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Analysis of Mathematical Reasoning Ability of High School Students on Newton's Law Material

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Abstract: Mathematical reasoning ability refers to the capacity to make strong assumptions and draw accurate conclusions regarding the relationships among mathematical ideas, as well as how these ideas are logically interconnected. This study employed a quantitative descriptive non-experimental research design. The research was conducted by administering a mathematical reasoning test consisting of five items related to Newton's laws, with a total duration of 2 × 45 minutes. The study took place in the second semester of the 2024/2025 academic year and involved 140 students from two public senior high schools in Jember City: SMAN 2 Jember and SMAN 4 Jember.The findings revealed that the average level of students' mathematical reasoning ability was distributed as follows: (1) formulating conjectures scored 77, which falls into the strong category. (2) predicting answers and calculation processes scored 39, categorized as weak. (3) Mathematical manipulation achieved a score of 52, indicating a moderate level. (4) drawing conclusions obtained the lowest score, 20, placing it in the very weak category. The results of this study can be used as a reference for educators in developing a series of lessons, in order to improve students' mathematical reasoning skills which are directly proportional to students' learning outcomes.
Keywords: penalaran, penalaran matematis, hukum newton.

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Introduction

Education in Indonesia in the 21st century requires students to be more innovative in facing rapidly developing global challenges. The learning objectives in the independent curriculum are to maximize conceptual understanding while strengthening student competencies (Ministry of Education, Culture, Research, and Technology, 2022). In the learning process, students are required to be able to analyze certain events and determine

priorities in learning. In the learning process, students are expected to be able to analyze priority themes, both inside and outside the classroom. One aspect that is emphasized is critical thinking skills, which include several phases to hone their mathematical reasoning skills (Purwanto et al., 2023).

Physics is one of the sciences that studies the natural world. According to Baktiarso et al. (2023), physics derives from the Greek word "physikos" or "physis," meaning nature, and is the science that studies matter and motion in the context of the relationship between force and energy. Physics also plays an important role in developing scientific knowledge and skills, as well as confidence in applying physics concepts. In practice, physics concepts can generally be formulated mathematically, enabling more precise and predictive analysis (Riyadi & Suprapto, 2020).

Mathematics is closely related to solving problems in physics. Istiqomah and Wijaya (2022) state that mathematics acts as a "language" in physics because many physics concepts are explained through mathematical equations. Therefore, mathematical reasoning skills are very important for students to learn in order to solve physics problems. Riyadi & Suprapto (2020) state that reasoning skills help students model, analyze, and solve physics problems systematically, from applying formulas to interpreting data and graphs. Logicians argue that there are three processes involved in reasoning: forming understanding, forming opinions, and forming conclusions (Syahnaz et al., 2021). This indicates that students' mathematical reasoning skills are very important to study in solving physics problems. Mathematical reasoning itself is the ability to make strong assumptions and draw accurate conclusions about the relationships between mathematical ideas and how those ideas are validly interconnected (Lestari et al., 2022).

There are several research findings that describe mathematical reasoning skills. The results of the 2018 PISA test show that Indonesia has a low average mathematical reasoning score of 379, compared to the OECD standard of 480 (Hamdi et al., 2024). TIMSS results also show that 17% of Indonesian students have low mathematical reasoning abilities (Hasna et al., 2023). However, students' mathematical reasoning abilities can have an impact on their learning outcomes and conceptual understanding. Hilaliyah & Annisa (2022) state that the higher the students' mathematical reasoning, the better their conceptual understanding will be, and thus their learning outcomes will also improve. Therefore, it can be concluded that there is a positive relationship between students' mathematical reasoning abilities and their learning outcomes.

Indicators serve as a measuring tool to assess something that is being studied. Indicators in mathematical reasoning ability research according to (Gultom et al., 2022) there are four indicators namely (1) writing conjectures (2) predicting answers and calculation process (3) manipulating mathematics (4) drawing conclusions. In this study, researchers focus on how students solve physics test questions and are classified in mathematical reasoning indicators as follows:

Table 1. Indicator of Mathematical Reasoning Ability

No	Indicator of Mathematical Reasoning Ability	Description
1.	Writing Conjectures	Learners' ability to write down known mathematical information, questions and units from the questions given.
2.	Predicting Answers And Calculation Process	Learners' ability to present information into a picture of the given problem.
3.	Manipulating Mathematics	Learners' ability to solve problems, perform calculations and units of the given problem.
4.	Drawing Conclusions	Learners' ability to draw conclusions from the final result of the calculation.

Mathematical reasoning plays an important role in solving physics problems that use mathematical solutions. One example is Newton's laws, which are formulated in mathematical equations. Newton's laws, as the basic foundation of physics, explain the correlation between force and motion of an object (Pratiwi et al., 2020). An empirical study conducted by Hasna et al. (2023) indicates that students face significant difficulties in calculating the total force on an object and determining the acceleration or velocity of the object within the context of Newton's laws. The findings of Baktiarso et al. (2023) reinforce this finding by showing that students are more likely to master the concepts of Newton's laws than the calculation skills related to the material, indicating difficulties in students' understanding of physics.

Based on the above explanation, it can be concluded that students' mathematical reasoning skills in Indonesia are still low, but it is not specified which areas need to be improved. Therefore, further studies are needed on students' mathematical reasoning abilities in each indicator as additional information for teachers and can be used as a reference in developing learning models according to the urgency of students who need to be improved, especially in physics, particularly Newton's laws. The contribution of students' mathematical reasoning abilities in solving physics problems can be identified from students' answers in solving physics essay questions.

Method

This study is a quantitative descriptive study, with data collected using tests, documentation, and observation. Quantitative descriptive studies are used to explain existing phenomena using numbers, tables, graphs, or descriptive statistics. Non-experimental research aims to observe and describe variables as they naturally occur without applying any treatment (Sugiyono, 2019). The test method was used to measure students' mathematical reasoning abilities on Newton's laws material through five essay questions. The test was adapted from a book related to Newton's laws material that had been validated by experts in the field of physics. The observation method was used to directly observe students' activities during the physics teaching and learning process and to collect data on phenomena observed at the research site. The documentation method was used to obtain a list of students' names and to document their answers. The research was conducted during the second semester of the 2024/2025 academic year at two public high schools in Jember Regency, namely SMAN 2 and SMAN 4.

Mathematical reasoning ability is reviewed from 4 indicators, namely (1) writing conjectures; (2) predicting answers and calculation processes; (3) manipulating mathematics (4) drawing conclusions (Gultom et al., 2022). The data were analyzed using the formula:

$$\% = \frac{\sum x}{N} \times 100\%$$

Description:

% = Percent value of each indicator of mathematical reasoning ability,

$\sum x$ = Number of scores obtained by students,

N = The maximum score of the test in question

The values obtained are then analyzed using criteria based on the following table 2:

Table 2. Score Interpretation Criteria Per Indicator

No.	Persentase	Criteria
1.	0 – 20	Very weak
2.	21 – 40	Weak
3.	41 – 60	Simply
4.	61 – 80	Strong
5.	81 – 100	Very strong

(Permatasari & Marlina, 2022)

Results and Discussion

Reviewing the results obtained using descriptive percentage, it is known that the mathematical reasoning ability of class XI students on Newton's Law material can be divided into 5 (five) category groups. The five categories are very weak, weak, sufficient, strong and very strong. The results and discussion of mathematical reasoning ability are seen from the test questions that have been tested to students as many as 5 questions, where each question contains 4 indicators of mathematical reasoning, namely (1) writing conjectures; (2) predicting answers and calculation processes; (3) manipulating mathematics (4) drawing conclusions.

Writing Conjectures

The first mathematical reasoning indicator is writing conjectures. Learners are considered capable of meeting the criteria of this indicator if they can identify the known and questionable quantities from the statements presented in the problem (Yuniati, 2018). Learners are trained to be able to analyze the problem and write correctly and completely the quantities and units known and the quantities asked. Writing this information is very influential because it will affect the completion of the next step. The ability of students in the indicator of writing conjectures can be seen from the following figure 1:

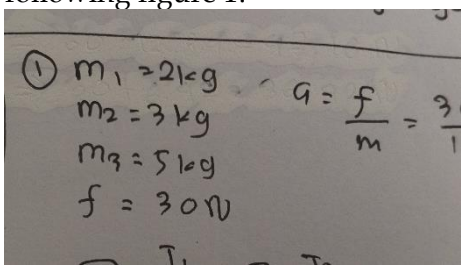

Figure 1. Sample answer to question 1

Based on Figure 1, it is known that students are able to analyze information quite well. Evidenced by students being able to write the known quantities of the given problem, namely m_1, m_2, m_3 and F along with the units correctly. However, students have not included questions from the problems presented in the problem. So that students are considered unable to fulfill the mathematical reasoning indicators of writing conjectures. Purwosetiyono et al (2022) revealed that the inability of students to write conjectures indicates that students do not understand the basic concepts of the importance of compiling hypotheses or conjectures as the first step in solving mathematics and physics problems.

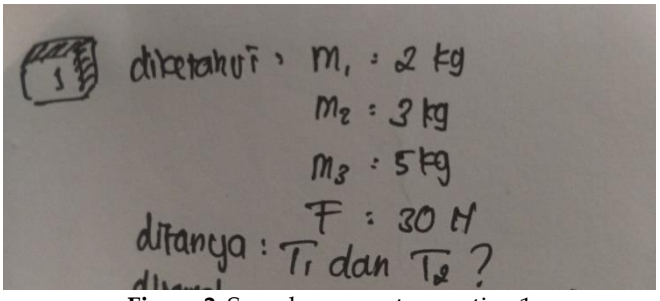

Figure 2. Sample answer to question 1

Based on Figure 2, it is known that students are able to analyze information very well. Evidenced by students being able to write m_1, m_2, m_3 and F and units correctly. And students are also able to identify questions from the problems presented, namely T_1 and T_2.. So that students are considered able to fulfill the mathematical reasoning indicator of writing conjectures. The mathematical reasoning ability of students of the first indicator is shown in Figure 3 below:

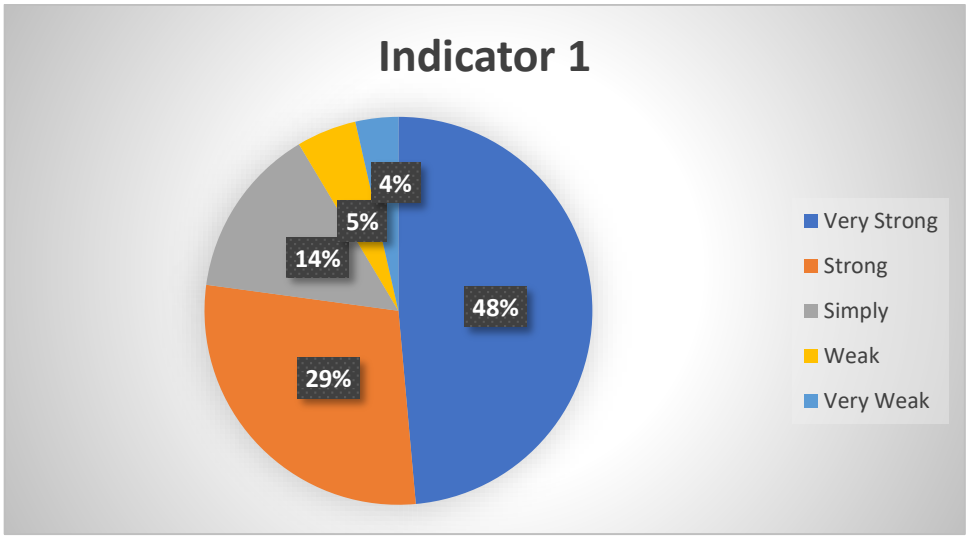

Figure 3. Percentage of Ability to Write Conjectures

Based on Figure 3 above, data on mathematical reasoning ability on indicator (1) writing conjectures are presented. From these data it is known that the majority of students are able to meet the criteria in writing conjectures. The percentage of students in the very strong category was 48%, in the strong category was 29%, in the moderate category was 14%, in the weak category was 5% and in the very weak category was 4%. The indicator of writing down the conjecture is influenced by several things, Pratama and Lestari (2022) revealed that this indicator is influenced by the experience of students in carrying out the investigation process and scientific discussions that stimulate the habit of students to express conjectures systematically.

Predicting Answers And Calculation Process

The second indicator of mathematical reasoning is predicting answers and calculation processes. The criteria for this indicator are that students can illustrate the answer from the given information and can analyze the problem and determine the applicable formula (Hamdi et al., 2024). In solving Newton's law problems, students are considered capable of fulfilling the indicator of predicting answers and calculation processes if they can depict a free-body diagram, apply Newton's laws to the free-body diagram, and write a linear equation from the given problem. Students' ability in the indicator of predicting answers and calculation processes can be seen in Figure 4.

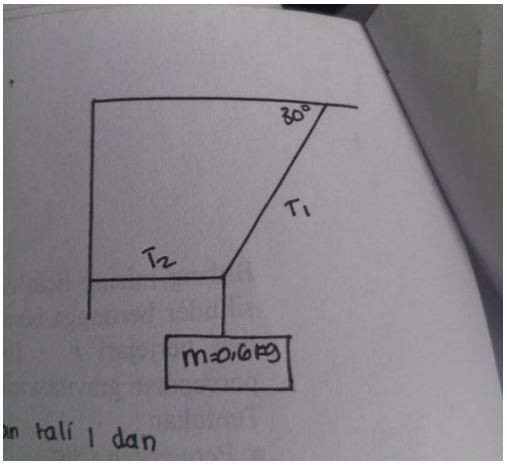

Figure 4. Sample answer to question 2

Based on Figure 4, students are categorized as less capable of meeting the criteria for the second indicator because, although they could depict the free-body diagram from the given problem, they were unable to identify the forces at play, could not apply Newton's laws to the

diagram, and did not write the appropriate linear equations. Consequently, students are considered not yet capable of fulfilling the mathematical reasoning indicator of predicting answers and calculation processes. According to Hartono and Purnama (2019), students' inability to predict answers and calculation processes indicates that students do not understand the steps of analysis systematically and are less able to decompose forces appropriately.

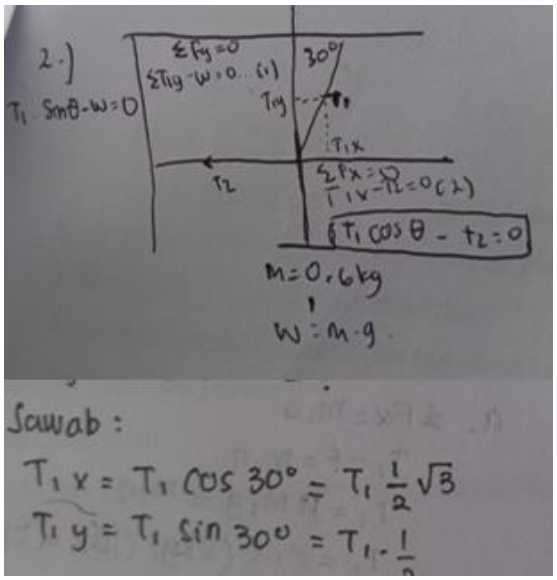

Figure 5. Sample answer to question 2

Based on Figure 5, it is known that students have met the criteria for predicting answers and calculation processes. This can be seen from the ability of students to describe the load force diagram of the problem given, as well as apply Newton's law and identify forces, angles and other things in the diagram, students can also write the linear equation used. Wahyuni (2019) students who are able to analyze completely and systematically will be better able to produce answers that are correct and can be scientifically justified. The mathematical reasoning ability of the second indicator students on newton's law material is shown in Figure 6 below :

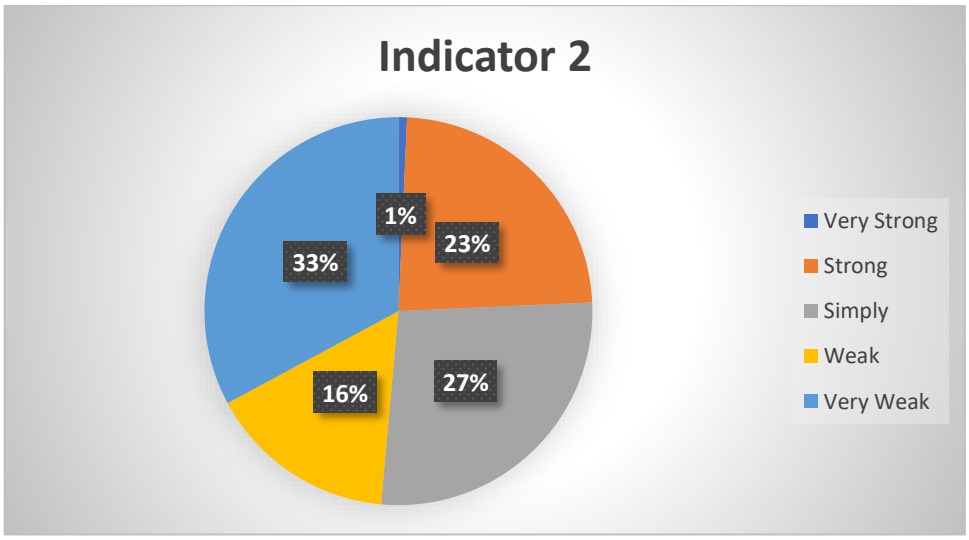

Figure 6. Percentage of Ability to Predict Answers and Calculation Processes

Based on Figure 6 above, presented data on mathematical reasoning ability on the second indicator, namely predicting answers and calculation processes. The mathematical reasoning ability of the third indicator was obtained by 1% of students in the very strong category, 23% of students in the strong category, 27% of students in the sufficient category,

16% of students in the weak category and 33% in the very weak category. The magnitude of this weak category is in accordance with Pratama and Wulandari's (2019) statement which states that students have enough difficulty in integrating physics and mathematics concepts, so that they are more likely to make mistakes in predicting answers and calculation processes.

Manipulating mathematics

The third mathematical reasoning indicator is manipulating mathematics. The standard indication for meeting the criteria for mathematical manipulation is that students can use the right formula and complete calculations accurately (Hamdi et al., 2024). In solving newton's law problems, students are considered capable of meeting the criteria for indicators of manipulating mathematics if they can write SPL (system of linear equations) and complete the calculations of the given problem correctly. The ability of students in the indicator of manipulating mathematics can be seen from Figure 7 below:

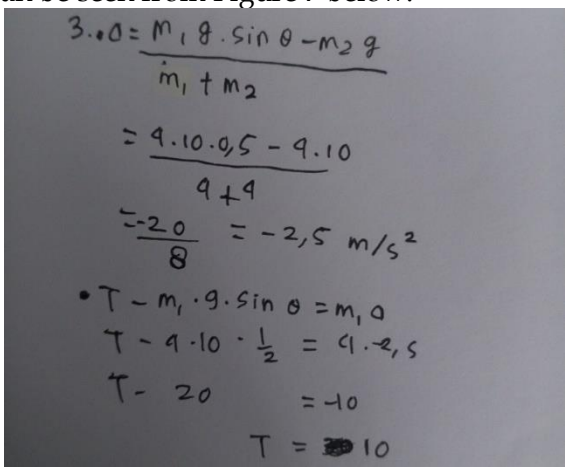

Figure 7. Sample answer to question 3

Based on Figure 7, students are categorized as not being able to meet the criteria for indicators of manipulating mathematics. Evidenced by students only being able to use formulas but not being able to write SPL (system of linear equations) and not completing calculations. Where students are asked to calculate the acceleration of the object system (a), the rope tension of object 1 (T_1) and the rope tension of object 2 (T_2). Students also cannot do the calculations correctly so that the results obtained are wrong / inappropriate. Research from Haris (2021) states that students who are less able to perform mathematical manipulations appropriately tend to have difficulty in understanding physics concepts in depth.

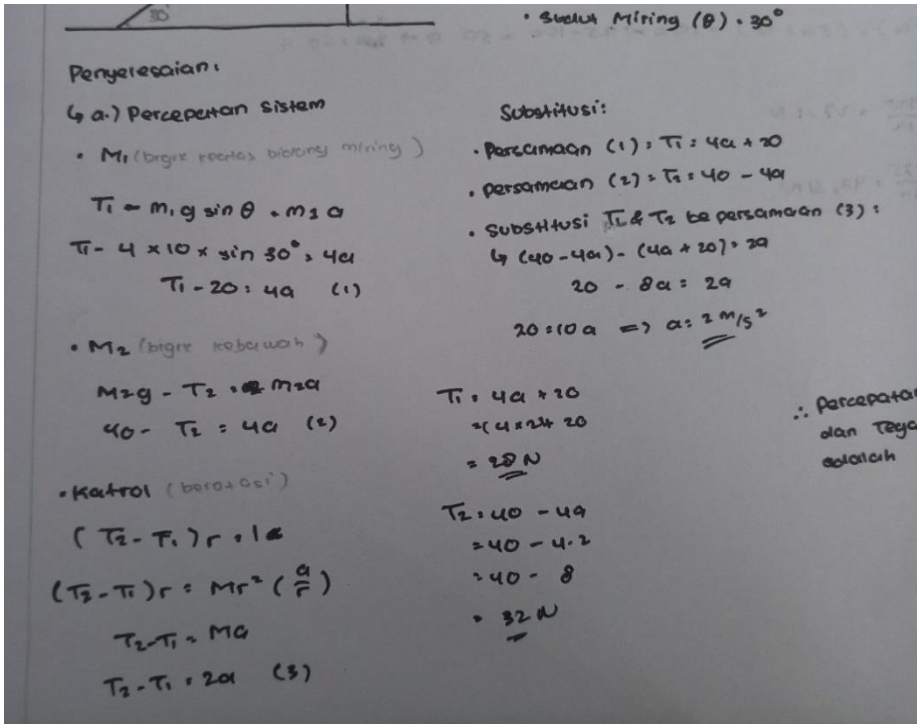

Figure 8. Sample answer to question 3

Based on Figure 8, students are quite capable of fulfilling the criteria for indicators of manipulating mathematics. This is evidenced by the learners' ability to solve SPL (system of linear equations) using identification from the second indicator phase. Learners can use the correct Newton's law formula when calculating the acceleration of the object system (a), the rope tension of object 1 (T_1) and the rope tension of object 2 (T_2), so that the calculation results that have been done get the correct results. These results are in accordance with the theory from Wibowo (2018), which states that good mathematical manipulation skills must follow procedures and be sequential so that the results are valid and can be accounted for.

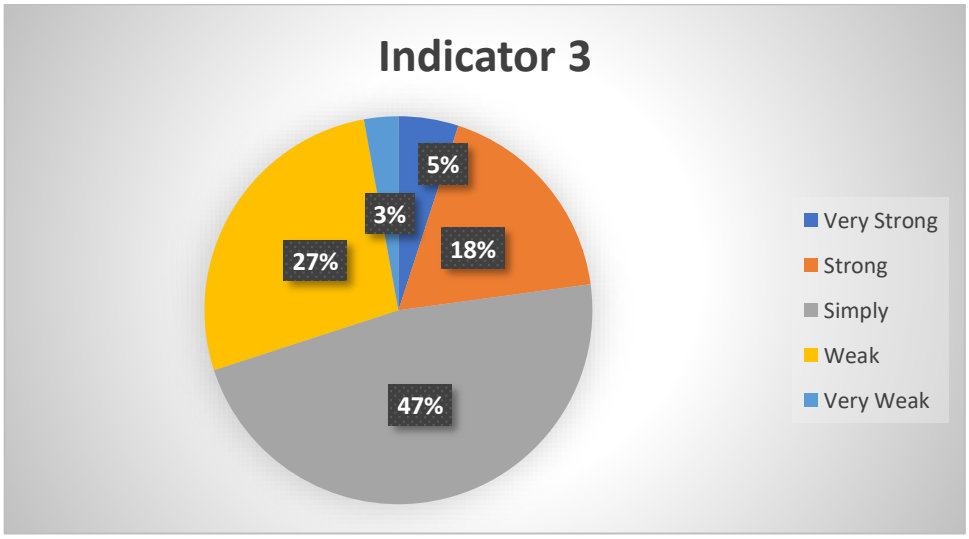

Figure 9. Percentage of Mathematical Manipulation Ability

Based on Figure 9 above, data on mathematical reasoning ability on the third indicator, namely manipulating mathematics, is presented. The mathematical reasoning ability of the third indicator was found to be 5% in the very strong category, 18% in the strong category, 47% in the sufficient category, 27% in the weak category and 3% in the very weak category. This result is influenced by students' ability to solve indicators 1 and 2. Research by Sari (2021) revealed that the low ability of mathematical manipulation contributes to the low success of

students in solving physics problems that require complex data management and precise formula conversion.

Drawing conclusions

The fourth mathematical reasoning indicator is drawing conclusions. Learners can rely on the calculation process in manipulating mathematics to structure and conclude the given problem. Learners can use their own sentences to describe conclusions (Gultom et al., 2022). So that in solving Newton's law problems, students are considered to meet the criteria if they can draw conclusions about all answers and units correctly accompanied by a description. The ability of students in the indicator of drawing conclusions can be seen from the following figure 10:

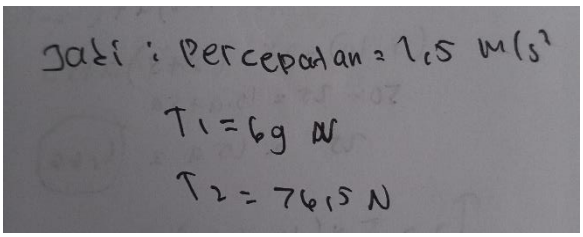

Figure 10. Sample answer to question 4

Based on Figure 10, it is known that students are able to analyze the results of calculations quite well. Evidenced by students being able to write the quantities obtained, namely ⟦a, T⟧_1, and T_2 along with the units correctly. However, students do not write a description of the calculations that have been done. So that students are considered unable to fulfill the indicator of mathematical reasoning drawing conclusions.

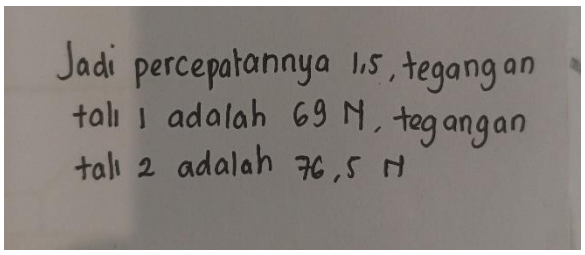

Figure 11. Sample answer to question 4

Based on Figure 11, it is known that students are able to analyze the results of calculations very well. Evidenced by students being able to write the quantities obtained, namely ⟦a, T⟧_1, and T_2 along with the units correctly. And also participants describe the results of the calculations that have been done. This is in accordance with the statement of Nurhidayah and Sari (2019), one of the indicators of success in drawing conclusions is the ability of students to integrate the analyzed data into a comprehensive explanation, so that students are considered capable of fulfilling the mathematical reasoning indicators of drawing conclusions.

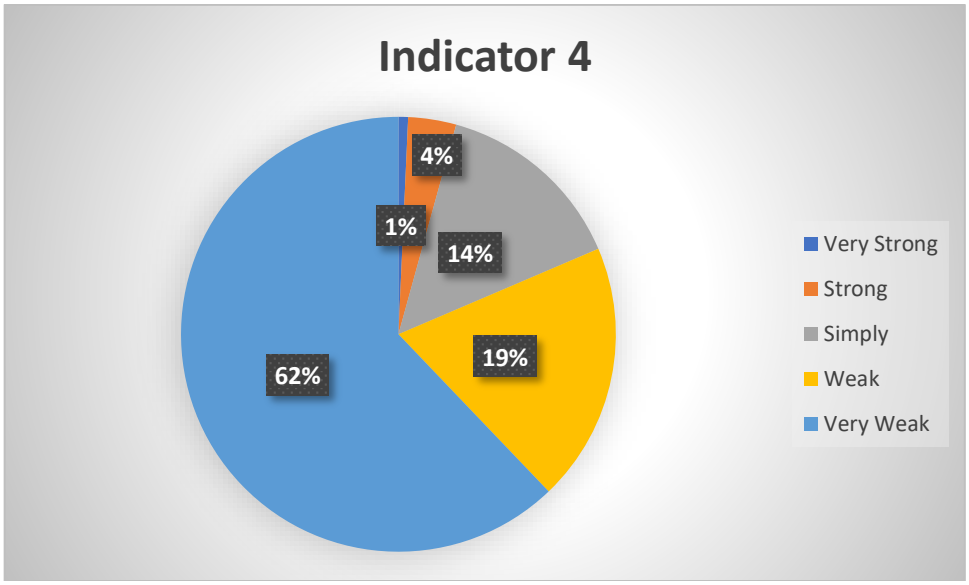

Figure 12. Percentage of Conclusion-Writing Ability

Based on Figure 12 above, data on mathematical reasoning ability on the fourth indicator, namely drawing conclusions, are presented. From the data presented, it is known that 1% of students are in the very strong category, 4% of students are in the strong category, 14% of students are in the sufficient category, 19% are in the weak category, and 62% are in the very weak category. This low result identifies that the majority of students cannot draw conclusions from the results of the calculations that have been carried out. The results of this study are in accordance with research conducted by Nurhidayah and Sari (2020) where the results of students' ability to draw conclusions are in the low category, namely 65%. This indicates that students have not been able to convey the processing data and are less able to relate data to concepts.

It can be concluded that the indicators are interrelated, where the work on the first indicator will affect the work at the next stage. The overall average value of mathematical reasoning ability in Jember District is described in Figure 13 below:

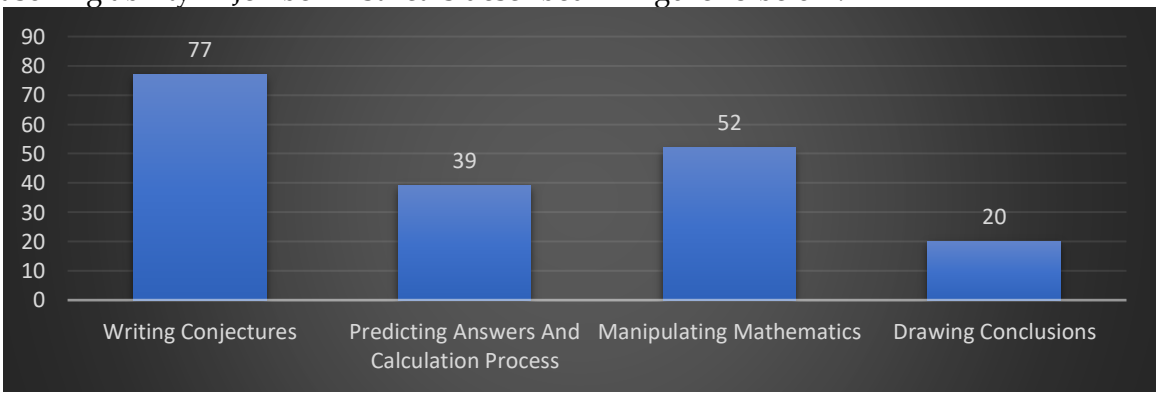

Figure 13. Mathematical Reasoning Ability Data in Jember City

From the data presented in Figure 13, it is known that the level of mathematical reasoning ability of students in the first indicator, namely writing conjectures, obtained a result of 77 so that it is in the strong category. This means that students in Jember Regency are able to analyze problem information by writing the known and questionable quantities and their units correctly and completely. According to the National council of teachers od mathematics (NCTM, 2000) that students are able to fulfill the indicator of writing a conjecture if they are able to compile an initial statement based on the available data and which is used as the basis for the next analysis process. there is a second indicator that predicts the answer and the calculation process obtained a result of 39% so that it is included in the weak category. This means that students in Jember Regency are less able to describe the diagram of the problem,

apply Newton's law to the load force diagram and write the linear equation of the problem given. The lack of student ability in this indicator is due to the unfamiliarity of students in describing and writing linear equations from problems that have been obtained from the problem. According to Hamdi et al (2024) students have difficulty in determining the formula to be used, this is due to the large number of physics formulas, the combination of existing formulas and the unfamiliarity of students practicing working on physics problems..

In the third indicator, namely manipulating mathematics, the result is 52 which is in the sufficient category. This means that students in Jember Regency are quite capable of completing calculations from the physics problems given. However, students are less able to develop existing formulas so that if there are problems that are different from the textbooks used, students have difficulty understanding and working on these problems. Suryadi and Fauzi (2020) revealed that the ability to manipulate mathematics of students is often lower than the ability to write conjectures. And in the fourth indicator, namely drawing conclusions, the results are quite low, namely 20 which is in the very weak category. This means that students in Jember Regency are less able to draw conclusions from the calculation results and describe the answers that have been done. The low results on this indicator indicate that only a small proportion of students can draw conclusions, or most students consider it not important to draw conclusions from a problem that has been done. Whereas the indicator of drawing conclusions is the culmination of various phases of mathematical reasoning ability (Hamdi et al., 2024).

Conclusion

Data on mathematical reasoning ability for each indicator from State High Schools in Jember Regency obtained an average level of mathematical reasoning ability of students in the first indicator of writing a conjecture of 77 so that it is in the strong category, in the second indicator predicting the answer and calculation process of 39 so that it is in the weak category, in the third indicator manipulating mathematics obtained a result of 52 so that it is in the sufficient category, while in the fourth indicator drawing conclusions obtained a fairly low result of 20 which is in the very weak category. This is in accordance with research conducted by Isti'anah (2018) which states that students tend to experience difficulties in the process of working on the 2nd and 3rd indicators so that it has an impact on the 4th indicator, namely drawing conclusions from the final results of the physics concept problem solving process. Pendagogically, this weakness in the mathematical reasoning process can cause students to have difficulty in understanding physics lessons which will have an impact on learning outcomes. So it is recommended for teachers to provide gradual practice and teach more systematic steps in solving problems. Teachers can also use problem solving, inquiry and group discussion learning models because they train students to think at a higher level.

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