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Research Article

The Effectiveness of Modeling Instruction Learning on Students' Conceptual Understanding of Rotational Dynamic

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Abstract

Rotational Dynamics is one of the physics topics which is quite difficult for students. Several previous studies showed students' difficulties on this topic, one of which is the aspect of students' conceptual understanding. Modeling instruction is the effective approach to improve students' understanding. This model is in line with constructivist theory and cognitive model theory. This research aimed to examine the effectiveness of modeling instruction that we developed to improve students' conceptual understanding of rigid body mechanics, where the knowledge of particle mechanics serve as anchor or bridging to develop model of rigid body. This research used mixed method with embedded experimental design. It used one group pretest-posttest design and involved 65 students of a high school in Malang as the subject. Data were gathered using test consisting of 17 multiple-choice items with explanation. The students' scores were analyzed quantitatively using t-test and N-gain to measure the improvement of students' understanding, while the students' reasons were analyzed qualitatively. The results showed the average students' score increased from 1.62 to 9.92 with N-gain of 0.54 (in upper medium category). We concluded that the modeling instruction was effective to improve students' conceptual understanding.

Keywords: *Conceptual Understanding; Modeling Instruction; Rotational Dynamic*

Efektivitas Pembelajaran *Modeling Instruction* Terhadap Pemahaman Konsep Siswa Topik Dinamika Rotasi

Abstrak

Dinamika Rotasi adalah salah satu topik fisika yang cukup sulit untuk siswa. Beberapa penelitian menunjukan permasalahan siswa pada topik ini, salah satunya pada aspek pemahaman konsep siswa. Modeling instruction adalah pendekatan yang efektif meningkatkan pemahaman siswa. Model ini sejalan dengan teori konstruvistik dan teori model kognitif. Penelitian ini bertujuan untuk melihat efektivitas pembelajaran dengan pemodelan (modeling instruction) yang kami kembangkan untuk meningkatkan pemahaman konseptual siswa tentang mekanika benda tegar, di mana pengetahuan tentang mekanika partikel berfungsi sebagai jangkar atau penghubung untuk mengembangkan model benda tegar. Penelitian ini adalah penelitian mixed method dengan desain embedded experimental. Penelitian menggunakan desain one group pretest-postest dan melibatkan 65 siswa sekolah menengah di Malang sebagai subjek. Data dikumpulkan menggunakan tes yang terdiri dari 17 item pilihan ganda dengan *penjelasan. Skor siswa dianalisis secara kuantitatif menggunakan uji-t dan N-gain untuk melihat peningkatan pemahaman siswa, sementara alasan siswa dianalisis secara kualitatif. Hasil penelitian menunjukkan skor rata-rata siswa meningkat dari 1,62 menjadi 9,92 dengan N-gain 0,54 (dalam kategori menengah atas). Kami menyimpulkan bahwa pembelajarn yang kami terapkan efektif untuk meningkatkan pemahaman konseptual siswa.*

Kata Kunci: *Pemahaman Siswa; Modelling Instruction; Dinamika Rotasi*

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I. INTRODUCTION

Conceptual understanding is an important goal of physics learning, so it has been a concern of many researchers since 1970 [1]. Most researches in conceptual understanding concerned with Newtonian mechanics where physical objects are modeled as particles. Some researches develop instruments to access students' understanding [2-7], and some others develop learning methods to improve students understanding [6-9]. Despite of its strong assumption, the particle model can explain well many phenomena of force and motion in daily life, as long as we concern only on translational motion.

For example, research that develops instruments to access students' understanding of FCI *(Force Concept Inventory)* [10] and its discussion [2-5], MDT *(Mechanics Diagnostic Test)*, MBT *(Mechanics Baseline Test)* [11] and FMCE *(The Force and Motion Conceptual Evaluation)* [12], describes the students' understanding [13] and develops learning to improve understanding [6-8]. The particle model is the simplest model in physics. It models the object as a point so that it moves translation. Although it is simple, the particle model can explain many things related to the movement of objects.

Since the movement of objects in nature not only translation but also rotation and vibration to the central mass, the students also need to learn a model in which the objects are not treated as particles. This is useful in providing immediate information to students on the idealization of the particle model and its transition to the real object model. Real object includes objects that do not easily deformed (fluid) and objects that do not change shape (rigid body). Research on the topic of fluids has been widely carried out [14-17]. Meanwhile, research about rigid body has not much been done. In fact, the rigid body model is a model that approaches real objects that are easy to learn. The rigid body model is the result of modifying the particle model by adding rotational motion to the object. Several studies that have been conducted on the topic of rotational dynamics, find some of student's difficulties, such as distinguishing force and torque [18], understanding that the linear velocity in the upper rolling wheel is greater than the lower wheel [19], applying the Law of Conservation of Energy for comparing rolling velocity on an incline, applying the axis parallel theorem to determine the moment of inertia about an axis outside the axis O that through the center

[20], understanding the concept of equilibrium, and drawing force diagram [21].

Students’ understanding can be improved through good learning. Based on constructivist theory, students build their understanding based on experiences [22]. Students’ understanding is saved as memories. The more concept learned, the more memory is stored. Cognitive model theory explains a lot of memory with poor storage can cause memory failed to recall. Good memory will be saved in related group. Active learning will involve students concepts building. This will be maximized if the concept of physics is built using concepts that students already have. This will enable the physics model to become smaller, interrelated, coherent and meaningful. To help students understand the integrity of physics, learning about rigid objects should be built based on concept of particle dynamics.

Several studies have been conducted on the topic of Rotational Dynamics. Rebello and Rebello [19] have developed instruments to access student difficulties and misconceptions. Rahmawati and Sutopo [23] have used computer-aided tutorial programs to improve students’ understanding after learning. Ambrosis et al. [24] applies learning using experiments and simulations on the topic of rolling motion by discussing related important concepts of the influence of static and kinetic friction forces on rolling motion and the role of forces on motion. However, research that applies learning, especially building models based on the concept of particle dynamics by explaining the transition from the particle model to the rigid body model, has not been yet existed. In fact, this is very important in learning, so the physics concepts obtained by students are more coherent and meaningful. This article intends to fill this gap.

Modeling Instruction is one of learning where students are invited to build models based on students' prior understanding. Students indirectly learn the unity of physics concept. This learning can improve student understanding well [25,26]. Modeling Instruction consists of model development and model deployment [26]. Model development is done qualitatively and quantitatively with the help of graphs, diagrams, charts and mathematical formulas. Active student involvement in building models has a positive effect on student understanding. Modeling instruction views physics as a unit consisting of a few interrelated models and can be applied in a broad context. Distinguishing from traditional learning, in modeling instruction learning, physics models are always reviewed and refined when students learn new material, so they naturally can understand the nature of physical concepts well. Students are given experimental experience like scientists, so they realize that science is a process and knowledge is the result of scientific work and science has limits [27]. A few physics model with the link between good physics concepts are in line with the cognitive model theory where a lot of memory will be more meaningful when grouped and interrelated. This is rarely presented in traditional learning.

Several studies applied modeling instruction to overcome problems in learning. Jackson [22] reported that training programs about modeling instruction learning have been conducted to thousands of high school physics teachers in USA. Brewe et al. [25] used modeling instruction in learning at university. While some studies use modeling instruction on specific topics, such as improving the conceptual understanding in parabolic motion [28], in work and energy [29], in heat and temperature [30] and AC and DC electricity [31]. The results showed that modeling instruction had a positive effect on student understanding. However, there is still no studies using modeling instruction learning reported on topic rotational dynamics.

The aim of this study is to determine the effectiveness of modeling instruction teaching on students' understanding. Modeling instruction consisted of model development and model deployment [26]. The construction of the model based on concept $\sum F = m.a$ developed into a rigid body model. The main model developed in the rigid body model is $\sum \tau = I.\alpha$ which consisted of new quantities τ and I.

II. METHOD

The study used a mixed method approach with embedded experimental design. The study was conducted in one of the high schools in Malang, Indonesia, grade XI with 65 research subjects. The data consisted of quantitative and qualitative data. The quantitative data was used to analyze the effect of modeling instruction to students' understanding. Meanwhile, the qualitative data completed and supported the quantitative data. The data was collected using pretest and posttest.

The research steps were: (1) students were given pretest to know students' early understanding, so that it can be obtained the result of pretest score, (2) students were given Modeling Instruction which concerned to the goal of the learning and difficulties to the previous learning. In this stage, it obtained the data in form of voice, video, and observation sheet, (3) students were given posttest to measure the students' understanding after learning, therefore the data of the posttest score can be obtained. Pretest and posttest items consist of 17 conceptual understanding questions with multiple-choice and the reasons. The questions are arranged based on important concepts in rotational dynamics and difficulties found in previous studies. The questions consist of 5 topics discussed in Table 1. Some questions were adopted from several sources [32] and previous studies [33]. Question indicator is explained in Table 1. The scores were analyzed quantitatively and students' reasons were analyzed qualitatively. Student reasonings were used to support quantitative data. The question tested on 225 students with reliability score of 0.76, $r_{bis} = 0{,}45$ the difference of the test is of 0.53 and the difficulty level is of 0.42. Scores on pre-test and post-test were analyzed using the normality test, the *Paired sample t-test,* and the calculated with *N-gain* [34] .

Table 1. Physics Concepts

Topics	Concept	Item Numbers
Torque	Explain the definition of torque	1, 2, 3, 5
	Analyze the direction of rotation	4
Moment of Inertia and Newton's Law	Count moment of inertia	6, 7, 8
	Apply Newton's Law to rotational motion	9, 10
The Law of Conservation of Angular Momentum	Apply the Law of Conservation of Angular Momentum in solving problems	11, 12, 13
Rolling Motion	Explain the definition of rolling motion	14
	Compare the translation speed in rolling motion	15
Equilibrium	Explain the definition of balanced object	16
	Analyze the equilibrium objects using force diagrams	17

III. RESULTS AND DISCUSSION

Descriptive statistics of pre-test, post-test and N-Gain scores are presented in Table 2. As seen, the students' conceptual understanding improved, by showing N-Gain (0.54) or in the upper medium [7]. Whereas, the achievement of students' understanding in each topic is described in Table 3. The improvement of students' understanding in each question is presented in Figure 1. N-Gain in topic of torque (N-Gain = 0.75) and Conservation of Angular Momentum (N-Gain = 0.52) are the higher than other topics.

Table 2. Descriptive Statistics of Pretest and Posttest

Descriptive statistics	Pretest	Posttest	N-Gain
Mean	1.62	9.92	0.54
Standard Deviation	1.13	2.40	.17
Minimum Score	0	3	.13
Maximum Score	6	15	.87

Scale: 1-17

Pre-test and post-test score were analyzed using skewness to determine data distribution. Next, a paired sample t-test was performed. It obtained p = 0.000 (the abbreviation for asymptotic significance) or $p < 0.05$ then there is a significant difference between pretest (before modeling instruction learning) and posttest (after modeling instruction learning). Some previous studies have also found that modelling instruction is effective to improve students' understanding [35].

The highest improvement occurred on torque topic (see Table 3). Students understand the need to modify particle dynamics model. The concept of force on particle dynamics cannot be directly used in the rigid body model, so it is changed to torque τ. Students have been able to explain definition of torque and analyze the direction of objects' rotation. Most students do not have trouble in distinguishing force and torque. It is one of the difficulties presented in previous study [18]. The improvement of students understanding also showed in other topics, such as the moment of inertia and the Conservation of Angular Momentum Law. The understanding about difficulties associated with difficulties in previous studies is very useful to anticipate these difficulties. At posttest, 40 students have been able to apply the parallel axis theorem to calculate the moment of inertia well. It is one of the difficulties in previous study [20]. Posttest and pretest crosstabulation of number 2 is presented in Table 4.

Table 3. Improving Student's Understanding in Each Topic

Topics	Average value		*N-Gain*	Category
	Pretest	*Posttest*		
Torque	0.20	0.80	0.75	High
Moment of Inertia and Newton's Law	0.01	0.50	0.49	Upper Medium
Conservation of Angular Momentum	0.06	0.55	0.52	Upper Medium
Rolling Motion	0.08	0.42	0.37	Lower Medium
Equilibrium	0.12	0.49	0.42	Lower Medium

Scale: 0-1

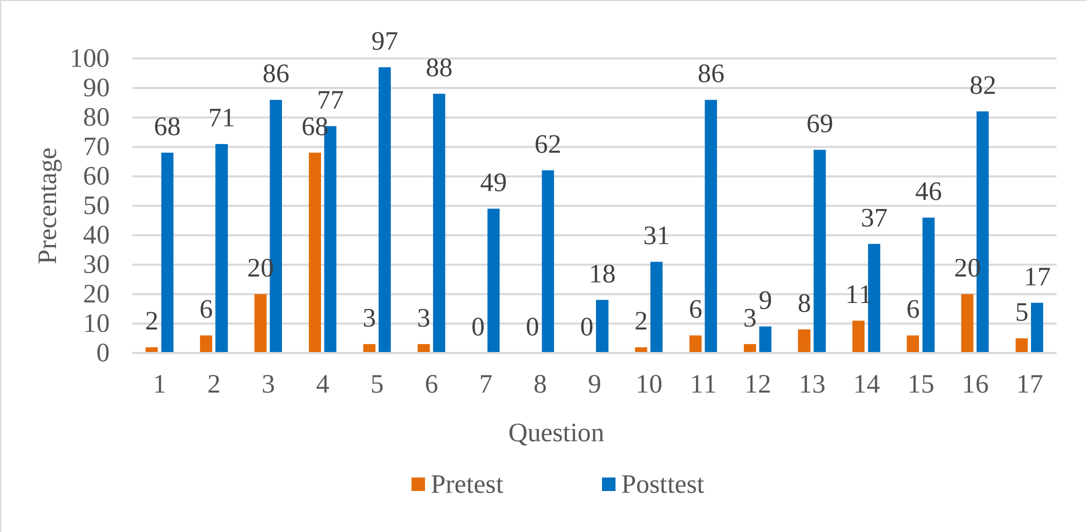


Figure 1. Improving Student's Understanding in Each Question

2. There are some statements about torque:
   (1) A large force always produces a large torque
   (2) A large force never produces a zero-torque
   (3) The position of rotation axis affect torque produced by a force

   The ***true statement*** is …
   A. (1)
   B. (2)
   C. (3)
   D. (1) and (2)
   E. (1) (2) and (3)

Figure 2. Question Number 2

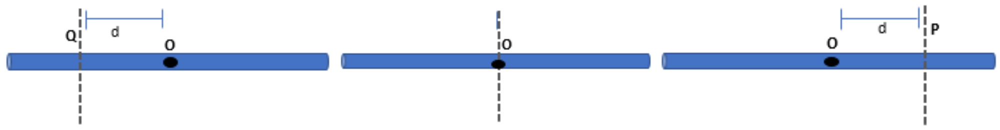
Table 4. Pretest-Posttest Cross Tabulation of Number 2

Pretest	Student Answers During Posttest						Total Pretest
	A	B	C *	D	E	N / A	
A	0	0	2	0	1	0	3
B	0	0	1	0	2	0	3
C *	0	0	2	0	2	0	4
D	0	0	21	0	10	0	31
E	0	0	15	0	1	0	16
N / A	0	0	5	0	3	0	8
Total Posttest	0	0	4 6	0	19	0	65

At the pretest, most students answered incorrectly. It is normal because the students have yet studied about torque. Later, the students' understanding improved significantly. In number 2 (Table 4), students were able to distinguish force and torque. It shows that the result of the research can solve the previous research problems which the students was difficult to distinguish force and torque [18,36]. However, 19 students still answered incorrectly by choosing the answer E. It triggered the students' understanding that force is directly proportional to torque. In fact, a large force does not always produce a large torque. The moment arm also affects the torque.

Another interesting finding in this study is the improvement of students' understanding on some physics concepts such as in calculating the moment of inertia using parallel axis theorem, solving problem using Conservation of Angular Momentum Law and analyzing objects using equilibrium concept.

A cylinder rod with a mass m and a length l rotates with rotation axis through center of mass O has a moment of inertia $I_O = \frac{1}{12}ml^2$. If the rotation axis is shifted d to P or Q, then the large of moment of inertia I_P and I_Q respectively is …



A. $I_P = I_Q = \frac{1}{12}ml^2$

B. $I_P = I_Q = \frac{1}{12}ml^2 + md^2$

C. $I_P = I_Q = \frac{1}{12}ml^2 - md^2$

D. $I_P = \frac{1}{12}ml^2 + md^2$ dan $I_Q = \frac{1}{12}ml^2 - md^2$

E. No correct answer

Figure 3. Question Number 8

Question number 8 is presented in Figure 3. In this question, student was expected to apply the parallel axis theorem to determine moment of inertia in the system when rotation axis shifted to outside of axis that passes through the center of mass. The correct choice is B. Before learning, most students could not answer, this was understandable once again because they had yet learned about this topic. Whereas, 12 students choose D.

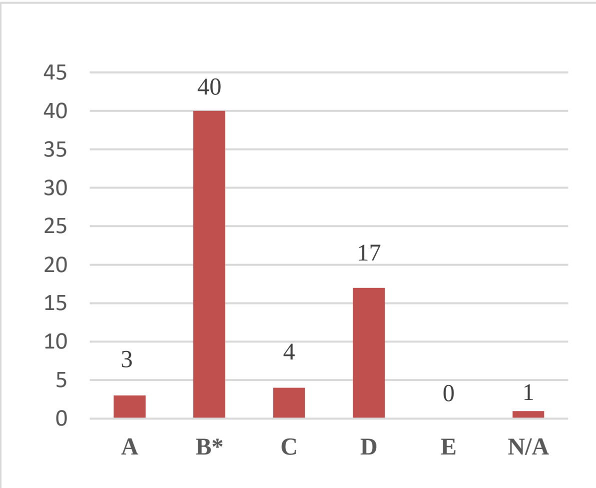


Figure 4. Student Answer During Posttest

Table 5. Pretest-Posttest Cross Tabulation of Number 8

Pretest	Student Answers During Posttest						Total Pretest
	A	B *	C	D	E	N / A	
A	0	1	0	1	0	0	2
B *	0	0	0	0	0	0	0
C	0	2	0	1	0	0	3
D	3	5	1	3	0	0	12
E	0	2	0	0	0	0	2
N / A	0	30	3	12	0	1	46
Total Posttest	3	40	4	17	0	1	65

After modelling instruction learning, number of students who answered correctly increased to 40 students. Students' answer during posttest is presented in Figure 4.

Posttest-Pretest crosstabulation is presented in Table 5. Most students have understood the inertia moment concept well. The learning with model development and active discussion effectively strengthen students' understanding [27]. Students who choose option D assumed that when the axis shifts to the right $I' = I_O + md^2$ and when the axis shifts to the left $I' = I_O - md^2$. This students' improvement was supported by learning in the classroom. Students observed a demonstration that initiates the need to build a moment of inertia model.

Students who answered incorrectly were triggered by the resources before learning, that the right direction is positive in vector quantity and the left direction is negative in vector quantity. Students who answered option A assumed that the magnitude of moment of inertia is the same wherever the axis was. The students who answered incorrectly experienced difficulties in accordance with the research conducted previously by [20] in which students had difficulty in applying the parallel axis theorem to determine the moment of inertia about an axis outside the axis O that through the central mass.

Students' understanding increased significantly on topic of Conservation of Angular Momentum Law. Students' answer during posttest is presented in Figure 5, meanwhile Figure 6 presents questions about Conservation of Angular Momentum Law.

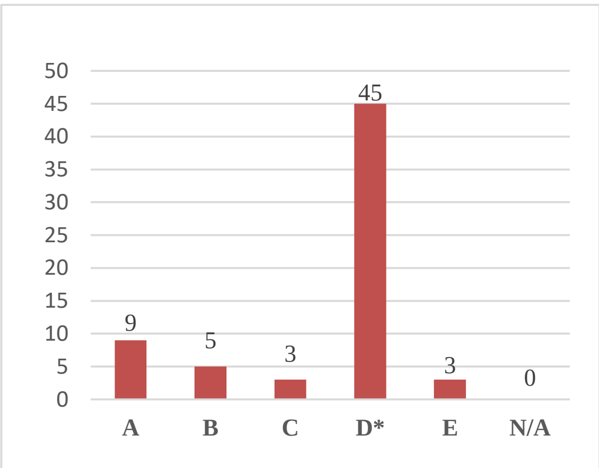
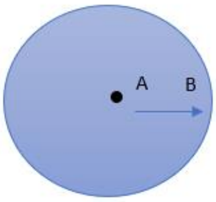


Figure 5. Student Answer During Posttest

Top view



13. A merry-go-round moves with a certain angular velocity. A child on merry-go-round moves from the center (A) to the edge (B). How does it affect to angular speed of merry go round?

A. Remain, because of conservation of angular momentum law

B. Increase, because torque increase

C. Decrease, because friction force decrease

D. Decrease, because moment of inertia

E. No correct answer

Figure 6. Question Number 13

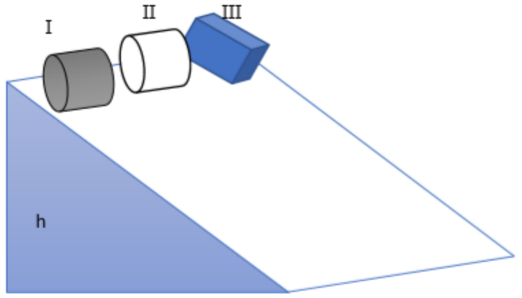
Table 6. Pretest Posttest Cross Tabulation of Number 13

Pretest	Student Answers During Posttest						Total Pretest
	A	B	C	D *	E	N / A	
A	0	2	0	8	0	0	1 0
B	5	2	2	30	0	0	3 9
C	1	0	0	2	0	0	3
D *	2	0	0	2	1	0	5
E	0	0	0	0	0	0	0
N / A	1	1	1	3	2	0	8
Total Posttest	9	5	3	45	3	0	65

Student's Difficulties in Conservation of Energy Law

Students' understanding on Conservation of Energy Law was good enough, but it needs to be improved. In problem number 15 presented in Figure 7, the student was expected to understand Conservation of Mechanical Energy Law in Rotational Motion and to use this concept to compare speeds of various objects in inclined plane. The correct answer is C. Rolling motion which does not work the kinetic friction force, applies the Conservation of Mechanical Energy Law.

However, objects that moves sliding like a beam, also applies Conservation of Mechanical Energy Law. Mechanical energy in solid and hollow cylinders are converted into translational and rotational kinetic energy. The mechanical energy in the beam is only converted into translational kinetic energy, so the translational velocity v on sliding beam in inclined plane is the greatest.



A solid cylinder (I), a hollow cylinder (II) with mass m moves rolling on a slope with a height h and a beam (III) that is lubricated using oil with mass m. It moves on inclined plane with height h. Which is the most immediate object to the bottom of slope? ($Isolid\ cylinder = \frac{1}{2}mr^2, Ihollow\ cylinder = mr^2$)

A. I
B. II
C. III
D. I and II
E. No correct answer

Figure 7. Question Number 15

Table 7. Pretest Posttest Cross Tabulation of Number 15

Pretest	Student Answers During Posttest						Total Pretest
	A	B	C*	D	E	N/A	
A	3	0	4	5	0	0	12
B	15	0	16	1	0	0	32
C*	0	0	4	0	0	0	4
D	0	3	3	1	0	0	7
E	0	0	0	0	0	0	0
N/A	3	2	3	2	0	0	10
Total Posttest	21	5	30	9	0	0	65

At the pre-test, most students chose option B, in which the hollow cylinder has the greatest translational velocity. Students assume that the lighter the object, the smaller the frictional force so the object can roll faster (Table 7).

After modeling instruction learning, students built the physics model of the Conservation of Energy Law in rolling motion. Students who answered correctly increased to 30 students (46%) by choosing C, while the other students (54%) still answered the wrong choice. Student answer during posttest is presented in Figure 8.

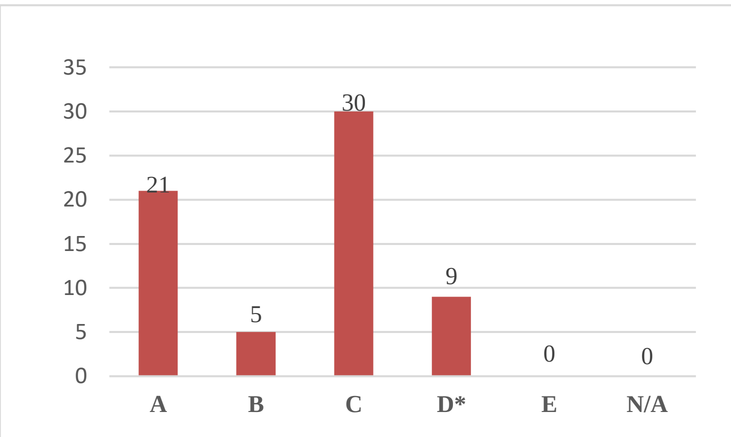


Figure 8. Student Answer During Posttest

The student who answered wrong are triggered by students' thoughts that "hollow cylinders have the lightest mass so it has small frictional force and roll faster" and "solid cylinders have greater mass so the downward force is greater and the rolling motion is faster". However, the assumptions of these students may not always reflect the students' different thoughts.

Some students with the correct answer (choosing C) explain the reason that “the inclined plane is sleek”. Students are still understand that “in the particle model, friction can cause objects to move more slowly”. Thus, the inclined plane will make the beam slide faster. Students who answered correctly with this reason will have difficulty to separate from particle model concept. Whereas, in the rigid body model, the absence of kinetic friction force is a requirement for conservation of energy. In general, students’ understanding has increased in topic of Conservation of Energy Law in rolling motion. Modeling instruction has a positive influence to initiate the need to build a model of the Conservation of Angular Momentum Law.

So, modeling instruction is effective to increase students' understanding on topic of rotation. This is in line with the previous studies [26–30,35,37]. A learning that involved students actively has a positive effect on students’ understanding [38] and self-confidence of the students [39]. A learning is designed using model development based on the concept which the students already have. Modeling instruction always begins with reviewing the previous concept to initiate the needs for a new model. It triggers students’ focus on the fundamental model of physics so that students understand the relationship between one concept to another [26,27]. Students also improved in depicting diagrams. The highest increase is on topic of torque. Students' understanding has also increased significantly on topic of moment of inertia and the Conservation of Angular Momentum Law. The students can distinguish the magnitude of force and torque. This was one of the students’ difficulties in previous study [18,36]. Another finding of the students’ difficulties in previous research was the difficulty in applying the concept of moment of inertia, parallel axis theorem and the Conservation of Angular Momentum Law [18–20,24]. The results showed that the students had a significant improvement in these topics.

However, some students still had difficulties in applying Conservation of Energy Law in rolling motion. Students’ difficulties were caused by students' reasoning that came from concepts that they build themselves based on their experiences [1,40]. Students had difficulty in using their understanding in physics to solve problems and students use their resources in unsuitable contexts.

This research has limitation, in which the N-Gain needs to be improved. Further research can do some improvement by developing a learning scenario using Modeling Instruction on topic that need to be improved.

The learning has a significant effect on improving students’ understanding. Students were actively involved to think the need of rigid body model development based on particle dynamics concept. Students understood the interconnectedness of a concept with each other and the need to build a new model, which was rarely found in traditional learning.

IV. CONCLUSION

Based on the result, modeling instruction had succeeded in significantly increasing students' understanding on topic of rotational dynamics. Students participate in learning enthusiastically, increase awareness of the coherence of physics and can draw diagrams well. N-Gain score showed that the learning was quite effective in improving students' understanding and creating physics coherence. Still, N-Gain score in this research was at upper-medium category. Therefore, this research needs further development to improve the N-Gain score and students' understanding toward the question of the test which is not good yet.

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