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Concept Acquisition of Rotational Dynamics by Interactive Demonstration and Free-Body Diagram

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Abstract

The concepts of force and motion are essential material in physics. However, students experience many difficulties in the concept of force in rotational dynamics. This research was conducted to measure students' concept acquisition of the rotational dynamics through Interactive Demonstration assisted by Free-body diagram. The mixed research method was chosen through the use of test instruments in the forms of 10 multiple-choice with open ended questions. The subjects of the research were 35 students XI IPA Senior High School 2 Sungai Penuh-Indonesia. Students' concept acquisition was measured before and after the intervention to be analyzed quantitatively. The obtained *N-gain score* was 0.41, and it showed that there was a moderate improvement in students' concept acquisition, while the effect size value was 1.82 showing that the intervention strongly affected students' concept aquisition. The data were also supported by the results of the qualitative analysis of the students' answers and worksheets given during the intervention process.

Keywords*: Concept acquisition, free-body diagram, interactive demonstration, rotational dynamics*

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Introduction

The most important concept is about force and motion (Carvalho & Sousa, 2005). Hence, such concept is crucial to be studied and mastered by students (Robinson, 2014). The concepts of force and motion always relate to the Newton's law. Newton's law in translational motions has frequently been studied in education research. However, there is a small amount of research conducted on Newton's law in rotational dynamics, even though it is one of the physics content that are difficult to be understand by students (Mashood & Singh, 2012; Kladivova & Mucha 2014). Students face difficulties in determining the effect of force on a rotational motion (Rimoldini & Singh, 2005; Mashood & Singh, 2012; 2015; Close, et al., 2013), and explaining the effect of mass distribution in moment of inertia (Leyvraz 2015).

Based on observations performed on schools where the research was conducted, physics learning focuses on the knowledge transfer from teachers to students and shown mathematically without consideration for the physical concept. The ways utilized by students in solving problems tend to be mathematical, and without paying attention to the concept (Close, et al., 2013). However, in fact, the main purpose of physics learning is to improve students' conceptual understanding in physics (Etikina, 2015; Steinberg, 2009).

Therefore, it is necessary to develop a learning method that can actively involve students in its process. Quality of learning depends not only on the form of how the process is carried out but also on what content is taught and how the content is presented (Nachimuthu & Vijayakumari, 2012). An appropriate learning method to involve students is an interactive learning (Sharma et al., 2010) and demonstration is an active and constructive learning approach (Meril 2013). A demonstration is an interesting process that can be used to illustrate a concept and to draw students' attention (Miller, 2013) and motivation because demonstration make it visible and clear (Bakar et al, 2014). It can assist the students in developing their conceptual understanding and connect the concept with their real lives (Miller, 2013). Hence, an interactive demonstration can be the solution for such problems. It was developed by Wenning (2011) through the Interactive Demonstration.

A representation is required to support learning through interactive demonstration. Representation will make the demonstration becomes more efficient (Miller, 2013). The representation used in the learning approach highly depends on the content of physics (Nieminen et al., 2013). The importance thing to achieve effectiveness in learning is the balance of the learning component (Yaniawati, 2013), so representation must choosen carefully. Representation in the form of a free-body diagram is considered as appropriate for the analysis of force as a vector quantity (Ayesh et al., 2010; Fredlund et al., 2014). The rotational dynamics is always related to the forces and vector, so a free-body diagram can be integrated with the interactive demonstration to measure students' conceptual acquisition. It is also supported by Carvalho & Sousa (2005) who revealed that teachers should encourage the students to use a free-body diagram when learning the dynamics material. The previous research also showed positive impacts of using a free-body diagram as it can visualize the situation of the problem (Ibrahim, 2012), provide an appropriate understanding of such problem (Ayesh, et al., 2010; Cock, 2012), and simplify the analysis of a force component to determine the velocity of an object (Etkina et al., 2006; Rosengrant, et al., 2009). Therefore, an interactive demonstration learning method integrated with free-body diagram was applied.

Method

This research was conducted by the mixed method. The subjects of this research were 35 students XI Sains Senior High School 2 Sungai Penuh. The interactive demonstration supported by a free-body diagram was applied during the learning process. Based on reasearch finding showed by Tanang et al, (2014), there was no worksheet to support student learning. In this research the worksheet was designed to support the learning process through interactive demonstration. There were five stages included in the Interactive Demonstration, namely observation, manipulation, generalization, verification, and application (Wenning, 2011). On the observation stage, students got explanations about the demonstration that was going to be given regarding the content. Then, in the manipulation step, students made predictions, illustrated the free-body diagrams, and provided explanations about the demonstration that was going to be given. Then, the students compared the predictions they made previously with the results of demonstration in the generalization stage. A discussion in small group was performed to find an explanation and develop an appropriate concept regarding the demonstration. Small group discussion can be support a reflection process in learning (McCoy, 2012). The verification stage aims to strengthen the concept developed by the students and then, once again, the students made predictions, free-body diagrams, and provide explanations related to the demonstration that was going to be given. On the application stage, students paid attention to the demonstration made by the teacher (student representative) and provided explanations that led to the conclusions. Subsequently, students practiced by doing some questions related to the relevant material.

The data of the students' concept acquisition were obtained from the students' worksheets during the learning process and the results of the tests performed before and after the intervention. The test instrument consisted of 10 multiple-choice with open ended question. The subjects of such empirical study were 139 students of class XII sains and it obtained average values of question validity amounted to 0.50 and of instrument reliability of 0.68. The N-Gain score measurement was done by comparing the students' scores before and after the intervention, and the results of such measurement were utilized to identify any improvements on the students' concept. Besides, the effect of the given intervention was also measured by calculating the effect size value.

Results

As shown by the skewness value, the data were normally distributed. The skewness value indicates the distribution of the data in a normal curve. Morgan (2004) explained that the normally distributed data are the data with the skewness values between +1 and -1. The data were then analyzed based on the correct answers (given the value of 1) and the wrong answers (value of 0). The N-gain score obtained was 0.41 that means there was a moderate improvement of the students' concept. The obtained effect size was 1.82, which means that the intervention given has a significant influence on the students' concept aquisition.

The multiple-choice questions only identified the correct and wrong answers, yet students who gave correct answers were not guaranteed to have mastered the concept. Also, the students with incorrect answers are not likely to have zero understanding of the concept. There are possibilities that the students have mastered the concept, yet could not provide the appropriate explanation, or that the students did not master the concept at all, yet had a correct guess. Therefore, multiple-choice with open ended question were chosen since they can reveal the students' concept of rotational dynamics before and after the intervention.

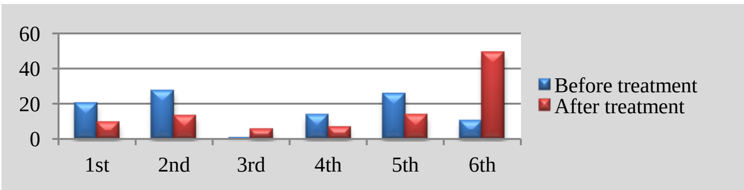

Figure 1. Students' Concept acquisition based on the Patterns of their Answers

The students' answers were shown by three patterns of incorrect answers and three patterns of correct answers for both before and after the learning as shown in Figure 1. The incorrect answers are presented by three answer patterns, namely the 1st until 3rd pattern. The 1st pattern represents the incorrect answers given without any explanations, the 2nd pattern represents the incorrect answers given with wrong explanations, and the 3rd pattern represents the incorrect answers given with explanations that are related to the appropriate concept to solve the problems. The correct answers were also represented in three patterns, namely the 4th until 6th pattern. The 4th pattern represents correct answer without any explanations, the 5th pattern represents correct answers with incorrect explanations, and the 6th pattern represents correct answers with correct explanations.

The 1st pattern shows that the students answered based on their guesses to choose one out of the five choices without any explanations. However, after the intervention was given, the percentage of answers in this pattern was reducedby almost a half than the percentage before the intervention. It means that the number of answers without explanations declined after the intervention was given. In 2nd pattern students showed some efforts to support their answers by providing explanations, although they were not correct. This pattern has the highest percentage among the six patterns, i.e. 27.34%. Such percentage ndicates that there was still a low understanding of rotational dynamics concept before the intervention. The percentage of this pattern was also reduced after the intervention. The 3rd pattern shows a possibility that the students had understood the concept, but answered incorrectly. This pattern of answers appeared in a relatively small percentage, either before (0.86 %) or after the intervention (5.43 %).

There are two possible explanations for the 4th pattern of answers, namely the students guessed the answer correctly without providing any explanations, and the students knew the correct answer but could not provide the appropriate explanations to support their answers. The 5th pattern represents the right answers with improper explanations. Students might have guessed the answer correctly and giving improper explanations, or they might have misconceptions regarding a material delivered in the questions. It would be discussed further in the discussion section. The percentages of the 4th and 5th patterns after the intervention were both lower than before the intervention. The students' answers in the 6th pattern were expected since it would show that the students have understand the concept of rotational dynamics. In this pattern, students provided correct answers with correct explanations. The percentage of this pattern was extremely low before the intervention (10.29 %) and increased significantly after the intervention (49.14 %). It can be concluded from the 6 patterns of answers that the students' concept acquisition in rotational dynamics was improved after the intervention. After the intervention, the percentage of the wrong answers (the 1st and 2nd patterns) was declining along with the increasing percentage of the correct answers (the 6th pattern). This fact was in accordance with the N-gain score showing that there was an improvement on the students' concept acquisition and on the effect size value proving that the given intervention highly influenced the students' concept acquisitionlevels.

Discussion

Torque

Based on the student explanations, some difficulties in responding to a question about torque were found. For a system with many forces, the torque can be calculated based on the vector rule or by using the positive sign rotational direction in a counter-clockwise orientation and the negative sign rotational direction in a clockwise direction. The students found difficulties in determining the direction to measure the torque of several forces through a free-body diagram. The students had the tendency to assume that the force acting downward (heading to the negative y-axis) has a negative rotational direction and that the force acting upward (heading to the positive y-axis) has a positive rotational direction as shown in Figure 2. Such assumption is categorized into the 2nd pattern of the answer, namely students gave wrong answers with improper explanations. The previous research revealed students' difficulties in the core concept of rotational dynamics by using graphical representation and students' misconceptions about resultant force on rotational dynamics (Kinchin 2012).

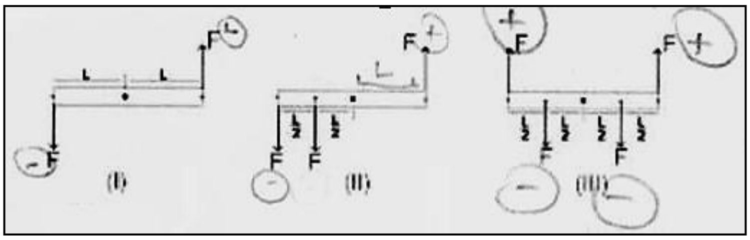

Figure 2. Students' Concept acquisition about Torque

Force on a translational motion that will make an object move in the same direction with the directions of force, students assumed the same effect of force on rotational dynamics. Mashood and Singh (2015) revealed that the difficulties faced by students in rotational dynamics are due to its connection with the translational motion so that the students are confused and show the effect of force on a translational motion. On a translational motion, an object moves in the same direction direction with the force or the resultant force, and an object can be treated as a particle when linked with a free-body diagram. If an object is considered as a particle, its rotational effect will be neglected. In other words, a force given to an object that is regarded as a particle only can affect its translational motion (Puri, 1999; Etkina et al., 2006; Ayesh et al., 2010). Based on the learning on rolling motion supported by a free-body diagram, Carvalho and Sousa (2005) concluded that students still assume an object as a particle on the rotational dynamics.

The motion of a rigid body do not only depend on the force and direction of force but also on the position of force acting on an object or system. A force heading upward (to the positive y-axis) or downward (to the negative y-axis) could results in a counter-clockwise rotation (positive), or a clockwise rotation (negative) depends on the position of force towards the rotation axis. When an applied force faces upward, an object will have a clockwise orientation if the force is acting on the left of the rotation axis, and an object will have a counter-clockwise rotation if the force is acting on the right of the rotation axis. Students also directly determine the rotational motion of an object based on force without firstly using the concept of torque. The students are not aware that it is not only force that determines the rotational motion of an object, but also the position vector. Through demonstration and interview, Rimoldini and Singh (2005) presented that students describe the rotational motion directly based on the acting force in a system without considering the concept of torque.

It can be seen that students still have difficulty indistinguishing between the concepts of force and torque. The same conclusion was also drawn by Carvalho and Sousa (2005) when teaching the effect of friction on the rotational motion of an object, and by Ortiz (2005) regarding the force and torque in a system of equilibrium. Students had difficulties in explaining the effect of force on a rotational motion. They neglect the position vector when they explain about the rotational motion and tend to assume that the concepts of force and torque are similar (Rimoldini & Singh, 2005). It was possible since the students still have a misconception about translational motion, i.e. the resultant force depends on the mass and direction of the force without considering the position vector.

Moment of Inertia

The inertia of an object in a translational motion is shown by its mass, while the inertia of an object on rotational dynamics is demonstrated by the moment of inertia. Moment of inertia is an integral part of the material of rotational dynamics (Kladivova & Mucha 2014; Leyvraz, 2015). Learning through interactive demonstration supported by a free-body diagram aims to reveal the effects of mass, mass distribution, and the rotation axis on the moment of inertia. Such three factors determine the moment of inertia. Some students faces difficulties when they try to explain those effects on the moment of inertia. Kladivova & Mucha (2014) revealed that students have problems regarding with the physical concept of moment of inertia. They have three common difficulties related to the idea of the moment of inertia. First, some of them do not know that the moment of inertia of an object is not only affected by its mass but also the mass distribution. Rimoldini and Singh (2005) also showed that students are not aware that the concept of moment of inertia is the function of mass distribution. Second, students do not have the knowledge that the selection of a rotation axis will also influence the moment of inertia of an object. Third, students assume that the moment of inertia is affected by the angular acceleration. Several students also stated that the larger the radius of an object, the more difficult it would be to rotate it. However, they chose an answer showing that a small radius shows a large moment of inertia or they concluded that moment of inertia is the level of an object's rotational ability (on the contrary with the level of inertia). Such answer is categorized in the 3rd pattern of answers, namely wrong answers with appropriate explanations with the concept in the question.

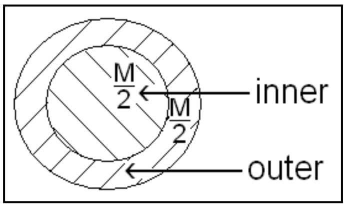

Figure 3. Students' Concept acquisition about Moment of Inertia

The difficulties faced by the students were due to the concept of mass as a contributing factor in inertia of an object still strongly used by the students, and they neglected the effect of mass distribution on an object's inertia in rotational dynamics. Based on problem shown in Figure 3, only 4 students (16 % of the students with a correct answer) who could provide the appropriate explanation or whose answers are categorized to have the 6th pattern before intervention and there were 10 students (66.67 % of the students with a correct answer) whose answers are classified to have the 6th pattern after intervention. Also, some students have not clearly understood about how a rotation axis could become a contributing factor in the moment of inertia of an object. It is shown by the small number of students who correctly answered a simple question that shows the variables affecting the moment of inertia.

Newton's Law of Rotational Dynamics

A problem about the angular acceleration of an object and its relation with torque and moment of inertia is governed by Newton's law of rotation. Most of the students gave correct answer accompanied by logical explanations for such problem before the intervention (the 5th pattern of the answer), and provided the right answer with the more conceptual explanations after the treatment (the 6th pattern of the answer). Three different diagrams of force (free-body diagrams) were given on such problem. The student was required to determine the appropriate sequence from the highest until the lowest angular acceleration based on the diagrams. The three objects in the diagrams have a similar moment of inertia. It turned out that the student was only asked to present the effect of torque on the angular acceleration of each diagram. Based on Figure 4, the student answered correctly both before and after the intervention. However, the explanations were different. Before the intervention, such student's explanation was "*the position of the applied force on number II is very potential to rotate fast*." Such explanation showed that he could predict the resulting event of diagram II. He determined that diagram II would rotate the fastest. However, he could not provide any conceptual ideas to support his answer so that he only said that diagram II is "*very potential*" to move faster. The expression of "*very potential*" is somewhat confusing, but the student intended to give his answer about the rotational dynamics of the object in diagram II that was the fastest one. An intervention was essential to build a better conceptual understanding. Ortiz et al. (2005) pointed out that the concept of rotational Newton's law should be given more attention and its related to the translational Newton's law.

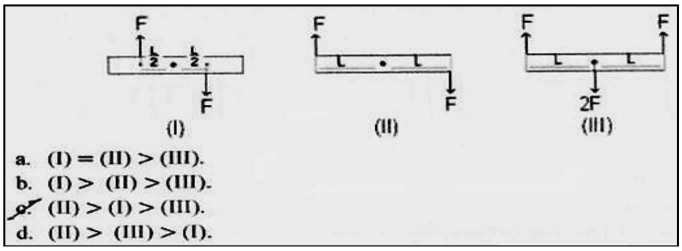

Figure 4. Students' Conceptual Understanding about angular acceleration

After the intervention, the student chose the same answer, but by providing a more conceptual reason than before the intervention. He mentioned that "*the amount of the applied force will affect the angular acceleration since it is far from the fulcrum*." Before the intervention, he did not know about the effect of the applied force distance on the fulcrum (position vector) so that he could only provide an explanation based on his reasoning. However, after the intervention, he could support his answer with a more conceptual explanationfor the effect of the position vector to the rotational motion of an object (angular acceleration of an object). Prior to the intervention, the student answered based on his intuition and give a logical reason. The student compared the three diagrams and the second force diagram was chosen as a diagram that shows the fastest rotation. After the intervention, the student had known about the effect of position vector to the rotational motion shown by the amount of the angular acceleration. During the learning process, such student could make predictions about the effect of distance on the rotational motions of the objects with a similar condition of the moment of inertia for each prediction. The student explained that "*the objects will rotate when the force is acting on points with a certain distance from the rotation axis, and the object will not rotate when the acting force is heading to the rotation axis.*" The student also stated that a force acting on the farthest point from point of rotation would rotate faster as shown in Figure 5.

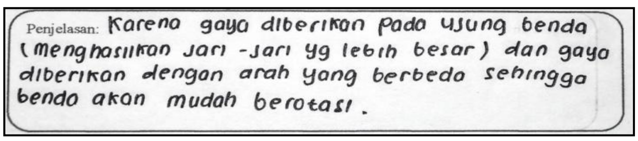	Explanation: Because of force in the farthest point from axis of rotation (with bigger radius) dan force is given in different direction, so the object will move faster.

Figure 5. Students' Conceptual Understanding about force in rotational motion

It showed that the interactive demonstration supported by free-body diagram affects the students' concept acquisition. Ortiz et al. (2005) concluded that lecture demonstration also has an impact on students' concept understanding when utilized in learning rotational dynamics. Even though it could improve students' conceptual understanding, there were some difficulties faced by the students related to the moment of inertia and angular acceleration in Newton's law of rotational dynamics. In rotational dynamics, if torque is increase, the moment of inertia of rigid body will not change, but angular acceleration will be increase. At the end of the discussions of torque, moment of inertia, and their relationships with the Newton's law of rotational dynamics would be discussed, the students had difficulties in determining the constant variable in Newton's law for rotational dynamics. It was because of the difficulties faced by the students in distinguishing the concepts of torque and force that had been discussed previously. Such facts strongly affected students' understanding about Newton's law of rotational dynamics. Close et al. (2013) pointed out that students still have a strong conception of the Newton's law of translational motion. Students also have problems when linking the concept of torque to the moment of inertia. It also showed by Mashood and Singh (2012) that students' difficulties when linking the rotational quantity with torque.

Conclusion

Based on the students' answers to the multiple-choice questions, there were found 6 patterns of answers. Such patterns are divided into three correct answer patterns and three incorrect answer patterns. In general, an intervention in the form of interactive demonstration supported by free-body diagram can improve students' concept acquisition. It was evidenced by an improvement in the percentage of the 6th answer pattern after the intervention. However, there were some difficulties faced by the students regarding the concept of rotational dynamics as follow:

1. The students were troubled when determining the concept of rotational dynamics in a complex system,
2. The students had a tendency to assume that the force facing upward always has a positive torque and vice versa,
3. The students were already aware that the moment of inertia of an object is affected by its mass and radius, but it is hard for them to summarize such effect,
4. The students had a complication in determining the constant and changing variables on Newton's second law of rotational dynamics when there is torque.

Based on the findings of this research, some students have difficulties when learning rotational dynamics regarding torque, amoment of inertia, and Newton's law of rotational dynamics. It is expected that further research can identify the students' misconceptions about rotational dynamics by using open-ended questions or multiple-choice questions, such as isomorphic questions.

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