude of F *sin* 75^o; he got the value F_y as 144, but it should have been 153.6.

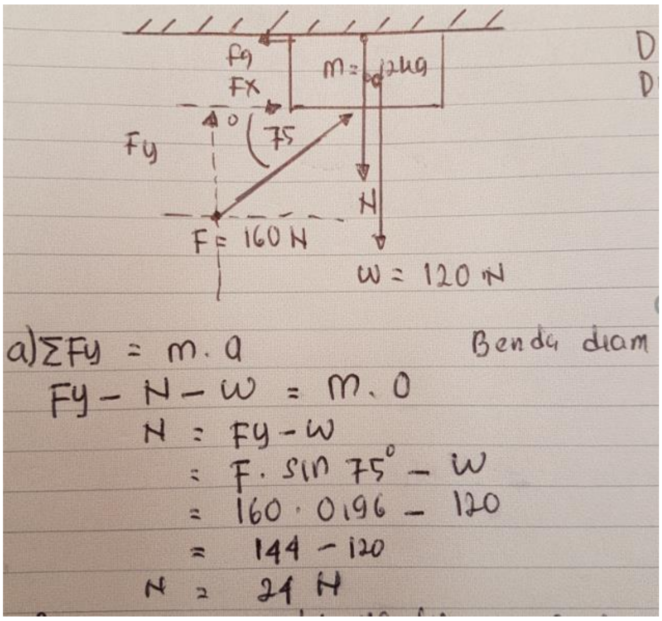


Figure 5. 11 Josh’s work solving interview problem 1

Joyce (a fourth-year student) explained how she obtained the component of F force from her diagram. She stated that “wait, because there is a kinetic friction so the object is moving. From this, I projected F force to x- and y-axis. Here F cos 75^o and F sin 75^o.” Her work in solving Q1 is shown in Figure 5.12. From her statement and force diagrams indicated that she drew the second diagrams to see clearly the component of F force. She was able to draw both F_x and F_y even though the position of the F shaped 75^o is not precisely and the length of both forces (F_x and F_y) is not proportional. Joyce was successful in determining the magnitude of normal force and the magnitude of block’s acceleration.

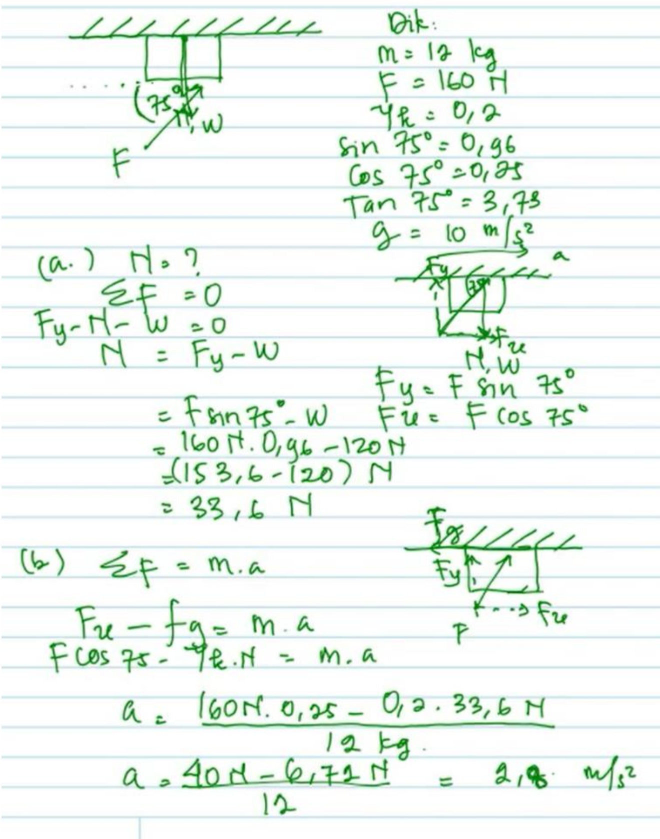


Figure 5. 12 Joyce's work solving interview problem 1

From the paired interview, Ana (a second-year student) analysed a student's diagrams relating to the component of a force in survey problem 2 (a block is at rest on an inclined plane) (section 4.3.2). A student's work is displayed in Figure 5.13. She said that "I understand the purpose of his/her diagrams. Here, s(he) wrote $\sum F_y = 0$ but why s(he) did not use $\sum F_x = 0$?. The friction force can be obtained from sigma $\sum F_x = 0; mg \sin\theta - friction\ force = 0$. So, the box will not move". From Ana's comment, she suggested that the component of weight force in *x*-axis would be used in mathematical equations for finding the magnitude of the friction force.

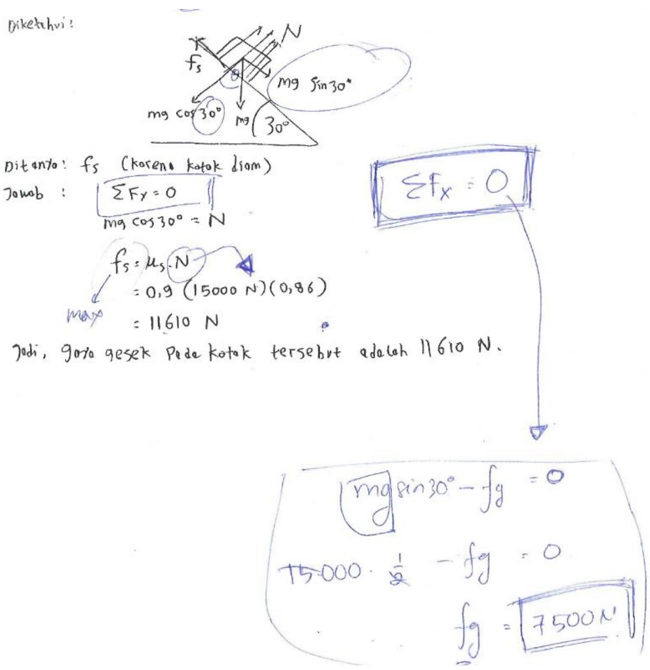
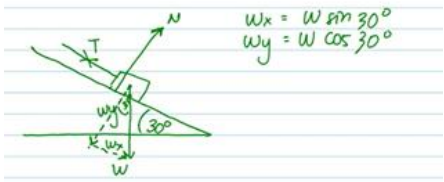


Figure 5. 13 A student's work solving survey problem 2

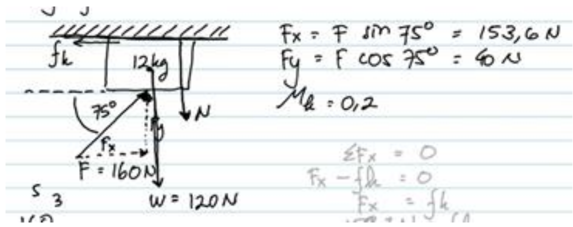
Determining the component of forces is one of the difficulties in drawing force diagrams correctly. For example, if an object is placed on the inclined plane, students should draw the components of weight force to find the net force in *x* and *y* axes. Some students mentioned that they had challenges 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 for all forces.*
> *Maria: While solving the problem, I am confused about the direction of force component.*
> *Evan: I think that it is more difficult in the context of inclined plane than horizontal surface because it has many forces and I have to find the component of forces in x and y axis.*

Ana drew force components while solving both Q1 (a block is placed below a ceiling) and Q2 (a block is placed on an inclined plane) as shown in Figure 5.14. For the inclined problem, she drew W_x and W_y correctly, as well as finding the magnitude $W_x = W\ Sin\ 30^o$ and $W_y = W\ Cos\ 30^o$. However, she could not apply her knowledge while determining the component of F in Q1, which is F shapes an angle 75^o to the *x*-axis. One possible reason is that she was not careful while drawing F_x and F_y and the position of 75^o. She should have put the angle 75^o between F_x and F. Another reason might be the Q1 is more familiar than Q2. Many textbooks provide the context in the inclined plane, even in the exercise. However, the context of Q1 is usually presented on the table, not below the ceiling.



(Q2)



(Q1)

Figure 5. 14 Ana’s work solving interview problem 2 and 1

5.2.4 Supporting in Selecting Mathematical Equations

To obtain the final answer, mathematical equations are usually needed to execute the problems. In the context of force problems, students mentioned that diagrams are useful to select the appropriate equations. Students’ comments relating the advantage of drawing diagrams in selecting mathematical equations are shown below:

Leo: I think that diagrams are needed for solving complex problems which involve many forces. It will help me in applying mathematical equations.
Chris: Drawing diagrams are needed to support solving force problems because from the diagrams, we can decide on which mathematical equation to be used for calculation.
Daniel: If I do not draw diagrams, I will have difficulties to determine which forces will be included in the 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 contexts.

From students’ statements above, they obtained the benefit of drawing diagrams connecting to mathematical equations, because physics contains many formulae that they might not be able to memorise completely. Thus, diagrams can be helpful to guide students to write down equations used to solve the problem because equations can be changed depending on the context, as Zack mentioned. Amy also recognised that drawing diagrams was very important for her. She said that “for me is very important because my mathematical equations depended on these diagrams. I drew incorrect normal force; consequently, all my calculations are incorrect” (Figure 5.4).

As Daniel (a second-year student) said, the diagrams assisted him to select which forces would be included in an equation. His work in solving Q2 and Q1 from survey is shown in Figure 5.15. He just needed two forces (T = cable force and W *sin* θ = the component of W in x-axis) to solve the problem in Q2 to determine the magnitude of T. Then, he wrote down three forces F_1, F_2, and F_{ges} to determine the magnitude of friction force in solving Q1of the survey problem.

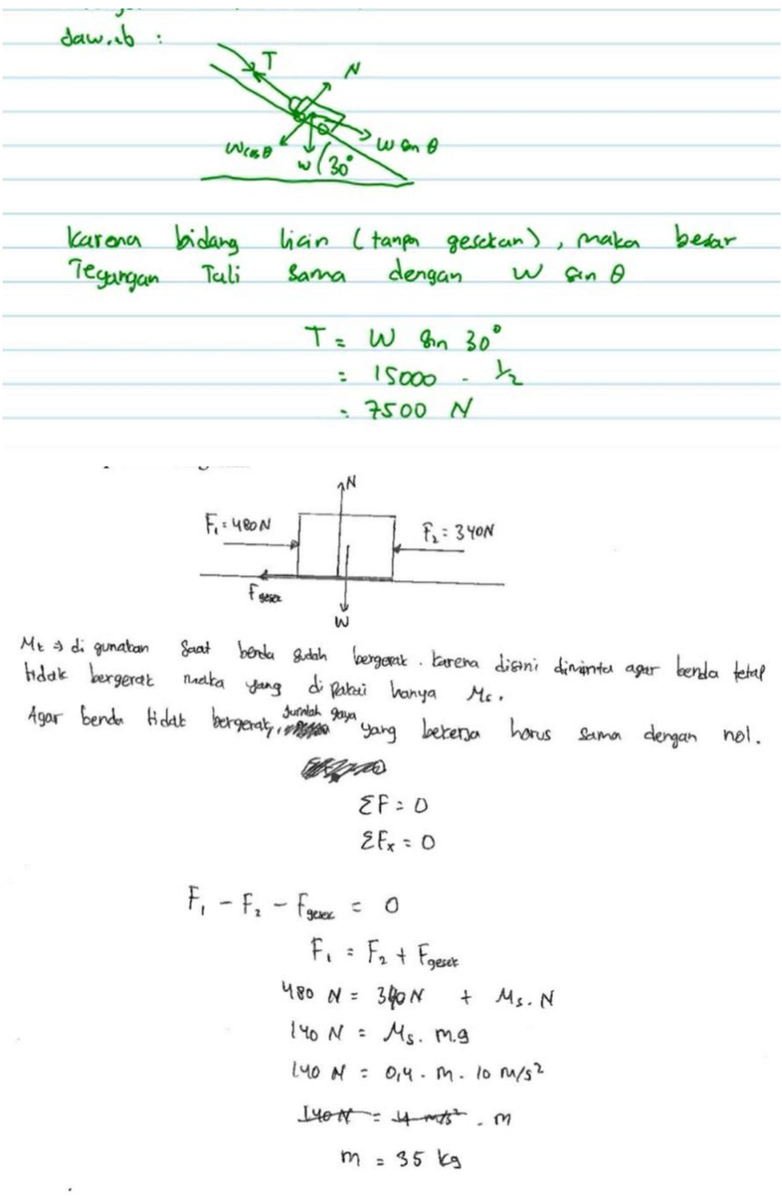


Figure 5. 15 Daniel's work on survey problem 1 and 2

From a paired interview based on another student's work (Figure 5.16), Harry stated that "his/her diagrams are not matched with mathematical equation. S(he) did not draw friction force but it came out in mathematical equation ($f_k = \mu_k\ N\ and\ f_s = \mu_s\ N$). I assumed that this student just drew the diagrams, s(he) did not use it for equation.” From Harry’s evaluation, he thought diagrams were useful to check the consistency of mathematical equations.

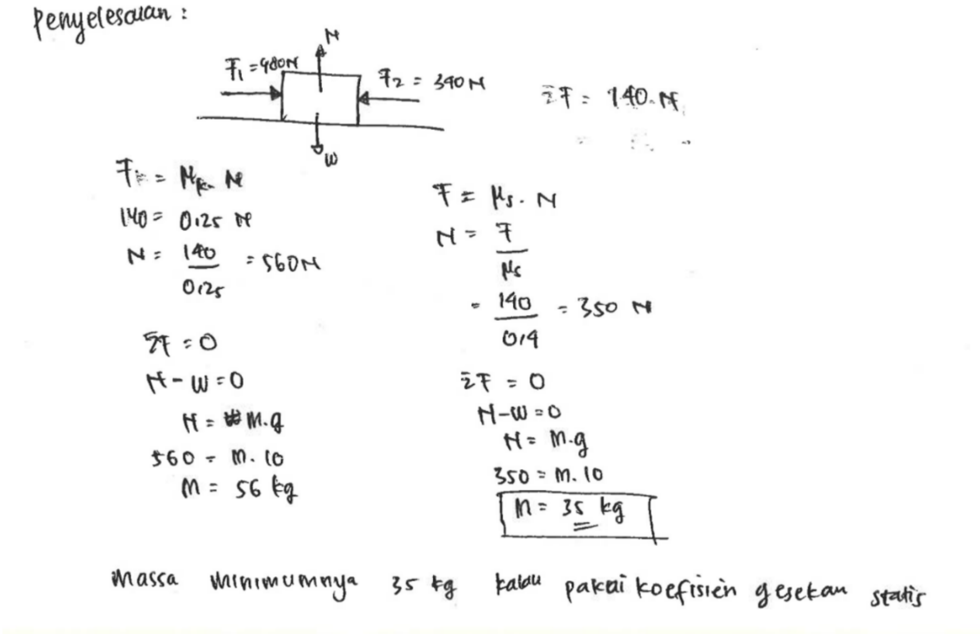


Figure 5. 16 A student’s work solving survey problem 1

5.3 External Reasons

The purposes of drawing force diagrams, such as identifying forces, determining the component of forces, finding the sign and the direction of forces, and supporting in selecting the appropriate mathematical equation have been presented in the previous section. These are ‘internal’ to the problem-solving process. The motivation of students to draw force diagrams might be affected by external reasons, including obtaining credit from instructors and learning in high school.

5.3.1 Obtaining Credit from Instructors

While solving the physics problems, students may have various motivations to include diagrams, such as force diagrams, in their answers. Teachers usually give appreciation to students who provide diagrams. Therefore, this may indicate that students usually draw diagrams because they hope that they will obtain an extra score for their answers. In the paired interviews, when students evaluated other students’ answers, one of the students (Nathan as a second-year student) stated that:

> *“s(he) may draw the force diagrams only for requirement because some lecturers give credit for it. S(he) actually does not know the meaning of*

diagrams. And s(he) recognises that diagrams and mathematical equations are separate."

He evaluated a students' work presented in Figure 5.17. Nathan may think that the diagrams drawn by the student are not used to determine the net force in x direction ($mg\ Sin\ \theta$ and f_s (static friction force)) and that the student just wrote friction force equations (static and kinetic) $N\ \mu_s\ and\ N\ \mu_k$ without connecting with the diagrams. That is why Nathan assumed that this student did not know the usefulness of the diagrams and the student drew diagrams and chose equations separately. From this example, the student may be comfortable in drawing diagrams because they will obtain extra credit whether it is useful in the problem-solving process or not.

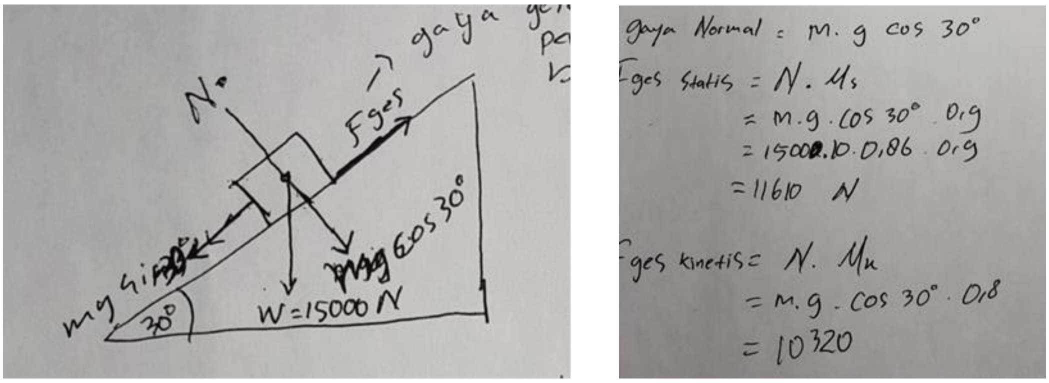


Figure 5. 17 An example of student's work solving survey problem 2

Moreover, some students also perceived that one of the reasons to draw diagrams was obtaining extra credit from teachers. Vera (a third-year student) gave comment while she evaluated a student's work in a paired interview:

> *Tina: the diagrams are obviously incorrect because she said the object is not moving but s(he) put a (acceleration). S(he) wrote equations without referencing with the diagrams. It commonly happens because some teachers told students that they will obtain extra credit if providing pictures/sketchers and diagrams. That is why students sometimes just drawing diagrams without matching mathematical equations and diagrams.*

In addition, Rose (a first-year student) also gave a comment regarding some teachers giving a bonus score for students presenting diagrams:

> *Rose: I think it depends on teachers. Some teachers sometimes gave extra credit for students who drew diagrams. If a teacher only recognised the final result, the scores of students are the same either providing diagram or not. But each teacher has different way to assess students' work. If I were a teacher, I will give different score for students who draw or not.*

5.3.2 Learning in High School

Students' learning in high school may affect their motivation to draw force diagrams while doing physics problems. Their teachers' strategies or methods taught relating to a specific concept, such as force, may have influenced students' ways of drawing force diagrams, and even students' approaches to solving problems. Students' views relating to learning physics in high school are shown below:

> *Leo: While studying in high school, a physics teacher taught that if an object is moving, the teacher directly wrote the coefficient of kinetic friction force without providing the coefficient of static friction"*
> *Daniel: My experience while studying in high school, there is only one friction force introduced. For example, there is only kinetic friction force so just using the coefficient of kinetic friction. I seldom find two coefficients in one question.*
> *Rose: My teacher taught drawing diagrams when solving a problem to help understand the problem. My teacher told me that when reading the problem, you directly imagine all forces exerted on an object then draw in the worksheet.*

From students' comments, Leo (a third-year student) and Daniel (a second-year student) had almost the same experience while learning friction force concepts in high school. Their teacher provided examples of the application of static and kinetic friction forces separately. For example, for *an object is at rest*, the teacher just provided the coefficient of static friction. Consequently, when students read survey Q1, some of them may have thought that there were two friction forces exerted on the block at the same time, and then they drew two friction forces (an example exhibited in Figure 5.18).

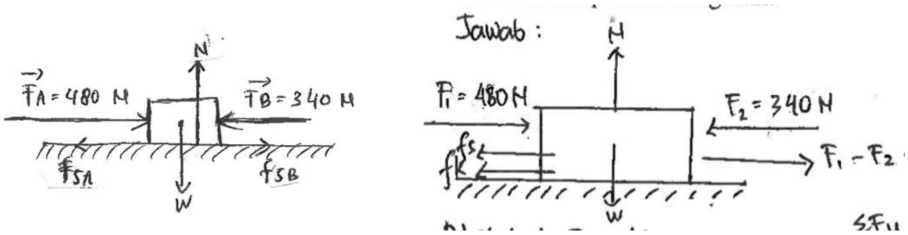


Figure 5. 18 Students drew two friction forces when solving survey problem 1

Furthermore, the way teachers show students how to draw force diagrams can influence students to draw diagrams. As Nathan (a second-year student) mentioned:

> *When I was studying in high school, I wrote friction force is equal to the resultant of forces. So, the resultant of forces is 140N to the right. In order to make the object remaining not moving, the friction force is to the left with the same magnitude with resultant of forces.*

His comment shows that Nathan remembered what his teachers taught, that ‘the friction force is equal to the resultant of forces’. He had a concept such that to help him in determining the friction force, he first found the resultant of forces. One of the students, Maria (a third-year student), also had the same idea as Nathan. Maria began drawing all forces exerted on the block, and she then continued drawing the net force and the friction force. From her work can be seen that the resultant of forces (F) is 140 N to the right (the second diagram), and then she drew the friction force to the left.

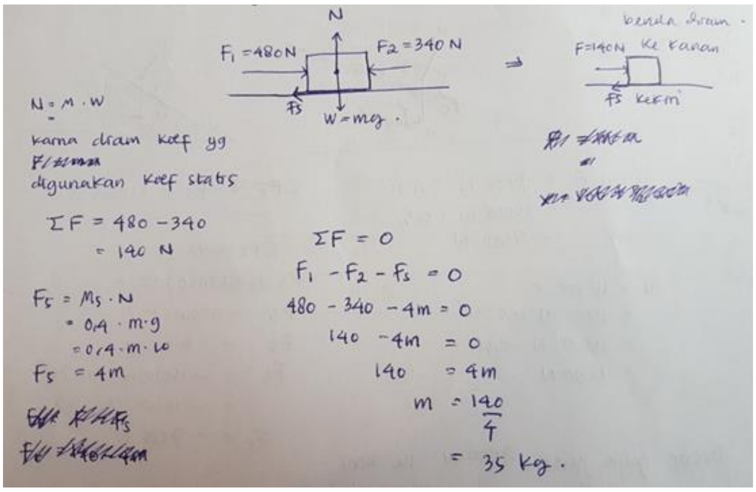


Figure 5. 19 Maria’s work solving survey problem 1

5.4 Conventions

How students drew their force diagrams is categorised as the *conventions* theme, including the labelling of forces, drawing diagrams either in the object or in the dot, and drawing dotted lines to represent a specific force. These themes are more about the features of force diagrams. Labelling forces is about how students name forces. Moreover, some students may be more comfortable in drawing forces in the real object rather than drawing forces in the dot that represents a real object.

5.4.1 The Labels of Forces

There are some characteristics or features of force diagrams drawn by students while solving problems. First, students have different opinions about the labelling of forces. To symbolise a force, some students were more comfortable using the symbol of a force with a letter rather than using two letters that show 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 $F_{E\ on\ B}$. 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 of the reasons to use one letter. An example of a student's work symbolising some forces such as normal force (N) and weight force (W) is shown in Figure 5.20. Below are students' comment about familiarity:

Frank: I am more familiar with the symbol W rather than force of earth on box $F_{E\ on\ B}$.
Steve: It is more obvious that force of surface on box. But I usually use N (normal force) and it is more familiar for me.

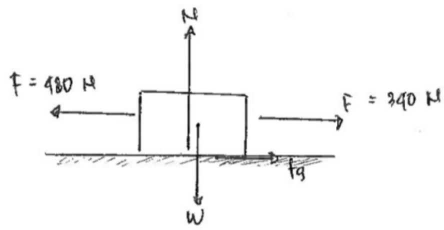


Figure 5. 20 Figure 5.20 The symbol of forces: N, W, f_g

Moreover, some students said that "a symbol of force with two letters that shows the interaction between two objects should be explained for beginner learner". Students' responses indicate that they represent a force by the simplicity and familiarity of the symbols.

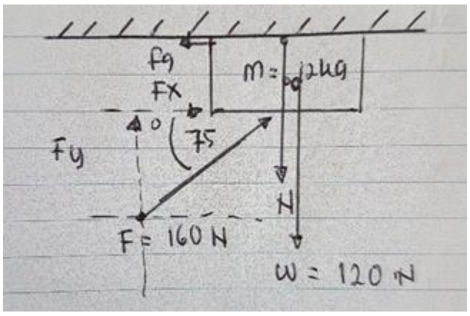
Besides weight and normal force, students were also concerned with the symbols of friction force. Generally, the symbol of friction force is f instead of F. Then, friction force is symbolised with f_s as static friction force and f_k as kinetic friction force. Students' comments from paired interviews 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.

5.4.2 Drawing in the Object

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

> *Frank: It is much easier for me if drawing 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 in the dot.*



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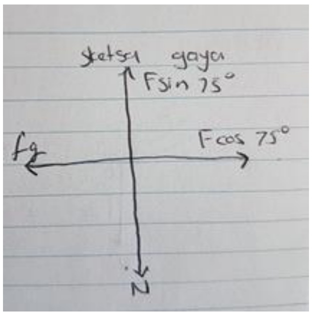


(b)

Figure 5. 21 Drawing forces in (a) real object; (b) in dot

5.4.3 Drawing in the Dot

Some students have opinions about drawing diagrams on a dot (in *x-y* axis). They argued that drawing diagrams in a dot will be easier to determine the direction of forces either in x- or y-axis and the resultant of forces. Here some comments of students

> *Ana: drawing in the dot will simply distinguish which forces in x- and y-axis and which forces are positive and negative direction.*
> *Maria: it is easier to determine the direction of forces and the resultant of forces.*
> *Jane: if only drawing in the object, it is not clear yet which forces in x- and y-axis.*

In addition, a student stated that drawing diagrams in the dot would be helpful, but it would require a longer 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 in the object was enough if they already understood the problems. This view indicates that drawing forces either in real objects or in the dot relies on the complexity of the problem.

Figure 5.22 shows two students who drew different diagrams while solving Q1 but found the same final result.

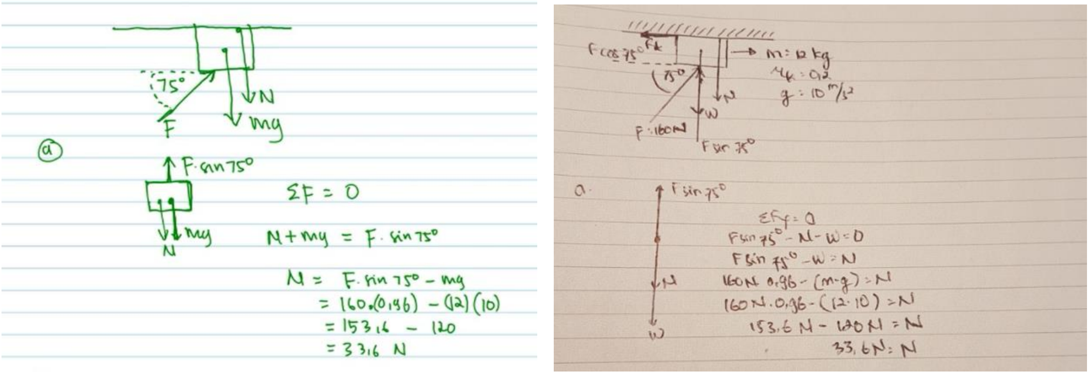


Figure 5. 22 Drawing forces in a real object and a dot with same final answer

5.4.4 Dotted line arrow representing the component of forces

Students were also concerned about how to represent a force in their diagrams. In many textbooks, a line arrow represents a real force such as weight force; meanwhile, the components of weight force in the *x* and *y* direction are depicted with a dotted line. Figure 5.23 shows how a student drew the component of W (W_x and W_y) with dotted line arrows.

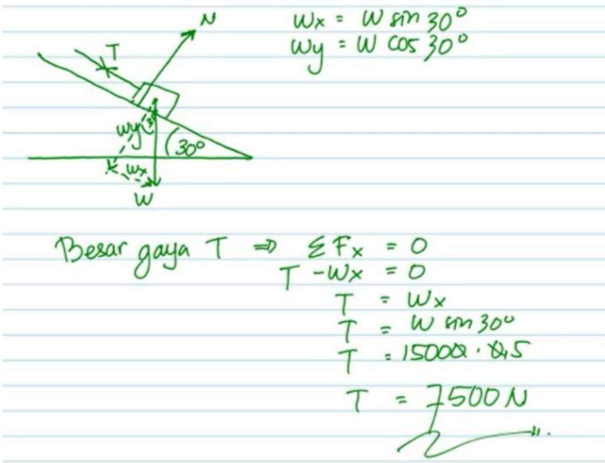


Figure 5. 23 Representing the component of forces with dotted lines arrows

Rose (a first-year student) commented on a student' work during paired interview: "I think the first time looking at this (diagram), his/her diagrams are not accurate while drawing the component of weight force. These should be dotted line arrow to represent the component of forces". Figure 5.24 shows a student's work commented on by Rose.

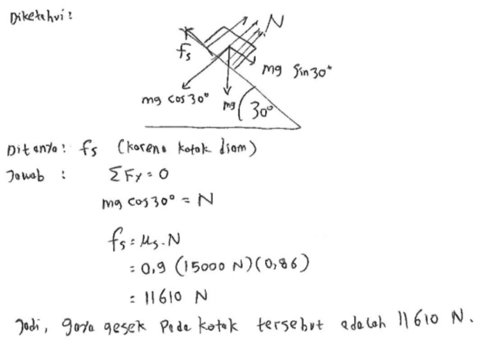


Figure 5. 24 A student's work solving survey problem 2

She suggested that the arrow of mg *sin* 30^{o} and mg *cos* 30^{o} should be dotted line arrows to distinguish between the 'real force' and the components of force. Rose was concerned about the form of the arrow in representing forces.

5.5 Physics Concepts

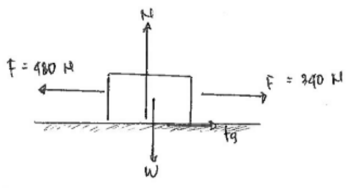
Students' knowledge about physics concepts may also affect how they draw diagrams. In this study, force concepts including normal force, weigh force, and friction force are needed while drawing force diagrams. In order to draw forces correctly, students must know the concepts of each force. For example, the normal force is perpendicular to the plane; the direction of friction force is always opposite to the direction of the net force exerted on an object. Students' views about the importance of physics concepts in drawing force diagrams are described in the following section.

5.5.1 Forces

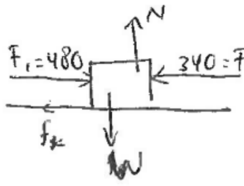
Students perceived that understanding the concepts also contributed solving the problems successfully. After identifying all forces that are exerted on an object, students then focused on how each force was drawn including the position, direction, and the connection with other forces. For example, the direction of normal force and weight force is the same direction in interview problem 1, while in interview problem 2 both forces are in different directions. 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 the place of the object. Generally, the normal force is drawn starting from the base of the object, and it is perpendicular to the surface. While an object is placed on the horizontal surface, the direction of the normal force is going up or in the opposite direction of the weight force, but the direction of normal force is different to when an object is placed on the inclined plane. In interview problem 1, the box is placed below the ceiling, so both the normal force and the weight force have the same direction going down.

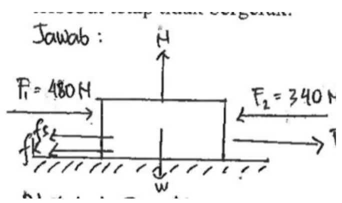
Figure 5.25 displays several examples of students' force diagrams, including normal force in two different situations: the first is the box placed on the table and the other one is the box placed below the ceiling. Students made different diagrams in drawing normal force while the box is on the table: the arrow started from the base of the box (i) and the arrow started from the edge of the box (ii and iii) where the direction is going up. Meanwhile, in drawing the normal force on the box below the ceiling, the arrow is started from the base of the box (v) and from the centre of the box (iv) where the direction is going down. From figures below can be seen that students had different ways to draw normal force even though in the same context.



(i)



(ii)



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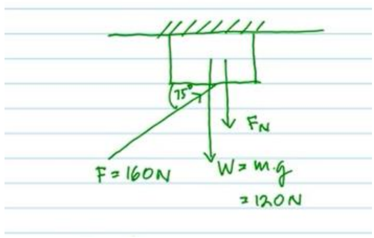

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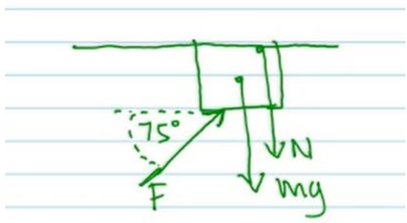


(v)

Figure 5. 25 Students' drawings of normal force

Students' conceptions about 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 the same direction with weight force.
Mike: I thought that the magnitude of normal force can be determined by employing the calculation of friction force.
Eva: The normal force is always going up and it is started from the center of the object.
Steve: For this question, why the normal force is going down not going up because the direction of normal force is keeping away from the horizontal

surface. For example, if the object is placed on the table so the normal force is going up while if the object is placed below the table, so the normal force is going down.

From the students' comments above, Ana and Steve show their conception about normal force which is the normal force is always perpendicular to the surface. Steve even explained more detail about the direction of the normal force for interview problem 1 which is not always going up as Eva said it is always going up. Meanwhile, Mike focused on using an equation (calculating the friction force) to determine the magnitude of normal force.

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 force times the magnitude of the normal force ($f \sim \mu N$). There are two types of friction force: the static friction force works when the object is at rest or until almost moving and kinetic friction force works while the object is moving, either with constant velocity or constant acceleration. Thus, the concept of friction force connects with the normal force and the motion of the object. The examples of friction force drawn by students are shown in Figures 5.24i, ii, and iii. From the figures, it can be seen that students had different conceptions about the friction force. In Figures i and ii, students drew friction force with different directions. Meanwhile, Figure iii shows that students drew two different friction forces exerted on the box. Students' views from individual interviews about friction force relating to drawing force diagrams are shown below:

Daniel: First checking whether the object is moving or not. Then comparing the magnitude of static friction and F cos teta. If F cos teta is bigger than static friction so the object is moving which has acceleration.
Joyce: The static friction is always opposite direction to the direction of object motion.

Furthermore, understanding the concepts of forces, including friction force, is also a challenge for students which affects students' performance in drawing force diagrams. Many students stated that they faced confusion distinguishing between static and kinetic friction forces. Consequently, they were not able to draw the direction of friction force correctly, and even drew both friction forces in a situation. For example, while an object is at rest, students may think that there are two friction forces (static and kinetic) exerted on that object. One of possible reason might be because both problems provided the coefficient of static and kinetic friction. So, students might think that those variables would be used in finding the solution. The two examples of students' attempts in drawing friction forces are displayed in Figure 5.26. The first example is about a box is placed on an inclined plane, a student drew the static friction (f_s) as opposite to the direction of kinetic friction (f_k). Due to the box not moving, the friction force exerted on the box is only static friction. This student might not fully understand the concept of friction force; it shows that the direction of kinetic friction drew with the direction of the box if is moving. Meanwhile, in the second example, a student also drew two friction forces (static and kinetic friction forces) in the context of horizontal surface. The direction of both friction forces are correct if the box is moving. This student might not recognise when static and kinetic friction forces are being exerted on an object.

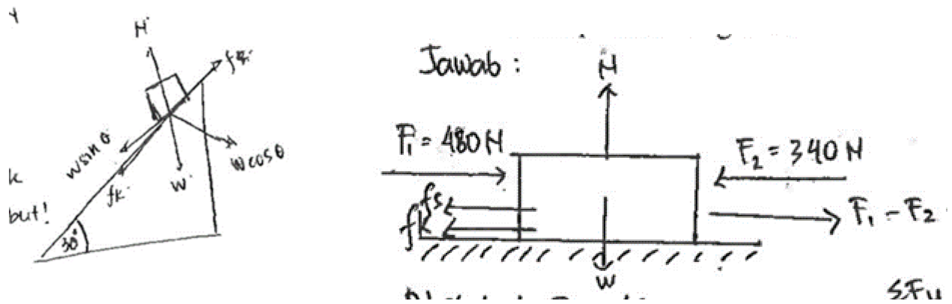


Figure 5. 26 Students' mistakes in drawing the friction force

Students' difficulties in drawing diagrams relating to the friction force are shown below

> *Mike: The difficulty is in the concept. I was ever taught that we have to determine the component of forces in x and y axis then we can find out the normal force. In fact, the magnitude of the normal force (N) is not always the same with the magnitude of 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 friction force. Which force is used? I am confused.*
> *Frank: The question made me confused because it asked the magnitude of friction force while the coefficient of friction force has been provided. Then the magnitude of friction force can be determined without using an equation* $f_s = \mu N$.

Mike thought the magnitude of the friction force was the same as the magnitude of the weight force. His assumption can be correct while the object is at rest on the horizontal surface. However, while there are other forces exerted on the object and while an object is placed on the 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 $f \sim \mu N$ (f is the friction force; μ is the coefficient of friction force, and it can be static or kinetic; N is the normal force). For some students, the use of static and kinetic friction force is interchangeable. For example, Ana had confusion about which friction force should be applied to determine the magnitude of the friction force in Q2 in the survey. Furthermore, the use of the friction force equation must be careful 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 (an example is in Q2 in the survey). Subsequently, while the object is moving, the equation of friction force can be determined in order to calculate the magnitude of the kinetic friction. Therefore, these two ideas made Frank confused.

5.5.2 Newton Laws

The concepts of Newton's Laws are also needed in drawing force diagrams. Those are beneficial to check whether an object is at rest, moving with constant velocity, and moving with constant acceleration. For example, the car is at rest in interview problem 2, so the net force in *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 (W_x).

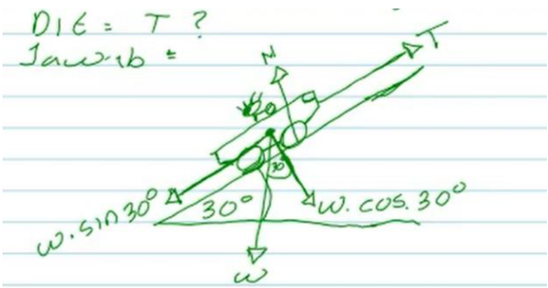


Figure 5. 27 A student's work (T = W_x) solving interview problem 2

Many students mentioned Newton' 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 $\sum F = ma$. The block is moving in x axis, so I wrote $\sum F_x = ma$. Meanwhile, the block is not moving in y axis, so the total force is zero.*
> *Harry: Does the object move?, let prove with $\sum F = 0$. 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 $\sum F \neq 0$, meaning that f_s is*

bigger than W_x. It means that the weight force (x component) is not able to make the object is moving.
Steve: I thought that the block is impossible moving in y axis, so Newton 1st law: $\sum F = 0$ was applied. Then, the block is moving to the right or x axis so Newton 2nd $\sum F_x = ma$ law was applied.
Tina: I directly solved in y axis because I thought the block is impossible falling down so $\sum F_y = 0$.

The concept of Newton's Laws corresponds to the forces exerted on the object and acceleration of the object. For example, the net force is 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 students' views above, understanding the concept of Newton's Laws helped them connecting all forces exerted in the object and checking whether the object is at rest or moving.

5.6 Mathematical Concepts

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. To determine the net force or the resultant of forces, students should add force vectors. 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.

5.6.1 Vector

Mathematics concepts also affect students' ways of drawing force diagrams. A vector which is part of mathematical concepts consists of an arrow, direction, and magnitude. One of the students (Steve) mentioned that:

I think that to simply draw the diagrams, we must understand the concept of vector because force is a vector which has the magnitude and the 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 with arrows, which consist of the direction and the magnitude. In other words, having a good understanding of vectors will help students to visualise a force. Another student (Harry) added the idea that "because force is a vector, so we do not only write the magnitude but also the direction." This means that it is not a complete understanding if students only know the magnitude of force without knowing the direction of a force. 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 were 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 are vectors that represent the magnitude of these forces.*

From paired interview, students also noticed the concept of vectors while evaluating other students' work. Some students mentioned that while drawing forces, the length of arrows is important because it represents the magnitude and the direction of a force:

> *Researcher: What do think the arrow of F_1 and F_2?*
> *Daniel: The length of F_1 should be longer than F_2. Vector shows the magnitude and the direction. So, the length of normal force (N) and weight force (W) must be equal.*
> *Jane: Here, the length of vector is incorrect, the length of vector normal force should be equal to the length of vector weigh force. Then the length of F_1 should be longer than F_2.*

5.6.2 Trigonometry

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. 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 triangle to get easier finding sin, cos, and tan using Phythagoras. For example, sin theta = 3/5.*
> *Zack: The concept of trigonometry is important because force problems are not only in horizontal surface but also in inclined plane.*
> *Rose: Actually, it is more difficult to solve a problem which is the context in inclined plane than horizontal surface because we have to analyse force component with angles.*

In this study, students applied trigonometry concepts to solve survey problem 2 and interview problems. In the first question, a force (F) is exerted on a box to make its position remain below on the floor and not falling. The position of the force is not really in *x*- and *y*-directions, but it shapes 75^o to the horizontal axis. Therefore, in order to determine the net force in both *x*- 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 interview problem 2, and students should apply trigonometry concepts to determine the components of weight force in *x*- and *y*-directions before determining the net force in *x*- and y-axes.

5.7 Using Incomplete Diagrams

Some students seem to need to draw the complete diagrams and others might not have shown such a need. Students who drew incomplete diagrams gave some reasons for not drawing the complete diagrams. For example, in the context of the inclined plane problem (interview problem 2), 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, weight force, and find the component of W in *x*- and *y*-axis. Due to the force T being parallel to Wx in *x*-axis, students determined the net force or the resultant of forces in the axis 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), weight force, and normal force. I did not draw normal because I think it is not used in calculation, but I know in my head.*
> *Harry: I should draw the normal force so that I know the component. I did not draw because I think it is not needed.*
> *Tina: before analysed, there are three force: weight force, T force, and normal force. Why I did not draw because there is no question asking the normal force. Actually, it is not good, I should draw but I was in a hurry.*
> *Rob: because in y direction is going up and down so, it is impossible the car is jumping up and down. We just calculate in x direction. Actually, there is normal force but we did not determine the normal force so we must be not draw.*

Joyce (a fourth-year student) and Harry (a first-year student) drew incomplete diagrams (both of them did not draw the normal force) while solving interview problem 2, which was asking the magnitude of T to make the car remain at rest. Joyce used F to represent T and drew weight force along with its components. However, she made a mistake in using the formula to determine the component though she wrote a correct equation to determine the magnitude T; consequently, she got an incorrect final answer. Moreover, Harry drew T force and weight force along with the correct components. He also added the explanation that W_x is parallel to T in x direction. He then wrote a correct mathematical equation and found a correct final answer.

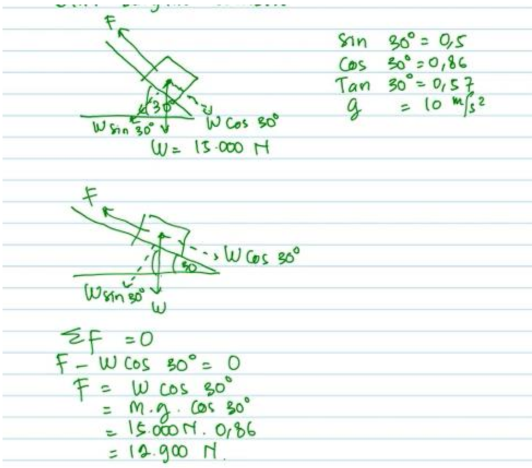


Figure 5. 28 Joyce’s work in solving interview problem 2

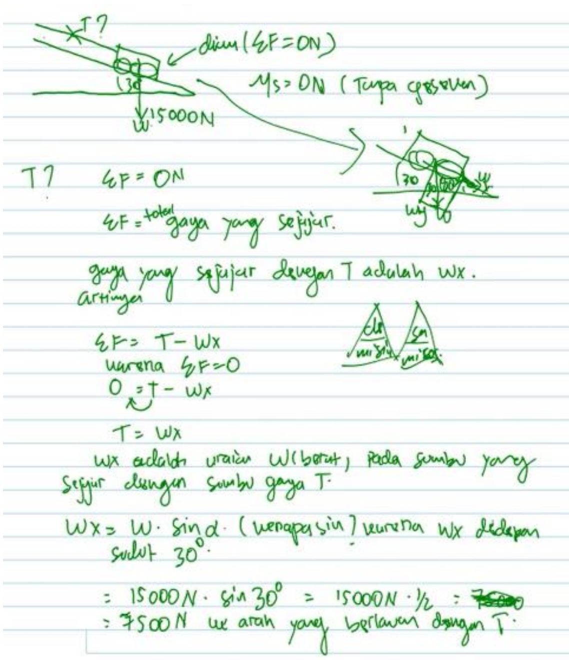


Figure 5. 29 Harry’s work in solving interview problem 2

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 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:

> *Researcher: Why did not you draw the normal force?*
> *Evan: Why I did not draw, I think if the surface is frictionless so 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 did not you draw all forces.
Mike: I think it is not needed.
Researcher: Why?
Mike: We can determine the normal force by using the friction force equation. The friction force is the normal force times the coefficient of friction force.

Some students also mentioned that if they have understood the problem, they do need to draw the complete diagrams:

Steve: Maybe because I memorised that in inclined plane, x axis, we used sin not cos, so no needed 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; he just 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.

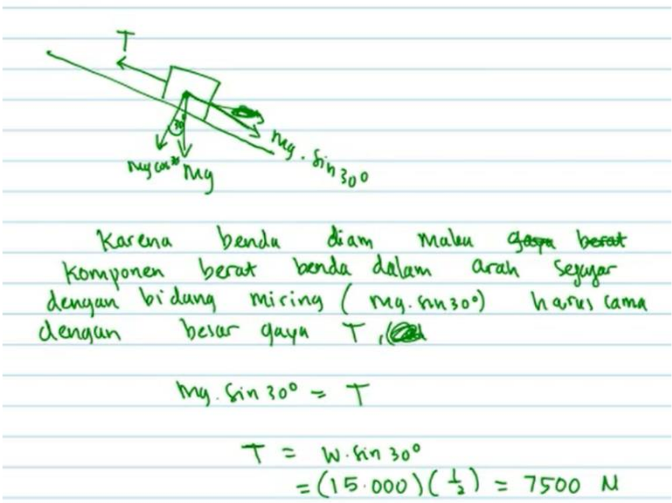


Figure 5. 30 Leo's work in solving interview problem 2

5.8 Summary

To obtain students' perception about force diagrams, interviews were conducted by involving 28 students for individual interview and 16 students for paired interviews. The process of interview and data analysis have been explained in the previous sections. Students' views about force diagrams were categorised into six themes including the purposes of drawing diagrams, the external reasons for drawing diagrams, scientific conventions in drawing diagrams, the need of physics and mathematics concepts for drawing force diagrams, and the reason using incomplete diagrams. Students mentioned several reasons for drawing force diagrams when solving force problems: identifying forces exerted on an object, determining the component of forces, finding the direction and sign of forces, and supporting in selecting mathematical equations. Students also mentioned that teachers' approaches and the motivation for obtaining extra credit from teachers affected them in drawing force diagrams. Labelling forces, drawing either in the sketch or in the dot were grouped as conventions for drawing diagrams. Then students mentioned that force concepts and Newton's Laws (physics concepts) are very important in the process of drawing force diagrams. In addition, vector and trigonometry as part of mathematical concepts are also important. Lastly, some students preferred to use incomplete diagrams because they have already understood the problems and they said that they drew forces if those are needed for calculations.

CHAPTER 6
DISCUSSION

In Chapter 4, I presented students' views about problem solving and representations obtained from surveys and the patterns of students' force diagrams obtained from force problem surveys. Then, in Chapter 5, I explained students' views about force diagrams while solving force problems obtained from both individual and paired interviews. By analysing quantitative and qualitative data, students' diagrams were categorised, and students' views have been obtained and categorised in several themes. In this chapter, I want to discuss those findings. Section 6.1 discusses students' diagrams in solving force problems. Students' reasons for drawing force diagrams are discussed in section 6.2. Students' views about problem solving are discussed in section 6.3.

6.1 Students' Diagrams in Solving Force Problems

This study explored students' problem-solving processes while solving force problems. Students may use force concepts, force diagrams, and mathematical equations in solving force problems. The relation of these three elements as a conceptual framework was utilised in this study to see how students use and move between concepts, diagrams, and equations: CDE triangle (section 2.7) when solving a problem. When students solve problems, they should be able to identify what concepts are applied to find out the solution (Leonard, Dufresne and Mestre, 1996). The force problems (survey and interview problems) used in this study involve several concepts including the normal force, the friction force, the weight force, and Newton's Laws. One of the steps that might be followed by students while solving problems is constructing diagrams (Docktor *et al*, 2015; Heller, Keith and Anderson, 1992; Huffman, 1997). Van Heuvelen and Zou (2001) added that "the goal of solving physics problems is to represent physical processes in different ways – words, sketches, diagrams, graphs, and equations" (p.184). When students are constructing a force diagram, they may include mathematics concepts such as vector and physics concepts including force concepts because a vector is needed to represent a force exerted on an object. The mathematical equations can be generated from diagrams by involving Newton's Laws.

Based on data analysis of students' answers while solving two problems given in a survey (horizontal and inclined plane problem described in section 4.3.1 and section

4.3.2), students' diagrams were classified into three categories: complete, incomplete, and inappropriate diagrams (Table 4.3 and Table 4.6). In addition, a few students did not draw diagrams to solve those problems. About half of the students drew incomplete diagrams for both questions (54% for horizontal problem and 42% for inclined problem). Meanwhile, the percentage of students who drew complete diagrams in solving horizontal and inclined surface problem are 18% and 35%, respectively. Then, 20% and 10% of students drew inappropriate diagrams in solving horizontal and inclined surface problem. In summary, about 90% of students drew force diagrams in solving both questions although they were not asked to draw diagrams. This is a higher percentage than in a previous study done by Rosengrant *et al.* (2009); they found that an average of 58% of students drew force diagrams in their exams. The number of students who drew force diagrams in this study aligns with students' response in the representation survey (item 2 and 8) where about 70% of students agreed that they often use representations while solving physics problems and that they usually drew representations although they did not obtain partial credit for drawing them (64%).

6.1.1 The Complete Diagrams

The category of complete diagrams means that all forces exerted on the object were drawn with correct positions and directions. Students who drew complete diagrams tended to obtain the correct answers (28 out of 42) while solving the horizontal plane problem (survey problem 1). A correct answer implies that the concepts involved and mathematical equations were used correctly to solve the problem. This relates to students' response in the representation survey in which three quarters of students agreed that using representation helps students to find the correct answer (item 4) and using representations to make a problem easier to understand (item 3) (four-fifths of students). This finding seems to align with the result of a previous study conducted by Rosengrant *et al.* (2009) which found that students who drew correct force diagrams were more likely to successfully solve the problems in both mechanics and electrostatic topics. I used the different terms in categorising students' diagrams. Three categories of students' diagrams were used in this study: complete, incomplete, and inappropriate diagrams. Meanwhile, Rosengrant *et al.* study just distinguished the correct and incorrect force diagrams. They categorised incomplete and inappropriate diagrams as incorrect diagrams. The incomplete diagrams in my study were not grouped as incorrect diagrams, because although they did not depict all forces, these diagrams were otherwise drawn correctly and some of the students who drew incomplete diagrams were able to find the correct solutions. It suggests that students have different ways to construct their knowledge and represent their understanding. The constructivist point of view states that knowledge is built in the mind of learner thorough personal experience (Bodner, 1986). In the context of constructing representations, students come to the classroom with an understanding of representation (diSessa and Sherin, 2000). In other words, students deployed their prior knowledge and previous experiences to create representations. For example, a student drew incomplete diagrams to solve survey problem 1 and interview problem 1; he may think that his diagrams contained enough information to enable him to reach the correct solution (section 4.3.1 Figure 4.13b). According to the conceptual framework, physics concepts and mathematical concepts were needed for drawing force diagrams. A student drew the external forces exerted on the box and the friction force; however, he did not draw the normal force and the weight force. For this student, drawing incomplete diagrams was already clear without depicting all forces and could be able to generate the appropriate equations in finding the correct final answer.

However, in the inclined problem (survey problem 2), the trend was different, only 28% (22/78) of students who drew complete diagrams could solve the problem correctly. Some students did not really use the complete diagrams to produce the correct mathematical equations in finding the magnitude of the static friction force. For example, solving survey problem 2 (inclined plane problem), some students drew complete diagrams but did 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 wrote the friction force equation ($f_s \max = \mu_s N$). An example of student work in this category can be seen in section 4.3.2 Figure 4.18b. In other words, some students did not demonstrate representational competence in being able to translate from diagram form to mathematical equations.

Representational competence is defined as the ability to construct, use, and modify representations and translate between representations (diSessa and Sherin, 2000; Kozma and Russell, 1997). To translate one form representations to another, students should understand the meaning of form of representations such as diagrams (Carolan, Prain and Waldrip, 2008). In this study, students' competence of representation is students' ability to translate written problem to the diagram representation and to generate mathematical equation from diagrams. Based on the conceptual framework for drawing force diagrams, students should have understanding of physics concepts and mathematical concepts because a force is represented with a vector. For example, when students solved survey problem 2, they needed to know force concepts including weight force, normal force, and friction force. In addition, students needed to determine the component of forces, which required knowledge of trigonometry.

Solving a force problem successfully involves the ability to explain the problem and identify concepts used. In this study, both the survey problems involved objects which were not moving, so students should recognise that Newton's First Law is applied in this problem. For example, a student wrote down in his/her answer while solving survey problem 2 "because the box is at rest, so the net force exerted on the object is zero". A student's solution is shown in Figure 6.1

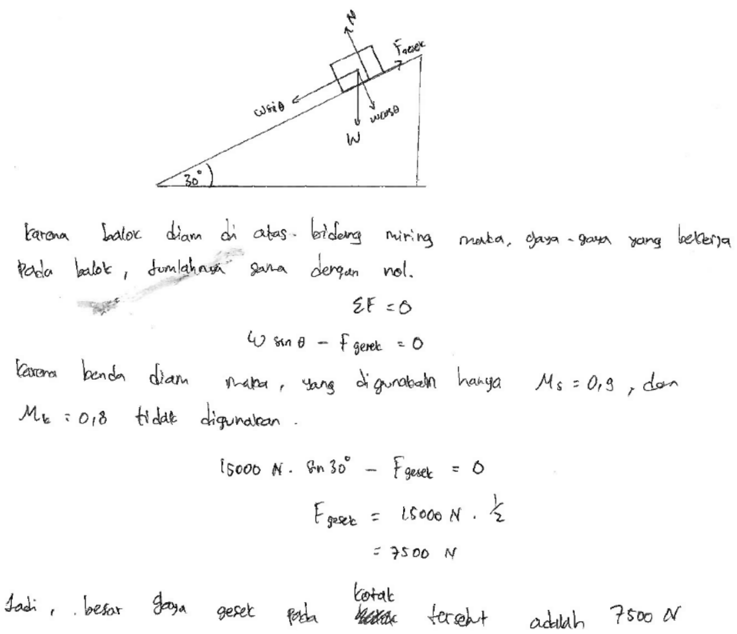
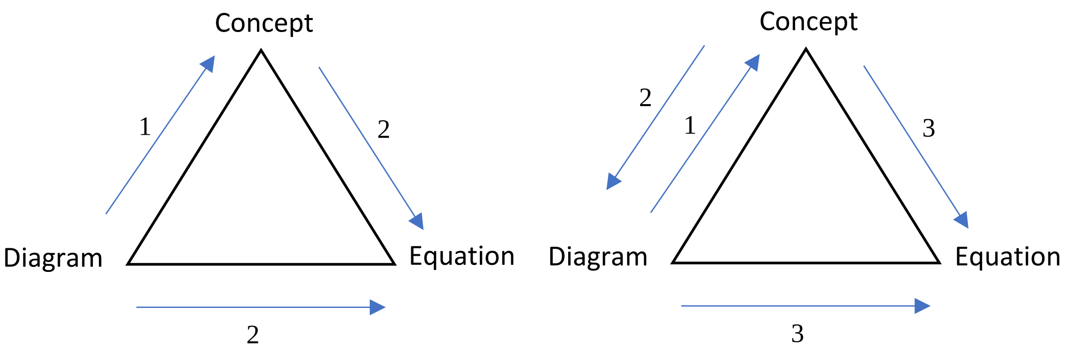


Figure 6. 1 An example of student solution drawing complete diagrams in solving survey problem 2

The pattern of student's solution according to CDE framework is shown in Figure 6.2a. This student started with drawing complete diagrams then followed by the concept of Newton's First Law and the concept of friction force. Then s(he) wrote the equation based on his/her diagrams.



(a) (b)

Figure 6. 2 The pattern of students' solution who drew complete diagrams when solving (a) inclined plane problem and (b) horizontal problem

A student also provided the explanation when solving survey problem 1 "because the box is not moving $f\_s = \mu\, N$ and N=W" (as shown in Figure 6.3). Based on the CDE triangle (the process of solving a problem), this student first drew complete diagrams on a sketch (including known and unknown variables).

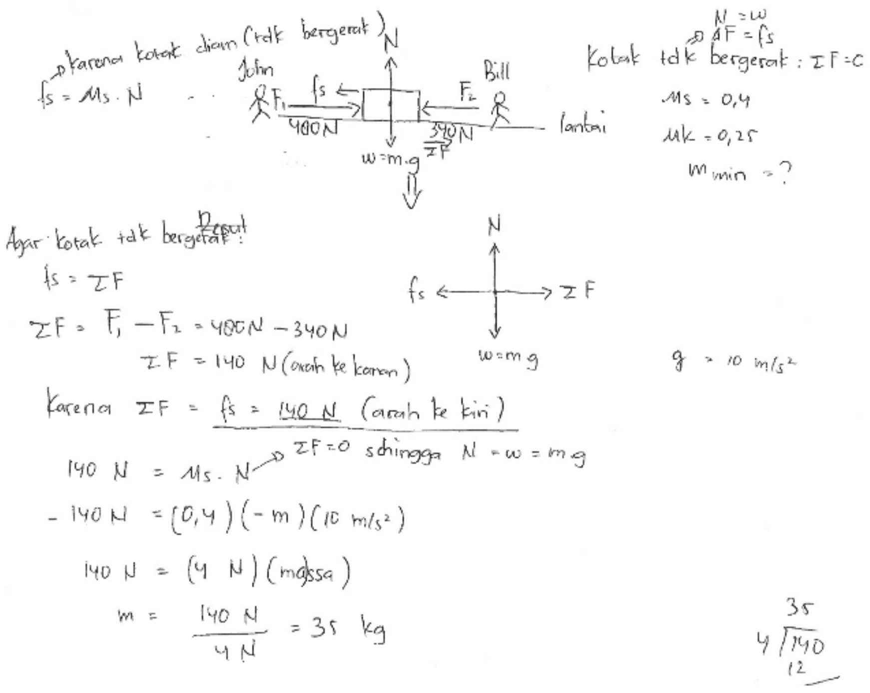


Figure 6. 3 An example of student solution drawing complete diagrams in solving survey problem 1

Then he wrote down Newton's First Law mathematically; this shows that he knew the appropriate concept used to solve the problem. After that he drew the second diagrams (drawing on the dot) before generating an equation to find the solution. The pattern of student's solution is displayed in Figure 6.2b. Based on the figure above, after students drew complete diagrams, they moved to write down the appropriate concepts, and finally generated equation based on diagrams and concepts.

Translating between representations is not easy because it needs fundamental knowledge about a concept (Cook, 2006). According to Rau (2017), representational competencies can be classified into conceptual and perceptual representational competencies. The ability to use and choose a certain representation is conceptual representational competence. In this case, students' ability to use force diagrams is conceptual representational competence. Moreover, the ability to know the meaning of representation as a means of translating among representations is perceptual representational competence. Examples of students' work can be seen in section 5.2.1 Figure 5.2 and Figure 5.3. These students seemed that they were able to present the problem by drawing the complete diagrams. Then they translated their diagrams into the appropriate equations. Based on Rau's argument, some students in this study were competent to use conceptual representation (using force diagrams) but they were not able to produce the meaning of their diagrams (perceptual representational competence) as a means of generating a correct equation.

After students drew diagrams, some of them may have directly focused on the friction force formula ($f_s = \mu_s N$). These students may have already known the formula or memorised it and put numbers in it without linking the diagrams and mathematical equations. The accepted approach such as the Newton's First Law ($\sum F_x = 0$) can be used to determine the net force in x direction: $\sum F_x = f_s - W_x = 0$; $f_s - W_x$. From this equation, the magnitude of static friction is equal to the magnitude of the component of weight force in x direction. Based on physics concepts (Etkina, Gentile and Van Heuvelen, 2014), "the friction force is just the component parallel to the surface of the force that the surface exerts on the object; the other component of the same force is the normal force". In other words, the force that a surface exerts on an object which is the component perpendicular to the surface is called the normal force and the component parallel to the surface is the friction force. Thus, these two forces relate to each other. The friction force exerted on a stationary object is called the static friction force in which the magnitude is from minimum to the maximum value. The maximum resistive force that the surface can exert on an object is called the maximum static friction force and this force is directly proportional to the magnitude of the normal force ($f_{s\,max} \approx N$). The maximum static friction force depends on the roughness of the surfaces of two objects, so $f_{s\,max} \approx \mu_s N$; μ_s is the coefficient of static friction force. Then the value of the static friction force is $0 \leq f_s \leq \mu_s N$. The static friction force exerted on an object begins from at rest up to almost moving. Once the object starts moving, the kinetic friction force is exerted on the object ($f_k = \mu_k N$); μ_k is the coefficient of kinetic friction force. Understanding these friction force concepts may help students to connect diagrams and equations.

Force is an abstract concept because it cannot be seen. For example, when a box is placed on the horizontal surface (survey problem 1), it is hard for some students to understand that there is a force of the earth exerted on the box (called weight force) because there is no effect of that force on the box which can be seen by eyes directly. Some students might just memorise the direction of weight force is always going down without considering an interaction between the Earth and the box. Then, when talking about the normal and friction forces, these two forces are the components of a force of the surface exerted on the box. These ideas are more abstract for some students because analysing force components needs mathematical concepts such as trigonometry. The relation of normal force and friction force is somewhat difficult to understand, that is why students might rely on the general friction force equation without thinking the relation of both forces conceptually. Some students might have partial understanding about these forces that the magnitude of friction force can be just derived from the magnitude of normal force. For example, some students who drew complete diagrams in solving survey problem 2 relied on the friction force equation ($f_s = \mu N$).

In addition, students tend to understand that the direction of normal force is always going up instead of recognising the position of an object. For example, while solving interview problem 1, some students drew the normal force as going up instead of going down because they might remember while solving problems where an object is placed on the horizontal surface like survey problem 1. This might be caused by their experience of learning this concept, in which instructors usually presented examples where the object is placed on a horizontal surface; some students did not recognise that 'the normal force is perpendicular to the object'. Students also have a conception that friction force is opposite to the external force instead of the net force. The external force means that a force exerted on the box such as John pushes a box ($F_{John\ on\ box}$) whereas the net force is the summation of forces in an axis such as x direction (survey problem 1).

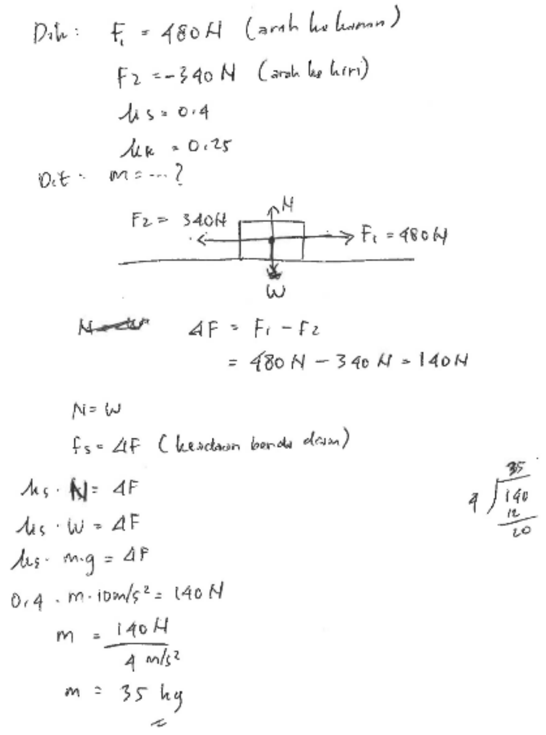
That is why in survey problem 1, some students drew two different friction forces exerted on the box while it is at rest because it was being pushed from two different directions. This shows that students have still developed their understanding about friction forces.

6.1.2 The Incomplete Diagrams

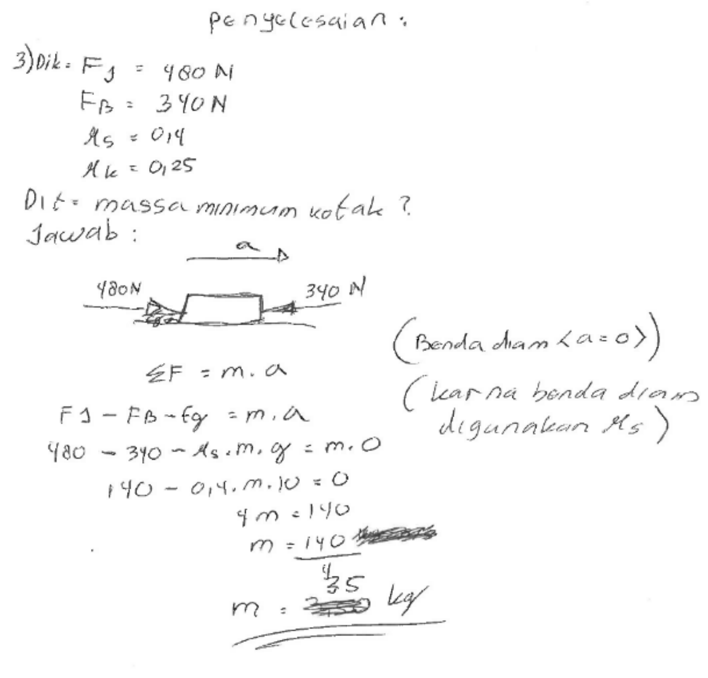
The answers of students who drew incomplete diagrams were categorised into three groups: correct, incorrect, and unfinished. These categorisations were derived from students answers while solving survey problems (section 4.3.1 and 4.3.2). The number of students who drew incomplete diagrams and obtained incorrect answers was higher than students who obtained the correct answers. Two thirds of students who drew incomplete diagrams obtained incorrect answers when solving survey problem 2. These students focused on friction force equations (displayed in Table 4.8) instead of the net force in the x-direction.

However, the results show an interesting finding that some students could solve the problems correctly even though their diagrams were incomplete. A previous study found that, for some students, adding information such as drawing force diagrams is useful because it can reduce working memory, whereas some students who are more knowledgeable are able to solve the problem without adding information or drawing force diagrams (Kalyuga *et al*, 2003). 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. For example, in survey problem 1, students were 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 survey problem 2, students may not have drawn the component of weight force because they were familiar with the context that the component of weight in the x-direction is using sin θ and using cos θ for y-direction.

Two students who drew the incomplete diagrams performed different procedures to find the same correct solution in solving survey problem 1 (as shown in Figure 6.4).



(a)



(b)

Figure 6. 4 Examples of students' solution drawing incomplete diagrams in solving survey problem 1

According to CDE framework, the first student did not draw friction force in his/her diagrams but s(he) knew a concept that the direction of friction force is opposite to the direction of net force by writing down mathematically ($f_s = \Delta F$; $\mu_s N = \Delta F$; $\mu_s\, m\, g =$

ΔF). Then, from that equation s(he) determined the magnitude of the mass of the box. This student solution is shown in Figure 6.5a based on the conceptual framework.

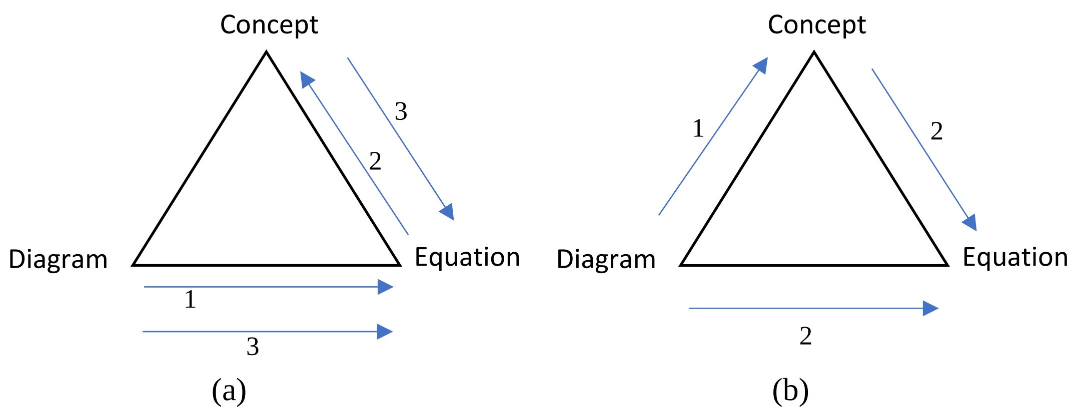
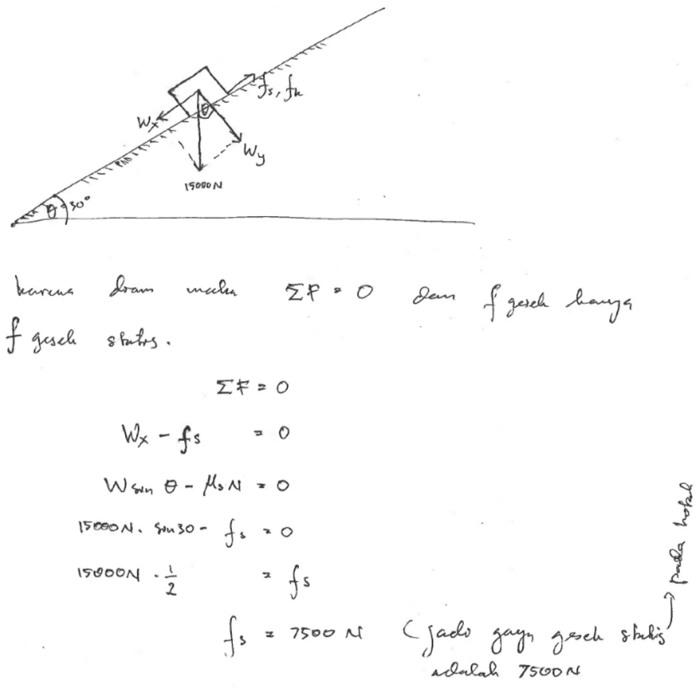


Figure 6. 5 The pattern of students' solution who drew incomplete diagrams while solving survey problem 1

Meanwhile, the second student drew directly the direction of the friction force which is opposite to the direction of the bigger force. This student did not show the calculation of the net force or did not draw the net force but s(he) might visualise in his/her mind. Then s(he) wrote down an equation by including all forces ($\sum F = m\,a; F_J - F_B - f_g = m\,0;\ F_J - F_B - \mu_s m\,g = m\,0$). The pattern of the student's solution is shown in figure 6.5b. This indicates that both students depicted different diagrams and wrote down different equation, but they knew the concept of friction force and applied the Newton's First Law to find out the solution.

In survey problem 2, two students provided different approaches in finding the magnitude of the friction force (as displayed in Figure 6.6). Both students drew incomplete diagrams where the difference is the first student (Figure 6.7a) depicted friction force whereas the second student did not. After drawing diagrams, the first student wrote down a concept "due to the box is not moving, the static friction force is exerted on the box" then wrote down Newton First Law mathematically and put forces exert on x-axis into equation ($\sum F = 0;\ W_x - f_s = 0$). From the equation, s(he) determined the correct solution. In contrast, after drawing diagrams, the second student (figure 6.7b) wrote down the static friction equation ($f_s = \mu_s\,N;\ f_s = \mu_s\,W\cos\theta$) and put the numbers into the equation. This indicates that both students drew the incomplete diagrams but one of them did not employ his/her diagrams to generate an equation in finding the solution.



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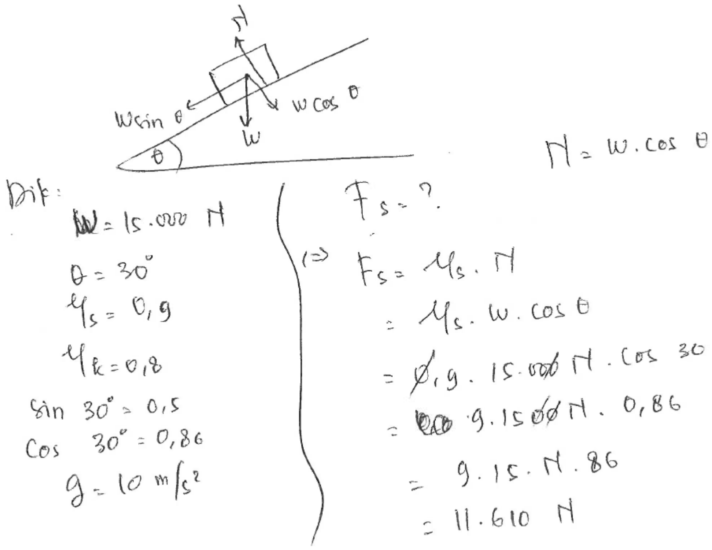


(b)

Figure 6. 6 Examples of students' solution drawing incomplete diagrams in solving survey problem 2

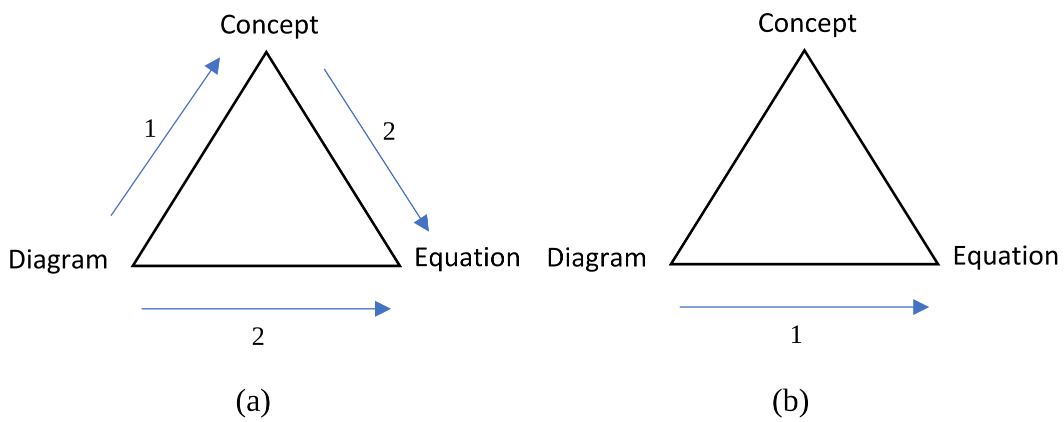
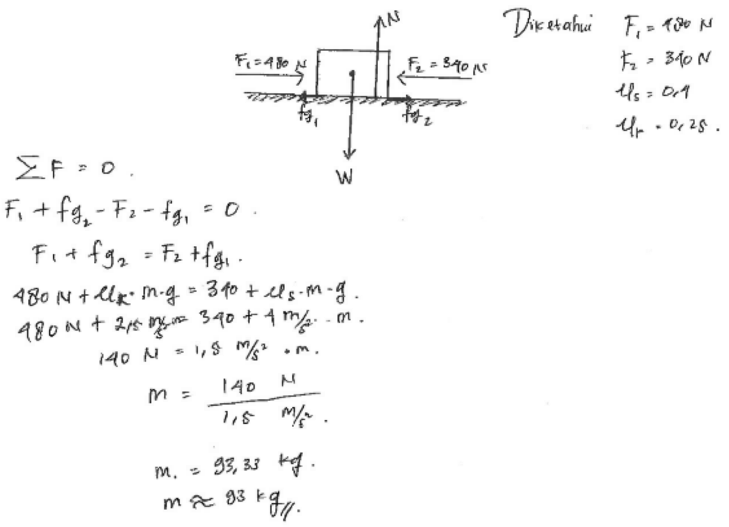


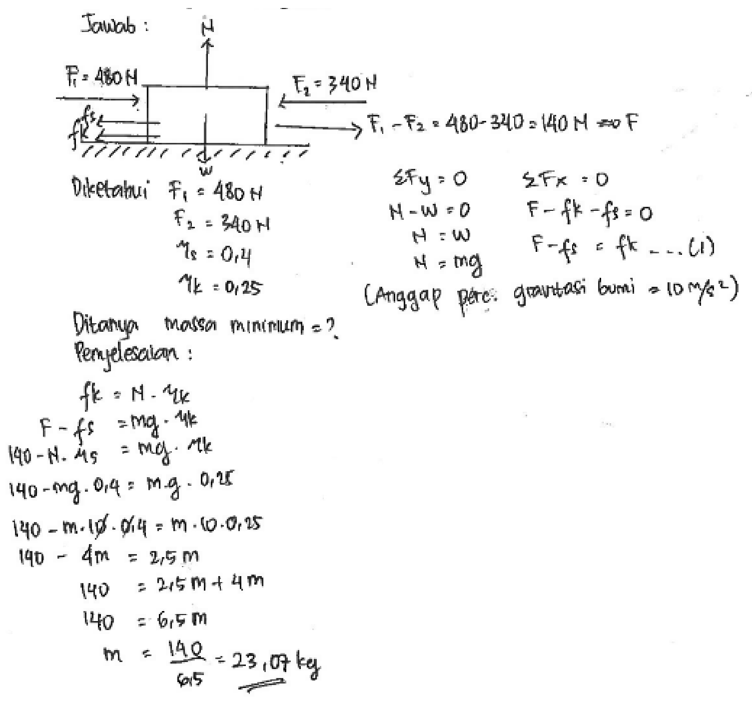
Figure 6. 7 The pattern of students' solution who drew incomplete diagrams while solving survey problem 2

6.1.3 The Inappropriate Diagrams

Students who drew inappropriate diagrams tended to obtain incorrect answers and some could not completely solve the problems. Based on students' answers, students who drew this kind of diagram drew incorrect diagrams such as incorrect direction of forces. In addition, some students also wrote incorrect mathematical equations. Students who drew inappropriate force diagrams seem to have partial understanding about physics concepts such as friction force. For example, while students solved survey problem 1, some students drew both friction forces (static and kinetic) in the same direction and 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 static friction force is always opposite to the external force'. Consequently, they drew two friction forces because two external forces 'force John and force Bill' were exerted on the box. A student's work can be seen in Figure 6.8. 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'.



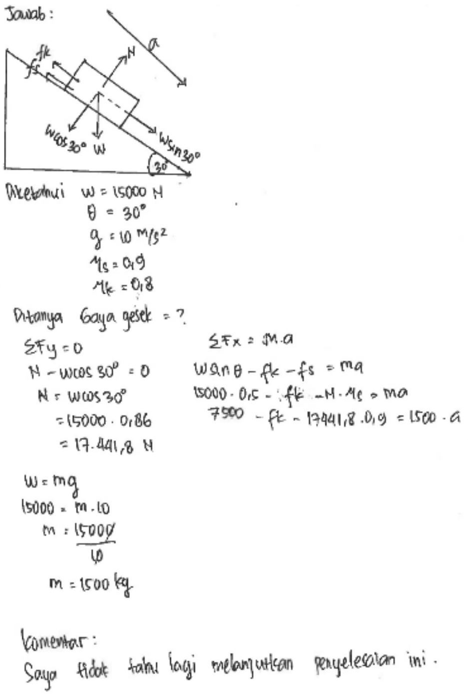
(a)



(b)

Figure 6. 8 Examples of students' solution drawing inappropriate diagrams in solving survey problem 1

According to the framework used in this study (CDE triangle), students who drew inappropriate diagrams tended to employ them to generate equations but the incorrect diagrams affected their incorrect equations as well as final answers. Examples of students' solution can be seen in Figure 6.8 and 6.9. Then, the pattern of students' solution is shown in Figure 6.10.



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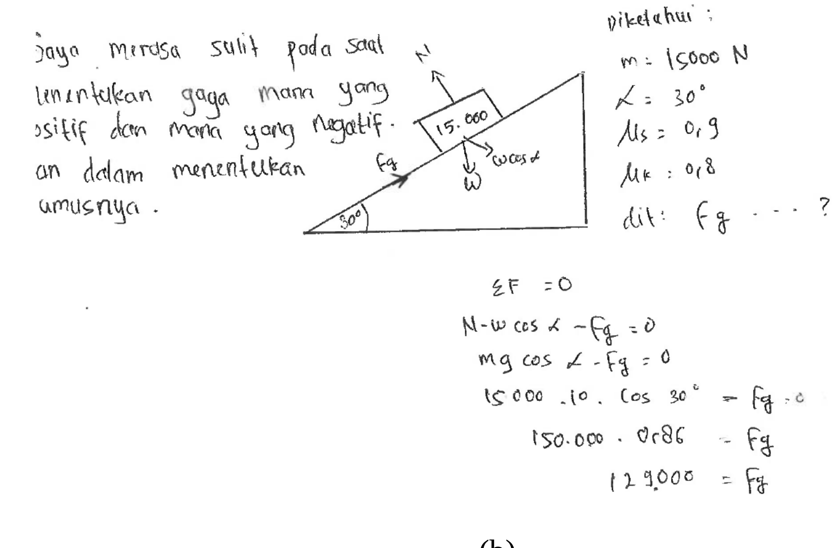

(b)

Figure 6. 9 Examples of students' solution drawing inappropriate diagrams in solving survey problem 2

Students' solution in Figure 6.8 and Figure 6.9a show that after drawing diagrams, students applied the concept of Newton's First Law to generate an equation. However, students drew two friction forces exerted on the box which is incorrect. In addition, in Figure 6.9b, student knew that the Newton's First Law was used to solve the problem but s(he) was not able to distinguish which forces included in equation.

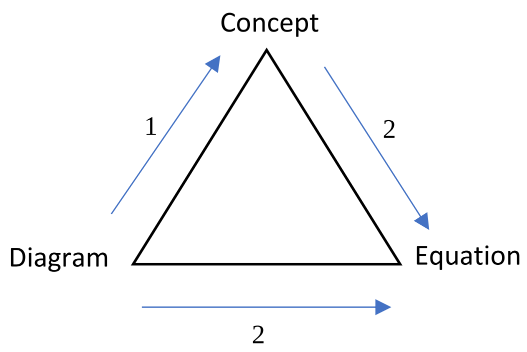

Figure 6. 10 The pattern of students' solution who drew inappropriate diagrams while solving survey problems

Hestenes, Wells and Swackhamer (1992) suggested that Newton's Laws of Motion are utilised to (1) infer unknown force from known force, and, (2) to predict motion from known force. In this case, the motion of the box is known (at rest) meaning that the net force is zero, so this can be used to determine the direction of static friction force. Then, the situation has been called a 'representation dilemma' (Rau, 2017), students should have conceptual knowledge while drawing diagrams but at the same time they need diagrams to help understand the concepts. Rau points out that students might be confused in using representations because they play a dual role: on one hand, students learn about representations to represent concepts; on the other hand, students learn new concepts from visual representations. The findings indicate that students who drew inappropriate diagrams might lack knowledge of force concepts, particularly understanding the static and kinetic friction forces. For example, a student mentioned during an individual interview". I think the direction of friction force is opposite to the direction of push force. If the push force is to the right, the direction of friction force is to the left". This student's statement shows that his conception about friction force is not yet complete. He should recognise that drawing all forces and determining the total forces exerted on an object may help him to determine the direction of friction force.

The abstract nature of representations, sketches, force diagrams, force component, and equations might be one of the factors why students face difficulties in drawing the complete diagrams. Force diagrams are abstract representations for some students because they should be able to imagine and depict non-contact force such as the weight force. The complexity of the friction force and the normal force might add to students' difficulties. When an object is placed on an inclined plane or an external force is exerted on an object, students need to determine the component of the forces which need trigonometry knowledge in order to find the net force or the resultant forces.

Students who drew complete and incomplete diagrams had the ability to construct the appropriate diagrams because in terms of correctness, they were able to depict forces exerted on the object correctly. But some students were not able to translate their diagrams into the appropriate equations. Students' answers show that some of them wrote incorrect equations and some of them did not utilise their diagrams in generating equations. However, students who drew inappropriate diagrams seemed to lack the knowledge to represent forces exerted on the object; these students drew incorrect forces in terms of direction and concepts. That is why students did not write the appropriate equations and some of them were not able to accomplish the problems. This suggests that some students who drew complete and incomplete diagrams were able to translate problems in to a sketch then draw diagrams and produce equations; whereas some of them could not see the meaning of their diagrams. In addition, students who drew inappropriate diagrams indicate that they are not able to represent problem into diagrams because they had partial knowledge.

6.1.4 Use of Diagrams by Students from Different Levels of Study

Analysis of the force diagrams drawn by students from different levels of study reveals some patterns. The fourth-year students who had more experience tended to draw incomplete diagrams while solving horizontal surface problem (63%). The proportion is lower while solving inclined plane problem (48%). These students are familiar with these kinds of problems and the underlying concepts. For example, in the horizontal problem, some students may not need to draw the weight force because they knew the direction of this force is always going down whatever the position of an object whether an object is resting on a vertical plane or below the ceiling (survey problem1 and interview problem 1). However, less experienced students (the first and second year students) may need to draw complete diagrams because they think this representation will be helpful in solving the problem. In addition, first and second year students tended to draw more inappropriate diagrams than fourth year students. Previous studies suggest that novice problem solvers who lack knowledge draw representations by using everyday or surface ideas; in contrast, experts incorporate concepts, principles, and relations in constructing representations (Maloney, 2011). This suggests that students who have partial knowledge may just focus on a question asked in a problem (unknown variable) and select a formula relating to the question. And also these students may think that drawing diagrams and selecting the appropriate equations are independent processes of problem solving. Meanwhile, students who have enough knowledge are able to integrate concepts and diagrams and employing diagrams to produce equations.

Regarding the relation between students' diagrams and their success in solving the problems, the more experienced students (the fourth year students) seemed more successful in obtaining the correct answers (as can be seen in Figures 4.11 and 4.17) even when they drew incomplete diagrams. Among the group of students who drew incomplete diagrams, the fourth-year students achieved higher success rate than other students while solving both horizontal and inclined plane problems. This finding shows that students (the fourth-year students) who have more practice solving physics problems and applying physics concepts knew when and how diagrams can effectively be drawn and used. Meanwhile, some of the first and second year students obtained incorrect answers and were unable to finish their solutions.

Previous research (Kohl and Finkelstein, 2008) has shown that experts are more flexible and efficient than novices in using representations and experts were tended to obtain the correct solutions (Dhillon, 1998). In these studies the term 'expert' and 'novice' are attached to groups who differ considerably in experience: expert are generally lecturers or teachers and post graduate students, and novices are under graduate students and high school students. Although the difference between student in different year-groups in my study is much smaller, the data suggests that experience is a factor in how students draw and use representations.

6.2 Students' Motivations for Drawing Force Diagrams

Students' survey responses about using representations have been presented in section 4.2. Most students (about 70%) responded that they often use representations including pictures, diagrams, graphics etc while solving problems. This relates to students' responses that they usually draw pictures or diagrams (64%) even if there is no partial credit for drawing them. Based on students' diagrams (section 4.3.1 and 4.3.2), about 90% of students drew diagrams of some kind (complete, incomplete, or inappropriate diagrams). Further, based on students' responses from the survey, most students (about 80%) agreed that their motivations to draw representations are to make the problem easier to understand, to find the correct answer, and to understand the physics concepts. This finding aligns with Van Heuvelen and Zou's (2001) claim that the role of representations in problem solving is to enhance students' understanding of the problems. This will work for students who know how to use diagrams. For example, students who knew that drawing forces exerted on an object and from that diagrams, they determine the total force or net force to find out the direction of friction force. Due to the abstraction of force concepts, drawing force diagrams will be helpful to depict the position of forces.

Students' responses about force diagrams from individual and paired interviews were categorised into six themes and 15 sub-themes (Table 5.1). Purpose is the first theme which includes students' reasons for drawing force diagrams. Students' learning in high school and obtaining credit from instructor were grouped as external reasons (the second theme) for drawing force diagrams. The third theme is convention of force diagrams. Physics concepts and mathematical concept were the fourth and the fifth themes respectively. The motivation to use incomplete diagrams is the sixth theme.

6.2.1 Purpose: Reasons for Drawing Force Diagrams

Identifying forces is the most frequent reason that students gave for drawing diagrams. Some students mentioned that drawing diagrams helped them to know all the forces exerted an on object such as weight force, normal force, and friction force. In other words, for some students, a benefit of drawing diagrams was to identify other forces that were not mentioned in the problem. For example, while solving force problems in the survey and the interviews, the friction force is not shown in the diagrams presented in the question. Evan mentioned, "I think I need to draw diagrams because the problem does not depict friction force" (Section 5.2.1, Evan's comment). In addition, in interview problem 1, just the F force was provided in the problem. Some students may need to draw diagrams as a means of knowing all the forces exerted on the box. For example, Eva provided her reason for drawing forces as "to know forces exerted on the block because the problem just displayed only F force". (as can be seen in section 5.2.1).

Finding the direction and sign of forces also emerged as one of the motivations for students to draw diagrams. Some students drew initial diagrams then revised them after drawing all the forces. For example, while solving interview problem 1, Amy drew the direction of the normal force as upward (as can be seen in section 5.2.2, Amy's comment). This means that drawing forces is a way to check the direction of forces. Moreover, some students also took advantage of drawing diagrams to determine the direction of the friction force. Some students first determined the net force before drawing a friction force. Evan said "I think the direction of friction force is opposite to the direction of push force. If the push force is to the right, the direction of friction force is to the left". The sign of force is also helpful in selecting mathematical equations. Mona said "ya, in vertical direction, there are normal force and weight force which are going down, meanwhile the component of Fy is going up. So, I gave the sign of forces which are going down is positive whereas going up is negative" (as can be seen in section 5.2.2, Mona's comment).

One of the reasons students gave for drawing diagrams is to determine the component of forces. Students need to determine the force component if a force exerted on an object is not precisely in a vertical or horizontal direction (like interview problem 1) and when an object is on an inclined plane (like survey problem 2 and interview problem 2). Some students determined the component of F in x- and y-axis before finding out the net force. Generally, when students solve a problem in which an object is placed on an inclined plane, some of them may need to know the component of weight forces. Meanwhile, students may not need to draw the component of forces for a certain problem because they are familiar with the component of W in x-axis uses sin θ whereas in y-axis uses cos θ. Further, from interview comments, some students have difficulties in finding out the component of forces. Evan mentioned that "I think that it is more difficult in the context of inclined plane than horizontal surface because I have to find the component of forces" (section 5.2.3). Ana also said that "the difficulty is to determine the component of forces because if one of the forces is wrong, it will affect for all forces" (section 5.2.3). For example, when students make a mistake in determining the component of Fx in interview problem 1, it will affect the component of Fy and mathematical equations are incorrect as well.

Some students from interviews mentioned that selecting mathematical equations is one of the motivations for drawing force diagrams. They thought that drawing diagrams will help them in generating the appropriate equations to find the correct solution especially for a complex problem which has many forces exerted on an object (like interview problem 1). Leo said, "I think that diagrams are needed for solving complex problems which involve many forces. It will help me in applying mathematical equations" (section 5.2.4). This student's comment shows that he recognised that he needed to draw diagrams to help him in identifying all forces and translated his diagrams into mathematical equations. In terms of problem solving process, he moved from diagrams into mathematical equations. Students who drew complete diagrams tended to select the correct equations. Moreover, some students who drew incomplete diagrams were also able to find the correct mathematical equations. This indicates that these students were able to integrate the referent, representation, and meaning (Carolan, Prain and Waldrip, 2008). In this case, the referent is a box moving below a horizontal ceiling then represented with forces diagrams as representations. From force diagrams, students can generate the meaning such as the net force in the vertical direction is zero by using Newton's First Law and students were able to determine the net force in the horizontal direction to know whether the box is moving with constant velocity or constant acceleration. However, students who drew inappropriate diagrams tended to generate incorrect mathematical equations.

6.2.2 External reasons: External Factors for Drawing Diagrams

Students' motivations for drawing force diagrams might be influenced by other factors including a motivation to obtain credit from teachers or instructors. Based on students' responses from both individual and paired interviews, some students mentioned that they might be motivated to draw force diagrams in order to get extra credit. They might think that drawing diagrams will get extra score although they are not able to completely solve a problem. Tina provided her comment while evaluating a student's diagrams:

> *"the diagrams are obviously incorrect because she said the object is not moving but s(he) put a (acceleration). S(he) wrote equations without referencing with the diagrams. It commonly happens because some teachers told students that they will obtain extra credit if providing pictures /sketches and diagrams. That is why students sometimes just drawing diagrams without matching mathematical equations and diagrams"* (displayed in section 5.3.1 Tina's comment).

This is supported by students' response from the representation survey (section 4.2 Table 4.2) that about 30% of students were neutral and 7% of students disagreed with the statement “I usually draw pictures and/or diagrams even if there is no partial credit for drawing them.”

Further, in an interview, a student said

> *“I think it depends on teachers. Some teachers sometimes gave extra credit for students who drew diagrams. If a teacher only recognised the final result, the score of the students are the same either providing diagrams or not. But each teacher has different way to assess students’ works. If I was a teacher, I will give different score for students who draw or not”* (can be seen in section 5.3.1 Rose’s comment).

This indicates that whether teachers provide instructions to draw or not representations in problem solving (homework and exams) might affect students, motivations to draw diagrams.

Another factor is teachers’ approaches to teaching physics concepts. Students mentioned how their high school physics teachers taught friction. Daniel mentioned that “my experience while studying in high school, there is only one friction force introduced. For example, there is only kinetic friction force so just using the coefficient of kinetic friction. I seldom find two coefficients in one question” (section 5.3.1). Leo added “while studying in high school, a physics teacher taught that if an object is moving, the teacher directly wrote the coefficient of kinetic friction force without providing the coefficient of static friction” (section 5.3.1). Therefore, while students solve problems in this study (providing both the coefficient of static and kinetic friction), some of them drew two friction forces while the object is at rest (survey problem 1).

6.2.3 Conventions

Students were also concerned about the features of their diagrams including the label of forces used. Force is defined as the interaction of two objects (Maloney, 1990). For example, survey problem 1 consists of interactions such as between John and box, surface and box, and Earth and box. Some students mentioned that they are more familiar with one symbol to represent a force. For instance, while representing the force of John on the box, they used F_J rather than $F_{J\text{ on }B}$. Then they used W (weight force) to represent the force of the Earth on the box; and used N (normal force) to represent the force of the surface on the box. A student mentioned “it is more obvious that force of surface on box. But I usually use N (normal force) and it is more familiar for me” (section 5.4.1).

Further, students have different ways to draw forces either on a shape representing the object or on the dot. Some students preferred to draw on a sketch (can be seen in section 2.4.2.2, Figure 2.4) to help them to know the position of the forces. Frank mentioned “it is much easier for me if drawing diagrams in the real box (or in the real object) because I know the position the forces and it also saves my time” (section 5.4.2). Drawing diagrams in the real object means that drawing all forces on a sketch which represents the object. In contrast, some students drew forces in the dot which represents the real object. Drawing forces in the dot may help students to see clearly the direction of forces as well as the component of forces. Maria said that “it is easier to determine the direction of forces and the resultant of forces” (section 5.4.3). The previous study by Rosengrant *et al.* (2009) recommended drawing diagrams in a dot (a representation of the real object) to see clearly the position of forces whether in vertical or horizontal direction. Besides where forces are represented, students were also concerned about the arrow used to represent forces. Some students distinguished the use of line arrow to represent forces and the use of dotted lines to represent the component of forces. Rose evaluated a student’s diagram during paired interview by saying “I think the first time looking at this (diagram), his/her diagrams are not accurate while drawing the component of weight force. This should be dotted line arrow to represent the component of forces” (section 5.4.4).

6.2.4 Physics Concepts

Students’ understanding about force concepts affected the forms of their diagrams. The normal force, weight force, and friction force were involved in force problems used in this study. Students said that understanding force concepts influenced the way they drew diagrams. A student mentioned, “we must know the concept of forces. For example, the normal force is always perpendicular to the surface”. However, based on students’ diagrams, they have different ways to draw the normal forces. Some of them drew from the bottom of the object whereas others started from the centre of the object. This indicates that the motivation of students to draw normal force might be just knowing the direction without recognising the concept of normal force. In addition, some students were also concerned about the direction of the normal force which depends on where an object is placed. Some of the students were familiar with drawing the direction of the normal force exerted on an object placed on the horizontal surface which is going up, so when students solved the interview problem 1, where the object is below a horizontal ceiling, some of them drew the direction of normal forced exerted on the box as going up instead of going down.

The second concept that concerned students is friction force which was often mentioned during interviews. Based on students' diagrams, some students were not able to distinguish between static friction force and kinetic friction force. So, some of them drew two friction forces (static and kinetic) while solving survey problem 1 in which the box is not moving meaning that the static friction force is exerted on the box. From students' answers, students have conceptions about friction force: the friction force is always opposite to the direction of a motion's object and the friction force is opposite direction to the acceleration of an object. Students felt that the friction force is difficult to understand. This might be because it is an abstract concept. Frank mentioned "the question made me confusion because it asked the magnitude of friction force while the coefficient of friction force has been provided. Then the magnitude of the friction force can be determined without using an equation $f_s = \mu N$" (section 5.5.1).

Newton's Laws were mentioned by students involved in drawing force diagrams. Some of the students perceived that these laws are useful to determine the net force exerted on an object either an object is moving or not. Evan said "The problem mentions that the block is moving so I thought $\sum \mathrm{F} = \mathrm{ma}$. The block is moving in x axis, so I wrote $\sum \mathrm{F_x} = \mathrm{ma}$. Meanwhile, the block is not moving in y axis, so the total force is zero" (section 5.5.2).

6.2.5 Mathematical Concepts

Besides physics concepts, mathematical concepts including vector and trigonometry were mentioned by students as factors that affect them in drawing force diagrams. To represent a force exerted on an object, physicists usually employ an arrow which shows the direction and the magnitude of that force. The length of an arrow shows the magnitude of the vector. Some students felt the concept of vector is important in drawing force diagrams. Steve mentioned "I think that to simply draw the diagrams, we must understand the concept of vector because force is a vector which has the magnitude and the direction. So, it is important to understand the vector" (section 5.6.1).

The concept of trigonometry was also mentioned by students that influences their diagrams. Some students recognised that understanding trigonometry helped them in determining the component of forces. For example, in interview problem 1 and 2, students determined the component of forces before finding the net force. Zack said that "the concept of trigonometry is important because force problems are not only in horizontal surface but also in inclined plane" (section 5.6.2). In addition, some students felt that it is more difficult to solve force problem in inclined context than horizontal context because it needs analysing force component (as can be seen in section 5.6.2). This shows that besides knowing the physics concepts such as the concept of forces in drawing force diagrams, students needed mathematical concepts such as trigonometry concepts – the use of sines and cosines in helping students to determine the component of forces when forces are not precisely in horizontal and vertical axis.

6.3 Students' Views about Problem Solving

In physics courses, students usually solve problems while doing homework, exercises, and exams. According to Dhillon (1998), students ascertain solutions based on information given in the problem by implementing strategies or approaches. Based on the survey, about half of the students responded that they enjoy solving physics problems. However, about 40% students gave a neutral response. One of the possible reasons might be that students associate solving problems with situations in which they are being assessed. Another reason why students choose this response might be affected by the form of problems such as symbolic or numerical problems. Some students might prefer to solve numerical problems rather than symbolic problems and vice versa. This aligns to a statement in the survey that 65% of students agreed that they faced difficulties in solving symbolic problems. This is also supported by a study conducted by Hung and Wu (2018) that a group of students who solve numerical problems was more successful than students who solve symbolic problems. Therefore, students' interest in solving problems might be influenced by several factors such as the form of problems and the complexity of problems. In this study, students solved all numerical problems (survey and interview problems). One of the problems is a complex problem (interview problem 1) which is the box placed below a horizontal surface and hold a force shaping a certain degree. This problem is not common for some students and they should identify many forces exerted on the box including the component of forces and friction forces.

Regarding the role of mathematics in problem solving, the majority of students perceived that mastering mathematics is the most important thing in successfully solving physics problems. Mathematics concepts as tools are needed to help students in solving physics problems (Bing and Redish, 2009; Uhden *et al*, 2012). Moreover, mathematical equations are used to represent physics concepts (Sherin, Bruce L., 2000). Students may think like that because they might often solve quantitative problems which need manipulating equations to determine the answer. For example, in this study, students solved problems (horizontal and inclined plane context) which need equations to find out the answer. A previous study conducted by Mason and Singh (2010) found that a half of their participants (undergraduate and graduate students) agreed to the statement "in solving problems in physics, being able to handle the mathematics is the most important part of the process". In addition, students might be more confident in solving problems if they have mathematical skills such as trigonometry, algebra, derivative, etc. This also correlates to students' response "problem solving in physics basically means matching problems with the correct equations and then substituting values to get a number". About a half of the students agreed to this statement.

One of the goals of physics problem solving is to assess students' conceptual understanding. Physics concepts are very important in physics problems (Adams *et al*, 2006; Elby, 2001). Leonard *et al.* (1996) suggested several points during solving problems: "students should be able to identify the major physics principles and concepts that are used to solve problems, they should be able to articulate the rationale for using a particular principle or concept, and they should be able to describe how principles and concepts are applied to construct solutions". The findings show that most students agreed with the statement "in solving problems in physics, I always identify the physics principles involved in the problem first before looking for corresponding equations". This indicates that students focus on concepts while solving problems. In this study, for example, several concepts were involved such as normal force, friction force, and Newton's laws.

6.4 Summary

The methods used in this study were designed to collect data to explore my research questions. The physics problem solving and representation surveys were given to students from across four year groups and constructed from statement which could give an overview of students' views about physics problem solving and representations. The force problems surveys, given to the same group of students was designed to obtain detailed observation of students' performance in solving physics problems and the ways in which students drew and used diagrams. Analysis of students' diagrams led to the construction of four categories (complete diagrams, incomplete diagrams, inappropriate diagrams, and no diagrams) which were used as the basis for selecting students who participated in clinical interview. Analysing students' responses from individual and pair interview generated several themes of students' perception about drawing representations particularly force diagrams.

This chapter has discussed students' views about problem solving and representations, students' force diagrams, and students' views about drawing force diagrams. Most students perceived that mathematical knowledge is the most important part in the process of solving physics problems. Then most students responded that they often use representations while solving problems including to make a problem easier to understand, to help find the correct answer, and to help understanding the concept. When solving force problems (horizontal and inclined plane context), students drew three different categories of force diagrams including complete diagrams, incomplete diagrams, and inappropriate diagrams. About a half of students drew incomplete diagrams for both problems. Students who drew complete diagrams tended to obtain the correct answers. Meanwhile, students who drew inappropriate diagrams tended to get incorrect solutions and could not completely solve the problems. The group of students who drew incomplete diagrams have three different solutions: correct, incorrect, and unfinished. An interesting finding shows that even though some students did not completely draw force diagrams, they were able to find the correct solutions.

The flow of students' solutions was represented in the CDE triangle in which students moved among concepts, diagrams, and equations. The patterns of triangles depicted students' thinking and the use of diagrams. Most students began with drawing diagrams then wrote down either concepts and equations. Students who drew complete diagrams tended to employ diagrams and correct concepts to produce equations. Meanwhile, students who drew inappropriate diagrams tried to use concepts and diagrams in generating equations but due to the incorrectness of diagrams and concepts used, they produced incorrect equations.

Students' views about drawing force diagrams were derived from both individual and paired interviews. Students' reasons to draw diagrams were generally for identifying forces, determining the component of forces, finding the sign and direction of forces, and helping in selecting mathematical equations. Based on the students' response from the interviews, the motivations of students to draw incomplete diagrams because they have understood the problem and some forces are not needed for the calculations. The next chapter (Chapter 7) will present the conclusion of this study including the answers to the research questions, the implications of the study to teaching and research, and the limitation of this study.

CHAPTER 7
CONCLUSION

7.1 Summary of Responses to the Research Questions

This study asked four research questions which focused on students' problem solving and representations. Research Question 1 is "*What are students' views about solving physics problems?"* To answer this question, physics problem solving surveys with 10 items were administered to elicit students' perceptions. About a half of the students (56%) responded that they enjoyed solving physics problems and 38% of students chose to be neutral; it is only a small percentage disagreed with this statement. Regarding the role of mathematics in problem solving, almost all students believed that mathematical knowledge was the most important in the physics problem solving process. Then, 50% of students agreed that solving physics problems basically means matching problems with the correct equations and then substituting values to get a number. Talking about the types of problems, 65% of students felt that it was more difficult to solve a physics problem with symbols than to solve an identical problem with a numerical answer. In other words, more students preferred to solve numerical problems than preferred to solve symbolic problems, and they perceived that mastering mathematics was one of the most important skills in successfully solving physics problems.

Research Question 2 asked, What are *students' views about physics representations*?" Physics concepts can be represented in several forms, such as sketches, graphs, diagrams, and equations. The physics representation survey, which consisted of 10 items, aimed to identify students' perceptions about using representations. The results show that most students agreed that they had learned representations (pictures, diagrams, graphs, equations), and often used these representations while solving physics problems. More than half of the students agreed that they usually drew representations even if there was no partial credit obtained from instructors. Relating to the role of representations, most students agreed that they used representations to make a problem easier to understand and to help them in finding the correct answer. They also agreed that drawing representations helped them to understand the physics concepts. However, 36% of students felt it was difficult to use representations presented in the textbook and 43% of students chose to be neutral. This indicates some students faced difficulties in understanding some representations. It can be concluded that students were familiar with using representations such as sketches, graphs, diagrams, etc. They gave positive responses about the role of representations in problem solving, including to assist in understanding the problems and concepts and finding the correct solution.

Research Question 3 focused on students' representations particularly using force diagrams: *How do students' production and use of force diagrams relate to their success in solving force problems?*" To address this question, two survey problems were given to identify students' performance in solving problems, including students' diagrams. Three categories of students' diagrams, including complete, incomplete, and inappropriate diagrams, were derived from students' solutions. 18% of students drew complete diagrams and 67% of these students obtained the correct answer. Meanwhile, the proportion of the students who drew complete diagrams in solving inclined plane problems was 35% and 28% of these students could find the correct solution.

The percentage of students who drew incomplete diagrams in solving horizontal and inclined plane problem was 54% and 42%, respectively. Even though students drew incomplete diagrams, some of them could solve the problems correctly, 35% for horizontal problems and 11% for inclined plane problem. Some students could not find the correct answer, as well as being unable to finish the problems. Further, the percentage of students who drew inappropriate diagrams was lower than for the two other types of diagrams, complete and incomplete. 20% drew inappropriate diagrams for solving horizontal problems and 11 % for solving inclined plane problems. Students who drew inappropriate diagrams tended to obtain incorrect answers and unfinished solutions. These students seemed to lack knowledge or have partial knowledge about concepts.

Based on the conceptual framework (CDE triangle), students had different movements among concept, diagram, and equation when solving the problems. All students started by drawing diagrams and then moved to either concepts or equations. The framework shows how students used diagrams and concepts to produce equations. Some students directly wrote down equation after drawing diagrams and others involved concepts and diagrams in generating equations.

In summary, students had different ways for drawing force diagrams when solving force problems: complete diagrams, incomplete diagrams, and inappropriate diagrams. Students who drew complete diagrams indicated that they had enough concepts and found the correct answers. Meanwhile, there seemed to be lack of knowledge for students who drew inappropriate diagrams. Then surprisingly, some students who drew incomplete diagrams could nevertheless solve the problems correctly.

Research question 4 asked "*In what ways do students think about, draw, and use force diagrams as they solve physics problems*?" Individual and paired interviews were conducted to answer this question. Six themes were generated including the purpose of drawing diagrams, the external reasons for drawing diagrams, conventions, physics concepts, mathematical concepts, and using incomplete diagrams. Students mentioned that the reasons for drawing diagrams included identifying forces, determining the component of forces, finding the direction and sign of forces, and supporting them in selecting mathematical equations. Students also recognised the conventions while drawing force diagrams such as the labelling of forces, drawing forces either in a sketch or in a dot, and representing forces with a dotted line. Students said that physics concepts and mathematical concepts are very important in successfully drawing force diagrams. For example, the concepts of forces, vector knowledge, and trigonometry are needed to draw force diagrams. Some students decided to draw incomplete diagrams because they understood the problems. In addition, some students only drew some forces which were helpful for calculations. Thus, in terms of motivations, students' reasons for drawing diagrams included identifying forces and using diagrams to produce mathematical equations. In terms of the process of drawing forces diagrams, students mentioned some aspects: physics concepts, mathematics concepts, and conventions.

7.2 Strengths and Limitations of this Study

7.2.1 Strengths

The previous studies discussed in the literature review focused on the correctness of drawing diagrams (a more positivist approach) and how students' diagrams relate to their success in solving problems (for example, the relation between the correctness of diagrams and the final solution). Most of the findings of these studies were for generalisation purposes. However, this current study used an interpretivist approach, which produced opportunities to explore students' diagrams in a more detail way and also to consider their views about drawing diagrams. The survey questions were used to develop categories for students' diagrams, and these became the basis for selecting interview candidates. The strength of this research is the use of interpretative analysis as methodology and clinical interviews as methods to describe students' use of diagrams in which students had different ways to draw force diagrams when solving force problems. Incomplete diagrams (in some cases) emerged as a sign of confidence and expertise rather than failure because some students were successful in solving problems without drawing complete diagrams. In appropriate diagrams can show up areas in which students are not confident about concepts, and so can give teachers/lecturers valuable information to inform their teaching. Then, students' views, including motivations and purposes for drawing diagrams which were not usually considered in quantitative studies were derived from analysing students' responses during interviews.

7.2.2 Limitations

Students might have provided positive responses when filling out surveys because most of them knew that the researcher was a teacher at a department of physics education. The results might have been different if the study was carried out at a different university. The physics problem solving survey has10 items which cover several aspects including strategies, approaches, difficulties, concepts, equations and interest in solving physics problems. This survey has given general views about physics problem solving. For example, what student view about mathematical equations and concepts in physics problem solving. However, this survey is limited for obtaining more detail views about students' perception about problem solving. Then, the physics representation survey also has only 10 items (the use of representations, the purpose of drawing representations, and the difficulties using representations), so these items are not enough for a standardised survey. But this survey gave general information regarding students' views about representations such as the motivation to draw representations including to understand the problem and to find the correct answers. An item of the surveys which is asking students whether they are good in representing problems in many forms is not really effective in this study. Other points that should be included in the survey include the use of representations to solve simple and complex problems and numerical and symbolic problems. The purpose of reducing students' views from five to three categories in the data analysis is to gain general pattern of students views who gave positive, neutral, and negative response. Although using the five categories might have given more detail, the simplification to three categories was effective in giving the overall picture needed in this study.

In order to explore students' performance in solving problems including diagrams, two survey problems (horizontal and inclined context) were given to students. These problems mostly addressed only one concept (three problems cover an object that is at rest and one problem addresses an object that is moving). So, students' diagrams from different concepts, such as an object moving with constant velocity and constant acceleration, have not been explored yet. In addition, problems with different contexts, such as two blocks connected to a rope, also needed to be explored in order to see various students' diagrams. Moreover, regarding the forms of problems, this study only covered numerical problems; therefore, students' approaches in solving symbolic problems have not been explored because based on problem solving surveys, students have different responses about the forms of problems. The decision to categorise students' diagrams into three categories (complete diagrams, incomplete diagrams, and inappropriate diagrams) was effective but the category inappropriate diagrams should be analysed in more detail instead of correct or incorrect diagrams.

Survey problems were given to all physics education students (first, second, third, and fourth year students) after they had learned force concepts. In fact, the concept of forces was taught in the first year of their studies, so some students might have forgotten the concepts.

7.3 Implications

7.3.1 Implications for Teaching

Based on findings from this study, students had different ways to draw force diagrams in solving force problems, including complete diagrams, incomplete diagrams, and inappropriate diagrams. One of the particularly interesting findings is that some students who drew incomplete diagrams could solve 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 does not mean that their diagrams are incorrect.

For some students, drawing force diagrams is not easy; difficulty 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 to generate equations. In addition, force concepts are also abstract whereas students needed physics concepts for drawing diagrams. At the same time, students draw diagrams to understand physics concepts. Consequently, some students might 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 be used to learn other concepts.

The results of the study show that students who drew inappropriate diagrams seemed lack to knowledge about forces. So, these kinds of diagrams can be used as diagnostic assessments to investigate students' understanding of force concepts. For example, some inappropriate diagrams can be used as options on multiple choice tests. In addition, inappropriate diagrams can also be used by instructors during lessons in obtaining students' comments.

Further, this study suggests that students had views about drawing force diagrams for such reasons as conventions, physics concepts, and mathematic concepts. Based on students' solutions and students' comments, they have different conventions about drawing force diagrams. For example, in labelling a force, some students used W (weight force) to represent the force of the Earth exerted on the object and other students used $F_{E \text{ on } O}$. Thus, when teaching force concepts, instructors should make an agreement with students about how to label forces that is clear for students. Moreover, an instruction should be developed to teach students to become competent in using representations so that they are able to transform from one representation into another representation. For example, students should have competence to transform from verbal representations to diagrammatic representations and from diagrams to mathematical equations.

7.3.2 Implication for Future Research

The results of the study give insights that students have different ways to draw force diagrams when solving problems. The topic covered in this study is the application of Newton's Laws in mechanics, so further study can be done on different topics, such as electrostatics, which use force diagrams to represent electric forces exerted in an electric charge to see the patterns of students' diagrams. Further, the same methods can be used to investigate students' representations, such as drawing graphs while solving kinematics problems, because graph representation is often used in learning physics concepts. Other topics in physics that use representations, including energy, optics, and thermodynamics, need to be explored.

In this study, the representation survey has only 10 items and the validity and the reliability of the survey have not been examined yet statistically. This is one of the limitations of the study. Therefore, the physics representation survey can be developed to produce a validated survey which does not yet exist in the existing literature. The items of the survey can be developed from the data set of this study (the motivation and reasons of students to draw force diagrams as presented in Chapter 5). The items of the survey can also be expanded in other representations such as graphs. Then, physics test such as force and motion test will also developed to see students' performance (students' movement between different representations) by using CDE triangle framework. Another possible further study can be done to investigate the relation between students' perception about physics representations and students' representational competence involving a larger population. The result of the study will be expected to give an understanding the extent to which these two variables are correlated.

7.4 Learning through Research

This study has been done to explore students' views about force diagrams while solving problems. A qualitative approach was employed in this study involving undergraduate students (physics teacher candidates). For a novice researcher, conducting a qualitative study was a new experience and not easy. This type of study was difficult because the position of the researcher was subjective, and the core idea was to make an interpretation of students' thoughts through written solutions and students' responses through interviews. When collecting data - particularly when conducting interviews, the researcher found that some students had short responses, and therefore learned how to encourage students in elaborating their thoughts or responses. Then, during the data analysis process, the researcher obtained valuable experience in how to transcribe students' talks from individual and paired interviews and employ NVivo software in producing themes. In addition, students' problem-solving attempts were recorded by Livescribe application, enabling the researcher to learn how to use it and introduce it to students.

From this study, the researcher learned how to write papers while presenting in international seminars. There were opportunities to present the findings of this study in international seminars, such as those organised by the European Science Education Research Association (ESERA), the American Association of Physics Teachers (AAPT), and the National Association for Research in Science Teaching (NARST). Attending these conferences gave valuable knowledge including feedback from experts and participants in improving this study. The researcher also obtained knowledge about the existing research in science education. Based on these experiences, a paper about this study will follow and that be published in an international journal, such as the *International Journal of Science Education*. Then the researcher will use knowledge obtained from this study to carry out research in developing a physics representations survey and investigating the relationship between students' views about representations and students' competence.

Appendices

Appendix 1: The themes of force diagrams research

The effect of teaching force diagrams						
No	Researchers	Year	Level	Design	Topic	Description
1	Rosengrant et al.	2009 PRPER	University students	Quantitative and qualitative studies	Introductory physics (Mechanics and electrostatics)	This study investigated three questions: 1. If students are in a course where they consistently use free-body diagrams to construct and test concepts in mechanics and in electricity and magnetism and to solve problems during the class, do they draw free-body diagrams on their own when solving multiple-choice problems on the tests? 2. Are students who use free-body diagrams to solve problems on tests more successful than those who do not? 3. How do students use free-body diagrams when solving problems? The experiment study was conducted for two years to investigate students' performance between a group of students who was taught representations in lecture and recitation class and a group of students who learned physics course without focusing specifically using representations.
2	Savinainen et al.	2004 SE	Secondary school students (aged 16; n = 45)	Experiment	Newton's Third Law	Research questions: 1. What is the effect of the instructional sequence, which utilizes the SRI Bridging Representation, on the development of the study group students' ability to apply Newton's third law in a range of contexts (i.e., on their contextual coherence in applying Newton's third law)?

						2. How do the results of the study group compare with those of the pilot group? The experimental group learned the content with using symbolic representation of interaction (SRI) as a tool to draw force diagrams. Meanwhile, the control group learned with regular curriculum. Students' performance was assessed by administering students the force concept inventory (FCI), Survey on Newton's Third law, and force and motion conceptual evaluation (FMCE).
3	Savinainen et al.	2013 PRPER	11 High school students (aged 16; n = 335)	Experiment	Introductory physics	Research questions: 1. Does using interaction diagram (IDs) help students to identify forces correctly? 2. Does using IDs help students to construct the correct FBDs? The participants of the study were grouped into three groups. First, Heavy use of IDs: in the learning process, students were taught using interaction diagrams to identify forces; students had many exercises. Second, Light use of IDs: the same treatment with Heavy IDs but in the light IDs, teachers only presented one example how to draw ID and give students two or three exercise. Third, No use of IDs: this group did not use ID, they just using regular physics textbook. To investigate students' performance, students (both Heavy and Light ID) were given eight questions which address how to construct FBD by implementing ID. Meanwhile, No ID just solved 2 questions about constructing FBD. In addition, all students were given other problems relating to Newton's laws

4	Aviani et al.	2015 PRPER	2 universities with different countries (first year university students; n1= 27 and n2 = 25)	Quasi experiment	Introductory physics (mechanics)	Research question: Is the approach to drawing and using FBDs which avoids specifying force components more effective than the traditional approach (in which the forces are resolved into the components) when it comes to developing students' understanding of Newton's laws including their ability to identify real forces? A group of students was taught using superposition approach whereas the other group was taught by decomposition approach. The researchers designed 12 item two-tier multiple choice survey to see the difference performance between those groups.
5	Tai and Yeo	2017 IJSE	High school physics teacher (n=1)	An exploratory case study	Introductory physics (Newton's third law)	Research question: 1. What pedagogical micro-actions were used by the teacher during the assessment and refinement phases of MBT? 2. What aspects of the students' models and modelling practices were addressed during the assessment and refinement phases of MBT? A teacher was observed while teaching students with model-based teaching (MBT) in the force topic particularly Newton's third law. The observations include how the teacher teach the concept and how the teacher interact with the students. The researchers analysed pedagogy micro actions of the teacher by using pedagogy content knowing (PCKg) perspective.
6	Bryce and Macmillan	2005 IJSE	Secondary school students (n = 21)	Qualitative study (grounded theory)	Physics (forces: action-reaction forces)	Research questions: 1. Does the use of bridging analogies assist students to construct and justify the existence of the reaction force in Newton's Third Law for themselves?

						2. Does the use of bridging analogies assist students to construct and understand the cause of the reaction force? 3. Do bridging analogies make a concept more understandable, believable and easier to explain? 4. Do bridging analogies result in genuine conceptual change and allow students to gain a better understanding of the concept of a reaction force? During interview, students were given some analogies including force diagrams as supports to answers force problems
7	Mualem and Eylon	2010 JRST	Junior high school (9th grade) and senior high school (12th grade)	Survey and Experiment	Physics subject (mechanics – Newton's laws)	Research questions: 1. What progress was made in solving qualitative problems that deal with everyday situations by junior high school students who were taught by the new approach? 2. What progress was made in determining students' understanding of the various problems characterised above? 3. How did students, who were taught by the approach, progress in their qualitative understanding? The researchers first gave all students 2 kind of questionnaires to attain the qualitative understanding of the students. Questionnaire which consists of 14 multiple choice questions is about real-life situations regarding Newton's laws. Whereas the second questionnaire also about Newton's laws which has 8 questions aims to understand students' performance. Then the researchers designed new approach instruction including drawing force diagrams to help qualitative understanding of students. The instruction was only applied for 9th grade.

						The interviews were also conducted pre instruction, during instruction, immediately after instruction, and 6 months after instruction to acquire the progress of students' understanding
8	Hubber et al.	2010 RSE	Three junior high schools (year 7) and students	Exploratory	Force	Research aims: 1. identify representational challenges and learning opportunities relating to key areas of science identified as problematic in the student conception literature 2. investigate the relation between student science conceptions, conceptual change, and representational issues in student learning in foundational science areas 3. develop evidence-based recommendation for effective pedagogies, focusing on representational issues, to support of learning fundamental science understanding 4. generate a set of assessment approaches, and representative materials, that will support significant student learning, and 5. document model teaching and learning activities and sequences, with sample student work, for wider dissemination. Teachers taught force concepts in the classroom by focusing on representations such as force diagrams. The teaching process including interactions between teacher and students and among students are recorded. The researchers analysed the video-audio recording to investigate teachers' pedagogy. Interviews with teachers and students were also conducted based on video recorded.
The effect of prompting students to draw diagrams and attaching force diagrams in problems						

No	Researchers	Year	Level	Design	Topic	Description
1	Heckler	2010 IJSE	University students (n = 891)	Experiment	Introductory calculus-based physics (Newton's laws)	Research questions: 1. Does prompting a diagram increase students' success at obtaining the correct solution? 2. Does prompting a diagram change the nature of the students' solution method? 3. What does students answering in these conditions tell us about student understanding of mechanics? There are two group of students; the first is traditional class which students were taught to use force diagrams in solving problems; and the second is honour class where the type of lecture is almost similar but in this class the lecture is more emphasising in using force diagrams especially in assessment. The researcher gave students force problems with two types of conditions. The first type of problem is asking students to draw force diagrams in their answers and the other is not.
2	Maries and Singh	2018 PRPER	University students	The first study is survey (n = 111). The second study is interview (n = 23)	Introductory algebra-based physics (electrostatics)	Research aims: Study 1: the extent to which asking students to draw a diagram or providing them with one drawn by an expert impacts their problem solving performance. Study 2: the extent to which providing diagram versus not providing a diagram influences how students engage in problem solving. Study 1. Students were divided into three groups to solve 2 problems. The first group are given prompting to draw diagrams, called prompt only group (PO). The second group is provided diagrams called diagram only group (DO). And the last group is not receiving diagrams and prompt called no support group (NO).

						Study 2. The interview aimed to get clarification how students solve the problems and what students think about the presence of diagrams in problems.
3	Chen et al.	2017 PRPER	College students (n = 480)	Survey	Introductory physics course (online course)	Research questions: 1. Do diagrams in general have an impact on students' problem solving performance (either percentage of correct answer or time spent on problem solving)? If so to what extent 2. Do diagrams given with problems change students' problem solving behaviour, or more specifically, their decision to draw their own diagram? 3. How does spontaneously drawing a diagram influence problem solving outcome? 4. Do students with different physics ability react differently to the presence or absence of a diagram? 5. What types of problems (if any) are more likely to require diagram Students were asked to solve six questions with two different formats: with diagrams and no diagrams. For example, a group of students who solve problem 1 with diagram will solve problem 2 without diagrams. After finishing each problem, students were asked to fill out a short survey which consists of four statements.
4	Kuo et al.	2017 IJSE	University students (n = 1136)	Survey with three steps: solving problems phase, filling out survey, and evaluating phase	Introductory algebra-based physics	Research question: Whether diagram prompts passively encouraged students to initiate standard procedures or actively discouraged pursuit of informal solutions? Students were divided into two conditions: control (n = 70) and prompt (n = 66). Prompt group is asking students to draw diagrams whereas control group is without

						receiving prompting. This study is almost similar with Heckler's study. After students finished solved the problems then they fill out 6 items of problem solving survey. The last, students were asked to evaluate problem solutions.
Representational competences and format of force diagrams						
No	Researchers	Year	Level	Design	Topic	Description
1	Nieminen et al.	2012	High school students (n =131)	Survey	Physics subject (Newton's laws)	Research questions: 1. Is there a relation between the preinstruction level of students' representational consistency (RCpre) and single student normalized FCI gain (GFCI)? 2. To what extent can we confirm earlier findings concerning the relation between FCI prescore ((RCpre) and Lawson prescore (Lpre) and their relation to GFCI? The researchers administered three kinds of surveys include Force Concept Inventory (FCI), Representational Force Concept Inventory (RFCI), and Lawson's Classroom Test of Scientific Reasoning. Both FCI and RFCI were given before and after instructions whereas Lawson Test was only given before instruction. The researchers then determined the correlations among those variables.
2	Meltzer	2005 AJP	University students (n = 400)	Survey	Introductory algebra-based physics	Research questions: 1. What subject-specific learning difficulties can be identified with various forms of representation of particular concepts in the introductory physics curriculum? 2. What generalizations might be possible regarding the relative degree of difficulty of various representations in learning particular concepts? That is, given an

						average class engaging in a typical sequence of instructional activities, do some forms of commonly used representations engender a disproportionately large number of learning difficulties? 3. Do individual students perform consistently well or poorly with particular forms of representation with widely varying types of subject matter? 4. Are there any consistent correlations between students' relative performance on questions posed in different representations and parameters such as major, gender, age, and learning style? Two similar Newton's third law questions with two different formats a verbal representation and diagram representation were given at the beginning of semester for five years. Then two additional questions quizzes (electrostatics and electric circuits) with four different formats: verbal, diagram, mathematical/symbolic, and graphical were given during lecturer.
3	Nieminen et al.	2010 PRPER	High school (n =168; age 16)	Survey	Physics subject (Newton's laws)	Research aim: To investigate the validity of R-FCI The researchers designed Representational Force Concept Inventory. 9 concepts which are each concept has 3 different formats: verbal, vectorial, and graphical representations. The total of the items is 27. The test was given to students before and after instructions to investigate representational consistency and scientific consistency of students.
4	Hung and Wu	2018 PRPER	Senior high school 10th grader. Numerical group is	Survey	Physics subject (Newton's laws)	Research questions: 1. Does the representational format of a physics problem and gender affect the self-efficacy of students in

			52 and Symbolic group is 42.			solving physics problems as well as their problem solving performance? 2. How does the numerical and symbolic representational formats affect the performance of students in the problem solving process? 3. What impact do different representational formats have on solving physics problem, according to the perceptions of students? How do students perceive the difficulties in solving physics problems in the numerical and symbolic formats? First stage, students were divided into two groups: symbolic and numerical group. Then students were asked to solve problems regarding Newton's laws with two different formats: numerical and symbolic formats. The problems are open-ended questions with aims to investigate students' approach and process in solving the problems. Besides problems, students were also given self-efficacy questionnaires. The second stage was conducting semi-structured. 6 students from each group were invited to participate in interview. Before conducting interview, students were asked to solve other problems. The purpose of interview was to gain students' difficulties while solving the problems.

Appendix 2: The CLASS Survey

Statement
1. A significant problem in learning physics is being able to memorize all the information I need to know.
2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.
3. I think about the physics I experience in everyday life.
4. It is useful for me to do lots and lots of problems when learning physics.
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.
6. Knowledge in physics consists of many disconnected topics.
[a]7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.
9. I find that reading the text in detail is a good way for me to learn physics.
10. There is usually only one correct approach to solving a physics problem.
11. I am not satisfied until I understand why something works the way it does.
12. I cannot learn physics if the teacher does not explain things well in class.
13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.
14. I study physics to learn knowledge that will be useful in my life outside of school.
15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.
16. Nearly everyone is capable of understanding physics if they work at it.
17. Understanding physics basically means being able to recall something you've read or been shown.
18. There could be two different correct values to a physics problem if I use two different approaches.
19. To understand physics I discuss it with friends and other students.
20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.
21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.
23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.
24. In physics, it is important for me to make sense out of formulas before I can use them correctly.
25. I enjoy solving physics problems.
26. In physics, mathematical formulas express meaningful relationships among measurable quantities.
27. It is important for the government to approve new scientific ideas before they can be widely accepted.
28. Learning physics changes my ideas about how the world works.
29. To learn physics, I only need to memorize solutions to sample problems.
30. Reasoning skills used to understand physics can be helpful to me in my everyday life.

Statement
31. We use this question to discard the survey of people who are not reading the statements. Please select agree—option 4 (not strongly agree) to preserve your answers.
32. Spending a lot of time understanding where formulas come from is a waste of time.
33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.
34. I can usually figure out a way to solve physics problems.
35. The subject of physics has little relation to what I experience in the real world.
36. There are times I solve a physics problem more than one way to help my understanding.
37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
38. It is possible to explain physics ideas without mathematical formulas.
39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.
[a]41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.
42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Appendix 3: The AAPS Survey

Attitudes and Approaches to Problem Solving Survey

by Andrew Mason and Chandralekha Singh

To what extent do you agree with each of the following statements when you solve physics problems?

Answer with a single letter as follows:
A) Strongly Agree
B) Agree Somewhat
C) Neutral or Don't Know
D) Disagree Somewhat
E) Strongly Disagree

1. If I'm not sure about the right way to start a problem, I'm stuck unless I go see the teacher/TA or someone else for help.

2. When solving physics problems, I often make approximations about the physical world.

3. In solving problems in physics, being able to handle the mathematics is the most important part of the process.

4. In solving problems in physics, I always identify the physics principles involved in the problem first before looking for corresponding equations.

5. "Problem solving" in physics basically means matching problems with the correct equations and then substituting values to get a number.

6. In solving problems in physics, I can often tell when my work and/or answer is wrong, even without looking at the answer in the back of the book or talking to someone else about it.

7. To be able to use an equation to solve a problem (particularly in a problem that I haven't seen before), I think about what each term in the equation represents and how it matches the problem situation.

8. There is usually only one correct way to solve a given problem in physics.

9. I use a similar approach to solving all problems involving conservation of linear momentum even if the physical situations given in the problems are very different.

10. If I am not sure about the correct approach to solving a problem, I will reflect upon physics principles that may apply and see if they yield a reasonable solution.

11. Equations are not things that one needs to understand in an intuitive sense; I routinely use equations to calculate numerical answers even if they are non-intuitive.

12. Physics involves many equations each of which applies primarily to a specific situation.

13. If I used two different approaches to solve a physics problem and they gave different answers, I would spend considerable time thinking about which approach is more reasonable.

14. When I solve physics problems, I always explicitly think about the concepts that underlie the problem.

15. When solving physics problems, I often find it useful to first draw a picture or a diagram of the situations described in the problems.

16. When answering conceptual physics questions, I mostly use my "gut" feeling rather than using the physics principles I usually think about when solving quantitative problems.

17. I am equally likely to draw pictures and/or diagrams when answering a multiple-choice question or a corresponding free-response (essay) question.

18. I usually draw pictures and/or diagrams even if there is no partial credit for drawing them.

19. I am equally likely to do scratch work when answering a multiple-choice question or a corresponding free-response (essay) question.

20. After I solve each physics homework problem, I take the time to reflect and learn from the problem solution.

21. After I have solved several physics problems in which the same principle is applied in different contexts, I should be able to apply the same principle in other situations.

22. If I obtain an answer to a physics problem that does not seem reasonable, I spend considerable time thinking about what may be wrong with the problem solution.

23. If I cannot solve a physics problem in 10 minutes, I give up on that problem.

24. When I have difficulty solving a physics homework problem, I like to think through the problem with a peer.

25. When I do not get a question correct on a test or homework, I always make sure I learn from my mistakes and do not make the same mistakes again.

26. It is more useful for me to solve a few difficult problems using a systematic approach and learn from them rather than solving many similar easy problems one after another.

27. I enjoy solving physics problems even though it can be challenging at times.

28. I try different approaches if one approach does not work.

29. If I realize that my answer to a physics problem is not reasonable, I trace back my solution to see where I went wrong.

30. It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer.

31. While solving a physics problem with a numerical answer, I prefer to solve the problem symbolically first and only plug in the numbers at the very end.

32. Suppose you are given two problems. One problem is about a block sliding down an inclined plane with no friction present. The other problem is about a person swinging on a rope. Air resistance is negligible. You are told that both problems can be solved using the concept of conservation of mechanical energy of the system. Which one of the following statements do you MOST agree with? (Choose only one answer.)
    A) The two problems can be solved using very similar methods.
    B) The two problems can be solved using somewhat similar methods.
    C) The two problems must be solved using somewhat different methods.
    D) The two problems must be solved using very different methods.
    E) There is not enough information given to know how the problems will be solved.

33. Suppose you are given two problems. One problem is about a block sliding down an inclined plane. There is friction between the block and the incline. The other problem is about a person swinging on a rope. There is air resistance between the person and air molecules. You are told that both problems can be solved using the concept of conservation of total (not just mechanical) energy. Which one of the following statements do you MOST agree with? (Choose only one answer.) A/B
    A) The two problems can be solved using very similar methods.
    B) The two problems can be solved using somewhat similar methods.
    C) The two problems must be solved using somewhat different methods.
    D) The two problems must be solved using very different methods.
    E) There is not enough information given to know how the problems will be solved.

Appendix 4: The Problem Solving Survey

No	Statement	Strongly Agree	Agree	Not Known	Disagree	Strongly Disagree
1	In solving problems in physics, being able to handle the mathematics is the most important part of the process					
2	In solving problems in physics, I always identify the physics principles involved in the problem first before looking for corresponding equations					
3	Problems solving in physics basically means matching problems with the correct equations and then substituting values to get a number					
4	If I used two different approaches to solve a physics problem and they gave different answers, I would spend considerable time thinking about which approach is more reasonable					
5	If I obtain an answer to a physics problem that does not seem reasonable, I spend considerable time thinking about what may be wrong with problem situation					
6	It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer					
7	There is usually only one correct approach to solving a physics problem					
8	If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works					
9	If I do not remember a particular equation needed to solve a problem on an exam, there is nothing much I can do to come up with it					
10	I enjoy solving physics problems					

Appendix 5: The Representation Survey

No	Statement	Strongly Agree	Agree	Not Known	Disagree	Strongly Disagree
1	I learned representations (picture, diagrams, graphs, equations, etc) while studying at high school/secondary school					
2	I often use representations (pictures, diagrams, graphs, etc) while solving physics problems					
3	I use representations while doing physics problems to make a problem easier to understand					
4	I use representations to help me find the correct answer					
5	I think that representations will help me understand the physics concepts					
6	I am a good at representing information in multiple ways (words, equations, picture, graphs, tables, diagrams, etc)					
7	When I am drawing representations such as force diagrams and equations, I check or evaluate my answer to make sure the diagram and equation are match well					
8	I usually draw pictures and or diagrams even if there is no partial credit for drawing them					
9	I have difficulties to use representations presented in the textbooks					
10	I often create my own representations (different from taught in the classroom and in the textbooks) while solving physics problems solving					

Appendix 6: Pilot Study Findings

Appendix 6a: Representation's Questionnaire

No	Statement	Strongly Agree	Agree	Not Known	Disagree	Strongly Disagree
1	I learned representations (picture, diagrams, graphs, equestions, etc) while studying at high school/secondary school	3	5			
2	I often use representations (pictures, diagrams, graphs, etc) while solving physics problems	7			1	
3	I use representations while doing physics problems to make a problem easier to understand	6	2			
4	I use representations to help me find the correct answer	2	5		1	
5	I think that representations will help me understand the physics concepts	3	4		1	
6	I am a good at representing information in multiple ways (words, equations, picture, graphs, tables, diagrams, etc)	3	5			
7	When I am drawing representations such as force diagrams and equations, I check or evaluate my answer to make sure the diagram and equation are match well	3	4		1	
8	I usually draw pictures and or diagrams even if there is no partial credit for drawing them	7			1	

Appendix 6b: Problem Solving's Questionnaire

No	Statement	Strongly Agree	Agree	Not Known	Disagree	Strongly Disagree
1	In solving problems in physics, being able to handle the mathematics is the most important part of the process	4	1		3	
2	In solving problems in physics, I always identify the physics principles involved in the problem first before looking for corresponding equations	3	3	2		
3	Problems solving in physics basically means matching problems with the correct equations and then substituting values to get a number	1	4		2	
4	If I used two different approaches to solve a physics problem and they gave different answers, I would spend considerable time thinking about which approach is more reasonable		7	1		
5	If I obtain an answer to a physics problem that does not seem reasonable, I spend considerable time thinking about what may be wrong with problem situation	3	4		1	
6	It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer	2	1	3	1	1

Appendix 7: Information Sheet and Consent Form

Appendix 7a: Information Sheet

INFORMATION SHEET FOR STUDENTS

STUDENTS' USE OF REPRESENTATIONS IN SOLVING PHYSICS PROBLEMS

You are being invited to take part in my PhD research about students' use of representations in solving physics problems. Before you decide on whether to take apart, it is important for you to understand why the research is being done and what will be involved. Please take time to read the following information carefully before you decide whether or not you wish to take part. You are welcome to discuss this project with others, if you wish, before make your decision. Please ask me (email:js864@leicester.ac.uk) if there is anything that is not clear or if you would like more information.

Purpose of research

The aim of this study is to investigate students' motivations and reasoning in using representations while solving physics problems qualitatively. Data will be obtained by questionnaire, test, and interview of students to obtain their views about problem solving and representations.

Participant of research

This project will involve students who intend to be physics teachers.

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep (and be asked to sign a consent form). You can still withdraw at any time without providing any reasons.

If you wish to take part in this study, I will need your time to fill out the survey (approximately 10 minutes) and solve a problem (approximately 20 minutes). Afterwards, I need to conduct an interview (approximately 30 minutes) to obtain more detail about your views of representations and problem solving. The interview will be recorded by audio recorder. If you wish to do that please provide your name and email in your answer sheet or questionnaire sheet.

All the information that we collect about you during the course of the research will be kept strictly anonymised. You will not be able to be identified in any reports or publications. Furthermore, in the future, if other researchers request access to your data and may use it in publications, permission will only be given if they agree to preserve the confidentiality of the information.

Finally, thank you for your willingness to read this information sheet.

Researcher: Judyanto Sirait

Email : js864@leicester.ac.uk
First Supervisor : Prof. Janet Ainley
Email : jma30@leicester.ac.uk
Second Supervisor: Prof. Martin Barstow
Email : mab@leicester.ac.uk
University of Leicester

October, 2017

Lembar Informasi Untuk Mahasiswa

PENGGUNAAN REPRESENTASI OLEH MAHASISWA

PADA PENYELESAIAN SOAL FISIKA

Anda diundang untuk mengambil bagian pada penelitian doctoral saya tentang penggunaan representasi oleh siswa pada penyelesaian soal fisika. Sebelum anda memutuskan untuk terlibat, hal yang sangat penting untuk dipahami adalah mengapa penelitian ini dilakukan dan siapa yang akan dilibatkan. Silahkan membaca informasi di bawah dengan teliti sebelum memutuskan apakah anda bersedia atau tidak. Untuk informasi lebih lanjut silahkan menghubungi saya lewat email: js864@leicester.ac.uk.

Tujuan Penelitian

Adapun tujuan penelitian ini adalah untuk menggali secara qualitative motivasi dan alasan mahasiswa dalam penggunaan representasi pada saat mengerjakan soal fisika. Data dikumpulkan melalui kuesioner, tes, dan interview.

Partisipan Penelitian

Penelitian ini akan melibatkan mahasiswa calon guru fisika.

Anda diberi kebebasan untuk memilih apakah bersedia atau tidak sebagai partisipan pada penelitian ini. Jika anda bersedia, anda akan diberikan lembar informasi untuk ditandatangani. Anda berhak untuk mundur kapanpun tanpa memberikan alasan.

Jika anda bersedia untuk ambil bagian dalam penelitian ini, anda diminta untuk mengisi kuesioner selama 10 menit dan mengerjakan soal selama 20 menit. Kemudian, saya akan melakukan wawancara (sekitar 30 menit) untuk memperoleh lebih jelas sikap anda terhadap representasi dan penyelesaian soal fisika. Interview akan direkam menggunakan perekam suara. Jika anda bersedia, silahkan menuliskan nama dan email pada lembar jawaban yang disediakan.

Semua informasi yang dikumpulkan pada saat penelitian ini akan dijaga kerahasiannya. Nama anda tidak akan teridentifikasi di laporan atau publikasi manapun. Selanjutnya, jika peneliti lain meminta akses data anda dan mungkin akan digunakan untuk publikasi, ijin akan diberikan jika mereka setuju tentang kerahasiaan data.

Akhirnya, terimakasih atas waktunya untuk membaca lembar informasi ini.

Researcher: Judyanto Sirait
Email : js864@leicester.ac.uk
First Supervisor : Prof. Janet Ainley
Email : jma30@leicester.ac.uk
Second Supervisor: Prof. Martin Barstow
Email : mab@leicester.ac.uk

University of Leicester

October, 2017

Appendix 7b: Consent Form

CONSENT FORM

CONSENT FORM FOR RESEARCH ON STUDENTS' USE OF REPRESENTATIONS IN SOLVING PHYSICS PROBLEMS

Please tick the appropriate boxes	**Yes**	**No**
Taking Part		
I have read and understood the project information sheet dated October, 2017.		
I have been given the opportunity to ask questions about the project.		
I agree to take part in the project. Taking part in the project will include being interviewed and recorded (audio)		
I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.		
Use of the information I provide for this project only		
I understand my personal details such as phone number and address will not be revealed to people outside the project.		
I understand that my name and identifying features of the university will not be revealed, thus will be identified only by codes		
I understand that my words may be quoted in publications, reports, web pages, and other research outputs.		
Use of the information I provide beyond this project		
I agree for the data I provide to be archived at the researchers' dissertation		
I understand that other genuine researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.		
I understand that other genuine researchers may use my words in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.		
So we can use the information you provide legally		
I agree to assign the copyright I hold in any materials related to this project to Judyanto Sirait.		

Name of participant :…………………Signature ………………Date ………………

Researcher: Judyanto Sirait Signature ………………Date ……………

LEMBAR ISIAN

PENGGUNAAN REPRESENTASI OLEH MAHASISWA
PADA PENYELESAIAN SOAL FISIKA

Silahkan beri tanda □	**Ya**	**Tidak**
Bersedia untuk ambil bagian		
Saya sudah membaca dan memahami informasi penelitian tertanggal September 2017		
Saya diberikan kesempatan untuk bertanya tentang penelitian ini		
Saya bersedia untuk ambil bagian dalam penelitian ini. Kesediaan dalam penelitian ini termasuk diwawancara dan direkam (suara dan gambar)		
Saya mengerti bahwa posisi saya adalah sukarela; saya dapat mundur dari penelitian ini kapan saja tanpa memberikan alasan mengapa tidak melanjutkan sebagai partisipan dalam penelitian ini		
Informasi yang saya berikan hanya untuk penelitian ini saja		
Saya mengerti bahwa data pribadi seperti nomor hand phone dan alamat tidak akan dipublikasikan kepada orang lain diluar penelitian ini		
Saya mengerti bahwa nama sebenarnya tidak akan dipublikasikan, namun menggunakan kode		
Saya mengerti bahwa percakapan saya akan dituliskan pada publikasi, laporan, hasil penelitian lain		
Informasi yang saya berikan di luar penelitian ini		
Saya setuju bahwa data yang saya berikan akan disimpan pada database disertasi		
Saya mengerti bahwa peneliti lain akan memiliki akses untuk data ini hanya jika mereka setuju untuk menjaga kerahasiaan informasi seperti yang diminta dalam lembar isian ini		
Saya mengerti bahwa peneliti lain akan menggunakan kalimat saya pada publikasi, laporan, dan hasil penelitian lain, hanya jika mereka setuju untuk menjaga kerahasiaan informasi seperti yang diminta dalam lembar isian ini.		
Menggunakan informasi secara sah		
Saya setuju untuk menandatangani lembar isian ini		

Nama Partisipan :…………………Tanda Tangan ………… Tanggal ……………

Peneliti : Judyanto Sirait Tanda Tangan ………………Tanggal ……………..

Appendix 8: Ethical Approval

University Ethics Sub-Committee for Sociology; Politics and IR; Lifelong Learning;
Criminology; Economics and the School of Education

06/10/2017

Ethics Reference: 13668-js864-education

TO:
Name of Researcher Applicant: Judyanto Sirait
Department: Education
Research Project Title: Students' Use of Representations in Solving Physics Problems

Dear Judyanto Sirait,

RE: Ethics review of Research Study application

The University Ethics Sub-Committee for Sociology; Politics and IR; Lifelong Learning; Criminology; Economics and the School of Education has reviewed and discussed the above application.

1. Ethical opinion

The Sub-Committee grants ethical approval to the above research project on the basis described in the application form and supporting documentation, subject to the conditions specified below.

2. Summary of ethics review discussion

The Committee noted the following issues:
We have approved this application. Best wishes.

3. General conditions of the ethical approval

The ethics approval is subject to the following general conditions being met prior to the start of the project:

As the Principal Investigator, you are expected to deliver the research project in accordance with the University's policies and procedures, which includes the University's Research Code of Conduct and the University's Research Ethics Policy.

If relevant, management permission or approval (gate keeper role) must be obtained from host organisation prior to the start of the study at the site concerned.

4. Reporting requirements after ethical approval

You are expected to notify the Sub-Committee about:

- Significant amendments to the project
- Serious breaches of the protocol
- Annual progress reports
- Notifying the end of the study

5. Use of application information

Details from your ethics application will be stored on the University Ethics Online System. With your permission, the Sub-Committee may wish to use parts of the application in an anonymised format for training or sharing best practice. Please let me know if you do not want the application details to be used in this manner.

Best wishes for the success of this research project.

Yours sincerely,

Dr. Laura Brace
Chair

References

Adams, W.K. *et al.* (2006) 'New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey', *Physical Review Special Topics - Physics Education Research,* 2(1), pp. 010101.

Ainsworth, S., Prain, V. and Tytler, R. (2011) 'Drawing to Learn in Science', *Science,* 333(6046), pp. 1096-1097.

Angell, C. *et al.* (2004) 'Physics: Frightful, but fun. Pupils' and teachers' views of physics and physics teaching', *Science education,* 88(5), pp. 683-706.

Arons, A.B. (1997) *Teaching introductory physics.* United States: Wiley.

Aviani, I., Erceg, N. and Mešić, V. (2015) 'Drawing and using free body diagrams: Why it may be better not to decompose forces', *Physical Review Special Topics - Physics Education Research,* 11(2), pp. 020137.

Balta, N. and Asikainen, M.A. (2019) 'A comparison of Olympians' and regular students' approaches and successes in solving counterintuitive dynamics problems', *International Journal of Science Education,* 41(12), pp. 1644-1666.

Balta, N., Mason, A. and Singh, C. (2016) 'Surveying Turkish high school and university student attitudes and approaches to physics problem solving', *Physical Review Physics Education Research, 12*(1), pp. 010129.

Barniol, P. and Zavala, G. (2014) 'Test of understanding of vectors: A reliable multiple-choice vector concept test', *Physical Review Special Topics - Physics Education Research,* 10(1), pp. 020115.

Bing, T.J. and Redish, E.F. (2009) 'Analyzing problem solving using math in physics: Epistemological framing via warrants', *Physical Review Special Topics - Physics Education Research,* 5(2), pp. 020108.

Bodner, G.M. (1986) 'Constructivism: a theory of knowledge ', *Journal of Chemical Education,* 63(10), pp. 874-878.

Bollen, L. *et al.* (ed.) (2017) ‘Student difficulties regarding symbolic and graphical representations of vector fields’, *Physical Review Physics Education Research, 13*(2), pp. 020109.

Boyatzis, R.E. (1998) *Transforming qualitative information: thematic analysis and code development.* Thousand Oaks, Calif; London: Thousand Oaks, Calif; London: Sage Publications.

Bryan, J.A. and Fennell, B.D. (2009) 'Wave modelling: a lesson illustrating the integration of mathematics, science and technology through multiple representations', *Physics Education*, 44, pp. 403.

Bryce, T. and MacMillan, K. (2005) 'Encouraging conceptual change: the use of bridging analogies in the teaching of action-reaction forces and the 'at rest' condition in physics', *International Journal of Science Education,* 27(6), pp. 737-763.

Campos, E. *et al.* (2019) 'Electric field lines: The implications of students' interpretation on their understanding of the concept of electric field and of the superposition principle', *American Journal of Physics,* 87(8), pp. 660-667.

Cao, Y. and Brizuela, B.M. (2016) 'High school students' representations and understandings of electric fields', *Physical Review Physics Education Research,* 12(2), pp. 020102.

Carey, S. (1986) 'cognitive science and science education', *American Psychologist,* 41(10), pp. 1123-1130.

Carolan, J., Prain, V. and Waldrip, B. (2008) 'Using representations for teaching and learning in science ', *Teaching Science,* 54(1), pp. 18-23.

Chang, H. (2018) 'Students' representational competence with drawing technology across two domains of science', *Science Education,* 102(5), pp. 1129-1149.

Chen, Z. *et al.* (2017) 'To draw or not to draw? Examining the necessity of problem diagrams using massive open online course experiments', *Physical Review Physics Education Research*, 13(1), pp. 010110.

Chi, M.T.H., Feltovich, P.J. and Glaser, R. (1981) 'Categorization and representation of physics problems by experts and novices', *Cognitive Science*, 5(2), pp. 121-152.

Cohen, L., Manion, L. and Morrison, K. (2011) *Research methods in education.* 7. ed., rewritten, expanded and updated edn. London: Routledge.

Cook, M. (2006) 'Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles', *Science Education; Sci.Educ.*, 90(6), pp. 1073-1091.

Creswell, J.W. (2005) *Educational research: planning, conducting, and evaluating quantitative and qualitative research.* United States.

Creswell, J.W. (2013) *Research design: qualitative, quantitative, and mixed methods approaches.* 4th ed. Los Angeles, Calif; London: SAGE.

De Cock, M. (2012) 'Representation use and strategy choice in physics problem solving', *Physical Review Special Topics - Physics Education Research*, 8(2), pp. 020117.

Dhillon, A.S. (1998) 'Individual differences within problem-solving strategies used in physics', *Science Education,* 82(3), pp. 379-405.

Disessa, A.A. *et al.* (1991) 'Inventing Graphing: Meta-Representationa Expertise in Children', *Journal of Mathematical Behaviour,* 10, pp. 117-160.

diSessa, A.A. and Sherin, B.L. (2000) 'Meta-representation: an introduction', *Journal of Mathematical Behavior,* 19(4), pp. 385-398.

Docktor, J.L. *et al.* (2015) 'Conceptual problem solving in high school physics', *Physical Review Special Topics - Physics Education Research,* 11(2), pp. 020106.

Elby, A. (2001) 'Helping physics students learn how to learn', *American Journal of Physics,* 69(S1), pp. S54-S64.

Elby, A. (2000) 'What students' learning of representations tells us about constructivism', *Journal of Mathematical Behavior,* 19(4), pp. 481-502.

Etkina, E., Gentile, M. and Van Heuvelen, A. (2014) *College physics.* Boston; Munich: Pearson.

Eysenck, M.W. and Keane, M.T. (2010) *Cognitive psychology.* 6th ed. Hove: Psychology Press.

Fay, B. (1996) *Contemporary philosophy of social science: a multicultural approach.* Oxford: Oxford: Blackwell.

Fraser, B.J. and Tobin, K.G. (1998) *International handbook of science education.* Dordrecht; London: Kluwer.

Frederiksen, N. (1984) 'Implications of Cognitive Theory for Instruction in Problem Solving', *Review of Educational Research,* 54(3), pp. 363-407.

Gebre, E.H. and Polman, J.L. (2016) 'Developing young adults' representational competence through infographic-based science news reporting', *International Journal of Science Education,* 38(18), pp. 2667-2687.

Ginsburg, H. (1981) 'The Clinical Interview in Psychological Research on Mathematical Thinking: Aims, Rationales, Techniques', *For the Learning of Mathematics,* 1(3), pp. 4-11.

Halloun, I. and Hestenes, D. (1998) 'Interpreting VASS Dimensions and Profiles for Physics Students', *Science Education,* 7(6), pp. 553-577.

Heckler, A.F. (2010) 'Some Consequences of Prompting Novice Physics Students to Construct Force Diagrams', *International Journal of Science Education,* 32(14), pp. 1829-1851.

Heijnes, D., van Joolingen, W. and Leenaars, F. (2018) 'Stimulating Scientific Reasoning with Drawing-Based Modeling', *Journal of Science Education and Technology,* 27(1), pp. 45-56.

Heller, P., Keith, R. and Anderson, S. (1992) 'Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving', *American Journal of Physics,* 60(7), pp. 627-636.

Hestenes, D., Wells, M. and Swackhamer, G. (1992) 'Force concept inventory', *The Physics Teacher*, 30(3), pp. 141-158.

Hillman, S. *et al.* (2016) 'My Attitudes Toward Science (MATS): the development of a multidimensional instrument measuring students' science attitudes', *Learning Environments Research,* 19(2), pp. 203-219.

Hubber, P., Tytler, R. and Haslam, F. (2010) 'Teaching and Learning about Force with a Representational Focus: Pedagogy and Teacher Change', *Research in Science Education,* 40(1), pp. 5-28.

Huffman, D. (1997) 'Effect of explicit problem solving instruction on high school students' problem-solving performance and conceptual understanding of physics', *Journal of Research in Science Teaching,* 34(6), pp. 551-570.

Hung, C. and Wu, H. (2018) 'Tenth graders' problem-solving performance, self-efficacy, and perceptions of physics problems with different representational formats', *Physical Review Physics Education Research,* 14(2), pp. 020114.

Ibrahim, B. and Rebello, N.S. (2012) 'Representational task formats and problem solving strategies in kinematics and work', *Physical Review Special Topics - Physics Education Research,* 8(1), pp. 010126.

Ivanjek, L. *et al.* (2016) 'Student Reasoning about Graphs in Different Contexts', *Physical Review Physics Education Research,* 12(1), pp. 010106-13.

Jonassen, D. (2003) 'Using Cognitive Tools to Represent Problems', *Journal of Research on Technology in Education,* 35(3), pp. 362-381.

Kalyuga, S. *et al.* (2003) 'The Expertise Reversal Effect', *Educational Psychologist,* 38(1), pp. 23-31.

Kamphorst, F. *et al.* (2019) 'Students' preinstructional reasoning with the speed of light in relativistic situations', *Physical Review Physics Education Research,* 15(2), pp. 020123.

Klein, P. *et al.* (2018) 'Instruction-based clinical eye-tracking study on the visual interpretation of divergence: How do students look at vector field plots?', *Physical Review Physics Education Research,* 14(1), pp. 010116.

Knight, R.D. (2004) *Five easy lessons.* San Francisco, Calif: Addison Wesley.

Kohl, P.B. and Finkelstein, N.D. (2008) 'Patterns of multiple representation use by experts and novices during physics problem solving', *Physical Review Special Topics - Physics Education Research,* 4(1), pp. 010111.

Kohl, P.B. and Finkelstein, N.D. (2005) 'Student representational competence and self-assessment when solving physics problems', *Physical Review Special Topics - Physics Education Research,* 1(1), pp. 010104.

Kozma, R.B. and Russell, J. (1997) 'Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena', *Journal of Research in Science Teaching,* 34(9), pp. 949-968.

Kuo, E., Hallinen, N.R. and Conlin, L.D. (2017) 'When procedures discourage insight: epistemological consequences of prompting novice physics students to construct force diagrams', *International Journal of Science Education,* 39(7), pp. 814.

Kuo, E. *et al.* (2013) 'How students blend conceptual and formal mathematical reasoning in solving physics problems', *Science Education,* 97(1), pp. 32-57.

Larkin, J. (1981) 'Cognition of learning physics', *American Journal of Physics,* 49(6), pp. 534-541.

Larkin, J. *et al.* (1980) 'Models of Competence in Solving Physics Problems', *Cognitive Science,* 4(4), pp. 317-345.

Larkin, J. and Reif, F. (1979) 'Understanding and teaching problem-solving in physics', *European Journal of Science Education,* 1(2), pp. 191-203.

Laudan, L. (1996) *Beyond positivism and relativism.* Boulder, Colo: Westview Press.

Leonard, W.J., Dufresne, R.J. and Mestre, J.P. (1996) 'Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems', *American Journal of Physics,* 64(12), pp. 1495-1503.

Lin, S. and Singh, C. (2016) 'Effect of Scaffolding on Helping Introductory Physics Students Solve Quantitative Problems Involving Strong Alternative Conceptions', *Physical Review Physics Education Research,*11(2), pp. 029901.

Madsen, A., McKagan, S.B. and Sayre, E.C. (2015) 'How physics instruction impacts students' beliefs about learning physics: A meta-analysis of 24 studies', *Physical Review Special Topics. Physics Education Research,* 11(1), pp. 010115.

Maloney, D.P. (1990) 'Forces As Interactions ', *The Physics Teacher,* pp. 386-390.

Maloney, D.P. (2011) 'An Overview of Physics Education Research on Problem Solving', in Anonymous *Getting Started in Physics Education Research.* PER, pp. 1-33.

Maries, A. and Singh, C. (2018) 'Case of two electrostatics problems: Can providing a diagram adversely impact introductory physics students' problem solving performance?', *Physical Review Physics Education Research,* 14(1), pp. 010114.

Mason, A. and Singh, C. (2010) 'Surveying graduate students' attitudes and approaches to problem solving', *Physical Review Special Topics - Physics Education Research,* 6(2), pp. 020124.

Mayer, R.E. and Moreno, R. (2003) 'Nine Ways to Reduce Cognitive Load in Multimedia Learning', *Educational Psychologist,* 38(1), pp. 43-52.

McDermott, L.C. and Redish, E.F. (1999) 'Resource Letter: PER-1: Physics Education Research', *American Journal of Physics,* 67(9), pp. 755-767.

Meltzer, D.E. (2005) 'Relation between students' problem-solving performance and representational format', *American journal of physics,* 73(5), pp. 463-478.

Merriam, S.B. (2009) *Qualitative Research.* Rev. and expanded 3rd ed. US: Jossey Bass Ltd.

Mualem, R. and Eylon, B.S. (2010) 'Junior high school physics: Using a qualitative strategy for successful problem solving', *Journal of Research in Science Teaching,* 47(9), pp. 1094-1115.

Mujtaba, T. *et al.* (2018) 'Students' science attitudes, beliefs, and context: associations with science and chemistry aspirations', *International Journal of Science Education,* 40(6), pp. 644.

Nie, Y. *et al.* (2019) 'Teaching towards knowledge integration in learning force and motion', *International Journal of Science Education,* 41(16), pp. 2271-2295.

Nieminen, P., Savinainen, A. and Viiri, J. (2010) 'Force Concept Inventory-Based Multiple-Choice Test for Investigating Students' Representational Consistency', *Physical Review Special Topics - Physics Education Research,* 6(2), pp. 020109.

Nieminen, P., Savinainen, A. and Viiri, J. (2012) 'Relations between representational consistency, conceptual understanding of the force concept, and scientific reasoning', *Physical Review Special Topics - Physics Education Research,* 8(1), pp. 010123.

Oppenheim, A.N. (1992) *Questionnaire design, interviewing, and attitude measurement.* New ed. London: London: Pinter Publishers.

Panaoura, A. *et al.* (2009) 'The structure of students' beliefs about the use of representations and their performance on the learning of fractions', *Educational Psychology,* 29(6), pp. 713-728.

Patton, M.Q. (1990) *Qualitative evaluation and research methods.* 2nd. ed. Newbury Park, Calif: Sage.

Planinic, M. *et al.* (2013) 'Comparison of university students' understanding of graphs in different contexts', *Physical Review Special Topics - Physics Education Research,* 9(2), pp. 020103.

Pocoví, M.C. (2007) 'The effects of a history-based instructional material on the students' understanding of field lines', *Journal of Research in Science Teaching,* 44(1), pp. 107-132.

Pring, R. (2004) *Philosophy of education: aims, theory, common sense and research.* London: Continuum.

Pólya, G. (1957) *How to solve it.* 2nd. ed. Garden City, NY: Doubleday.

Rakkapao, S., Prasitpong, S. and Arayathanitkul, K. (2016) 'Analysis test of understanding of vectors with the three-parameter logistic model of item response theory and item response curves technique', *Physical Review Physics Education Research,* 12(2), pp. 020135.

Rakkapao, S. and Prasitpong, S. (2018) 'Use of model analysis to analyse Thai students' attitudes and approaches to physics problem solving', *European Journal of Physics,* 39(2), pp. 25707.

Rau, M. (2017) 'Conditions for the Effectiveness of Multiple Visual Representations in Enhancing STEM Learning', *Educational Psychology Review,* 29(4), pp. 717-761.

Redish, E.F. (1994) 'Implications of cognitive studies for teaching physics', *American Journal of Physics,* 62(9), pp. 796-803.

Redish, E.F., Saul, J.M. and Steinberg, R.N. (1998) 'Student expectations in introductory physics', *American Journal of Physics,* 66(3), pp. 212-224.

Redish, E. and Kuo, E. (2015) 'Language of Physics, Language of Math: Disciplinary Culture and Dynamic Epistemology', *Science & Education,* 24(5), pp. 561-590.

Rosengrant, D., Van Heuvelen, A. and Etkina, E. (2009) 'Do students use and understand free-body diagrams?', *Physical Review Special Topics - Physics Education Research,* 5(1), pp. 010108.

Sabella, M.S. and Redish, E.F. (2007) 'Knowledge organization and activation in physics problem solving', *American Journal of Physics,* 75(11), pp. 1017-1029.

Savinainen, A. *et al.* (2013) 'Does Using a Visual-Representation Tool Foster Students' Ability to Identify Forces and Construct Free-Body Diagrams?', *Physical Review Special Topics - Physics Education Research,* 9(1), pp. 010104.

Savinainen, A. *et al.* (2015) 'The Effect of Using a Visual Representation Tool in a Teaching-Learning Sequence for Teaching Newton's Third Law', *Research in Science Education,* 47(1), pp. 119-135.

Scheid, J. *et al.* (2019) 'Improving learners' representational coherence ability with experiment-related representational activity tasks', *Physical Review Physics Education Research,* 15(1), pp. 010142.

Scott, D. (2006) *Key ideas in educational research.* London: Continuum.

Scott, D. (2010) *Researching Education Data, methods and theory in educational enquiry.* 2nd ed. London: Continuum International Publishing.

Selling, S.K. (2016) 'Learning to represent, representing to learn', *Journal of Mathematical Behavior,* 41, pp. 191-209.

Sherin, B.L. (2000) 'How students invent representations of motion', *Journal of Mathematical Behavior,* 19(4), pp. 399-441.

Sherin, B. (2006) 'Common sense clarified: The role of intuitive knowledge in physics problem solving', *Journal of Research in Science Teaching,* 43(6), pp. 535-555.

Sirait, J. *et al.* (2017) 'The development of questionnaire to investigate students' attitudes and approaches in physics problem solving', *Jurnal Pendidikan Fisika Indonesia,* 13(2), pp. 79-87.

Summers, R. and Abd-El-Khalick, F. (2018) 'Development and validation of an instrument to assess student attitudes toward science across grades 5 through 10', *Journal of Research in Science Teaching,* 55(2), pp. 172-205.

Sweller, J. (1988) 'Cognitive load during problem solving: Effects on learning', *Cognitive Science*, 12(2), pp. 257-285.

Tay, S.L. and Yeo, J. (2018) 'Analysis of a physics teacher's pedagogical 'micro-actions' that support 17-year-olds' learning of free body diagrams via a modelling approach', *International Journal of Science Education*, 40(2), pp. 109-138.

Thomas, G. (2013) *How to do your research project: a guide for students in education and applied social sciences.* 2nd ed. London: SAGE Publications Ltd.

Tippett, C.D. (2016) 'What recent research on diagrams suggests about learningwithrather than learningfromvisual representations in science', *International Journal of Science Education*, 38(5), pp. 725-746.

Treagust, D.F. and Tsui, C. (2013) *Multiple Representations in Biological Education.* 1. Aufl. edn. Dordrecht: Springer Netherlands.

Treagust, D., Chittleborough, G. and Mamiala, T. (2003) 'The role of submicroscopic and symbolic representations in chemical explanations', *International journal of science education,* 25(11), pp. 1368.

Tytler, R. *et al.* (2019) 'Drawing to reason and learn in science', *Journal of Research in Science Teaching,* 57(2), pp. 209-231.

Uhden, O. *et al.* (2012) 'Modelling Mathematical Reasoning in Physics Education', *Science & Education*, 21(4), pp. 485-506.

Van den Eynde, S. *et al.* (2019) 'Translating between graphs and equations: The influence of context, direction of translation, and function type', *Physical Review Physics Education Research*, 15(2), pp. 020113.

Van Heuvelen, A. (1991a) 'Learning to think like a physicist: A review of research-based instructional strategies', *American Journal of Physics*, 59(10), pp. 891-897.

Van Heuvelen, A. (1991b) 'Overview, Case Study Physics', *American Journal of Physics*, 59(10), pp. 898-907.

Van Heuvelen, A. and Zou, X. (2001) 'Multiple representations of work–energy processes', *American Journal of Physics*, 69(2), pp. 184-194.

Wong, D. *et al.* (2011) 'Learning with multiple representations: an example of a revision lesson in mechanics', *Physics Education*, 46, pp. 178.

Young, J.M. and Shepardson, D.P. (2018) 'Using Q methodology to investigate undergraduate students' attitudes toward the geosciences', *Science Education*, 102(1), pp. 195-214.

Zhang, J. (1997) 'The Nature of External Representations in Problem Solving', *Cognitive Science*, 21(2), pp. 179-217.