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# STUDENTS' MENTAL MODEL ABOUT NEWTON'S THIRD LAW IN INDONESIA: ANALYSIS AND SUGGESTION TO OVERCOME IT

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## Abstract

The effective learning can be built by comprehending the students' prior knowledge. However, it is rare for teacher to arrange learning based on students' alternative concepts, particularly be related to force and motion concept. Based on those problems, this research aims to describe students' mental model about Newton's Third Law. The method is testing by four essay items about the action-reaction forces. Those items asked students to explain, predict, and evaluate the phenomenon which is related to Newton's Third Law. The sample includes 140 students from 3 provinces in Indonesia, that consist of D.I Yogyakarta, South Borneo, and East Borneo. The results showed that there are many students held diverge mental model about action-reaction forces. The divergences among others are: the greater the mass, the greater the force in collision phenomenon; the resting object can't exert reaction force; the action-reaction forces can be canceling each other. We suggest to integrating modelling cycle to learning process to overcome those mental model and use computer simulation program to generate better concept about Newton's Third Law. We hope these results can be applied by others teachers to construct better learning about Newton's Third Law.


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## INTRODUCTION

Newton's Third Law (NTL) is one of the most fundamental laws in classical mechanics. The Newton's Third Law explain by Halliday *et al* (2005) as "when two bodies interact, the forces on those bodies always come in equal magnitude and opposite direction". This law could explain about interacted forces in microscopic and macroscopic level (O'Leary, 2011; Phelan, 2004). There are many others concepts in physics that related with NTL, such as gravitational, electrical, and magnetostatic forces. Therefore, students need to understand the concept of this law in order to make them easier in mastery the advanced physics (Halloun & Hestenes, 1987).

When a student could understand the causes, effects, or influences of a phenomenon about NTL in right way, it can be sait that he has the correct concept or complete mental model. Mental model is internal representation about reality as result from interaction to environment. (Johnson-Laird, 1980; Greca & Moreira, 2010; Greca & Moreira, 2002). The information about real world could enter our brain by the senses. Then it will be processed in the schemata to create various perception about outside world. By this perception someone could understand, explain, or even predict the behavioral of the world (Greca & Moreira, 2010; Greca & Moreira, 2002; Haili, 2017).

The basic competences in Indonesian educational curriculum which related to force and motion concept is "analysing interaction of forces and relationship between force, mass and linear motion with its application in daily life"(Permendikbud No 20 Tahun 2016). According to the curriculum, the goal of physics learning in senior high school is making students understand how to describe phenomenon in real world by scientific laws. Therefore, learning physics should be designed for involving students to create and use model because scientific activity consist of construct, validate, and apply the scientific model. (Haloun & Hestanes, 1987; Ornek, 2008). By create mental model, students will have personal understanding about the matter that be taught, then they could get the meaningful learning (Greca & Moreira, 2002).

The process to arrange good learning is not easy. A teacher should use pedagogical content knowledge (PCK), that is knowledge about the ways to pack material content in order to be learned in easy way by students (Shulman, 1986). According to it, teachers need to understand the content material, students difficulty in learning the content, their interest and motivation, and also their necessity (Gess-Newsome, 2017; Sarkim, 2015). If the goal is improving students' mental model, then teachers need to assess and identify students' prior mental model and knowledge. By understanding what students have gotten about physics concept that will be learned, a teacher could construct the correct learning scenario, stimuly, the suitable problem stimulans, the appropriate investigation, and the correct evaluation (Dekkers & Thijs, 1998; Kurt & Akdeniz, 2004; Narjaikaew, 2013).

The researchs that related to model, technique, and method of learning about Newton's laws of motion have much been done in Indonesia (Jayanti, 2016; Martono, 2016; Nurcahyo, 2017; Primayoga, 2013; Susanti, 2015; Zulvita, 2017). But it is rare to find research about how students in indonesia comprehend the Newton's laws of motion, especially the third law. There is no research to reveal students' initial model mental in action-reaction concept. Whereas, comprehension what students have understood about a concept and construct the learning based on students' necessity is the success key in physics education (Dekkers & Thijs, 1998; Kurz & Akdeniz, 2004).

According to backgrounds, this research was done to describe students' mental model about Newton third law. The students were asked to explain, predict, and evaluate the concept related with NTL. By these ways, we can get the information about how students understand the link between the concept and the daily life practice (Buaraphan, 2018). In the Result section we describe and categorize the students' mental models based on their answer. Furthermore, we try to analyze and discuss what the cause of its divergences. In the Discussion section, we suggest to use mental modeling process to reconstruct students' mental model. We also recommend two computer simulation programs that can be used to investigate the action-reaction forces concept.

## METHODS

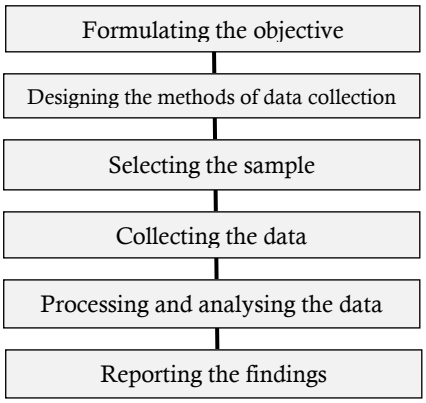


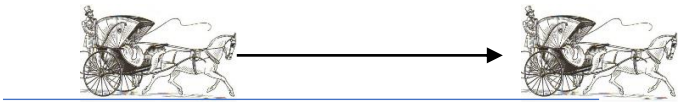

**Figure 1.** Research Design

The design of this research is showed at Figure 1. The research design consist of six stages which are: formulating the objective, designing the methods of data collection, selecting the sample, collecting the data, processing and analysing the data, and reporting the findings (Kothari, 2004)

This study is descriptive research which is concerned to describe students' mental model about Newton's third law. The data was collected by testing. The instrument is four essay items that related to Newton's third law. The essays was choosen because it can describe students' understanding more comprehensive than multiple choice item. The essay items is showed in Table 1.The sample of this research is 140 students of senior high school in D.I Yogyakarta, South Borneo, and East Borneo provinces. Those samples consist of students of grade $10^{th}$ to $12^{th}$ that have been received instruction of Newtons' laws of motion, at least once in junior high school. The students' answers were analyzed qualitatively and reported on percentage by equation (1).

$$p = \frac{number\ of\ revealed\ model}{total\ students} x\ 100\ \% \quad (1)$$

**Table 1.** The items for reveal students' mental model

| No | Item |
|---|---|
| 1 | A horse pulls a cart forward as showed in figure below  a b How can the horse move from point a to point b even the cart also pulls the horse with the equal forces ? |
| 2 | Doni (70 kg) and Andre (55 kg) are sitting face to face on the wheel chair. What will happen if Doni push Andre by his leg ? Explain your analysis by assume the floor is slick.  Doni Andre |

| | |
|---|---|
| 3 | A car (1,5 ton) crash a truck (7 ton) that park on a bridge.<br>  <br><br>The result of the crash is the car flung to the river. However, the truck still on the bridge. Based on that description, is it true if we said that the truck exerts greater force than the car? Explain your reason. |
| 4 | The small car push the big car until they move forward as showed in figure below<br>  <br><br>Is it true if we said the small car push the big car with greater force than the big car push the small car ? Explain your reason ! |

## RESULTS AND DISCUSSION

### Results

The summary of students' mental model on the first item is showed in Table 2. The table shows various students' mental model when be given the first item about a pulled cart by a horse. 74 % from totally samples think that the horse pulls the cart with greater force. Even 41 % samples believe the cart didn't exerts forces at all to the horse because the cart is dead body that stuck to the horse. So wherever the horse move, then the cart will follow it. These mental models is not fit with scientific model about Newton's third law which explain if there is action then there is reaction with same magnitude and opposite direction. Therefore, when the horse pulls the cart with certain force then the cart also pulls the horse with same magnitude of force.

The erroneous learning on concept "same magnitude of forces" and "opposite direction of forces" could cause the divergence to students' mental model. When the given learning only "tell" about "the action-reaction force have same magnitude and direction of it is opposite", whereas the usual example in books is "someone pushes wall; the man and the wall did not move at all", then students could think the third law concept as same as "equilibrium of forces". Then the formed mental model from that misconception is "action-reaction forces is equal forces and direction of it is opposite, then the body which received it will be in equilibrium of forces".

Actually, the concept of action and reaction forces is different with the concept of equilibrium forces. Teachers are seldom to teach that action and reaction forces act on different body, therefore it can't cancelled each other. In the case of a horse pulls a cart, the horse's force acts on the cart and the cart's force acts on the horse. The horse's force cause the cart move forward, while the cart's force impede the motion of the horse. The horse get merit because it has friction force on its foot to against the cart's force. Beside that, the circular shape of cart's wheel also make horse easier to pull it. 14 % samples realize this concept and only 3% samples could understand that action-reaction forces act on different bodies.

The summary of students' mental model on the second item is showed in Table 2. The second item need experiment by imagination, or can be called "thought experiement". 68 % samples argue Andre will move backward and Doni just will stay in his position. It is all because Doni was active and Andre was "just" passive. This mental model also not fit with the agreement of scientist, whereas if Doni pushes Andre with certain force, then Andre will pushes Doni with equal magnitude of force. Then both of them will move backward because of the forces, but their acceleration will be different. 27 % samples realize that the acting body will receive the equal magnitude of forces from the reactioning body, then Andre and Doni will move backward. Even more, only 11 % samples could imagine more

that Andre and Doni will get different acceleration or shift.

The description of students' mental model on the third item can be seen in Table 2. The third item reveal about divergence of samples' mental model. 76 % samples assert that the truck exerts greater force in collision. They said that the truck has greater force than the car because its mass greater than the car's mass. The prove of it is the car flung away from the road. This explanation revealed that samples has mental model like "mass could generate force". In other word, the samples also kept divergence mental model about Newton's second law.

**Table 2.** Description of students' mental model on each essay item.

| Item | Mental Model | Percentage of total samples |
|---|---|---|
| 1 | • The horse pulls the cart with greater force than the cart pulls the horse | 74 % |
| | • The cart can not exert force to the horse | 41 % |
| | • There is friction force between horse's foot and the ground. | 14 % |
| | • There is influence of the cart's wheel in order to make the horse easier to pull it | 14 % |
| | • The action-reaction force between the horse and the cart acts on different bodies | 3 % |
| 2 | • Only Andre will move backward | 68 % |
| | • Only Doni will move backward | 5 % |
| | • Both of Andre and Doni will move backward | 27 % |
| | • Andre and Doni will get different acceleration or shift because the different of their body mass. | 11 % |
| 3 | • The truck exerts greater force than the car because the truck has greater mass | 76 % |
| | • The truck can not exert force to the car because the truck just in idle state. | 12 % |
| | • The car is the one that exerts greater force | 17 % |
| | • The truck is motionless because its inert. | 7 % |
| | • The truk's forces is equal to the car's force in collision | 11 % |
| 4 | • The small car pushes the big car with greater force | 71 % |
| | • The small car can not push the big car because the big car gives greater force | 26 % |
| | • The force between two cars is equal | 3 % |

The Newton's second law often be taught to the students by the equation "F=m.a". That equation very familiar to students because it is one of the earliest equation for them when learning physics. However, teachers should be cafefull in teach that equation because it can be seem correct in mathematically but mistake in physics aspect. The given answer by the samples for the third item reveal that they comprehend the "F=m.a" equation as "the greater the mass, then the greater the force. the smaller the mass, then the smaller the force". It is correct if we consider mathematical aspect only, because if the "m" variable is greater, then its multiplication to the "a" variable will be resulting the greater "F" variable. However, if we consider in physics aspect, this model is wrong. In Newton's second law concept, force is the one to generates acceleration. And the mass, as a part of inertia concept, also has influence to acceleration. Both of force and massa have

influence to acceleration, but they are not directly connected whereas the force can't influence the massa and the mass can't generate the force. Therefore, physics learning should consider the physics concept first, then the mathematical relationship of it later. So, it is better to introduce the equation of Newton's second law as equation (2) below.

$$a = \frac{F}{m} \qquad (2)$$

Seventeen percent of samples believe that the force of the car even greater than the truck because the car in the only one who cause the crash. They said the truck is motionless, so it is impossible for it to exert force to the motion object. In fact, if we go back to the Newton's third law, the truck and the car exert equal force. According to Newton's second law, with equal force and different mass, the car will get greater acceleration than the truck and it make the car flung away. The mass of the truck is greater than the car, so it make the truck more inert than the car and the truck only stay at the bridge when collision occur. 11 % realize the actioan-reaction forces is equal in magnitude and 7 % could explain deeper about inertia of the truck

The description of students' mental model on the fourth item can be seen in Table 2. The variation of revealed mental model from fourth item is fewer than others item. In this case, 71 % samples declare the small car pushes the big car with greater force than the big car pushes the small car. They explain that mass of the small car is less than the big car, so the small one needs greater force to equalize the big one. This answer revealed the samples misunderstand in comprehend action-reaction interaction and inertia concept.

In Newton's first law, the greater the mass then the greater inertia of the body. It needs greater force to push it forward with equal acceleration. This concept can be correct if we only consider "the pushing object" and compare it with its state before. But if we consider about interaction forces between two bodies, the pushed body also exerts same amount of forces as the pushing body. The greater the mass of the big car then the small car needs greater force than before. However, in interaction of action-reaction forces on the contacted surface between two cars, the big car also pushes the small car with equal force. Only 3 % samples realized this concept.

In other side, 26 % of the others samples assert that the small car even can not push the big car forward. It is because the mass of the big car is greater than the small car so the big car will exert greater force. They argue that instead of push the big car forward, the small car will be pushed backward by the big car. This mental model as same as mental model on the third item, which is the samples believe that the mass has direct connection to the force.

**Discussion**

The results showed even the students that have studied Newton's law of motion still held uncompleted mental model. The diverge mental model among others are the action-reaction forces cancelled each other, the rest body can not exert reaction forces, and the greater the mass then the greater the force of it. Therefore, there are some concepts must be noticed by the teachers to arrange better learning. The concepts can be seen at Table 3.

The divergence of mental model is difficult to change (Pfundt & Duit, 1991). Just "telling" students about how two bodies interacted each other is not effective way to construct the better comprehension of Newton's third law (Savinainen & Scott, 2002; Zhou *et al*, 2015). The conceptual change can be occured when the students have opportunity to realize their misconception, then they revise it with their own awareness (Posner, Strike, Hewson, & Gertzog, 1982).

**Table 3.** Concepts of Newton's third law

| No | Concept |
|---|---|
| 1 | The action and reaction forces act on different body |
| 2 | The action and reaction forces can not cancelled each other. |
| 3 | The body that exert action will receive reaction in equal but opposite direction |
| 4 | The influence of action-reaction forces to the bodies with different mass. |
| 5 | The mass has no effect to the magnitude of action-reaction forces |
| 6 | The motion state of a body has no effect to the magnitude of action-reaction forces |
| 7 | It is the forces which cause the acceleration. And it doesn't the mass which generate the forces. |

The students' prior knowledge, alternative concept, of initial mental model has important role in process of construct knowledge. The teachers should consider students' prior knowledge when design the learning (Buaraphan, 2018). The piaget's learning theory explain that learning is done by process of assimilation and accomodation. The assimilation process is occured when the input information adapt to existing structures in brain. In other side, the accomodation is occured when the kognitif structures adapt to input information (van den Berg, 1991).

The students enter the class with fully of preconceptions or mental model about nature and physics. The teachers who didn't realize and utilize it can be fail in teaching (van den Berg, 1991). Therefore, the teacher should take advantage of students' prior knowledge in designing problem, learning activity, and the given information for suit to students' necessity to reconstruct their mental model (Barrett *et al.*, 2013; Buaraphan, 2018; Haili, 2017). Furthermore, teachers can build better conceptual understanding if they use active learning for the students (Hutomo, Parmin, & Khusniati, 2016).

.The process to reconstruct mental model in order to fit with scientific model is called mental modeling. The mental modeling need some stages that called modeling cycle (Figure 2), that consist of explore, create, test, evalulate, and revise (Campbell, Oh, Maughn, Kiriazis, & Zuwallack, 2015). Explore is phase when students' collect and explore every information that related to the object. Create is phase to construct mental model based on gotten information. Test is phase to judge the created mental model. Evaluate is phase to evalute mental model based on the test. And revise is phase to rebuild mental model if there is divergence of it.

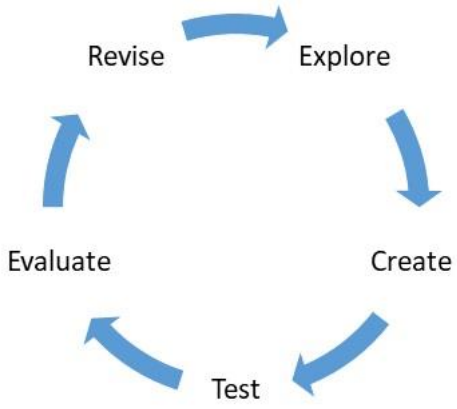


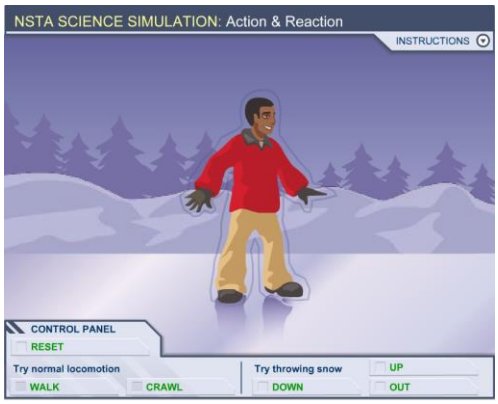

**Figure 2.** Modeling cycle

The scientific learning in 2013 curriculum can be integrated to modeling cycle. Scintific learning in this curriculum based on discovery, inquiry, and problem solving where the students conduct observation and experiment to get the needed data. The learning based inquiry and problem solving is the appropppriate way to rebuild mental model (Stewart, Cartier, & Passmore, 2005). In the process, the students explore, develope, reject, revise, or evaluate their mental model. The students is given problems or tasks that need cause to effect reasoning (make prediction) or effect to cause reasoning (make explanation). By both of reasoning process, the students test and evaluate their mental model based on investigation and it lead to reinforcement or revision model (Buckley, 2012). When students' prediction or explanation has been agreed with scientific model, so it can be said that they have built better mental model (Greca, 2010).

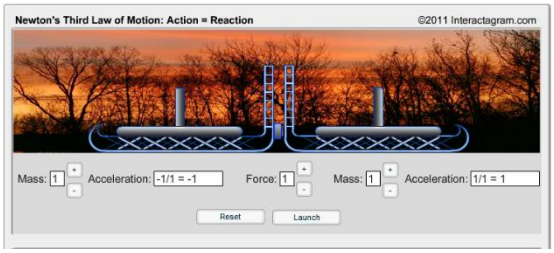
The role of the given problem is very important to assimilate mental model (Redish, 1994). The given should be close to students in order make them easier to imagine it. The process to train students to create mental model can be started in phase by ask them to explain phenomenon (Hailiy, 2017). The training of causal analysis and apllying the use of a concept also can improve mental model and the generated solution is better (Barret, 2013; Hester, 2012). The availability of information also important factor, the more information about the model, the easier for student to create mental model of it (Darabi, 2010). Beside the given problem, the other influencing factor toward the success of scientific learning is the process of investigation. The conducted investigation should generate the usefull concept or data to solve the problem. Consider about Newton's third law concept, so the experimen should prove that action-reaction forces act on different bodies, can not cancelled each other, and the resting body can exert reaction force.

The concepts about action-reaction forces are hard to get by experiment in real laboratorium. To overcome this problem, we suggest to utilize virtual laboratorium by computer. The recommended programs by us to facilitate inquiry activity are throwing program from National Science Teacher Association and Newton's Third Law program from

interactagram. The description of the programs can be seen in Figure 3 below.




(a)




(b)

**Figure 3.** (a) program *throwing*; (b) program *Newton's third law*

The throwing program accomodate simulation of a standing man on the ice layer. The man can be controlled to throw snow up, down, or out. When he throw snow up or down, there is nothing happen. But when he throw the snow out, suddenly he move backward on the ice. This simulation can be used to get concept about action-reaction forces act on different body and the dead body could exert the reaction force. On other side, the interactagram program is related to simulation of two ice carts that connected by springs. When the spring is released, both of carts will move to opposite direction. The mass of the carts can be increased or decreased to see the effect of equal forces can get different effect. The utilization of these programs need to be planned to get optimum modeling process.

Intruducing computer to the classrom can elaborate mental model more effective (Carmichael, 2000). Computer simulation such as virtual laboratory can be used as simplicity of real world, so we can focus to the concept that we want to investigate only (Permana, Widiyatmoko, & Taufiq, 2016). The students can make model to represent the behavioral either real or imaginary object. This process can be integrated to the scientific learning as part of investigation process to generate better learning result (Siswanto, Gumilar, Yusiran, & Trisnowati, 2018). The students can execute virtual experiment which is actually impossible to make it in reality. By virtual world, the model creator has a chance to interact with strange material, ignore the physical aspect, and observe the macrosize or microsize object.

## CONCLUSION

There are many students who kept mental model about Newton's third law which is not fit with scientific model. Those mental models is generated by daily experiences, disinformation, or inappropriate learning by the teachers. To improve mental model, we need to use mental modeling process that integrated to scientific learning. The investigation process to solve the problem is better if use computer simulation because it can present concepts of Newton's third law in ideal form. We hope these results can be applied by others teachers in Indonesia to arrange better learning about Newton's third law

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