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Students' difficulties regarding vector representations in free-body system

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Abstract. Research has been conducted relating to the use of representation in physics learning. The aim of the research is to identify the difficulties of students in using vector diagrams in solving the problems of various free body systems, then to determine the effect of the students' prior knowledge on the implementation of representation in physics learning. The study was conducted on two groups of students, who only learned Introductory Physics and students who had studied Introductory Physics and Mechanics. The findings of the study is almost no difference between groups of students who only have Introductory Physics and groups of students who have learned the knowledge of Introductory Physics and Mechanics. More than 75% of students cannot correctly draws vector diagrams of weight and weight projections in inclined plane, normal force, friction forces and tension. The implication of the research is the need to organize the physics education curriculum for freshman students at the university which gives sufficient prior knowledge on Vector Analysis, especially students in physics departement and engineering departement.

1. Introduction

The studies on problems and research about representation and use of representation in physics education have been carried out by many experts [1-8]. Physics often involves the modelling of real world physical fenomena using external representations that range from concrete to abstract forms: pictures, diagrams, words, graphs and equations [3]. Pedagogically, the use of concept networks, data-meaning tables, conceptual change texts, analogies and pictorial representations gives contribution to students' meaningful learning during the teaching process [4]. And the use of multiple representation in teaching and learning helps students become better problem solvers [9]. Mesic, explained the results of his study that consistency between internal and external representations of knowledge is a very important requirement for effective problem solving and effective learning of physics, in general [10]. Typical visual representation associated with specific physics topics: Kinematics – Motions diagrams, Forces and Dynamics – Free body diagrams (FBD), Energy – Energy bar charts, Field – Field line diagrams, Electric circuits – Electrical circuit diagrams, Geometrical optics – Ray diagrams, Waves – Wavefront diagrams, Quantum Physics – Energy level diagrams [11]. This study reports the use of representations in free body systems. The author's experience shows that students cannot answer correctly regarding the problem of drawing vector diagrams in some cases of free body systems. The

problem of understanding free body diagram is not new, at 1982 Clement's conducted a study related to a number of common misconception student have when describing what forces act on a body, and at 1993 Lane wrote his paper "Why can't physicist draw FBS's"?, furthermore at 2004 Sharp and Zachary suggest that geometry and spatial thinking needs to be taught in a specific sequence covering three levels, and at 2009 Rosengrant conducted a study written in a paper "Do students use and understand free-body diagram?"[12]. With a number of reasons mentioned above, a research was carried out aimed to identify the difficulties of students in using vector diagrams in solving the problems of various free body systems, then to determine the effect of the students' prior knowledge on the implementation of representation in physics learning.

2. Conceptual framework

The force concept is the core of Newton's laws of motion and is a central concept in the theory of classical mechanics that is taught from lower secondary school to university level, especially important pictorial representation used in the teaching of forces in free-body diagram (FBD), which depicts force vectors acting on a target object [5]. Indeed, to be able to solve the problem of cases of free object systems requires good vector knowledge, as reported by Barniol and Zavala (2010), that is important to note that even though most students solve the problems correctly, some students, even after taking introductory physics courses, still show difficulties with basic vector operations [13].Research has shown that students have difficulties with vectors in college introductory physics courses and high school physics courses; furthermore, students have been shown to perform worse on a vector task with a physical context when compared to the same task in a mathematical context [14]. Therefore, correctly drawing of vector diagram representations helps students understand concepts and solve problems procedurally and systematically. Founded that small-scale changes in the representation of graphical vector addition questions can affect the distributions of students' drawn solution methods and written explanations of their solutions, and the arrangement of vectors into head-to-tail (aligned) or tail-to-tail (divergent) arrangements has a significant effect on the way students respond [15]. The role of visual representation helps students in generating students' memory as obtained from prior knowledge, as reported by Cock, that learners have a limited working memory, and instructional representations should be designed with the goal of reducing unnecessary cognitive load. However, cognitive architecture alone is not the only factor to be considered; individual differences, especially prior knowledge, are critical in determining what impact a visual representation will have on learners' cognitive structures and processes. Prior knowledge can determine the ease with which learners can perceive and interpret visual representations in working memory [16].With regard to physics education, the goal of physics learning is to make students have the competence to understand the correct concepts of physics and to be able to solve physical system problems, so we want students to be like experts. Rosengrant, quoting Gerace W (2001) [17], presents an indicator of differences in experts and beginners or novices as shown in Table 1.

Table I. Differences in problem solving between experts and novices [18]

| 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 concept-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.

3. Method

This research starts from the study of physics literature especially in mechanics for several cases of free-body system in order to make test instruments related to representation diagrams. The questions asked are questions that are often found in university physics reference handbooks written by Alonso-Finn, Sears-Zemansky, Giancoli, Halliday-Resnick, Young-Freedman and Schaum's Series. The questions given require special answers only in the form of drawings or diagrams. Test in the form of essay tests with a total of 6 questions. Test time for 30 minutes. The instrument is tested for content validity and construct validity. Content validity based on test content. Construct validity based on internal structure, response processes and consequences of testing. Participants in this research were 37 students the pre-service teacher. The test material is shown in Table II.

Table II. Test for identification of vector representation

Material of test	Vector representations observed
Free fall	Identify weight and direction of vector of weight, position of tail-head of vector
Block static on the horizontal plane	Identify position and direction of weight, normal forces, position of tail-head of vector
Block move on the inclined plane no friction	Identify position and direction of weight, projection of weight in inclined plane, position and direction of normal forces, position of tail-head of vector
Block move on the rough inclined plane	Identify position and direction of weight, projection of weight on the inclined plane, position and direction of normal forces, position and direction of friction, position of tail-head of vector
Ladder resting against a frictionless wall on the rough horizontal floor	Identify position and direction of weight of ladder, position and direction of normal forces on the wall and floor, position and direction of friction in rough floor, position of tail-head of vector
Pulley with two mass	Identify weight and direction of vector of weight, tension on the ropes, position of tail-head of vector

Answer worksheets are written directly in the test instrument. Tests are given to two groups of students. Group 1 consists of 16 students who have studied Introductory Physics (IP). Group 2 consist of 21 students who have studied Introductory Physics (IP) and Mechanics (M). Identification of the number of students who answered incorrectly, shown in Figure 1.
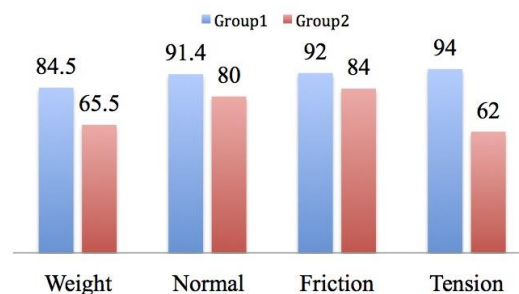
Figure1. The percentage of students does not answer correctly.

With carefully examined one by one worksheet, then identify students' difficulties in drawing vectors of weight, normal force, friction, and tension on the rope, then compile a table identifying students' difficulties as shown in table III, IV, V, and VI.

Tabel III. Identification of difficulties of vector representations of weight (W)

Identification of difficulties	Group 1 (%)	Group 2 (%)
Weight W is not done	50	43
W is not in the center of mass or center of gravity	59	53
W is not on the trajectory of motion (free fall)	25	24
W is not in the vertical downward (inclined plane)	38	43
Projection components of W is not done (inclined plane)	91	60
Components of W is incorrectly (inclined plane)	25	72
Misplaced component (inclined plane)	28	45

Tabel IV. Identification of difficulties of vector representations of normal (N)

Identification of difficulties	Group 1 (%)	Group 2 (%)
Normal forces N is not done	49	38
N misdirected	31	21
N is not from the boundary (inclined plaed)	54	78
N is not perpendicular to the plane	23	24
N on the wall is not made (ladder)	94	100
N on the wall misdirected (ladder)	69	90
N on the floor misdirected (ladder)	69	90

Tabel V. Identification of difficulties of vector representations of friction (f)

Identification of difficulties	Group 1 (%)	Group 2 (%)
Friction f is made even though the block does not move in the horizontal plane	38	52
f is made in the inclined plane no friction	50	62
f is not made on the rough plane (inclined plane)	69	67
f misdirected (inclined plane)	44	38
f is not on the boundary plane (inclined plane)	31	43
f is made on the wall no friction (ladder)	63	95
f on the rough floor is not made (ladder)	69	90
f on the floor misdirected (ladder)	81	90

Tabel VI. Identification of difficulties of vector representations of tension (T)

Identification of difficulties	Group 1 (%)	Group 2 (%)
Tension T is not made	63	57
T is not drawn on the rope	63	52
T misdirected	50	57

4. Discussion

Reading the data shown in the table, III, IV, V and VI, pedagogically there are several things that require attention in physics education. There have been many research findings related to the role of vector representation and its relation to the problem of free-body systems, as stated by Sirat (2017) that the most difficult task for the students in terms was identifying the force diagram representing forces exerted on an object on in an inclined plane [19]. However, in this study new things were found relating to the effects on the equilibrium system of objects in both translation and rotation. The data in table III shows that there are 59% in group 1 and 53% in group 2 which incorrectly place tail-vector of weight (W) at the center of mass or center of gravity (CoG). When students' misunderstanding places tail-vector of weight, so this has the potential to become a problem in solving free-body systems that not only use translation equilibrium requirements $\Sigma Fx = 0$, and $\Sigma Fy = 0$, but also require completion

using the rotation equilibrium requirement $\Sigma\tau = 0$, example for problem ladder system. Jason et.al. (2015) pointed out that student difficulties in science learning are frequently attributed to misconceptions about scientific concepts, with using the concept of center of gravity (CoG), we show how student difficulty in applying CoG to an object such as a baseball bat can be accounted for, at least in part, by general principles of perception (i.e., not exclusively physics-based) that make perceiving the CoG of some objects more difficult than others [20]. Based on data obtained from 25 items identifying student difficulties found there was no influence of prior knowledge either those who only studied IntroductoryPhysics or who had studied Introductory Physics and Mechanics. By using student distribution statistics (t-test), an examination is conducted whether the two groups (i.e group 1 and group 2) are different or not different.

Table VII. Independent samples test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
NILAI	Equal variances assumed	.614	.437	-1.016	48	.315	-6.32000	6.21942	-18.82498	6.18498
	Equal variances not assumed			-1.016	46.992	.315	-6.32000	6.21942	-18.83192	6.19192

Levene's test results, the sample is homogeneous, then used df = 48 (first row). Based on the table above p value, 0.315> 0.05, Ho is accepted, meaning that there are no significant differences between the two groups of group 1 and group 2.The results above are shown by not making vectors and misdirected of the normal vector (N), friction (f) and tension (T) which means that there is indeed no significant difference between Group 1 and Group 2. Found freshman years students who wrongly answered the basic concepts of physics such as drawing normal forces not perpendicular to the plane, drawing friction on slippery surfaces indicating of incomplete information about physics concepts learned from high school to university level. For this reason, it is important that Waldrip's(2013) views relate to the didactic process of physics learning, which is necessary there to be an explicit teacher focus on representational function and form, with timely clarification of parts and their purposes. For example: ''what is a graph and why do we use them in science?''. There needs to be a sequence of representational challenges which elicit student ideas, guide them to explore and explain representations, to extend to a range of situations, and allow opportunities to generate representations and integrate these meaningfully. Assessment through representations: Formative and summative assessment needs to allow opportunities for students to generate and interpret representations [21].

5. Implications

The discovery of misconceptions in drawing a vector such as misplaced tail-vector, misdirected head-vector, vector not in the trajectory of motion giving an indication of the importance of complete vector learning. As written by Barniol (2010), that is the understanding of vectors is important for science and engineering students, not only to understand introductory-level physics concepts but also to understand more advance topics in their curriculum [13]. In line with the above, Aviani(2015) said that vector calculus, in most physics courses, is carried out by the traditional algebraic methods, i.e., by resolving the forces into the components and then summing up the components that have the same line of action. This method has some advantages, particularly in the treatment of a large number of vectors and complicated geometry. In this way a geometrical problem is transformed to an algebraic problem, which facilitates solving even for those students who are less talented in geometry [22]. Because it is an important requirement to make vector analysis courses as a prerequisite for physics students in the first semester of the first level at university. Finally, every physics and engineering

student must pass the vector analysis course and introductory physics courses to further study mechanics courses.

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