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[Research Article]

ANALYSIS OF THE CAUSES OF DIFFICULTIES FACED BY PHYSICS EDUCATION STUDENTS IN ANSWERING QUESTIONS ON ROTATIONAL DYNAMIC EQUILIBRIUM

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ABSTRACT

This study aims to analyse the difficulties faced by Physics Education students in answering questions on the topics of equilibrium and rotational dynamics. The study employs a qualitative descriptive approach with a quantitative component in the form of an analytical test comprising six items. The study population comprised all 305 Physics Education students at the Faculty of Teacher Training and Education, Syiah Kuala University, with a sample of 58 students currently taking the 'School Physics Studies II' course. Data were collected through essay tests and documentation, then analysed based on sub-topics and causes of difficulty, which were classified into five main categories: mastery of basic mathematics and trigonometry; lecturers' delivery of material; difficulty in reading and analysing diagrams; insufficient mastery of theory; and the complexity of the material. The research results indicate that the dominant factor causing students' difficulties is an inability to read and analyse diagrams (33.75%), particularly in the sub-topics of equilibrium of rigid bodies and rotational dynamics. These difficulties are also influenced by limited mastery of theoretical concepts and difficulties in determining the appropriate formulae. These findings underscore the importance of learning strategies that emphasise the strengthening of visual representation skills, conceptual analysis, and problem-solving skills to enhance students' understanding of the equilibrium and rotational dynamics material.

Keywords: Student Difficulties, Problems, Equilibrium of Rigid Bodies

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1. INTRODUCTION

The dynamics of rotation is a central topic in classical mechanics, covering key concepts such as moment of inertia, torque, angular momentum, the relationship between torque and angular acceleration, and the application of Newton's laws to rotational motion. Mastery of this topic is important for Physics Education students because, in addition to serving as a theoretical foundation, rotational concepts frequently arise in the context of laboratory work, the application of mechanical technology, and further study in other courses. However, learning experiences and empirical studies indicate that students' understanding of rotational dynamics is often insufficient, both conceptually and procedurally (Stewart et al., 2021).

According to the latest literature, there are several recurring patterns of difficulties when students encounter problems involving rotational dynamics. Firstly, there are conceptual misconceptions such as misunderstanding the direction of torque, confusion between angular velocity and angular momentum, or difficulty understanding the vector nature of rotational quantities which lead to incorrect answers even though students may have memorised the formulas. Studies in both Indonesian and international contexts indicate that misconceptions regarding the subtopics of rotation and rolling motion remain prevalent across various levels of education (Rafika & Syuhendri, 2021). Secondly, there are weaknesses in the application of mathematics and visual representations when solving rotation problems: students often struggle to apply the concept of moment of inertia to different mass distributions, to construct and use appropriate rotational free-body diagrams (torque diagrams), and to combine linear and rotational concepts for composite systems. These limitations in problem-solving ability are often linked to a lack of varied practice problems and a shortage of teaching that emphasises the transformation of representations (textual ↔ mathematical ↔ graphical) (Stewart et al., 2021).

Thirdly, evidence from intervention studies suggests that innovative learning approaches can alleviate these difficulties, but the results are context-dependent. Recent R&D studies have found that interactive media (e.g. e-books combined with Augmented Reality for spinning top/traditional games) and project-based learning (PBL) models can improve visual representation, critical thinking skills, and problem-solving in rotational material; however, their effectiveness is highly dependent on instructional design and sample characteristics. In other words, although interventions show potential, there is as yet no comprehensive mapping linking question types to specific error patterns among physics education students in university-level courses. (Sebastian & Kuswanto, 2025).

Fourthly, much previous research has used total scores as an indicator of mastery, which is insufficient for identifying the specific types of misconceptions or incorrect strategies. Therefore, item-level analysis and the use of diagnostic instruments (e.g. four-tier diagnostic tests or analysis of open-ended responses) are essential for mapping patterns of difficulty: whether students are making errors due to misconceptions, limitations in algebraic skills, or oversights in visual representation. Such analysis also helps formulate appropriate remediation strategies (e.g. an emphasis on the transfer of concepts from linear to rotational, or specific exercises on moments of inertia for non-homogeneous objects) (Lubis & Bunawan, 2024).

In the context of physics education (for trainee teachers and physics students), a lack of understanding of rotational dynamics has practical implications: future teaching ability, the development of valid assessment tools, and the ability to design teaching materials that bridge abstract concepts with real-world phenomena. Against this backdrop, research focusing on analysing the difficulties faced by Physics Education students in answering questions on rotational dynamics is both relevant and urgent. This study is expected not only to identify the level of difficulty quantitatively, but also to trace patterns of errors, the roots of misconceptions, and their relationship with question characteristics (concepts being tested, representations used diagrams/text/formulas, cognitive levels according to Bloom's Taxonomy/Revised, etc.). The results will provide an empirical basis for improving the design of learning and assessment in the Mechanics/Rotational Dynamics course (Majidy, 2024).

The dynamics of rotation encompass a number of interrelated concepts in physics: torque, moment of inertia, angular momentum, the relationship between torque and angular acceleration ($\tau = I \times \alpha$), and the modelling of rotating rigid-body systems. A comprehensive understanding requires cognitive skills in vector abstraction, integration/continuous mathematics, and the transfer of principles from linear motion to a rotational context. Empirically, this topic is known to demand strong representational skills (mathematical, diagrammatic, verbal) so that students can solve problems both conceptually and procedurally (Majidy, 2024). Based on constructivist theory (Piaget; Vygotsky as the general foundation of learning theory), students construct new knowledge upon existing preconceptions.

In physics, everyday (intuitive) preconceptions often conflict with formal concepts; for example, the intuition that a 'force' causing linear motion is directly projected onto rotational motion, without understanding that torque depends on the line of action of the force and the moment arm. These erroneous or partial concepts (alternative conceptions/misconceptions) tend to resist traditional teaching and require specific diagnosis and intervention. Recent studies confirm that misconceptions in mechanics including rotational dynamics often persist at university level unless identified and addressed through diagnostic remediation. (Pranata & Noperma, 2023). Dual-coding theory and the literature on representational competence emphasise the need for the ability to switch between representations: images/diagrams (e.g. free-body/torque diagrams), mathematical equations, motion sketches, and verbal descriptions. Research shows that students trained to use visual representations (e.g. free-body diagrams for rotational systems) tend to be more accurate in formulating equations and predicting the direction of torque/angular acceleration. Therefore, a lack of practice with multiple representations is a significant source of difficulty.

Problem-solving models (e.g. Heller & Heller; steps: visualisation → qualitative description → planning → computation → evaluation) are relevant for analysing where students struggle with rotational dynamics problems. Studies in physics education indicate that, in rotation problems, weaknesses often emerge in the early stages (visualisation of the system and identification of torque), so improvements to learning should emphasise explicit problem-solving strategies and scaffolded practice (Siantuba et al., 2023).

2. METHOD

This study employs a qualitative descriptive approach with the aim of describing the difficulties students face in answering questions on rotational dynamics. This approach was chosen because the study focuses on an in-depth analysis of error patterns, misconceptions, and the factors causing students' difficulties, rather than on quantitative generalisations. The quantitative component of this study consists of an analytical test comprising six items, whilst the qualitative component consists of the content of the answers provided by the students. The population comprises all 305 Physics Education students at the Faculty of Teacher Training and Education, USK, whilst the sample consists of 58 Physics Education students at the Faculty of Teacher Training and Education, USK, who are currently taking the 'School Physics Studies II' course, The research was conducted at the Department of Physics Education from 1 September 2025 to 5 September 2025.

The data collection techniques used in this study involved essay tests and documentation. The research instruments consisted of questions directly compiled by the lecturer and validated by a team of lecturers teaching the School Physics Studies II course.

The data analysis technique used in this study involved classifying the sub-topics within the subject matter of rotational dynamic equilibrium into six groups, whilst the causes were divided into five categories, as shown in Tables 1 and 2, and analysed using the percentages specified in Equation 1.

$$N = \frac{Score\ Achieved}{Maximum\ Score} \times 100 \qquad (1)$$

As for the difficulty criteria, please refer to the table below .

Table 1. Sub-Topic: Equilibrium in Rotational Dynamics.

No	Subtopic
1	Torque
2	Equilibrium of Point Masses and Rigid Bodies
3	Angular Momentum
4	Moment of Inertia
5	Centre of Gravity
6	Rotational Dynamics of Rigid Bodies

Table 2. Causes of Difficulty.

No	Causes of Difficulty
1	mastery of related categories: Basic Mathematics, Trigonometry
2	Presentation of Material by the Lecturer
3	Difficulty in reading diagrams and analysing them
4	Mastery of theories that have not yet been mastered
5	the material presented is too complex

3. RESULT AND DISCUSSION

Based on the questions presented in the test, there are six analytical questions, namely.

Question 1
Six forces act on the rod as shown in the following diagram. Determine the resultant force acting on the rod if the point of reference is at point A.

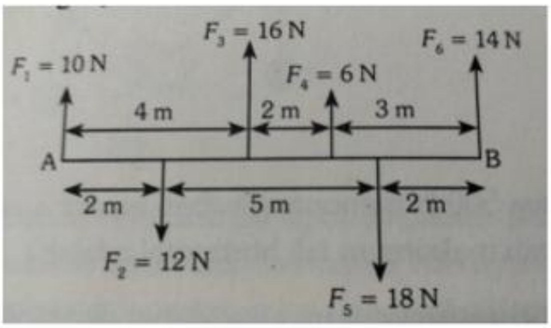

Figure 1. Force distribution diagram on a rigid rod with point A as the reference point for Question 1.

Of the 58 participants, only 1 (1.78%) reported experiencing difficulties with the material on moments and forces; the reason given by that participant for Question 1 was a lack of proficiency in the relevant categories of Basic Mathematics and Trigonometry

Question 2
If the mass of the rod is 1 kg, its length is L, and the system is in equilibrium, determine the tension T in the string.

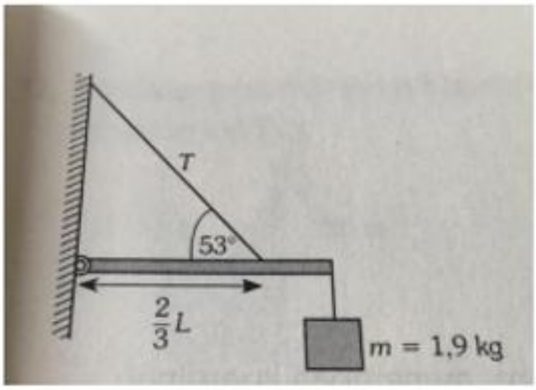

Figure 2. Equilibrium system of a uniform rod with a hanging mass and a supporting string for Question 2.

The use of subtitles in the discussion follows the discussion's needs. Example:

Of the 58 participants, 27 (46.67%) reported experiencing difficulties with the material on the equilibrium of point masses and rigid bodies. The reasons given by participants for Question 2 comprised four main factors: first, a lack of mastery of the relevant categories within Basic Mathematics and Trigonometry (11.11%); the second reason was the lecturer's delivery of the material (33.33%), the third reason was difficulty in reading and analysing diagrams (25.92%), and the fourth reason was a lack of mastery of the theory (29.64%).

Question 3
A homogeneous solid cylinder has a radius of 20 cm and a mass of 10 kg. The cylinder is initially at rest. When a force F is applied, the cylinder rolls along a rough horizontal floor. After travelling a distance of 2 metres, the cylinder's angular velocity is 10 rad/s. Calculate the magnitude of force F and the magnitude of the frictional force experienced.

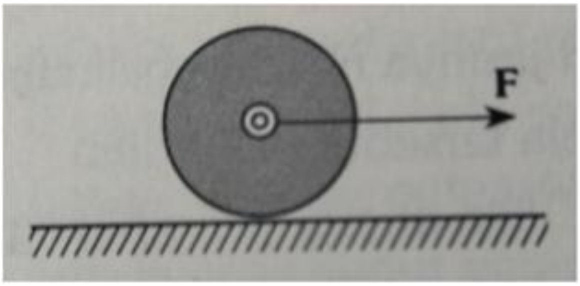

Figure 3. Motion diagram of a cylinder on a horizontal surface subjected to a force F for Question 3.

Of the 58 participants, only 1 (1.78%) reported experiencing difficulties with the angular momentum material; the participant's reason for question No. 3 was difficulty in reading the diagram and analysing it.

Question 4
Four particles, as shown in the diagram, are connected by a circular frame of negligible mass. Determine the moment of inertia of the system about an axis passing through the centre of the circle and perpendicular to the plane of the paper.

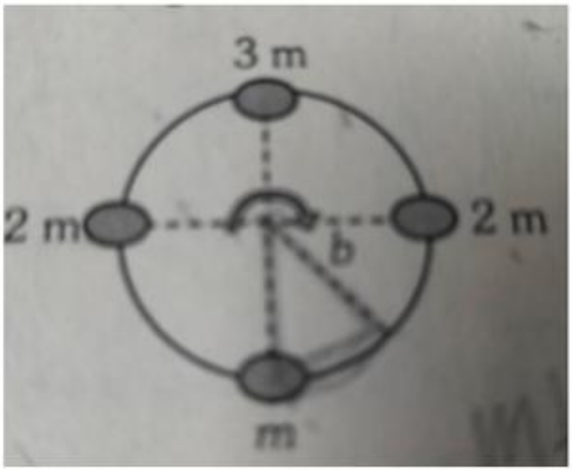

Figure 4. Configuration of a four-particle system connected by a circular frame rotating about the central axis for Question 4.

Of the 58 participants, 9 (15.51%) reported experiencing difficulties with the material on moments of inertia. The reasons given by participants for Question 4 comprised four main points: first, a lack of mastery of the relevant categories within Basic Mathematics and Trigonometry (11.11%); the second reason was the lecturer's delivery of the material (11.11%), the third reason was difficulty in reading and analysing diagrams (22.22%), and the fourth reason was a lack of mastery of the theory (55.56%).

Question 5
Determine the position of the centre of gravity in the arrangement of the following figures.

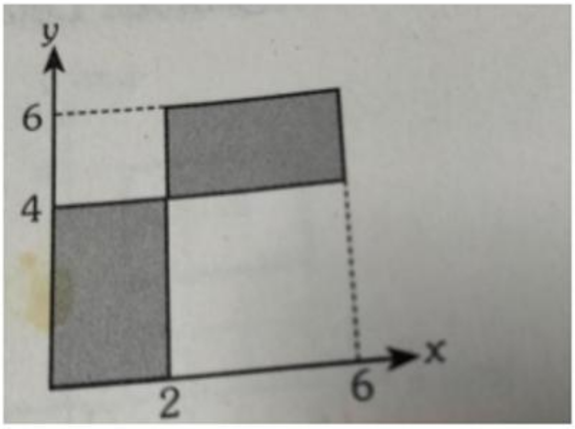

Figure 5. Geometric configuration of a combined planar shape for determining the centre of gravity in Question 5.

Of the 58 participants, 6 (10.34%) reported experiencing difficulties with the centre of gravity material. The reasons given by participants for question No. 5 comprised two main factors: firstly, difficulty in reading and analysing the diagram (83.33%); and secondly, the way the material was presented by the lecturer (16.67%).

Question 6
A solid ball of radius R and mass m is placed at the top of an inclined plane and rolls down the plane. If, during its motion, the ball does not slip and has an initial velocity of zero, determine the velocity of the ball when it reaches the bottom of the inclined plane.

Of the 58 participants, 14 (24.13%) reported experiencing difficulties with the material on the rotational dynamics of rigid bodies. The participants' reasons for Question No. 5 comprised four main points: first, difficulty in reading diagrams and analysing (21.14%); the second reason was the lecturer's delivery of the material (14.28%); the third reason was a lack of mastery of the theory (21.14%); the fourth reason was that the material presented was too complex (7.14%); whilst the final reason was a lack of mastery of basic mathematics and trigonometry (14.28%).

As for the reasons behind the difficulties, these can be seen in the following graph.

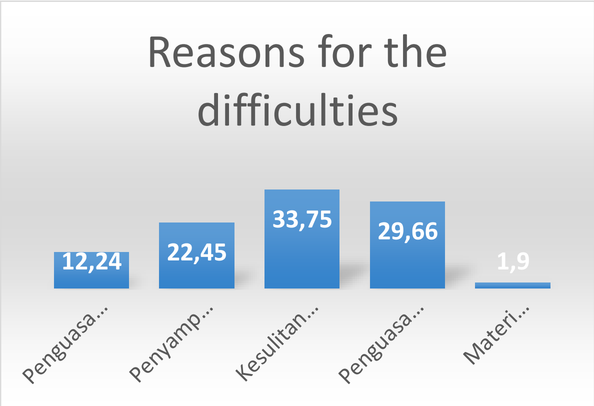

Figure 6. Distribution of factors contributing to students' difficulties in solving rotational dynamics problems.

Based on an analysis of the reasons for difficulties in answering questions on rotational dynamics, as well as interviews conducted, the greatest proportion of difficulties (33.75%) related to reading diagrams and analysing them. This is because the material concerning diagrams in the topics of rigid-body equilibrium and rotational dynamics has not yet been fully understood, and because of the difficulty in determining which formula to use, and a lack of understanding of how to interpret the diagrams. This is consistent with the findings of (Rahmawati et al., 2016), who noted that the equilibrium of rigid bodies and rotational dynamics constitute complex material containing intricate diagrams.

This view is echoed by (Amnirullah, 2015). Students' conceptual understanding of the topics of the rotation of rigid bodies and angular momentum provides an indication of their level of conceptual understanding. Students' conceptual understanding is influenced by their prior knowledge of linear motion, as discussed in previous chapters. Furthermore, misconceptions frequently arise in questions requiring an analysis of the direction of an object's rotation relative to a pivot point. Most students assume that all forces acting downwards will cause clockwise rotation, without considering the position of the force relative to the pivot point. This indicates weaknesses in vector visualisation and understanding of the rotational reference system (Musdar et al., 2025)

The same point was also highlighted by (Jatmika et al., 2021), who noted that students' mathematical ability remains low, particularly in trigonometry; students are not accustomed to answering questions systematically through a sequence of interpretation, analysis, evaluation, and conclusion; and students are not accustomed to sketching diagrams before answering questions.

4. CONCLUSION

Based on the research findings, the conclusion drawn regarding the causes of difficulties in learning rotational dynamics, as revealed by a study of Physics Education students at the Faculty of Teacher Training and Education, USK, who were taking the School Physics II course in the 2025–2026 academic year, is that the most common cause is difficulty in interpreting diagrams and analysing (33.75%). Based on the interview results, when students were working on the questions, they not only had difficulty reading and analysing the diagrams, but also in determining which mathematical equations or formulas to use to answer the questions, whilst others struggled with determining the centre of mass in the diagrams

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