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The Role of Visual Representation for High School Physics in Teaching of Classical Mechanics

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Abstract

This study aims to highlight the importance of visual representation skills in classroom practice, especially in classical mechanics physics, by discussing (1) free-body diagram representation, (2) resultant force system, (3) types and directions of quantities, (4) representation of results and units. This research was conducted on 30 students in second grade at Beringin Kupang High School. The research method was carried out experimentally using a special image representation test tool for classical mechanical materials. The research data were analyzed by descriptive method. The results showed that (1) more than 50% of students did not draw FBD before solving the problem, (2) the success rate of students in representing the resultant force system was the highest at 33%, (3) determining the type and direction of motion the success rate was 67%, and (4) representation results and units with a success rate of 40%. The results of this study become a reference for increasing the role of visual representation in learning physics.

Keywords: visual representation, physics, classical mechanics

INTRODUCTION

All existing knowledge cannot be separated from its visual presentation in the development and investigation of the science. Visual presentation of information is a form of non-verbal communication that is not limited to pictures, symbols, signs, maps, diagrams, graphics, photos, and modeling but includes semiotics, film-audio conventions, and illustrations (Raiyn 2016). Various research results report that 75 percent of all information processed by the human brain comes from visual formats. This happens because our brains are mostly image processors (most of our sensory cortex is devoted to vision), so visual information is mapped better in the brain than information in words or sentences (Lindner, Blosser & Cunigan 2009; Aisami 2015). Description of knowledge like this is a form of visual representation that is part of communicating information in all fields of science. For example, in chemistry, chemical structures are visualized in the form of diagrams (Brecher 2008), visualization of tissue structures in plants in biology (Utami & Subiantoro 2021), and dynamic fluid flow visualization in physics (Suyatna et al. 2017).

In physics learning, the teacher always visualizes models such as drawing the motion of the solar system, galaxies, motion of point objects, and others as an instructional method in learning to access abstract mathematical ideas, describe situations, create graphs, make coordinates so that abstract concepts become more concrete (Forbus et al. 2011), (Rakbamrung, Thepnuan & Nujenjit 2015). The role of visualization in learning has received the attention of researchers in educational fields such as

(Gilbert 2005) and the field of representational (Carolan, Prain & Waldrip 2008) to support and increase engagement, strengthening concepts and reasoning processes in the classroom. Given that students have different characteristics and knowledge, teachers must investigate the types of representations through more appropriate learning approaches such as mathematical representations, verbal representations, visual representations (diagrams, pictures) or multiple other representations (Masrifah et al. 2020).

The existence of visual data in textbooks is an important part that supports the representation process of students to recognize an object or phenomenon shown (Nielsen 2022). Researchers found that students' visual representations enable them to find meaning and reason (Jägerskog 2020), support and increase student engagement (Raiyn 2016), and reinforce concepts (Guler & Ciltas 2011), as an essential source of reducing learning difficulties. students, helping students to quickly read or represent information or data that is displayed in a visual way (Cankoy & Ozder 2011) so that their visualization skills can become a cognitive picture (cognitive tool) and a picture of a person's social interaction (Social Interaction). (Yoon, Kim & Lee 2021). The presence of research on visual representation is a way to support and increase engagement, strengthening concepts and reasoning processes in the classroom.

Physics mechanics requires visualization as a means to access complex information to make it easier for students to understand its implementation (Vellido et al. 2011). The main goal of mechanics is to formulate laws of motion that are suitable for the investigation of a wide variety of natural, solid, liquid, and gaseous bodies and which can be modeled as a collection of particles. The branches of mechanics include 1) rigid body mechanics (statistics and dynamics); 2) mechanics of deformable objects (strength of materials, theory of elasticity, plastics, or rheology); 3) fluid mechanics: incompressible (liquid mechanics) and compressible (gas mechanics, aeromechanics), incompressible fluid mechanics or known as hydraulics, (Awrejcewicz 2012). Students in learning are found to have difficulties when solving principles and concepts of mechanics due to misunderstandings and even challenges in representing graphically (visually) and mathematically (Nguyen, Gire & Rebello 2010). The phenomena or concepts in each of these branches of mechanics require visualization in the description of each phenomenon and concept so that it becomes more concrete, simple, and easy to interpret the meaning correctly (Suyatna et al. 2017).

In studying physics, we often find it challenging to visualize and understand physical phenomena. This difficulty is seen when abstract concepts are involved, such as the interaction of attraction and friction, electromagnetic, or others (Neri et al. 2018). The meaning of phenomena or concepts from or to visual forms in mechanics becomes easier if someone has good visual representation skills (Jauhariyah & Wasis 2018). In learning, the concept of visual representation and its methods have a strong influence on the achievement of mastery of concepts (Gieskes, Watson & DeRusso 2012) and problem-solving by students (Munfaridah, Avraamidou & Goedhart 2021). If the visuals displayed are confusing or difficult to understand, it will hinder the delivery of the information to be conveyed.

Multi-representation ability (Rosengrant, Van Heuvelen & Etkina 2009) investigated that multiple representations affect problem-solving during quizzes and tests. It was further stated that most students used multiple representations such as pictures, free-body diagrams, and graphs when working on tests. Representations in physics can include external representations (such as interpreting text, symbols, graphics, or images) and internal representations (mental representations that students acquire in connection with learning content) (Opfermann, Schmeck & Fischer, 2017). External representations allow us to think symbolically about phenomena that are difficult to explain verbally (Eilam & Poyas 2010). Examples are line graphs, bar graphs, and number tables are used to convey quantitative relationships, and diagrams or figures to convey different types of qualitative relationships between entities such as spatial, structural, or functional. Visual representation is essential for communicating ideas in science and has been shown to have a positive effect on physics learning (Munfaridah, Avraamidou & Goedhart 2021). Concepts or phenomena that will be socialized are often abstract and difficult to understand by students, so several representation models need to be chosen in the application of science learning (Suyatna et al. 2017).

The implementation of learning mechanics that we have done so far usually explains the topic or problem to be solved, sketches the problem to help solve the problem, and applies mathematical equations to find the solution. In the process of making sketches or drawings according to the rules, students have difficulty. Some of the problem models produced in mechanics are system schematic drawings, free-body diagrams, their component directions, and motion through spatial solutions (Gieskes, Watson & DeRusso 2012). Given the importance of this, this study aims to analyze students' visual representation skills in mechanics, including kinematics, the motion of objects on a flat plane, and the motion of objects on an inclined plane for the case of smooth and rough surfaces. To solve questions or questions about kinematics and the motion of objects on flat and inclined planes, it would be better if the questions were interpreted into pictures before being solved mathematically (Kohnle, Ainsworth & Passante 2020).

METHODS

The type of research used is descriptive research. The procedure in this study is that students are provided with an explanation in advance about the importance of visualization in physics. The instrument used in this study is a mechanics test item which contains ten description items. Each student takes the given test within 90 minutes. Students work on their own on the worksheets provided without the help of people or other sources. The scope of the test is the force acting on the system, work, displacement, tension in the rope on a flat, inclined plane, and the acceleration of an object when it reaches the ground when the object is dropped from a certain height. The participants who took the test were 30 students of science class XI SMA Beringin Kupang. The research data comes from student worksheets. The questions in the test did not specifically ask them to draw a free-body diagram (FBD), but we believe that before working on the problem (FIGURE 1-3), they should first make an FBD.

Drawing FBD is the first step in doing the test in this research. In the test, there are several numbers that require students to draw a free-body diagram (FBD) because, through FBD, one by one, the forces in the system are seen how large and their direction affects a particular system. The point of this study is that students represent visually by drawing a free diagram first before determining the forces that work and the work on a flat and inclined plane, determining the acceleration of objects, rope tension, and the magnitude of the thrust. Here is an example test for drawing FBD shown in FIGURE 1-3.

Question 1:
Determine the acceleration of the system and the tension in the rope
The pulley is smooth, and the mass of the pulley is neglected

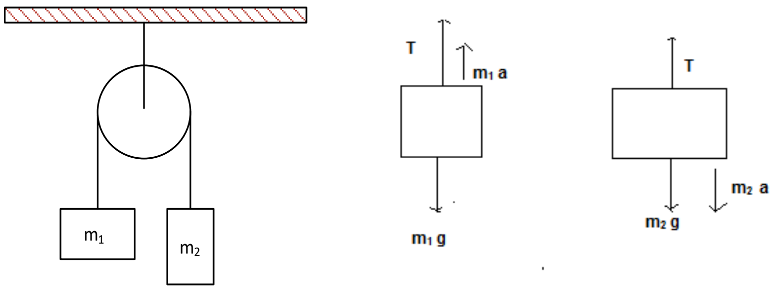

FIGURE 1. FBD of at Atwood machine and FBD

Question 2:
Two objects are connected, as shown in the following figure! If the surface is smooth and the mass of the pulley is neglected, then determine the acceleration of the system and the tension in the string on each object.

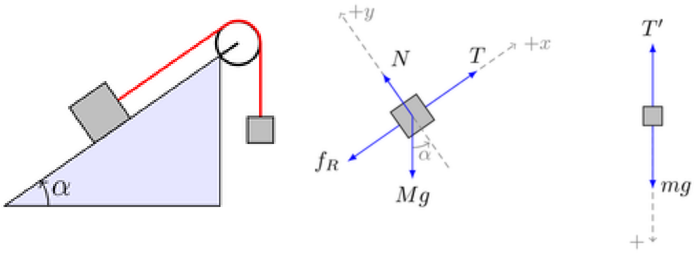

FIGURE 2. A block on the ramp and FBD of block

Question 3:

If the object is at rest, determine the tension in the horizontal rope

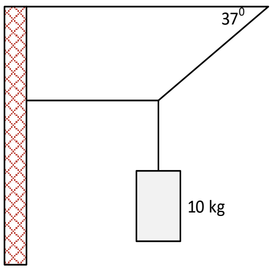

FIGURE 3. Objects in a hanging position

Aspects of the assessment of the mechanical representation in this study include (1) determining the forces acting on a flat and inclined system; (2) determining the work done by the system; (3) describing the graph of position (x), velocity (v), acceleration (a) as a function of time (t); (4) determine the amount of tension in the rope in a moving and balanced system; (5) determine the magnitude of the thrust (F) and friction (f); (6) solve equations on Newton's laws of motion. This study's assessment uses a rubric adapted to words (Kocakülah 2010). Descriptive statistics were used for analyzed the evaluation results. Each assessment aspect is calculated as the percentage of students who do it right.

RESULTS AND DISCUSSION

Visual representation ability in this study was reduced to four main parts of the assessment according to the rubric (Kocakülah 2010), including: (1) drawing FBD; (2) the representation of the force component and the resultant; (3) determining the type and direction of motion; (4) find the solution to the problem and its units.

Free Body Diagram

FBD has a coordinate system and dimensions such as lengths and angles. Generally a coordinate system *xy* , but when in three-dimensional space, a coordinate system is used *xyz*. The coordinates x are usually placed parallel to the plane, whereas the coordinates are parallel to the normal force *(N)*. In a free diagram, objects are expressed simply as lines or points. The vector of the forces *(F)* acting is denoted by a straight arrow ($\rightarrow$). The force vector shows the magnitude and direction of the force acting on the object. Direction is often indicated by degrees from the vertical or horizontal axis, while the magnitude is indicated by units of force.

FIGURE 4 presents data on how many students drew FBD before taking the test. This data was obtained by counting the number of students who drew FBD on the given test number. From the calculation results, it was found that more students worked on questions without being preceded by drawing FBD. Moreover, the students' consistency in drawing the FBD correctly (TABLE 2) was also calculated.

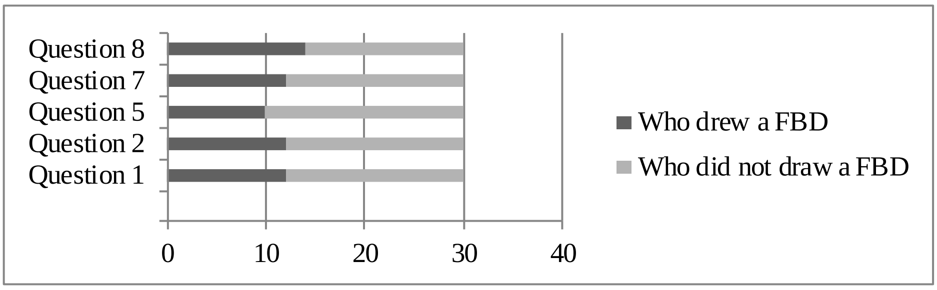

FIGURE 4. Comparison of Students who Drew an FBD and those that did not (N=30)

The results in FIGURE 4 show that more students do not draw FBD in solving problems. On test number 1, as many as 60% of students did not draw. In question number 2, as many as 60% of students do not draw, and in question number 8, as many as 67% of students do not draw. What was found was that most of them worked on the questions directly using formulas and concepts that they already knew without the need to draw FBD first. From the FBD image results, it is known that not all draw correctly. Some of the errors include placing the coordinate system, misplacing the direction of the magnitude, and incorrectly determining the location of the quantities such as normal force (N), object weight (W), rope tension (T), and frictional force (f). From the information (TABLE 1), it is known that (TABLE 2) 7% of students drew the FBD correctly, 10% drew more correctly, 16% the number of incorrectly equaled correctly, 27% drew, but incorrectly, 7% drew only one number, the remaining 33% did not draw.

TABLE 1. Consistency of Student's Usage of FBD Associated with Correctness of Use (N=30)

Case	Percentage (%)
All FBD Correctly	7
Majority of FBD Correct	10
Number correct = incorrect	16
All incorrect	27
One FBD Drawn	7
None Drawn	33

Drawing FBD in mechanics is part of the visual representation ability for that a temporary explanation that might be the answer why many students have difficulty in drawing FBD, wrongly determine the direction (vector) and misplace the related quantities in the FBD system because they do not have the ability to represent questions in the form of free-body diagrams. Whereas (Aviani, Erceg & Mešić 2015) argue that at least drawing FBD can prevent conceptual errors of mechanics. (Rosengrant, Van Heuvelen & Etkina 2005) also suggested that drawing FBD allows students to visualize concepts in mechanics as a whole, such as calculating rope tension, and determining object acceleration. The purpose of free-of-body diagrams (visually represented) is to deconstruct or simplify a problem (question) by conveying only the necessary information. Students use this free diagram as a reference for preparing calculations to find the quantities in a system. From the results of the tests that we provide, the conclusion that may be drawn is that students do not understand the mechanics material well. In another study, students drew FBD outside the object, directly on the object, and drew both ways, namely outside and directly on the object under review (Rahmaniar, Heni & Asep 2016). This is in accordance with (Ayesh et al. 2010) which states that students who can draw FBD correctly tend to solve questions correctly than those who do not draw. (Sari, Sutopo & Wartono 2015) also found that the use of mathematical representations and diagrams in Newton's second law can improve students' conceptual mastery of related materials.

Force System and Resultants

Force is a part of vector quantity because it is expressed as a significant (positive numerical value that represents the size and amount of the force and direction). In mathematical solutions such as determining the acceleration of a system, and contact forces (such as thrust, friction, tension forces) rope, normal force) always begins with a visualization of the decomposition of the forces into the components of the axes *x* and axes *y*. The results of the representation of the decomposition of forces on the system are stated in TABLE 2.

TABLE 2. Resultant force representation

Exam Question (Rubrik Score)	Directions and magnitudes of the forces correct (2)	Directions and magnitudes of the forces Incorrect (1)	No work done (0)	Success rate
Mechanics Exam: Question 1	23%	23%	54%	23%
Mechanics Exam: Question 5	13%	20%	67%	13%
Mechanics Exam: Question 6	30%	50%	20%	30%
Mechanics Exam: Question 7	13%	17%	70%	13%
Mechanics Exam: Question 8	13%	33%	54%	13%
Mechanics Exam: Question 9	33%	40%	27%	33%

TABLE 3 presents the fact that more students who did not draw FBD (see table 2) ensured that they also did not draw the magnitude and direction of the force *(F)*. More students miscalculated the components of the force and quantity acting on the system both on a plane and an inclined plane). for the case of a stationary object moving on a smooth and rough surface. More than 50% of the number who took the test were wrong in describing the components of the force acting on the system in the axes *x* and axes *y*. The errors found were in the form of incorrectly placing the object's weight *(W)* on an inclined plane, misrepresenting the normal force *(W)*, and misplacing the frictional force *(f)*. Another fact that was seen was that not many students (15%) could project the gravity on the inclined plane and on the axis correctly. The representation of the force component was carried out to find the resultant force (∑F), which works on the system associated with the acceleration *(a)* generated. This method is done in addition to helping men find a mathematical solution, and this process also indicates the flow of thinking and students' understanding of the solution. (Taqwa 2017) states that in determining the direction of the resultant, students need first to understand the mechanics material well. However, the results of his research show that more students still have difficulty determining the direction of the resultant force.

Types and Directions of Motion

Determining the type and direction of motion in the image needs to be done because the quantities in physics do not only consist of scalar quantities but also vector quantities. Force *(F)*, friction *(f)*, gravity *(W)*, and normal force *(N)* are vector quantities, so it is necessary to give the appropriate sign (positive or negative) on the magnitude. The sign on the quantity is adjusted to the direction of motion and the location of the quantities.

TABLE 3. Representation of the type and direction of motion

Exam Question **(Rubrik Score)**	**The resultant force was found correctly** **(2)**	**The resultant force was found incorrect Incorrect** **(1)**	**No work done** **(0)**	**Success rate**
Mechanics Exam: All Question	67%	17%	16%	67%

In TABLE 3, it can be seen that quite a number of students got the maximum score, meaning that in determining the type and direction of movement, their magnitude was quite thorough, but on each test item, it was also seen that there were also some who made a mistake in determining the direction or did not do it at all. To be able to determine the direction and type of quantities correctly, students need to draw free diagrams and place the quantities in the system must also be appropriate. The frictional force *(f)* in the system is always directed against the direction of the force exerted on the object, in the opposite direction to the object's motion, opposite to the object's acceleration. When the object is moving, kinetic friction acts on the contact area. When the object is pulled at a constant speed, the attraction or push force is equal to friction (Prasitpong & Chitaree 2010).

Solution of Equations and Units

Solution of equations and units is one component of the assessment in this mechanics representation test which is inseparable from the other assessments above. This is done to assess the results of student answers comprehensively and uninterruptedly. The accuracy of the solutions of the collected equations and units can be seen in TABLE 4 and TABLE 5.

TABLE 4. The accuracy of the solution to the equation

Exam Question	The solution of an equation is correct	The solution of an equation is incorrect	No work done	Success rate
Mechanics Exam: All Question	40%	27%	33%	40%

The equation solution represents the relationship between symbols by mathematically modeling the conceptual knowledge of physics. TABLE 4 shows that there are only 40% of students write equation solutions before getting the results or answers from the test they are doing. Some of them (27%) wrote the equation wrong, and the rest (33%) didn't write the equation, meaning they didn't work to the end. According to (Kim, Cheong & Song 2018), teaching and learning the meaning of physics equations can indirectly improve the understanding of physics concepts.

TABLE 5. The accuracy of writing the units for each quantity

Exam Question	The solution of the equation is written correctly	The solution of the equation is written incorrectly	No work done	Success rate
Mechanics Exam: All Question	78%	5%	17%	78%

TABLE 5 shows that still 23% of students are wrong and do not include units in the calculation results. In physics, every quantity can be measured and represented in terms of quantities and units. Units in physics are critical as a standard or measure of a quantity. According to (Mari, Ehrlich & Pendrill 2018), placing the unit after the measurement results or absolute calculations are carried out because the unit of measurement shows the specific nature of an object (the quantity being measured or calculated). In the results of measurements or calculations in the absence of units, the value of a quantity becomes meaningless.

CONCLUSION

The ability of visual representation makes it easier for us to make hypotheses, interpret data, understand the phenomena involved, and present breakthroughs. Physics requires a visual representation in its presentation, such as pictures, graphs, diagrams, and another visual modeling. Visual representation in this study was represented by (1) drawing the FBD, showing that as many as 40% of students who took the test were able to represent the questions in the FBD; (2) decomposing the force and resultant on the system, as many as 27% of them can do it; (3) determine the type and direction of motion of magnitude, (60%) are able to (4) represent results and units, (<50%) students. Furthermore, a good step is to get used to reading a phenomenon, a concept that is displayed in graphs, pictures, diagrams, or tables, and vice versa, describing concepts or solving mechanical problems in pictures, graphs, or tables. Visualization of a phenomenon or concept will reduce the abstract nature and communicate ideas or meanings so that phenomena or concepts in mechanics are easier to interpret.

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