Identification of high school students’ problem-solving skills on rotational dynamics

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Abstract. This study aimed to identify students’ problem-solving skills on rotational dynamics. Thirty-two high school students were given five multiple-choice questions where the students should explain their answers. Then, the students’ explanations were analysed to identify their problem-solving skills according to five aspects, including useful description, physics approach, specific application of physics, mathematical procedure, and logical progression. The students’ skills in each aspect were categorised into expert and novice solvers. The results showed that the average percentage of expert solver students in the five aspects were 64.4%, 70.6%, 51.9%, 35.2%, and 38.1%. Students who were in the expert category on the aspect of useful description, physics approach, and specific application of physics were not certainly categorised as an expert on the mathematical procedure aspect. The mistakes in mathematical procedures were mainly caused by the students’ carelessness in formulating a moment arm or their failure on the previous steps. This finding can be used as a useful input for designing a learning sequence to improve students’ problem-solving skills, especially in the aspect of mathematical procedure about rotational dynamics.

1. Introduction

In this globalisation era, problem-solving skills are important basic skills that students need to grasp. These skills are the competence needed for determining a solution of problems using the information related to the problems [1-2]. Generally, a problem-solving process includes information categorisation from the problem statement to be visual symbolic information, as well as a writing that applies an appropriate concept for problem-solving. In learning physics, problem-solving skills are also needed to build in-depth physics knowledge [3]. Students’ proficiency in solving physics problems systematically can be applied in daily life [4].

Several studies have revealed the way novice students solve physics problems. Generally, students tend to list all known quantities as well as unknown quantity then put them into the equations that they remember [4-5]. Another tendency is using analogy to a problem that has been solved. They analyse all variables in the question and match them to the question they have already solved [6]. Certain learning experiences are needed to guide the students to be an expert problem solver. To becoming expert problem solver, students need to grasp five aspects of physics problem solving; including useful description, physics approach, specific application of physics, mathematical procedure, and logical progression [7].

Most physics problems dealing with students’ daily life are related to mechanics (kinematics and dynamics). Some studies show that students face difficulties in solving rotational dynamics problems
Most students cannot operate vector manipulation and apply mathematical procedure appropriately [14-16]. It shows that students' inability to apply mathematical procedure has impacts on the success of problem-solving [16-17]. Students' difficulty in problem-solving is also due to the lack of conceptual understanding. The appropriateness of physics concept and principles to the problem is a key to get the right solutions of a problem [19-20].

In general, the identification of students’ problem-solving skills is to comprehend the students’ knowledge [21]. Studies about physics problem-solving skills are abundant. However, a specific research on students’ problem-solving skills on rotational dynamics has not been a concern of many researchers. This article aimed to identify students’ problem-solving skills in solving rotational dynamics problems. The identification was done on each aspect of problem-solving skills to investigate how well the students comprehend the concept and process to solve the problems.

2. Research Method
The reasoning multiple-choice questions were given to 32 Senior High School students to identify students’ problem-solving skills in solving problems of rotational dynamics. Besides choosing the right answer, the students were asked to describe in detail about their thought according to the five aspects of problem-solving namely useful description, physics approach, specific application of physics, mathematical procedure, and logical progression [7]. Before solved the problems, the students were previously trained to solve physics problems using those aspects. The students’ descriptions were then analysed to be categorised as expert or novice based on the categorisation rubric (rubric adapted from [4, 7, 22-24]). The proportion of expert-novice students in solving each question were calculated based on every aspect of problem-solving.

3. Results and Discussion
On the five aspects of problem-solving namely useful description, physics approach, specific application of physics, mathematical procedure, and logical progression the results showed that the average percentage of expert solver students in the five aspects were 64.4%, 70.6%, 51.9%, 35.2%, and 38.1%.

The followings are the descriptions of each student’s problem-solving skill aspects.

3.1. Useful Description
Useful description aspect explores the students’ ability in describing the problem and obtaining the essence from the problem given. Based on Figure 1, it can be seen the number of students categorised as an expert on each question.

![Figure 1. The percentage of expert students on useful description aspect](image-url)
expert solver by providing the useful description qualitatively and the moment of inertia constant is symbolically about the energy problem of rolling motion (Figure 1).

Example of expert and novice students’ answer at this aspect are presented in Table 1. In Table 1, it can be seen that the expert student describes the problem using drawings or qualitative descriptions. The descriptions given can be qualitative descriptions (questions 2 and 5), torque direction images (question 1), and torque direction images on a seesaw system with 3 rotation of axes (question 4). Meanwhile, the novice solver provides a quantitative description of the problem and/or provides an imperfect qualitative description. For example, in Problem 4 (see Table 1), some un-categorised students as expert solver provide a useful description in the direction of torque direction only on one axis and or more than one axis but not complete. Some students think that on a balanced teeter, the axis of rotation always rests on the lever [25]. This causes the percentage number of the expert students is low and does not reach 50%.

| Number | Example of expert students’ answer | Example of novice students’ answer |
|--------|-----------------------------------|------------------------------------|
| 1      | ![Translation: F = F; L = L](#) | ![Question: \( \tau = 0 \)](#) |
| 2      | **Translation:** Ciko is like dust on a disc with \( I = m r^2 \). when ciko is on the edge of the swivel comedy (SC), \( I_C = I_{SC} \) | ![No novice answer available](#) |
| 4      | ![Translation: 4 objects rolling over sloping fields, rough floors. (1) Ring \( I = m R^2 \); (2) Spherical shell \( I = \frac{2}{5} m R^2 \); (3) Solid cylinder \( I = \frac{1}{2} m R^2 \); (4) Solid sphere \( I = \frac{2}{5} m R^2 \)](#) | ![Translation: Useful description: \( I = \frac{2}{5} m R^2 \)](#) |

The useful description acts as an initial process given by the expert students. The initial step given was a qualitative description as the essence of the problems, drawing, graphics, or symbol [26]. In this material, the initial step given was by drawing the force diagram, torque direction, and giving a short explanation qualitatively about the presented problems. This initial step will later be used by expert students in determining the process of problem-solving that will be used [27] and supporting the process of students’ problem-solving [28].

3.2. Physics Approach

The physics approach aspect examined the students’ ability in choosing the physics principles or concepts would be used in problem presented. Based on Figure 2, it can be seen that the majority of students on questions 1, 3, 4, and 5 have used the appropriate physics concept in completing this process. The students are able to determine what concept should be used in problem-solving in accordance with the problem context presented. However, in question 2, the percentage of the number of expert students in the physics approach is still low. In question 2, the student assumes that the concept used is limited.
to rotational motion (since it deals with a roundabout where circulation is identical to rotation). In this case, the students only look at the problem based on what appears on the surface of the problem [29], not making an in-depth analysis of the given problem [30], and solving the problem regardless of the most underlying concept of the problem [31,32].

![Figure 2. The percentage of expert students on physics approach aspect](image)

### Table 2. Example of students’ answer on the physics approach aspect

| Number | Example of expert students’ answer | Example of novice students’ answer |
|---|---|---|
| 1 | Pendekatan fisika
   
   Torque dan Newton kedua hukum rotasi
   
   Translation: Torque and Newtons’ second law for rotation | Pendekatan fisika
   
   Gaya
   
   Translation: Torque |
| 2 | Pendekatan fisika
   
   Hukum kecepatan sudut (momentum angular)
   
   Translation: The law of angular momentum conservation (angular momentum) | No novice answer available |
| 4 | Pendekatan fisika
   
   Keberadaan sifat benda tegar
   
   Translation: Equilibrium of a rigid body | Pendekatan fisika
   
   Momens
   
   Translation: Moments of equilibrium |
| 5 | Pendekatan fisika
   
   Energi gerak, energi potensial, hukum kekekalan energi
   
   Translation: Rolling motion energy, the law of energy conservation | No novice answer available |

Some examples of expert and novice solver students’ answers at this aspect are shown in Table 2. It can be seen in Table 2 that the expert students solve problems using the appropriate principles and are relevant to the problems presented. While novice students write the concept of physics by matching the variable or manipulating the vectors that exist in the questions. For example on problem A, the student chooses to use the force moment concept because the problem only provides information about the \( F \) force and \( L \) force arm. It is in line that the novice solves the problem that focuses on the quantitative value and matches it with the formula [7]. Although some students have successfully described the solution of the problems presented, there are some students who are still filling out the answers incompletely to the phases of the physics approach. As an example in question 1, some students just fill the physics approach stage with the concept of force moment only and does not include the second Newton law of rotation. In this case, the student does not conduct an in-depth analysis of the given problem [29, 31]. The incompleteness of the answers causes students to not produce solutions and categorised as a novice solver.
3.3. Specific Application of Physics

The aspect of applying the specific physics concept accesses the students’ ability in choosing the appropriate concept application based on the presented problem. This aspect is closely related to the previous aspect that is the aspect of physics approach. Figure 3 shows the percentage of expert students number in the aspect of applying the specific physics concept. The sample answers of expert and novice solver students at this aspect are presented in Table 3.

![Figure 3](image)

**Figure 3.** The percentage of expert students on the specific application of physics aspect

| Number | Example of expert students’ answer | Example of novice students’ answer |
|--------|------------------------------------|-----------------------------------|
| 1      | \[ \tau = r F \] and \[ \tau = r \alpha \] | \[ \tau = r F \sin \theta \] |
| 2      | Ciko spins along with the carousel and Ciko can be stated as a dust on a disc thus, \( I_{	ext{ciko}} = I_{	ext{carousel}} \) then \( L_{	ext{ciko}} = L_{	ext{carousel}} \) (when he is on the edge of the carousel) when Ciko is near to the rotation center, \( r \) Ciko becomes smaller, and \( \omega \) ciko gets bigger than the initial condition. | No novice answer available |
| 3      | \[ I = I_{	ext{table}} + m d^2 \] | \[ I = m r^2 \] |
| 4      | \[ \Sigma \tau = 0 \] and \[ \Sigma F = 0 \] | No novice answer available |
| 5      | Mechanical energy (\( E_m \)) = Kinetic Energy (\( E_k \)) + Potential Energy (\( E_p \)); \( E_{\text{peak}} = E_{\text{base}} \); Kinetic translation energy = \( \frac{1}{2} m v^2 \); Kinetic rotation energy = \( \frac{1}{2} I \omega^2 = \frac{1}{2} k m r^2 \omega^2 \) With \( v = \omega r \) and \( \omega^2 = \frac{v^2}{r^2} \); Potential energy (\( E_p \)) = \( m g h \) | No novice answer available |
Some students have succeeded in applying the concept to the problems presented appropriately and in accordance with the context of the questions presented. This is an indication that students have understood the concept well. However, in question 3 (related to moments of inertia) and 5 (related to the energy of rolling motion), the percentage of the number of expert students is still low.

Many students have problems when dealing with the concept of moment of inertia. Some students are also unsure and unfamiliar with the concept of moment of inertia [12]. For example in question 3, students do not know that rotary axis selection influences the object’s moment of inertia [33] which has been discussed in sub-discussion of the parallel axis theorem. This makes the student only match the known variables to the problem with the existing formula and perform mathematical manipulations by relying on the variables known in question [32, 34]. Moreover, students who are identified as novice solver gives wrong answers and or less complete in writing the equation that will be used in solving the problem. This happens to novice solver students on question 5. Based on Table 3, it can be seen that the expert students can apply the physics principles and concepts in an organised manner with the coherent knowledge. It is different from the novice students who tend to manipulate the equation by matching what is known to the used formulation [7, 23, 35].

3.4. Mathematical Procedure
The aspect of mathematical procedures is used to probe the accuracy of students in problem-solving in mathematics. In question 2, the mathematical procedures was not used because it presents the problem with a solution that is enough to be solved by the elaboration of related concepts without mathematical calculations so that the mathematical procedure in question 2 is considered as NA problem.

![Figure 4. The percentage of expert students on mathematical procedure aspect](image)

Figure 4 shows that the percentage of the number of expert students in all questions is still relatively low. The percentage of the lowest number of expert student on mathematical procedure is in question 1 related to material of force moment and the second Newton law about the rotation. Although students can already draw the force diagram and determine the concept used, students make mistakes in determining the direction and summing the resultant torque generated by several forces. In the basic concept of force moment, the direction of the force is very important to determine how the object moves [36-37]. In this case, students determine the motion of direct object rotation based on the force without showing the concept of torque [12]. Students tend to define a negative sign for downward direction (negative Y-axis) and a positive sign of upward force (positive Y-axis) [38]. This makes the procedure mathematical process used by students to be incorrect. This explanation also applies to question 5 about the objects’ equilibrium.

In question 3, the low percentage of the mathematical procedure aspect is due to students' mistakes in the previous aspect that is the specific application of physics aspect. In this case, the student has not understood that the axis of rotation can be a factor affecting the moment of inertia [38]. Thus, the student merely writes the known formulation about the moment of inertia that is I = mr^2. Similar with question 5, the mistake in the mathematical procedure aspect is also due to the mistakes in the specific application
of physics aspect and the mathematical incompleteness provided by the students. Although students have been able to determine what concept would be used in solving the problems presented, not many students successfully solved the problem from the useful description aspect to the mathematical procedures and produced a complete and appropriate solution. This shows that not all students can use appropriate mathematical procedures to produce the expected solution to the problem. The inability to apply mathematical procedures will have an impact on students' problem-solving abilities [16]. An example of student expert and novice solver's answers at this aspect is presented in Table 4.

| Number | Example of expert students' answer | Example of novice students' answer |
|--------|------------------------------------|-----------------------------------|
| 1      |                                    | No novice answer available        |
| 3      | ![Procedur matematis](image)        | ![Procedur matematis](image)      |
| 4      | ![Procedur matematis](image)       | ![Procedur matematis](image)      |
| 5      | ![Procedur matematis](image)       | No novice answer available        |

The students who are categorised as expert solvers have mathematics proficiency thus can produce a correct problem-solving. Meanwhile, the students who are categorised as novice solver tend to make mathematical mistakes and manipulations with the variables as described previously in question 3 (see Table 4) and do not analyse the problem condition thoroughly thus giving the wrong solution [32, 34]. Based on Table 4, it can be concluded that the students categorised as novice give the answers with some lacking points and mistakes in doing the calculation thus the students cannot get the perfect score and categorised as novice solver [7]. One of the reasons for the students’ failure in making the problem-solving is because the students do not give the descriptions thoroughly and make it difficult for them to solve the problems [4].

3.5. Logical Progression

This aspect was used to assess the consistency of students in the overall answers that students provided. Although the number of expert students was high in the aspects of useful description, the physics approach, and the specific application of physics concepts, only a few students successfully provided the correct, complete, and logical answers from the useful description until the mathematical procedure. Students who are categorised as an expert in logical progression aspect is the students who provide correct solution or correct answers from the useful description aspect until mathematical procedures. Figure 5 shows the percentage of expert students on logical progression aspect. In the case of 1, 3, 4, and 5, the low percentage of expert students in logical progression aspect because many students write wrong or incomplete answers to the mathematical procedure. An example of student answers in question 4 (see Appendix 2) is presented in Figure 6.
Figure 5. The percentage of expert students on logical progression aspect

Based on Figure 6, the 2 types of expert and novice students’ answers can be seen in one of the problem-solving skills. Expert student has a coherence of knowledge and consistent use of such knowledge in solving the problem. In Figure 6(b), students consistently use the science of equilibrium and it is appropriately applied in the context of questions on the questions given. Unlike the case of novice students, in Figure 6(a) it appears that students do not focus on the purpose of being able to answer questions on a given question. Students are only fixated on one solution with the assumption that the object will be in equilibrium when the shaft is located on the lever. The knowledge used is also still fragmented and incomplete to form the science of equilibrium. Novice students will see the problem cut off and from the surface (visible) [7].
Through the above discussion, it can be seen that the expert solver has an organised and structured knowledge structure and solved the problems based on the fundamental concept of the problem [4, 39]. Experts begin the problem-solving process by describing the problem as a whole qualitatively [3], such as describing the direction of torque and force diagrams. Many students who become expert solvers on the aspects of useful description, physics approach, and application of physics concept but categorised as a novice at mathematical procedures. The inability of students to apply mathematical procedures has a major impact on students’ problem-solving abilities [16-17]. In addition, novices also tend to do mathematical manipulations by relying on known variables in question [32, 34] and do not solve the problem qualitatively [3] such as describing the direction of torque and force diagrams so that students find it difficult to solve the related problems. In sum, the presented five aspects of problem-solving skills indeed have interconnected between one aspect and another. For example, students who succeed in the aspect of useful description will facilitate themselves in choosing the mathematical concepts and procedures to be used. But sometimes students can only succeed in the useful description aspect but not in other aspects because students do not have a complete knowledge of the concept. Thus, the interrelationship between the aspects of problem-solving skills must be supported by a good and complete understanding of the concept so that students can choose the physics concepts and principles according to the context of the problems and get the solution of a problem [19-20].

4. Conclusion
Based on the research conducted on the identification of students’ problem-solving skills in rotational dynamics, it was found that the majority of the students are capable of going through the aspects of useful description, physics approach, and specific application of physics. It is still proven that the percentage mean of expert students is above 50%. Meanwhile, on the mathematical procedure and logical progression aspects are categorised as low with the percentage of each number of expert students in a sequence are 35.2% and 38.1%. Expert students tend to begin the problem-solving by describing the problem qualitatively for example by making the force diagram or giving a short description. While the novice students tend to do mathematical manipulation according to the known variables in the questions. The students who are categorised as an expert on the aspect of usefull description, physics approach, and specific application of physics were not certainly categorised as an expert on the mathematical procedural aspect, thus it affects the students’ problem-solving final result. The categorisation of students to be a novice solver is due to the lack of students’ conceptual understanding related to the rotational dynamics and or the students’ knowledge is still in the forms of unconnected knowledge fragments to form a whole concept.

References

[1] Gok T and Silay I 2008 J. Theo. Pract. Educ. 4 253.
[2] Selcuk G S, Calistan S, and Erol M 2008 Latin Am. J. of Phys. Educ. 2 153.
[3] Docktor J L, Strand N E, Mestre J P, and Ross B H 2015 J. Phys. Rev. ST 11 1.
[4] Walsh L N, Howard R G, and Bowe B 2007 J. Phys. Rev. ST. 3 1.
[5] Rosengerant D, Van Heuvelen A, and Etkina E 2009 Phys. Rev. ST. 5 1.
[6] Riantoni C, Yuliati L, Mufti N, and Nehru N 2017 J. Pend. IPA Indonesia, 6 55.
[7] Docktor J L, Jay D, Evan F, Kenneth H, Leonardo H, Koblar A J, Andrew M, Qing X R, and Jie Y 2016 J. Phys. Rev. Phys. Educ. Res. 12 1.
[8] Ambrosis A D, Malgieri M, Mascheretti P, and Onorato P 2015 Euro. J. of Phys. 36 1.
[9] Ayesh A, Qamhieh N, Tit N, and Abdelfattah F 2010 Educ. Res. 1 505.
[10] Duman I, Demirci N, and Sekercioglu A 2015 Int. J. Educ. Their Impli. 6 46.
[11] Ortiz L G, Heron P R L, and Shaffer P S 2005 Am. J. Phys. 73 545.
[12] Rimoldini L G and Singh C 2005 J. Phys. Rev. Phys. Educ. Res. 1 1.
[13] Mulyastuti H, Sutopo, and Taufiq A 2018 J. Pend. Teo. Pen. Pengemb. 3 598.
[14] Flores S, Kanim S E, and Kautz C H 2004 Am. J. Phys. 72 460.
[15] Shaffer P S and McDermott L C 2005 Am. J. Phys. 73 921.
[16] Jones H G and Mooney R J 1981 J. Phys. Educ. 16 356.
[17] Sarkity D, Yuliati L, and Hidayat A 2016 Pros. Sem. Pend. IPA 1 166.
[18] Ceberio M, Almudí J M, and Franco Á 2016 J. of Sci. Educ. and Techno. 25 590.
[19] Azizah R, Yuliati L, and Latifah E 2015 J. Pen. Fis. Apl. 5 44.
[20] Mason A and Singh C 2016 J. Phys. Educ. 5 1.
[21] Adams W K and Wieman C E 2015 Am. J. Phys. 83 459.
[22] den Brok P, Taconis R, and Fisher D 2010 Open Educ. J. 3 44.
[23] Ryan Q X, Frodermann E, Heller K, Hsu L, and Mason A 2016 J. Phys. Rev. Phys. Educ. Res. 12 1.
[24] Singh C and Mason A 2009 AIP Conf. Proc. 1179 273.
[25] Rahmawati I, Sutopo, and Zulaikah S 2017 J. Pend. IPA Indonesia 6 95.
[26] Docktor J L and Heller 2009 Proc. of the NARST 2009 Annual Meeting, California.
[27] Murray M A and Byrne R M J 2013 J. Cogn. Psycho. 25 210.
[28] Ganina S and Ly Soord 2011 Phys. Educ. 46 376.
[29] Docktor J L and Mestre J P 2014 Phys. Rev. Phys. Educ. Res. 10 0201191.
[30] Mason A and Singh C 2011 Phys. Rev. Phys. Educ. Res. 7 0201101.
[31] Ibrahim B and Rebello N S 2012 Phys. Rev. ST. Phys. Educ. Res. 12 1.
[32] Meli K, Zacharos K, and Koliopoulos D 2016 Can. J. Sci. Math. and Tech. Educ. 16 48.
[33] Klodivova M and Mucha L 2014 Eur. J. Phys. 35 1.
[34] Novick L R and Sherman S J 2008 The Quart. J. Exp. Psycho. 61 1098.
[35] Hull M M, Kuo E, Gupta A, and Elby A 2013 J. Phys. Rev. ST. Phys. Educ. Res. 9 1.
[36] Zhou Yan 2011 J. of Applied Phys. 109 0239161.
[37] Kinchin J 2012 J. Phys. Edu. 47 15.
[38] Danika P O, Yuliati L, Wartono 2017 J. Edu. and Learn. 11 291.
[39] Chi M T H, Feltovich P J, and Glaser R 1981 J. Cogn. Sci. 5 121.
### Appendix 1

The rubric of students categorisation on expert and novice solver (adapted from [4, 7, 22-24])

| Process                        | Expert                                                                                                           | Novice                                                                                                           |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| **Useful Description**        | - Giving the appropriate and complete useful description, and or making little mistakes but not affecting on the answer correctness on the next process. | - Giving only some parts of the useful description, containing the mistakes that will affect the problem-solving and the answer correctness on the next process, and or not giving any answer description at all (except NA solver) |
|                               | - Obtaining the essence of the problem and describing it qualitatively                                          | - Giving an answer description that focuses on quantitative and matching it to mathematics manipulation and or doing a qualitative analysis but not thoroughly |
|                               | - Not giving any useful description but there answer in the next process is correct (NA solver)                  | - Not using the appropriate physics principles or concepts for problem-solving and or doing little mistakes that will affect the answer correctness on the next process and or not giving physics concept at all (except NA solver) |
| **Physics Approach**          | - Using the appropriate physics principles or concepts for problem-solving and or doing little mistakes not affecting on the answer correctness on the next process | - Not solving the problem based on the principle and the relevant physics fundamental concepts, but based on the variable and equation manipulation |
|                               | - Categorising and solving the problem based on the physics principles or related fundamental concepts         | - Not applying the appropriate physics concept and making mistakes that will affect the problem-solving and the answer correctness on the next process and or not applying the physics concept or principle in problem-solving in an organised manner (except NA solver) |
|                               | - Not giving any physics approach but the answer on the next process is correct (NA solver)                    | - Having disconnected and unrelated knowledge                                                                          |
| **Specific Application of Physics** | - Applying the appropriate and complete physics concept, and or making little mistakes but not affecting the answer correctness on the next process | - Not applying the appropriate physics concept and making mistakes that will affect the problem-solving and the answer correctness on the next process and or not applying the physics concept or principle in problem-solving in an organised manner (except NA solver) |
|                               | - Not applying the physics concept but the next answer on the next process is correct (NA solver)            | - Having difficulties in applying the mathematical procedures and low mathematics proficiency, slow in finding the answer alternative that leads to the problem-solving. |
| **Mathematical Procedure**    | - Using an appropriate and complete mathematical procedure in problem-solving, and or making little mistakes but not affecting the answer correctness on the next process | - Using an appropriate and incomplete mathematical procedure for problem-solving and or making mistakes that will affect the answer correctness of the solution of the problem |
|                               | - Having a competence in mathematics, having the ability to find answer alternatives that lead to the solution of the problem | - Having difficulties in applying the mathematical procedures and low mathematics proficiency, slow in finding the answer alternative that leads to the problem-solving. |
| Process                  | Expert                                                                 | Novice                                                                 |
|-------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------|
| Logical Progression     | • Giving an appropriate and complete problem-solving and or making     | • Giving an inappropriate and incomplete and or not making the         |
|                         |   little mistakes but not affecting the answer correctness              |   mistakes that will affect the answer correctness                     |
|                         | • Giving the problem-solving that focuses on the objectives and         | • Giving an unfocused and inconsistent problem-solving in using the   |
|                         |   consistent in using the knowledge                                    |   knowledge                                                            |
|                         | • Having a strong metacognitive competence by monitoring the           | • Having a low metacognitive competence and not monitoring the         |
|                         |   solution they made whether the way they choose has the potential to  |   progress of the solution made                                         |
|                         |   obtain the results                                                   | • Using incoherent knowledge in problem-solving                        |
|                         | • Managing their knowledge coherently and relating to each other       | • Fixed on one solution                                                |
Appendix 2

Test item of Problem-Solving Skills on Rotational Dynamics

1. A rod has a length of 2L and a shaft at the center of the rod. The rod is given a force as shown in the picture. The following true statement about the angular acceleration is …
   A. \( \alpha_I = \alpha_{II} > \alpha_{III} \)
   B. \( \alpha_I > \alpha_{II} > \alpha_{III} \)
   C. \( \alpha_{II} > \alpha_I > \alpha_{III} \)
   D. \( \alpha_{II} > \alpha_{III} > \alpha_I \)
   E. \( \alpha_I = \alpha_{II} = \alpha_{III} = 0 \)

2. A roundabout is spinning at a constant rate. Suddenly Ciko, whose mass is much smaller than the mass of comedy, sprints toward it, ride it, and Ciko moves near the center of the rotation with a constant linear rate. The following correct statement is …
   A. Ciko’s angular momentum increases
   B. Ciko’s moment of inertia decreases
   C. Ciko’s moment of inertia increases
   D. Ciko’s rotation rate decreases
   E. Ciko’s rotation rate is at a constant rate

3. A solid ball with mass \( m \) and radius \( R \) passing through the center of mass has a moment of inertia of \( \frac{2}{5} mR^2 \). The moment of inertia of a solid ball for a shaft located at the edge of the ball is …
   A. \( \frac{2}{3} mR^2 \)
   B. \( mR^2 \)
   C. \( \frac{7}{5} mR^2 \)
   D. \( \frac{5}{3} mR^2 \)
   E. \( \frac{2}{5} mR^2 \)

4. Look at the force diagram that of a seesaw used by a daughter and her father as shown in the picture. If the seesaw is in equilibrium, the equation that is appropriate to the picture is …
   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 choice (A) to (D) is correct
   F. All choice (A) to (C) is correct

5. Each of four objects is in the form of a ring, a solid cylinder, a hollow ball, and a solid ball. Simultaneously, the four objects are released from the top of the peak of an inclined plane whose path is rough. The strong object that reaches the bottom of the first incline is....
A. solid ball
B. hollow ball
C. solid cylinder
D. rings
E. They all reach the bottom of the incline at the same time