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Analysis of Senior High School Students' Multi-representation Skills on Newton's Laws

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ABSTRACT

Physics learning is often considered difficult by students because it requires the ability to understand concepts verbally, mathematically, graphically, and diagrammatically. One of the subjects that demands these skills is Newton's Law. This study aims to analyze the level of students' multi-representation al skills in understanding Newton's Law in high schools in Palu City. This study uses a descriptive method with a quantitative and qualitative approach. Data were collected through a multi-representation skill essay test consisting of 5 questions and interviews. The research subjects were 12th grade students at four public high schools in Palu City (SMAN 1, SMAN 3, SMAN 4, and SMAN 7). The results showed that, in general, students' multi-representation skills were in the moderate category. A small number of students were in the high category, able to use various forms of representation consistently, while others were still in the low category, especially in graphical and mathematical representations. The conclusion of this study is that the multi-representation skills of high school students in Palu City regarding Newton's Laws are not yet uniform, with a tendency to be in the moderate category. This indicates the need for learning strategies that emphasize the use of multi-representation to strengthen the understanding of physics concepts.

INTRODUCTION

Physics education is one of the science subjects, including processes, scientific attitudes, and products. Science or Natural Sciences (IPA) is a field of study that deals with the structured study of nature, so that science studies information in the form of facts, concepts, or principles and the process of their discovery [1]. Physics is one of the subjects considered difficult in the Natural Sciences [2].

In Natural Sciences (IPA), physics is a subject closely related to verbal concepts, mathematics, images, and graphics. Multi-representation can be said to be something that symbolizes or represents both objects and processes. Representations can be in the form of words, images, diagrams, mathematical equations, or other forms [3].

Multi-representation is considered important because it can be used as a tool to describe a problem and help find the appropriate mathematical equation. When used consistently during the learning process, multi-representation can improve students' academic results. In addition, multi-representation is used to help students solve problems in physics questions. One physics topic that requires multi-representation skills is Newton's Laws [4].

Multi-representation skills in Newton's Laws involve students' ability to solve problems related to the concepts of force and motion through various forms of representation, such as verbal, force diagrams, graphs, and mathematical equations [5]. These representations complement each other to build a complete understanding of Newton's laws, which cover the relationship between force, mass, and acceleration. With these skills, students can describe physics situations visually, explain them verbally, and formulate appropriate mathematical relationships [6].

Based on observations conducted by researchers in several high schools in Palu City, it was found that some students often had difficulty connecting concepts with other representations, such as images, graphs, and mathematical equations. These findings indicate a gap between students' conceptual understanding and their ability to apply various forms of multi-representation in the context of physics, particularly in Newton's laws.

Several previous studies have examined multi-representation skills in physics learning in various regions, but not many studies have specifically examined these skills in high school students in Palu City [7]. Students' representation skills in fluid material still vary, where some students are able to write equations and understand symbols correctly but still experience difficulties in translating concepts into verbal and visual forms [8]. The test results show that only a small number of students are able to correctly connect formulas to the context of the questions. Overall, students' representation skills are at a moderate level because errors are still found in converting mathematical representations into other forms.

Therefore, this study has an element of novelty in the form of applying a multi-representation essay test on Newton's Law material to measure students' ability to connect conceptual, visual, and mathematical representations in the local context of schools in Palu City. Based on the above description, the purpose of this study is to determine the extent of high school students' multi-representation skills in Palu City in understanding and solving problems in Newton's Law material through essay-type tests. This study is expected to provide an empirical description of the level of students' multi-representation skills and serve as a basis for the development of more effective and contextual physics learning strategies.

METHOD

This study uses a descriptive method with a quantitative and qualitative approach (mixed methods). The quantitative approach is used to describe the level of students' multi-representation skills through essay-type tests, while the qualitative approach is used to deepen the results through interviews with selected respondents. The descriptive method was chosen because it aims to provide an objective picture of students' multi-representation skills in understanding Newton's Law material without giving special treatment [6].

This study was conducted in the odd semester of the 2025/2026 academic year in four public high schools in Palu City, namely Palu 1 Public High School, Palu 3 Public High School, Palu 4 Public High School, and Palu 7 Public High School. The research subjects were grade XII students at the four schools. The subjects were selected because they had received comprehensive instruction on Newton's laws, enabling them to provide relevant responses to the multi-representation test instrument. The number of respondents in the test phase was adjusted to the number of students in each school, while three respondents were selected for interviews from each school based on high, medium, and low categories according to the initial test results. The selection of interview respondents used purposive sampling, which is the deliberate selection of subjects based on certain criteria [9].

The data collection techniques used in this study consisted of two methods, namely tests and interviews. Tests were conducted to obtain quantitative data on the level of students' multi-representation skills in Newton's Law material and were administered in the form of five essay questions covering four types of representation: verbal, graphic, tabular, and mathematical. In addition, interviews were used as supporting qualitative data to gain a deeper understanding of students' abilities to understand and connect various forms of representation. The interviews were conducted with three selected respondents from each school representing the high, medium, and low categories [4].

The main instruments used in this study were a multi-representation skills test and an interview guide. The multi-representation skills test was developed based on indicators of students’ ability to explain physics concepts using various forms of representation, including verbal, graphical, tabular, and mathematical, in accordance with Newton’s Laws [3]. The test consisted of five essay questions that required students to explain and relate different representations in the context of force, mass, and acceleration. In addition, the interview guide was used to confirm the test results and to explore students’ in-depth understanding of Newton’s Law concepts as well as their difficulties in using multi-representation.

The research data were analyzed using descriptive analysis. Quantitative data obtained from the essay test results were analyzed by calculating the mean and standard deviation to determine the categories of students’ multi-representation skill levels, which were classified into high, medium, and low categories. The analytical ability score of students for each question item was calculated using the following formula:

$$\mathrm{A} = \frac{x}{n} \times 100 \qquad (1)$$

Where A represents the student’s analytical ability score for each item, x is the score obtained from the question item, and n is the maximum score for that item. Furthermore, the overall analytical ability score for all questions was calculated using the formula:

$$A_{\mathrm{rata}} = \frac{\Sigma A}{Maximum\ Score} \times 100 \qquad (2)$$

After obtaining the total score for each student, the mean and standard deviation were calculated to analyze the distribution of students’ scores. The mean score was calculated using the formula:

$$\bar{x} = \frac{\Sigma xi}{n} \quad (3)$$

While the standard deviation was calculated using the formula:

$$SD = \sqrt{\frac{\Sigma(x_i - x)^2}{n}} \quad (4)$$

Where x̄ represents the average score obtained by students, xi is the individual student score, and n is the number of samples. Based on the results of these calculations, students' multirepresentation skill levels were categorized into three levels. Students were classified into the high category if their score was greater than the mean plus the standard deviation, into the medium category if their score fell between the mean minus the standard deviation and the mean plus the standard deviation, and into the low category if their score was less than the mean minus the standard deviation.

RESULTS AND DISCUSSIONS

These research results were obtained after administering a multi-representation skills essay test on Newton's Laws to 12th grade students at four public high schools in Palu City, namely Palu 1 Public High School, Palu 3 Public High School, Palu 4 Public High School, and Palu 7 Public High School. In general, the results show that the multi-representation skills of students at the four schools are at a moderate level. This indicates that most students are able to use several forms of representation, but are not yet consistent in linking them comprehensively. A small number of students have demonstrated a high level of ability in accurately linking representations, while others still have difficulties, especially in reading graphs and interpreting data in tables. The level of multi-representation skills of students in each school can be seen in Table 1.

Table 1. Results of the Analysis of Multi-representation Skills of Students at Senior High Schools in Palu City

School	Avg	SD	Dominant Category	Category (Number of Students)			General Description of Test Results
				High	Medium	Low	
SHS 1	75	15	Medium	3	22	3	Students are quite good at verbal and mathematical representation, but still weak at graphs and tables.
SHS 3	77	10	Medium	5	11	7	Students are beginning to be able to relate verbal representations to mathematical ones, but have difficulty understanding graphs and force diagrams.
SHS 4	60	20	Medium	6	21	4	Multirepresentation skills vary; most can explain concepts verbally, but err when interpreting graphical data.
SHS 7	63	14	Medium	4	18	5	Students are weak in mathematical and graphical representation; some are only

School	Avg	SD	Dominant Category	Category (Number of Students)			General Description of Test Results
				High	Medium	Low	
							able to explain verbally without accurate calculations.

Table 1 shows that students' multi-representation skills across the four senior high schools in Palu City are generally classified into the moderate category, with average scores ranging from 60 to 77. SMA Negeri 3 Palu obtained the highest average score (77), while SMA Negeri 4 Palu showed the lowest average score (60). This pattern indicates that students have acquired basic multi-representation abilities but have not yet developed strong integration among different forms of representation, suggesting that their understanding of Newton's Laws remains partially constructed rather than conceptually coherent [6].

Although the dominant category across schools is similar, the differences in average scores suggest that instructional practices and learning environments influence students' representational development. Schools that provide more frequent opportunities for students to engage with various representations, such as graphs, tables, and diagrams, are likely to support deeper conceptual understanding. Conversely, learning environments that emphasize routine problem solving and formula substitution may limit students' opportunities to translate concepts across representations, resulting in moderate rather than high multi-representation performance [4].

Analysis based on representation types reveals that students demonstrate stronger performance in verbal and mathematical representations compared to graphical and tabular representations. Verbal explanations and mathematical equations are commonly emphasized in physics classrooms, making students more accustomed to these forms. In contrast, graphical and tabular representations require students to interpret relationships between variables, recognize patterns, and translate abstract concepts into visual forms. These skills involve higher-order cognitive processes that are less frequently trained in traditional instruction, leading to persistent difficulties in visual representation tasks [5].

The dominance of students who are able to use only one or two representations indicates that many students are still operating at lower mental model levels. At these levels, conceptual understanding is fragmented, meaning that students may understand force, mass, or acceleration individually but fail to connect these concepts when confronted with problems requiring representation translation. This fragmented understanding prevents students from constructing a unified conceptual framework and limits their ability to apply Newton's Laws flexibly across different contexts [10].

Interview findings provide further insight into students' representational abilities. Students in the high category demonstrated representational fluency, characterized by the ability to move flexibly between verbal explanations, mathematical expressions, and visual representations. This fluency reflects a deeper conceptual understanding in which representations are not treated as separate entities but as complementary tools for explaining physical phenomena. In contrast, students in the medium category tended to rely heavily on a single dominant representation and experienced cognitive overload when required to transform information into other forms. Students in the low category often provided brief, unsubstantiated answers, indicating weak conceptual foundations and a lack of confidence in using representations meaningfully [8].

Overall, the findings indicate that students' multi-representation skills in Palu City still require substantial improvement, particularly in graphical and tabular representations. The imbalance between strong verbal–mathematical skills and weak visual skills suggests that students' learning experiences have not sufficiently emphasized representation translation. This imbalance can contribute to superficial understanding, where students are able to manipulate equations without fully grasping the physical meaning underlying the mathematical relationships [6, 11].

From a pedagogical perspective, these results highlight the importance of integrating multi-representation explicitly and systematically into physics instruction. Rather than treating representations as optional or supplementary, teachers should design learning activities that require students to interpret, construct, and compare multiple representations within a single problem context. Such approaches can help students recognize the equivalence and complementary nature of different representations, thereby strengthening conceptual coherence [11].

Furthermore, diagnostic-oriented learning strategies are essential for identifying students' representational weaknesses and misconceptions. Diagnostic assessments can provide detailed information about students' conceptual gaps and difficulties in representation translation, allowing teachers to design targeted interventions. Research has shown that diagnostic instruments are effective in revealing students' misconceptions and supporting more informed instructional decision-making [12].

The use of multimodal and multi-representation based learning media also offers promising potential for enhancing students' representational abilities. Learning media that integrate text, images, animations, and mathematical expressions can reduce cognitive load and support students in visualizing abstract concepts. Such media can facilitate the development of connections among representations and promote more meaningful learning experiences, particularly for complex topics such as Newton's Laws [13]. Furthermore, these learning experiences contribute to the development of essential 21st-century skills, including conceptual understanding, problem-solving skills [14], and the ability to communicate scientific ideas through multiple forms of representation.

This study contributes to the existing literature by providing a comprehensive analysis of students' multi-representation skills across four senior high schools in Palu City using a mixed-method approach. By combining quantitative test data with qualitative interview findings, this study offers a nuanced understanding of how students at different achievement levels use and connect representations. The results confirm that while verbal and mathematical representations are relatively well developed, graphical and tabular representations remain a significant challenge. Consequently, the findings underscore the need for multi-representation oriented physics learning strategies that emphasize representational integration to foster deeper conceptual understanding and improve students' ability to apply Newton's Laws meaningfully across diverse problem contexts [4, 11].

CONCLUSION AND SUGGESTION

Based on the results of the analysis and discussion, the multi-representation skills of senior high school students in Palu City on Newton's Law material are generally categorized as moderate. The average scores obtained were 75 for SMAN 1 Palu, 76 for SMAN 3 Palu, 60 for SMAN 4 Palu, and 63 for SMAN 7 Palu. These results indicate that although students have begun to develop multi-representation skills, their abilities have not yet been evenly distributed across all forms of representation.

Most students were able to use verbal and mathematical representations relatively well; however, they still experienced difficulties in interpreting and constructing graphical and tabular representations. Students in the high category were able to connect various forms of representation consistently and coherently, while students in the moderate and low categories were still limited in their ability to apply and translate between representations. This finding confirms that students' mastery of multi-representation is not yet comprehensive, highlighting the need for more integrated Multi-representation-based physics learning to improve students' conceptual understanding and problem-solving skills.

Considering these findings, there is still considerable potential to further develop students' multi-representation skills. Future research is recommended to explore the factors contributing to students' difficulties in using multiple representations, such as limited conceptual understanding, classroom learning habits, and teachers' instructional strategies. In addition, further studies should examine the relationship between representation errors and misconceptions in physics in order to identify the underlying causes of low multi-representation skills. The results of this study are expected to serve as a foundation for subsequent research and instructional development efforts aimed at strengthening and improving students' multi-representation skills in physics learning.

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