Analysis of College Students' Conceptual Understanding on Work and Energy Topic in Various Representations

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***Abstract** – The study aims to determine students' conceptual understanding of work and energy in various representations. The research method used in this study is a mixed method with a sequential explanatory design. The data in this study were quantitative data and qualitative data. Quantitative data analysis was performed using descriptive statistics. The research subjects consisted of 45 physics students at Universitas Negeri Malang who had taken the fundamental of physics course I. In this study, 10 multiple choice questions were used on the work and energy topic presented in various representations. The results showed that the understanding of concepts in the work and energy topic in various representations was still relatively low, which was indicated by the average score of students only reaching 42.22. The lowest concept of understanding occurs in the sub-topic of work and kinetic energy, which is presented in a mathematical representation. Some of the errors experienced by students in the concept of work include: (1) students assume that gravity is the same as the tensile force on the block, (2) work is an ordinary product of force and displacement, and (3) do not pay attention to the meaning of the multiplication symbol between vector quantities. While in the concept of kinetic energy, the errors experienced include: (1) students use equations in the form of conclusions without starting from the variables raised in the problem and (2) assume that kinetic energy is only influenced by mass, so that they do not consider the speed of the two objects.*

***Keywords**: Conceptual Understanding; Work and Energy; Various Representations*

INTRODUCTION

Physics is one of the sciences that has an important role in shaping the mindset of students so that they can become qualified. This will be achieved if students have a good understanding of physics concepts (Kaur et al., 2018). Many studies reveal that conceptual understanding is one indicator of success in learning (Kaur et al., 2018). A good and precise understanding of physics concepts can help students solve a physics problem (Rivaldo et al., 2019; M R A Taqwa et al., 2019). One of the topics in physics that requires a good understanding of the concept is work and energy.

Work and energy are important concepts in physics (Rahmatina et al., 2017). Work and energy is a topic that has many applications in everyday life (Sholikah et al., 2020) and are very complex because they relate to other physical concepts (Robertson et al., 2017; Serway & Jewett, 2018). Therefore, the concepts of work and energy must be mastered properly to assist in understanding other physics concepts (Dega, 2019).

Based on previous research, it is known that students have a low understanding of the concept of work and energy (Dienyati et al., 2020). Most students also still experience misconceptions about work and energy (Mustofa et al., 2016). In solving a problem, students are often inconsistent. This happens not because students do not have relevant knowledge, but students fail to activate their knowledge (Afwa et al., 2016; Hammer, 2000). The ideas used in solving problems also depend on the context of the given problem (Muhammad Reyza Arief Taqwa et al., 2017).

So that students' understanding of concepts can be built properly and deeply, multi-representations are needed. This is because in physics, there are many phenomena and problems that can be solved with various representations (M. R.A. Taqwa et al., 2020). Multi-representation is used to represent the same concept but in different formats such as pictures, verbal, mathematical, and graphical (De Cock, 2012). If students can understand concepts in a variety of ways, form of representation, it can be said that the student has understood the concept in depth (Muhammad Reyza Arief Taqwa & Rivaldo, 2018).

Several studies related to business and energy materials have been carried out before. In research (Rivaldo et al., 2019), prospective physics teachers' conceptual understanding of the material on work and energy was identified. This research was carried out by distributing reasoned multiple-choice questions and then analyzing them based on the answers and reasons given by students. Research has also been carried out by (Dienyati et al., 2020) to analyze students' conceptual understanding based on multiple representations in work and energy material. The research was carried out by distributing reasoned multiple-choice questions and then conducting interviews. Of this two research, none has specifically discussed how students understand the concepts of work and energy in various representations. The research conducted by (Rivaldo et al., 2019) also did not use interviews in data collection. Previous research has used interview techniques but the research subjects were high school students. The novelty in this research is that testing of understanding of the concepts of work and energy was carried out on college students using various representations so that it can be seen whether students' understanding of the concepts of work and energy is good and complete.

Based on the problems and shortcomings of previous research, the aim of this research is to determine students' understanding of the topic of work and energy in various representations. The questions given in this research are presented in various contexts and representation formats. The form of questions in various contexts and representation formats is also the novelty of this research. This is very important considering the need for a complete understanding of concepts and understanding of concepts in various representations. In exploring students' understanding of concepts on the topic of work and energy in various representations, tests are also carried out on students. Interview techniques were also applied in this research to explore broader and deeper information regarding students' conceptual understanding of work and energy topic.

RESEARCH METHODS

This study is descriptive research. The research method used in this study is a mixed method, which is a combination of qualitative and quantitative research. The research design used is sequential explanatory where the data to be collected first is quantitative data and analyzed, then followed by qualitative data collection and analysis. The subjects of the study were 45 physics department students at Universitas Negeri Malang who had taken the taken the fundamental of physics course I.

We have collected data by survey technique and interview. The test instrument consists of 10 multiple choice questions. The topics tested in the problem consist of work, potential energy, kinetic energy, the conservation law of mechanical energy. All problems on the instrument were adapted from several previous studies and university physics books. The instrument that we used were valid according to the expert and feasible based on the criteria of validity, reliability, discrimination index, and level of difficulty referring to Table 1, Table 2, Table 3, and Table 4.

Table 1. Question validity criteria

Score of r_{xy}	Category
0,81 < r ≤ 1,00	Very high
0,61 < r ≤ 0,80	High
0,41 < r ≤ 0,60	Enough
0,21 < r ≤ 0,40	Low
0,00 < r ≤ 0,20	Very low

(Arifin, 2013)

Table 2. Reliability Level Based on Alpha Value

Alpha	Category
0,00 – 0,20	Not reliable
0,21 – 0,40	Less reliable
0,41 – 0,60	Enough
0,61 – 0,80	Reliable
0,81 – 1,00	Very Reliable

(Arikunto, 2009)

Table 3. Discrimination Index Category

Score	Category
0,200 – 0,299	Low
0,300 – 0,399	Medium
>0,400	High

(Viana & Subroto, 2016)

TABLE 4. Level of Difficulty Category

Score	Category
0,100 – 0,299	Difficult
0,300 – 0,700	Medium
0,701 – 0,900	Easy
0,901 – 1,000	Very Easy

(Viana & Subroto, 2016)

Interviews were conducted to consider the reasons for each answer selection. We conducted interviews to 10 students. We obtained quantitative data from the test instrument and qualitative data from interviews. Quantitative data were analyzed using descriptive statistics. The results of our interviews were coded based on the tendency of similar conceptual understanding.

RESULTS AND DISCUSSION

Results

The study aims to analyze the understanding of students' concepts in the topic of work and energy. This research was conducted on physics education students at the State University of Malang who have taken the fundamental of physics course I. In this study, 10 multiple choice questions were used to determine students' understanding of the concept of work and energy in various representations. The questions used are taken and adapted from previous research and from university physics books where the validity of the items has been well tested. The results of the students' scores can be seen from the statistical descriptions in Table 5. The results of the research that have been carried out show that students' understanding of the concepts of work and energy in various representations is still relatively low. This can be seen from the average score of students which only reached 42.22%.

Table 5. Descriptive statistics on the score of understanding the concept of work and energy in various representations

	Score
N	45
Minimum	10,00
Maximum	90,00
Mean	42,22
Modus	20,00
Median	40,00
Standard Deviation	21,63

The distribution of questions in several sub-topics and the correct answers chosen by students are as shown in Table 6. Based on the distribution of the percentage of students' correct answers contained in Table 6, the lowest concept understanding ability is found in the work and kinetic energy sub-topics presented in mathematical representation. This can be proven by the percentage of students' correct answers in the work sub-topic, which is 20% and in the kinetic energy sub-topic, which is only 8.9%. While the questions with the highest percentage of students answering correctly were found in the sub-topic of the law of conservation of mechanical energy, which was presented in verbal representation, which was 86.7%. In this article, the questions that will be discussed are work and kinetic energy sub-topics, which are presented in a mathematical representation where both have the lowest percentage of correct answers.

Table 6. Distribution of questions in sub-topics and students' correct answer choices

Subtopics	Question	Representation	Pecentage of Correct Answers
Work	1	Verbal	35,6%
	2	Mathematical	20%
Potential Energy	3	Picture	51,1%
	4	Diagram	33,3%
Kinetic Energy	5	Graphical	46,7%
	6	Mathematical	8,9%
Conservation Law of	7	Verbal	86,7%
Mechanical Energy	8	Picture	68,9%
	9	Mathematical	40%
	10	Diagram	31,3%

Discussion

Understanding of Work Concepts

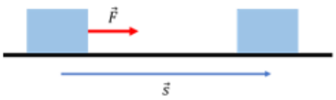
To find out the understanding of the concept of work in mathematical representations, this study used items that discuss the concept of work as a dot product between the magnitudes of force and displacement. The work questions presented in the mathematical representation are contained in item number 2 as shown in Figure 1. Based on Table 1 it can be seen that students who answered correctly on item number 2 were only 20%. This shows that students' understanding of the concept of work presented in mathematical representations is still very low. The low understanding of the concept of work in mathematical representation is caused by students' confusion regarding the meaning of dot product multiplication which is used to determine effort. This is supported by the results of previous research. Many students know how to determine work, namely by multiplying the dot product between the force exerted on an object and its displacement. However, students are still confused and do not understand that dot product multiplication will result in using a cosine in their calculation (Barniol & Zavala, 2014; Rahmatina et al., 2017).

Table 7. Distribution of Student Answers on the Sub-topic of Work in Mathematical Representation

Answer Options	Percentage
A	33,3%
B	31,1%
C	6,7%
D*	20%
E	8,9%
Total	100%

In item number 2 as shown in Figure 1, students are asked to determine the amount of work done by gravity on the block in mathematical form. In answering this question, many students answered incorrectly. Only 20% of students can answer correctly, namely the answer choice D. While the rest choose the answer that is less precise. The distribution of student answers on item number 2 is as shown in Table 7. Based on the data in Table 7, the largest distribution of answers is in answer choice A, which is 33.3%. Based on the results of interviews, students who chose the answer option A revealed that the gravity on the block is the same as the tensile force on the block so that it is considered that the gravity that works does not form an angle to the displacement and its work mathematically becomes $W_{\vec{w}} = (m)(\vec{g})(\vec{s})$. Some students also do not consider that what is being asked is the work by gravity on the block.

Look at the following picture!



Annisa pulls a block of mass m that is in a smooth horizontal plane with a force $\vec{F}$. Annisa pulls the block for 10 seconds so that the block moves $\vec{s}$. The amount of work done by the weight on the block is...

A. $W_{\vec{w}} = (m)(\vec{g})(\vec{s})$
B. $W_{\vec{w}} = (m)(\vec{g}) \times (\vec{s})$
C. $W_{\vec{w}} = (m) \times (\vec{g}) \times (\vec{s})$
D. $W_{\vec{w}} = |m\vec{g}||\vec{s}| \cos\theta$
E. $W_{\vec{w}} = |m\vec{g}||\vec{s}| \sin\theta$

Figure 1. *Question with Sub-topics of Work in Mathematical Representations*

Most students assume that the work that is calculated is only worked by the tensile force acting on the block. There is another reason that some students do not recall that work is a form of the dot product between the magnitudes of force and displacement. Students assume that the work done by gravity on a block is just an ordinary product of gravity and displacement. These thoughts are not correct because students do not understand that the gravity on the block and the displacement are perpendicular to each other. In accordance with the concept that work is the dot product between the magnitudes of force and displacement, the amount of work by gravity should be mathematically expressed as $W_{\vec{w}} = |m\vec{g}||\vec{s}| \cos\theta$.

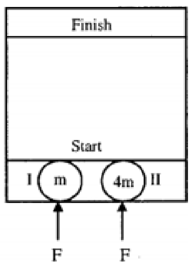
The next highest distribution of answers is found in answer choice B, which is 31.1%. Students who choose the answer options B can already understand that what is being asked is the work of the gravity acting on the block. The student is already able to decompose gravity into mass times the acceleration due to gravity, but the student still thinks that to calculate the effort, all you have to do is use the ordinary multiplication between gravity and displacement. A fatal error is that students do not realize that the multiplication symbol contained in answer option B is a cross multiplication symbol which in physics the multiplication symbol has a special meaning in the multiplication of vector quantities. The error in using the multiplication symbol for vector quantities also occurred in students who chose answer option C. Meanwhile, students who chose answer option E revealed that they did not understand how to determine the use of sine or cosine in business calculations. As many as 20% of the interviewed students also revealed that in choosing the answer, they only guessed without thinking about using the correct concept.

The low level of understanding of the concept of work in mathematical representation is in line with the results of research (Mustofa et al., 2016), which states that students' understanding of the basic concepts of mechanical energy about work as a result of dot multiplication between force and displacement is still very low. Some students also have misconceptions about effort and difficulty in determining the dot (Barniol & Zavala, 2014) product. It is very important to pay attention to mathematical representation skills because if someone has good mathematical representation skills, it can help someone build concepts, understand concepts and express mathematical ideas, and make it easier to develop their abilities (Mandur et al., 2016).

Understanding the Concept of Kinetic Energy

To find out the understanding of the concept of kinetic energy in mathematical representations, in this study used items on the concept of kinetic energy presented in mathematical representations. The question of kinetic energy present in the mathematical representation is contained in item number 6 as shown in Figure 2. Based on Table 1 students who answered correctly on item number 6 were only 8.9%. This shows that students' understanding of the concept of kinetic energy presented in mathematical representations is still very low.

Look at the following picture!



Two objects with different masses that are initially at rest are pushed with the same force so that they move towards the finish line. If the two objects are on a smooth path, the ratio of the kinetic energy of the two objects is…

A. $K_1 = K_2$
B. $K_1 = 4K_2$
C. $K_1 = \frac{1}{4}K_2$
D. $4K_1 = K_2$
E. Information is not sufficient to answer the questions.

Figure 2. *Question with Sub-topics of Kinetic Energy in Mathematical Representations*

In item number 6, students are asked to determine the ratio of the kinetic energy of two objects that have different masses and are pushed with the same constant force F. In answering this question, many students answered incorrectly. Only 8.9% of students can answer correctly, namely the answer choice A. While the rest, choose the wrong answer. The distribution of student answers on item number 2 is as shown in Table 8.

Based on the data in Table 8, the largest distribution of answers is in answer choices B and D. Students dominantly answered that the kinetic energy of the first object was four times that of the second object and vice versa.

Table 8. Distribution of Student Answers on the Sub-topic of Kinetic Energy in Mathematical Representation

Answer Options	Percentage
A*	8,9%
B	42,2%
C	20%
D	26,7%
E	2,2%
Total	100%

The answer is obtained from writing the equation that the kinetic energy of two objects is the same or $K_1 = K_2$. After writing the equation, the student then performs calculations using the reference that $K = \frac{1}{2}mv^2$. After doing the calculations, the students found that $K_2/4K_1 = v_2/v_1$, so that students conclude that $K_2 = 4K_1$. From these calculations, there are also students who also conclude that $K_1 = 4K_2$. Students also reasoned that the greater the mass of an object, the greater its kinetic energy. The use of the equation is not appropriate because it is a form of conclusion. Students do not assume that the two objects have different speeds so that kinetic energy is not only affected by mass. Students do not start from the variables that appear in the questions first. For constant force F, obtained $v^2 = 2Fs/m$ so that $K = \frac{1}{2}m(2Fs/m) = Fs$. Based on the equation, for the same F and s, it can be concluded that the kinetic energy of the two objects is the same.

The students' reasons for answering the questions above show that the students understand the use of the kinetic energy equation to solve problems. However, students do not activate previously acquired knowledge in solving problems. Students should be able to reactivate the concept of the relationship between work and kinetic energy. This condition can be explained using cognitive model (Redish, 2004) that students' failure in answering problems is possible because they fail to activate previously held knowledge in long-term memory into their working memory. Even if students have succeeded in activating previous knowledge, students still fail to select appropriate knowledge that can be used to solve problems. The reasons expressed by students in answering the questions above also indicate that students still have limited mathematical abilities which hinder them in solving physics problems (Haryadi, 2016; Nurlailiyah & Delta, 2015; Rusilowati, 2006). This is supported by previous research which revealed that there were several errors experienced by students in solving kinetic energy problems, namely: 1) students were not able to use the equation for the relationship between work and kinetic energy; 2) students are not yet able to identify systems and model them to apply the work - kinetic energy theorem; 3) students assume that the slope of the path an object passes has an effect on changes in the object's kinetic energy; 4) students assume that moving objects are always caused by a resultant force or effort that is not zero (Mustofa et al., 2016).

CONCLUSION

Based on the results of the study, it can be concluded that students' understanding of the work and energy topics in various representations is still relatively low. This is evidenced by the average student score, which only reached 42.22. Students' understanding of the concept of work and energy is lowest in the sub-topics of work and kinetic energy which are presented in mathematical representations. From the results of the study, there were several errors experienced by students in the concept of work including: (1) students assume that gravity is the same as the tensile force on the block, (2) work is an ordinary product of force and displacement, and (3) do not pay attention to the meaning of the multiplication symbol between vector quantities. While in the concept of kinetic energy, the errors experienced include: (1) students use equations in the form of conclusions without starting from the variables raised in the problem and (2) assume that kinetic energy is only influenced by mass, so that they do not consider the speed of the two objects. These errors occur because students' understanding is not complete and tends to be inconsistent in working on different problems. In addition, students also cannot recall the knowledge they have correctly when faced with questions with different representations.

Referring to the research findings, it is necessary to have a learning design that involves multiple representations in its teaching. The use of multiple representations is not only able to facilitate students in understanding concepts but can strengthen students' understanding of concepts. If students can master concepts strongly and deeply, then students will find it easier to call the knowledge they already have correctly when solving problems with different representations.

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