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ANALYSIS OF STUDENTS' DIFFICULTIES ABOUT ROTATIONAL DYNAMICS BASED ON RESOURCE THEORY

I. Rahmawati[1]*, Sutopo[2], S. Zulaikah[2]

[1]Postgraduate Physics Education, Universitas Negeri Malang, Indonesia
[2]Physics Department, Universitas Negeri Malang, Indonesia

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ABSTRACT

Students' difficulties commonly are analyzed based on misconception theory. This paper aimed to analyze students' difficulties on the rotational dynamic based on resource theory. The subject of research consisted of 108 first-year undergraduate students of Physics Education, State University of Malang. Firstly, the students were asked to solve 15 multiple-choice questions and gave open explanation. We then implemented a constant comparative method to identify and categorize some resources that students employed in solving several problems that most the students failed to respond correctly. The results indicated that the students had difficulties in solving problems related to the torque and the equilibrium of rigid body. The students' difficulties were not merely caused by the lack of correct knowledge. Instead, they have the correct knowledge or resources but they activated them on inappropriate context. The students will be successfully used the resources to solve problems if they activated them in the right context.

Keywords: students' difficulties; rotational dynamics; resource theory

INTRODUCTION

Understanding fundamental concepts and the relationship between concepts, and able to use the concepts to solve problems are ones of objectives to be achieved by students in learning physics. However, many students have difficulty in understanding and applying physics concepts to solve the problems (Demirci 2008; Gracia et al., 2008; 2010; Nguyen & Rebello, 2011; Maries & Singh, 2016; Bollen et al., 2016). Students difficulties to solve physics problems can be explained using two different viewpoints; they are misconceptions and resource theory (Docktor & Mestre, 2014). According to the misconceptions theory, students failure in solving a problem is caused by the students' knowledge that is irrelevant to the scientific concept called misconception (Clement, 1982; Khazanov, 2010; Leinonen, 2013; Widarti et al., 2016). Misconceptions are difficult to change (Berek et al., 2016; Wijaya et al., 2016; Docktor & Mestre, 2014), consistently used to solve several problems presented in various contexts (McDermott, 2001; Sabo et al., 2016), and need a great effort to replace them with the appropriate knowledge that in line with the scientific concept (Sencar & Erylmaz, 2004).

On the other hand, resource theory suggests that students who fail in solving a problem do not necessarily hold incorrect knowledge or resources. However, in fact, they might have right knowledge, but they fail to activate the knowledge in the right context (Hammer, 2000). It is because their knowledge is still in pieces, and tend to be activated in a certain context (DiSessa et al., 1998). For example, two stones of the same shape but different mass dropped from the same height

***Alamat korespondensi:**
E-mail: irmarahmawati531@gmail.com

at the same time, which one will first reach the ground? Students might answer that the rock with greater mass will reaches the ground first. In this context, students activate the resource that heavy objects fall faster than light objects. Students answer is incorrect, but the resource is correct. The resource is right if it is activated in the context of a rock and a piece of paper are dropped together from the same altitude and the air friction can not be neglected.

Based on the illustration, the resources that students activated are not merely wrong or irrelevant to the scientific concept. But it could be right if it is activated in the right context. In other words, the activated resource is highly dependent on the context (Hammer, 2000; Docktor & Mestre, 2014).

Unlike the misconception theory that only looks at the pattern of understanding which is not in accordance with the scientific concept (Sabo et al, 2016), the resource theory considers more on all resources that are activated to develop or build the concept that is in accordance with the scientific concept (Hammer, 2000; Jeličić et al., 2017) .Therefore, the view of resource theory give more in-depth explanation related to knowledge that is owned and activated by the students when troubleshooting.

Rotational dynamics is an important topic in physics. This material is classified as complex because it assesses the rotational motion and the cause of the motion and it is elusive for students (Lopez, 2003; Phommarach, 2012). Several studies have revealed students difficulty to understand rotational dynamics (Ortiz et al, 2005; Rimoldini and Singh, 2005; Unsal, 2011; Mashood and Sigh, 2012; Close et al, 2013; Ambrosis et al, 2015; Khasanah et al, 2016; Rahmawati et al, 2016). Students difficulties that were revealed by Rimoldini & Singh (2005) and Rahmawati et al. (2016), are including 1) distinguishing the amount of speed at some points on the wheel that rolls without slip, 2) distinguishing between torque and force, 3) interpreting the relation of net torque and the angular acceleration. Ortiz et al. (2005) also found out that students experienced difficulties regarding 1) distinguishing between torque and force, and, 2) interpreting the definition of torque $\vec{\tau} \equiv \vec{r} \times \vec{F}$ primarily determining the practical vector point of force towards a particular axis ($\vec{r}$). Mashood & Singh (2012) found out that students had difficulties in determining the speed and direction of the angular acceleration of the pendulum swinging. Students also believed that the direction of the vector $\vec{\omega}$ and $\vec{\alpha}$ are in the direction of motion of a body.

While many researchers had already revealed student's difficulties in understanding rotational dynamics, but so far not many of them that revealed the cause of the difficulties. This article is focused on identifying the student's difficulties in understanding the rotational dynamics material observed by the resource theory.

METHODS

This study used the descriptive qualitative method to reveal the difficulties and resources which were activated when the students solved problems related to the rotational dynamics. The subjects of this study consisted of 108 first-year undergraduate Physics Education students of Malang State University who had learned rotational dynamic concepts in an academic year of 2016/2017.

The data were obtained from the student's responses when answering 15 multiple-choice questions and explaining their arguments. The sub-material that were presented in are rotational kinematics (Question 1-5), torque (Question 6-9), rolling motion (Questions 13 and 14), the angular momentum (Question 10-12), and equilibrium rigid body (15). However, this article only analyzed sub-materials that were elusive for students.

From the 15 questions that were tested, it was obtained two problems with the lowest percentage of correct answers which is the question number 9 (17.4% of subjects) and number 15 (17.4%). The low percentage of correct answers show that the problems were difficult to solve by students so that they need the more in-depth discussion of the student's difficulties regarding resource theory. Furthermore, the analysis of students' wrong answers on numbers 9 and 15 is conducted. In the first phase, the students' wrong answers were grouped according to the option they chose. Secondly, students' reasons were inventoried from each group of choices; then they were grouped into several categories of resources which were activated by students using the constant comparative method (Luehmann, 2009; Middendorf & McNary, 2011; Anderson & Wall, 2015; Demirdogen, 2016). Interviews were also conducted to deepen further the students' reasons in answering the questions.

RESULTS AND DISCUSSION

The question number 9 access students' ability to determine the direction of torque produced by the gravity of a wheel against a particular axis. The question used in the tests can be

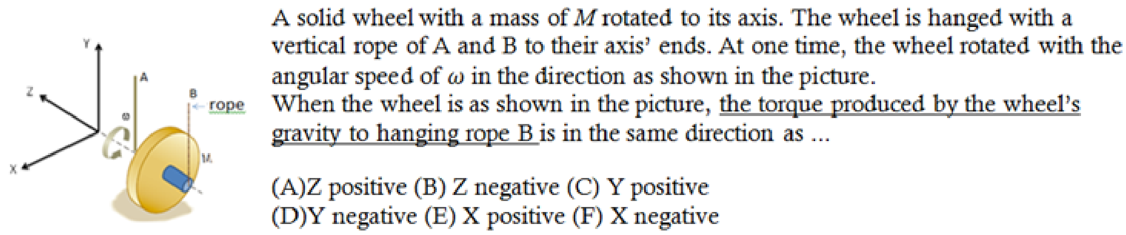


Figure 1. Question Number 9 on The Test

seen in Figure 1.

To successfully solve the problem, the students should be able to activate multiple resources properly as follows: 1) the definition of torque is $\vec{\tau} \equiv \vec{r} \times \vec{F}$ and apply it to the torque by gravity $\vec{\tau}=\vec{r} \times \vec{w}$ with $\vec{r}$ as position vectors of the gravity working point (positive direction of the Z-axis) and $\vec{w}$ as gravity vector (negative direction of the Y-axis), 2) the center of gravity concept and apply it to determine the position of the center of gravity wheel (i.e. in the middle of the axle), 3) The rotary axis to which gravity provided the torque (same as the direction of the rope B in accordance to the question), 4) determines the direction of the cross product result $\vec{\tau} = \vec{r} \times \vec{w}$ (because $\vec{r}$ towards Z positive and $\vec{w}$ to Y negative thus $\vec{\tau}$ directed to X positive axis) as shown in Figure 2 or may follow the right-hand rule.

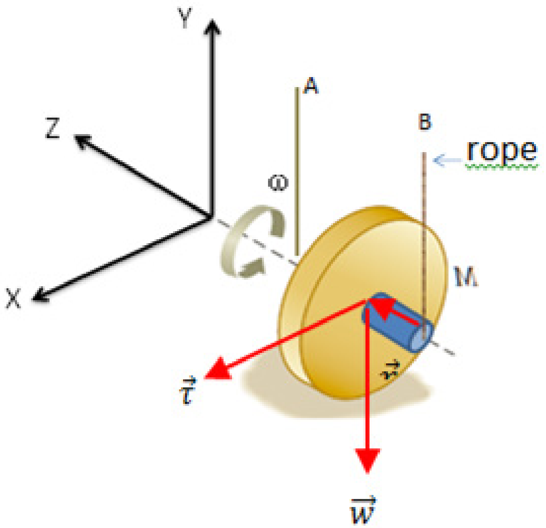


Figure 2. The Torque's Direction Produced by Wheel's Weight

The students who answered the question correctly had successfully activated and assembled some of these resources. The other students chose the wrong answers by activating some resources as distributed in Table 1. The students thinking, and resources that were activated in selecting the wrong answers are described as follows.

A total of 29.6% of the students chose B that the direction of the torque produced by the wheel's gravity of a hanging rope B is in the direction of the Z negative axis. Those who chose this answer have arguments that were grouped into two categories as shown in Table 1. The students who chose answer B category 1 thought that the torque is the cause of the rotating object. The direction of torque determine the rotation direction, and the magnitude of torque determine the magnitude of the angular velocity. So, the magnitude and direction of the torque are proportional to the magnitude and direction of the angular velocity. By using the right-hand rule, when the wheel rotate counter clockwise then $\vec{\omega}$ to the Z negative so that the direction of $\vec{\tau}$ is also to the Z negative Z.

Based on the thinking above, it can be identified the resources that had been activated by students in choosing answer B category 1. First, students had been able to determine the direction of $\vec{\omega}$ with the right-hand rule so that it is obtained $\vec{\omega}$ is in the direction of Z negative axis. The activated resources are the right knowledge. However, they are inappropriate if activated in the context of the questions asked. Second, students activated that $\vec{\tau}$ is the cause of a rotating object. The direction of $\vec{\tau}$ determine the rotation direction, and the magnitude of $\vec{\tau}$ determine the magnitude of $\vec{\omega}$. So, the magnitude and direction of τ are proportional to the magnitude and direction of $\vec{\omega}$. This resource is the wrong knowledge. The resource is built from the first experience in studying the torque which is when pushing or pulling the door until the door opened and closed. The direction of the door rotation depend on the direction of the force. The door rotation speed depend on the strength of the given push or pull and the location of the working point of the push or pull force. Having introduced the concept of torque; concerning the events of opening and closing the door, the students built the knowledge of phenomenological "torque is the cause of rotating object; the magnitude and direction of the torque determine the magnitude and direction of the object's rotation speed or $\vec{\omega} \sim \vec{\tau}$." This

Table 1. The Wrong Answers Distribution and Resources that Activated to Solve Question Number 9

Answer Choices	The Number of Students	Resources that were Activated by the Students
A	16 (14.8%)	Unclear
B	32 (29.6%)	1 $\vec{\tau}$ as the cause of the rotating object. The direction of $\vec{\tau}$ determine the direction of rotation and the magnitude of $\vec{\tau}$ determine the magnitude of $\vec{\omega}$. So, the magnitude and direction of $\vec{\tau}$ are proportional to the magnitude and direction of $\vec{\omega}$. The direction of $\vec{\omega}$ determined by the right-hand rule. Since the wheels are rotating counter clockwise, then $\vec{\omega}$ in the Z negative direction. Because the direction of $\vec{\tau}$ is the same with $\vec{\omega}$, then $\vec{\tau}$ in Z negative direction.
		2 $\vec{\tau}$ is the cause of the rotation speed change according to the relation of $\sum\vec{\tau}=I\vec{\alpha}$. The direction of $\vec{\alpha}$ is the same with $\vec{\omega}$ because it is accelerated. The direction of $\vec{\omega}$ determined by the right-hand rule. Since the wheels are rotating counter clockwise, then $\vec{\omega}$ in the Z negative direction so that the direction $\vec{\tau}$ in the Z negative.
C	20 (18.5%)	There is always a torque in a rotating object. Force generates torque on a rotating object. The torque is associated with the force, the direction of torque is the same with the force on the wheel which is the tension straps.
D	12 (11.1%)	There is always a torque in a rotating object. Force generates the torque on a rotating object. The torque is associated with the force, the direction of torque is the same with the force on the wheel which is the wheel's gravity $\vec{W}$
F	7(6.5%)	Unclear

knowledge is included in the category of p-prime because it was built without sufficient abstraction (DiSessa, 1993; Hammer, 1996). In constructing the knowledge, the students did not pay attention to the beginning of the movement of the door before affected to torque, that was at rest. If the students were watching it, then the rotation speed was not of concern, but the rotation speed changes.

The students who chose answer B category 2 argued that the torque is the cause of change in the rotation speed according to the relation of $\sum\vec{\tau}=I\vec{\alpha}$. The direction of $\vec{\alpha}$ is the same as the direction of $\vec{\omega}$ because they perceived that the wheel was idle at first to move at the speed of ω or accelerated. The direction of $\vec{\omega}$ determined by the right-hand rule. Since the wheel is rotating counterclockwise, then $\vec{\omega}$ to the Z negative direction so that the direction of $\vec{\tau}$ is also in the Z negative.

The students who chose answer B category 2 activated resources that are more sophisticated than students who chose answer B category 1. First, because they paid attention to the initial state of the door which was idle, so that the activated resource "the torque is the cause of rotation speed changes according to the relation of $\sum\vec{\tau}=I\vec{\alpha}$." Second, they activated that the direction of α is the same with $\vec{\omega}$ because they perceived that the wheel was idle at first then it moved at the speed of $\vec{\omega}$ or accelerated. Third, the direction of $\vec{\omega}$ is determined by the right-hand rule. The three resources which were activated are all the right knowledge and will be successfully used to solve the problem in the context of a spinning wheel to the axis through the axle. However, because the question asked about the torque generated by the gravity of the hanging rope B, then the concept of torque which is activated should be the torque generated by each force that worked on the wheel, not the resultant torque according to the relation of $\sum\vec{\tau}=I\vec{\alpha}$.

Based on the written arguments on the answer sheet and from interview, the students who chose answer B category 2 had two correct resources torque-related, they are $\vec{\tau}\equiv\vec{r}\times\vec{F}$ and $\sum\vec{\tau}=I\vec{\alpha}$. However, resource $\sum\vec{\tau}=I\vec{\alpha}$ is more dominant and easily activated to solve question number 9, because, in the question, it is presented that $\vec{\omega}$ is considered to be more related to $\vec{\alpha}$. It indicated that resources which activated by students relied heavily on the dominant context in the question (Hammer, 2000; Docktor & Mestre, 2014).

Students who chose answer C (18.5%) and D (11.1%) were both activated the resource that there is always a torque on rotating object. The torque generated by the force which works on a rotating object. Therefore, students in this group associated torque with force and found out that the direction of the torque is the same as the working force on the wheel. The activated resource was the correct knowledge. Nevertheless, this activated resource is not enough to solve the question number 9.

The students who chose answer C only recognized the tension rope that worked on the wheel as shown in the figure in the question. Because the rope tension working on the wheel is in the direction of the Y positive axis, and the direction of the torque is the same as the force, then the torque's direction is also to the Y positive. This reasoning showed that the students had difficulties in analyzing other objects which interacted with the wheel, so they did not succeed in identifying the forces that worked on the system (Savinainen et al., 2013; Aviani et al., 2015). Meanwhile the students who chose answer D had been able to identify the direction of gravity, which produced the torque to the axis of hanging rope B. But because the resource of torque is the cause of objects' rotation and generated by the force that was working on a rotating object was activated, without being followed by the activation of a resource that defines the torque as $\vec{\tau} \equiv \vec{r} \times \vec{F}$, then it is obtained a false claim that the torque is in the same direction of the force.

Based on the students thinking above and confirmed in interview, it was found that the students have had the correct resources to be used to solve question number 9. Their resources are 1) there is always a torque in rotating objects, 2) the torque is generated by the forces working on rotating objects, 3) $\vec{\tau} \equiv \vec{r} \times \vec{F}$. However, the concept of the force that they have is more dominant than the concept of torque, so the concept of force is activated more quickly to resolve the problem in question number 9. It showed that the students' resources had not been coupled coherently so that the less dominant resource will be delayed to activate than the more dominant resource (Hammer, 2000).

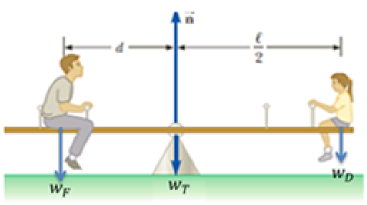
The question number 15 access students' ability in determining the torque equation to a particular axis when the system is in a static equilibrium state. The tested question can be seen in Figure 3.

To solve the question correctly, students should be able to activate the following resources: 1) the requirements of static equilibrium system are $\sum\vec{\tau}=0$ and $\sum\vec{F}=0$, 2) the definition of torque is $\vec{\tau} \equiv \vec{r} \times \vec{F}$, 3) the rotary axis can pass through or outside of the body. If all of these resources are correctly activated, then the equation (A) met $\sum\vec{\tau}=0$ with the vertical axis passing through seesaw's fulcrum. The equation (B) also met $\sum\vec{\tau}=0$ with the vertical axis passing through the Father. Likewise, the equation (C) met $\sum\vec{\tau}=0$ with the vertical axis passing through the Daughter. While equation (D) is not correct because the equilibrium condition $\sum\vec{F}_y=0$ obtained $\vec{n}=\vec{w}_T+\vec{w}_F+\vec{w}_D$. Thus the most appropriate answer is (F).

Only 17.4% of the students chose the correct answer. Others chose the answer with some resources that were activated as shown in Table 2. The students activated thought and resource that chose the wrong answer is described as follows.

A total of 43.5% students chose answer A thought that on the balanced seesaw, the spin axis always lied at the fulcrum. The balanced seesaw meant fulfilling the equation $\sum\vec{\tau}=0$. Each torque generated by force is defined as $\vec{\tau} \equiv \vec{r} \times \vec{F}$ so that it is obtained that equation $w_F \times d = w_D \times \frac{\ell}{2}$ is a correct equation in describing the state of the seesaw. In the context of this question, the students had managed to activate some of the resources, which are: 1) the requirements of a static equilibrium system is $\sum\vec{\tau}=0$, 2) the definition of the torque is $\vec{\tau} \equiv \vec{r} \times \vec{F}$, 3) the spin axis passing through the fulcrum. The resource that has been activated is a correct knowledge and will be appropriately used to solve the question with the spin axis at the fulcrum. The students in this group only activated resource with just one spin axis at the

Look at the force diagram that worked on a seesaw that was played by the Daughter and Father in the picture. If it is in the balanced state, which of the following equation that is appropriate to the picture?



(A) $w_F \times d = w_D \times \frac{\ell}{2}$

(B) $n \times d = w_T \times d + w_D \times (d + \frac{\ell}{2})$

(C) $n \times \frac{\ell}{2} = w_T \times \frac{\ell}{2} + w_F \times (d + \frac{\ell}{2})$

(D) $n = w_T$

(E) All choices (A) to (D) is correct

(F) All choices (A) to (C) is correct

Figure 3. Question Number 15 on the Test

Table 2. The Wrong Answers Distribution and Students Resource in Solving Question Number 15

Answer Options	The Number of the Students	Students Activated Resource
A	47 (43.5%)	The spin axis is always located in the fulcrum The requirement for equilibrium is $\sum\vec{\tau}=0$ $\vec{\tau}\equiv\vec{r}\times\vec{F}$
B	5 (4.6%)	Unclear
C	2 (1.9%)	Unclear
D	(10.2%)	Unclear
E	23 (21.3%)	The requirement for equilibrium are $\sum\vec{\tau}=0$ and $\sum\vec{F}=0$ $\vec{\tau}\equiv\vec{r}\times\vec{F}$ $\sum F=0$, $n-w_T=0$, $n=w_T$ The spin axis can pass through the Father, Daughter, and fulcrum

fulcrum. When confirmed in the interview, they knew that the spin axis could pass through or outside of the body. However, because the question is presented in the form of a seesaw, they were more quickly activated the resource that the axis is at the fulcrum. It suggested that in addition to the activated students' resource which depended on the context (Sabo et al., 2016), the students' ability to solve problems are often seen the dominant matter presented in the question (Docktor & Mestre, 2014).

The students who chose answer E thought that in the balanced system is applied $\sum\vec{\tau}=0$ and $\sum\vec{F}=0$. The torque generated by each force defined as $\vec{\tau}\equiv\vec{r}\times\vec{F}$. The spin axis can be selected to pass through the Father, the Daughter, and the fulcrum so that referring to the equation $\sum\vec{\tau}=0$ and $\vec{\tau}\equiv\vec{r}\times\vec{F}$, the equations in options A, B, and C are correct. The requirement of translational equilibrium fulfilled the equation of $\sum F=0$ and $n-w_T=0$ or $n=w_T$.

Based on the students thought, they have activated resources in the right context, which are: 1) In an equilibrium system applied the condition of equilibrium $\sum\vec{\tau}=0$ and $\sum\vec{F}=0$, 2) $\vec{\tau}\equiv\vec{r}\times\vec{F}$, 3) the spin axis can pass through the Father, the Daughter, and the fulcrum. However, when applying the translational equilibrium condition of $\sum\vec{F}=0$, students simply activated the forces working on the fulcrum. When confirmed in the interview, they argued that since the seesaw is in an equilibrium state and the axis through the fulcrum, the force on the right side (gravity by Daughter) and the left side (gravity by Father) canceled each other out. Therefore, only two forces that were working, they are w n and w_T, so that by referring to the equation of $\sum\vec{F}=0$, then $n-w_T=0$ or $n=w_T$. This reasoning indicated that the students had all the resources necessary to solve the problems. But the structure of this resource is not coupled coherently (DiSessa et al., 1998).

CONCLUSIONS

The results showed that students had difficulty in solving problem related to the torque and rigid body equilibrium. This difficulty is not caused by their misconception, but the knowledge or resource that they activated was not appropriate in the questions' context. For example, a student failed to determine the direction of the torque generated by the gravity of the hanging rope because he activated the resource of equation $\sum\vec{\tau}=I\vec{\alpha}$. This equation is not wrong, but it was not activated in the proper context. The students have had resource $\vec{\tau}\equiv\vec{r}\times\vec{F}$ and $\sum\vec{\tau}=I\vec{\alpha}$, but resource $\sum\vec{\tau}=I\vec{\alpha}$ is more dominant in students cognitive structure and easily activated to solve the questions. Therefore, the student's resource, which is activated dependently on the context that emerged dominant in the questions.

Based on these findings, in teaching the material of rotational dynamics, it is suggested that the teachers presented a phenomenon or problem that multi-context and multi-representation. It will help students activated and assembled its multiple resources coherently to be applied in the right context.

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