

# Implementation of a Multi-Representation Approach to Enhance Students' Learning Outcomes in Rigid Body Equilibrium

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## Abstract:

The equilibrium of rigid bodies is often regarded as a difficult topic in physics education as it requires a complex integration of verbal understanding, visualisation of force diagrams, and mathematical formulation. This study aims to evaluate the effectiveness of the multi-representation approach (MRA) in improving students' cognitive learning outcomes on this subject matter. This study employed a quasi-experimental method with a one-group pretest–post-test design involving 20 students in Class 11 at SMA Negeri 2 Tomohon. The research instrument consisted of a validated essay test using Aiken's V coefficient and the Content Validity Ratio. Data were analysed using a paired t-test and the normalised gain score. The results showed a significant increase in the mean learning outcome score, from 55.50 in the pre-test to 75.85 in the post-test. Statistical analysis yielded a  $t_{count} = 13.81$  that exceeds  $t_{tabel} = 2.09$ , indicating a rejection of the null hypothesis. An N-Gain score of 0.62 places the effectiveness of the intervention in the 'Moderate' category. These findings demonstrate that the MRA effectively minimises students' cognitive load by providing a transitional bridge from visual representations (Free Body Diagram) to accurate mathematical solutions. This study recommends the use of MRA as an essential instructional strategy to enhance conceptual understanding of abstract mechanics material.

## 1. Introduction

Physics education in the 21st century has shifted from the mere transmission of factual knowledge towards an emphasis on the scientific process, which involves modeling, critical thinking, and scientific literacy (Bao & Koenig, 2019). Globally, a solid grasp of physics concepts—encompassing cognitive, attitudinal, and skill-based aspects—is a cornerstone for developing competent human resources in the STEM fields (Science, Technology, Engineering, and Mathematics). However, significant challenges remain in the context of physics education in Indonesia, where students' ability to construct knowledge through a systematic scientific process still requires serious attention to meet international standards (Poluakan et al., 2019; Qadar et al., 2025) (Qadar et al., 2025).

The study of physics involves phenomena in our daily lives, whether macroscopic (large-scale) or microscopic, that relate to changes in matter or energy. The scope of physics is vast, ranging from atoms measured in nanometres to the universe measured in light-years. One characteristic of physics is that its subjects of study are abstract. It is this abstract nature that causes many students to struggle with understanding physics concepts. Yet, many of the noble values of physics are beneficial in daily life. However, in reality, physics at school is still regarded as a difficult subject, even frightening, and some even view it as a nightmare.

A common problem in physics education is the weakness of classroom instruction. Most students consider physics to be a very difficult subject. The main factor is the large number of mathematical equations in physics. Most students believe that these mathematical equations must be memorized, which causes many students to struggle with learning physics, resulting in a low level of conceptual understanding in physics; the problems relating to conceptual understanding experienced by students are documented in several research findings (Azizah & Suprpto, 2020). This problem naturally results in a decline in students' learning outcomes (LO). Difficulties in learning Physics are influenced by the broad scope of the subject matter, the consistently challenging nature of examination questions, and the sometimes overly in-depth nature of the subject, which requires time and extensive practice to grasp the basic concepts. Consequently, there is a need for innovation to develop students' critical thinking skills, enabling them to acquire knowledge independently and achieve optimal learning outcomes through the use of real-world events and media found in their immediate environment.

A clear gap in physics learning is currently evident in the low level of student achievement in advanced mechanics topics. Various sources indicate that learning outcomes, such as standardized test results and project assignments, often reveal a low level of conceptual understanding, as students tend to rely on memorizing formulas without understanding the underlying physical principles (Bao & Koenig, 2019; Qadar et al., 2025). At the national level, students' difficulties in solving both theoretical and applied physics problems are often reflected in examination scores that fall short of the minimum pass mark, a situation exacerbated by a lack of visualization skills when it comes to accurately representing physical phenomena (Aryani et al., 2022).

One approach that has proven effective in supporting the science learning process is the multi-representation approach (MRA). This approach emphasizes the use of various forms of representation—such as verbal, visual, mathematical, and concrete—to build a comprehensive conceptual understanding (Fischer et al., 2018). Although MRA has been extensively tested at the undergraduate level (Kohl et al., 2007; Niyomufasha et al., 2024), its application at the secondary school level still requires more extensive empirical evidence, particularly for material with a high degree of visual complexity. Furthermore, the effectiveness of MRA has been demonstrated in the context of work and energy (Taqwa et al., 2020), yet its application in the field of the equilibrium of rigid bodies has yet to be explored in depth at the secondary school level (Astuti, 2014; Nisa, 2017). Previous studies have also tended merely to describe students' multi-representational ability profiles without implementing interventions to measure tangible improvements in learning outcomes (Aryani et al., 2022; Sarizan et al., 2022).

The MRA presents a significant opportunity to improve learning outcomes by providing students with a variety of cognitive channels. Unlike conventional methods, the MRA offers a functional advantage in training students to translate information from verbal to visual formats (such as free-body diagrams) and then to mathematical formats simultaneously (Wong et al., 2011). The use of MRA is predicted to significantly improve learning outcomes as it reduces the cognitive load on students when dealing with complex problem structures involving rigid bodies (Hochberg et al., 2020; Nisa, 2017). By mastering various modes of representation, students have a greater chance of achieving a more comprehensive grasp of concepts, which is an essential requirement in modern physics education (Munfaridah et al., 2021; Taqwa et al., 2020). In the context of learning the equilibrium of rigid bodies, the multi-representational approach is crucial. For example, students' ability to draw and interpret force diagrams (free-body diagrams) is vital for determining moments of force and understanding the conditions  $\sum F = 0$  and  $\sum \tau = 0$ . This ability cannot be developed through a purely computational

approach alone; rather, it must be supported by strong visual and verbal understanding (Kohl & Finkelstein, 2008). This study is expected to make a theoretical contribution to the development of representation-based physics learning models and to provide practical recommendations for teachers on designing more effective and contextually relevant learning strategies. Numerous studies suggest that MRA can help students understand physics concepts. The repetition of physics concepts is based on selecting representation formats that are appropriate to the material's characteristics, such as abstract physics concepts, and to visualizing phenomena, thereby facilitating the learning process. Based on this gap in the literature, this study aims to explicitly measure the effectiveness of applying an MRA in improving students' cognitive learning outcomes on the topic of the equilibrium of rigid bodies. By comparing results before and after the intervention, this study is expected to provide practical solutions for educators in addressing students' difficulties with this topic.

## 2. Theoretical Framework

### 2.1. *Physics Education*

The teaching of physics can be defined as a long-term process of interaction between students and teachers, in which the learning resources utilized during the transfer of knowledge and experience employ various teaching methods to develop students' potential by organizing or structuring the learning environment as effectively as possible to achieve optimal results. The teaching of physics faces various challenges in achieving optimal educational outcomes. Many students regard physics as a difficult subject because it involves many formulas and theories that must be memorized, whereas physics education actually places greater emphasis on conceptual understanding than on rote learning (Riani et al., 2021). Students' poor understanding of physics concepts will affect their ability to learn physics (Santhalia & Sampebatu, 2020). This is exacerbated by the misconceptions held by students, which arise because physics is perceived as an abstract subject among students (Santhalia & Sampebatu, 2020). Research shows that even after completing hundreds of physics problems, many students still fail to acquire adequate conceptual understanding (Gjerde et al., 2021).

To address these issues, an innovative teaching approach is required that is tailored to the nature of physics. The aim of physics education is to develop analytical thinking skills, using physics concepts and principles to explain everyday phenomena and solve problems—both qualitatively and quantitatively. Innovative teaching methods in physics can make it easier to understand the subject matter. Teaching abstract concepts naturally requires resources that can present these concepts in a more concrete way, such as images, videos, or animations, so that the concepts are presented more clearly. Consequently, physics teaching needs to be tailored to the subject matter's characteristics and delivered systematically so that students can fully grasp the concepts presented, thereby ensuring that the learning objectives are achieved.

### 2.2. *Multi-Representation Approach*

The Multi-Representation Approach (MRA) is an instructional strategy that presents scientific concepts through more than one form of representation, such as verbal (text/spoken), visual (pictures/diagrams), mathematical (equations/formulas), symbolic, and concrete (Fischer et al., 2018). MRA operates within the framework of Design, Functions, and Tasks, which states that multiple representations serve to complement one another (complementary), prevent misinterpretation (constraining), and foster a deeper understanding (constructing) (Hochberg et al., 2020; Wong et al., 2011).

Psychologically, the effectiveness of MRA is rooted in Cognitive Load Theory (Cognitive Load Theory) developed by Sweller. This theory explains that human working memory capacity is very limited; by distributing information across various channels (e.g., visual and verbal), MRA can reduce extrinsic cognitive load and maximize memory capacity for processing relevant information (Hahn & Klein, 2023; Hochberg et al., 2020). Furthermore, MRA supports constructivism, whereby students actively construct their own knowledge by synthesizing information from various sources of representation in order to achieve a comprehensive conceptual understanding. The key strength of MRA lies in students' ability to perform translation between representations (Niyomufasha et al., 2024). In the context of physics, this ability enables students to accurately translate physical phenomena from visual diagrams (such as free-body diagrams) into mathematical equations (Newton's laws) or verbal explanations. Students' failure to understand concepts is often due to their inability to make the connection between one form of representation and another; therefore, practicing this ability to translate between them is key to mastering physics concepts (Munfaridah et al., 2021).

MRA serves as a cognitive bridge to achieve these learning outcomes. MRA provides various modes of information, each of which plays a unique role in supporting specific learning outcome domains: (1) Verbal Representation (Text/Oral): Serves to identify concepts and define variables. This representation supports learning outcomes at the Understanding (C2) level, where students are able to describe the physical conditions of a system in a state of equilibrium. (2) Visual Representation (Pictures/Diagrams): Enables students to visualize invisible entities, such as force vectors. This representation is crucial for supporting the Analyzing skill (C4) as it helps students break down interactions between objects without the excessive cognitive load of mathematical symbols. (3) Mathematical Representation: Functions as a precision computational tool. This representation supports learning outcomes at the Applying (C3) level, where students transform physical relationships into quantitative models that can be solved. (4) Graphical Representation: Helps students identify patterns of relationships between variables, such as the relationship between the force arm and the magnitude of the moment of force, which supports the development of critical thinking skills. The strength of MRA lies in its ability to translate between formats. When students are able to translate visual diagrams into mathematical equations, the extrinsic cognitive load is reduced, thereby significantly improving cognitive learning outcomes.

### 2.3. Learning Outcomes

Cognitive learning outcomes are behavioral changes in intellectual aspects that occur following the learning process. Educational theorists such as Robert Gagné define learning outcomes as human abilities that encompass verbal information, intellectual skills, cognitive strategies, attitudes, and motor skills (Gagne, 1985). In this study, the primary focus is on intellectual skills and conceptual mastery, which are measured quantitatively. To systematically assess students' conceptual understanding, this study refers to the Revised Bloom's Taxonomy by Anderson & Krathwohl (Bao & Koenig, 2019; Qadar et al., 2025). This taxonomy divides the cognitive domain into six levels: Remembering (C1), Understanding (C2), Applying (C3), Analyzing (C4), Evaluating (C5), and Creating (C6) (Bao & Koenig, 2019). In the context of the topic of equilibrium in rigid bodies, this study identifies the following learning outcome indicators at the cognitive level: (1) C2: Students' ability to interpret the conditions for static equilibrium ( $\sum F=0$  and  $\sum \tau=0$ ) from descriptions of physical phenomena. (2) C3: Students' ability to use formulas and the principle of torque to solve problems involving lever systems or ladders leaning against a wall. (3) C4: Students' ability to break down the components of force in a free-body diagram (visual representation)

and relate them to the stability of an object in a state of equilibrium. By targeting cognitive levels (CL) C2 to C4, this study aims to assess whether MRA actually helps students move away from simply memorizing formulas towards an integrated and functional understanding of concepts (Bao & Koenig, 2019; Danielson & Mehta, 2002).

#### 2.4. Multi-representation mapping in the study of the equilibrium of rigid bodies

The topic of the equilibrium of rigid bodies serves as an ideal example for the application of MRA, as its structure requires the integration of multiple concepts. Table 1 provides a comprehensive mapping of this topic, breaking down each sub-topic into verbal, visual, mathematical, and concrete representations alongside their corresponding teaching strategies.

**Table 1.** Multi-representational strategic mapping of the equilibrium of rigid bodies

Sub-topic	Types	Operational Description in Teaching	CL & LO
The Concept of Torque	Verbal	Explain, either orally or in writing, how a force produces torque that causes rotational motion about a particular axis..	C2: Students are able to define the variables that cause rotational motion.
	Visual	Draw a sketch of the position of the force relative to the axis, identify the direction of rotation (clockwise or anti-clockwise), and determine the lever arm graphically.	C3: Students are able to visualise force vectors in a rotating coordinate system.
	Mathematical	Derive the equation for the moment of force based on the angle formed: $t = rF\sin\theta$ .	C3: Students are able to perform quantitative calculations of torque.
Conditions for Static Equilibrium	Visual	Drawing a complete Free Body Diagram ( <i>Free Body Diagram</i> ), including the force of gravity, normal force, friction, and cable tension in systems such as staircases or bridges.	C4: Students are able to accurately analyse the components of force in complex systems.
	Mathematical	Translating the visual diagram into the equation for the resultant force ( $\sum F = 0$ ) and the resultant of the moments ( $\sum \tau = 0$ ) (Niyomufasha et al., 2024).	C4: Students are able to link different representations to problem-solving strategies.
Centre of Gravity	Concrete / Graphic	Conducting an experiment to determine the centre of gravity of a non-homogeneous rigid body or a two-dimensional shape using a coordinate graph.	C3: Students are proficient in modelling the centre of mass of an object geometrically.
	Mathematical	Using average coordinates ( $\bar{x}, \bar{y}$ ) to determine the object's equilibrium position with precision.	C3: Students are able to calculate the origin of a combined coordinate system.

### 3. Method

This study was conducted at Tomohon State Senior High School No. 2 during the 2024/2025 academic year. This study employed a quantitative approach using a pre-experimental method through a One-Group Pretest-Posttest Design, which involves observing a single experimental group before and after they receive a specific treatment. The implementation of this design consists of three sequential steps. First, a pre-test ( $O_1$ ) is conducted as an initial measurement to assess the baseline condition or performance of the subjects before any intervention is introduced. Following this, the experimental treatment ( $X$ ) is administered to the group. Finally, a post-test ( $O_2$ ) is conducted after the intervention has concluded to evaluate any effects or changes resulting from the treatment. By comparing the results of the post-test ( $O_2$ ) against the baseline established in the pre-test ( $O_1$ ), we can determine the impact of the applied treatment ( $X$ ).

The population of the study consists of all Class 11 students, and the sample comprises 20 students selected using Purposive Sampling. This technique was chosen because these students are currently studying the topic of equilibrium of rigid bodies in the current semester, thereby enabling the research to be conducted.

The variables in this study are operationally defined as follows: Independent Variable: Multi-Representation Approach. This variable is operationalized through a series of learning processes that utilize MRA-based Student Worksheets. Students are trained to perform translation between representation formats, namely translating data from verbal to visual form (free-form diagrams), from visual to mathematical form (equations of torque and force), and into graphical form. Dependent Variable: Students' cognitive learning outcomes. This variable is measured through students' scores on a test instrument designed based on Bloom's Taxonomy Revised by Anderson & Krathwohl, with a focus on the cognitive levels of C2, C3, and C4.

Data were collected through the administration of a pre-test and a post-test. The instrument used consisted of five essay questions, detailed in Appendix A (Table 8), designed to assess an in-depth understanding of the concept of equilibrium in rigid bodies. Prior to use, the instrument underwent content validation testing carried out by two physics education experts to ensure the questions aligned with the learning indicators (see Appendix B, Table 9, for expert validation scores). Validity estimates were calculated using the Aiken V-Model, the final results of which are presented in Appendix B (Table 10). Empirical Validation: A pilot test was conducted on a group outside the sample to calculate item validity using the Pearson correlation, Product-Moment, and reliability using the Cronbach's Alpha coefficient. In addition, an analysis of item difficulty levels and discrimination indices was carried out to ensure that the instrument was capable of accurately distinguishing between students' abilities. The measurement of cognitive learning outcomes through five essay questions was carried out using objective assessment guidelines. This rubric was designed to assess the extent to which students were able to use various representations in solving rigid-body equilibrium problems. The scoring criteria, ranging from 0 to 4 based on representational accuracy, are outlined in Table 2

**Table 2.** *Assessment Rubric for the Learning Outcomes Test Instrument*

Score	Assessment Criteria
4	Comprehensive & Accurate: The answers demonstrate a full understanding; free-body diagrams are drawn correctly (visual), mathematical equations are written correctly, and the final results are accurate.
3	Good, but with a few errors: The visual representation is correct, but there are minor errors in the mathematical calculations, or vice versa.
2	Partial: The student is able to present one form of representation (e.g. only a diagram or only a formula) but fails to link (translate) the two to arrive at a solution.
1	Minimum: Students simply list the known variables or attempt to provide verbal explanations that are not particularly relevant.
0	No Answer: The student did not answer, or the answer was completely irrelevant to the concept of equilibrium.

The intervention was carried out in three main stages, with each session lasting  $2 \times 45$  minutes, over a total of three sessions. To provide a clear picture of the classroom intervention, this study followed the phases of the MRA, which integrates various modes of information. Details of the activities undertaken by the teacher and students, and their relationship to cognitive levels, are presented in Table 3.

Data analysis techniques using statistical analysis were employed to test the following research hypotheses:

- Null Hypothesis ( $H_0$ ): There is no significant difference in students' learning outcomes before and after the implementation of the MRA on the topic of equilibrium in rigid bodies.

- Alternative Hypothesis ( $H_1$ ): There is a significant difference (improvement) in students' learning outcomes before and after the implementation of the MRA on the topic of equilibrium in rigid bodies.

**Table 3.** *Learning Syntax for the MRA*

No	Phase MRA	Teacher Activities	Student Activities	Cognitive Levels
1	Orientation & Verbal Representation	Present real-life examples (e.g. people carrying loads or ladders leaning against a wall) and ask a prompt question.	Observing the phenomenon and providing an initial explanation, either orally or in writing, regarding the conditions for equilibrium.	C2: Identifying the concept of equilibrium.
2	Visual Representation	Guiding students to convert physical phenomena into free-body diagrams ( <i>Free Body Diagram</i> ).	Accurately draw the force vectors (weight, normal force, friction) acting on the object under observation.	C3: Visualise the forces at work.
3	Mathematical Representation	Guide the students to derive the equation from the diagram they have drawn.	Writing equations $\sum F = 0$ dan $\sum \tau = 0$ to determine the unknown force.	C3: Using mathematical procedures to solve problems.
4	Translation and Synthesis	Presenting new problems that require students to make connections between different forms of representation independently.	Translating information: from the question text (verbal) to a diagram (visual), and then to a calculation (mathematical).	C4: Linking different representations to arrive at logical solutions.
5	Evaluation and Reflection	To provide feedback and assess the accuracy of the representations chosen by the students.	Summarising the interrelationships between representations in order to develop a comprehensive understanding of equilibrium.	C4: Evaluating the validity of the concepts developed.

Quantitative data analysis was performed using SPSS 20 software, beginning with a descriptive analysis to illustrate the shift in the distribution of student scores from the pre-test to the post-test. Prior to hypothesis testing, a prerequisite normality test was conducted using the Shapiro-Wilk method. The criterion for normality was established at an alpha level of 0.05; specifically, the data distribution is considered normal if the significance value is greater than 0.05 ( $p > 0.05$ ). Following the verification of this assumption, a paired-samples t-test was employed to evaluate the difference in mean scores before and after the intervention. This specific parametric test was selected because it is designed to detect significant interventional effects within the same sample group across two different time points. Improvements in learning outcomes were analyzed using the *Normalized Gain* score. This analysis is crucial as it not only demonstrates the presence of differences but also the extent of the increase in students' cognitive capacity following exposure to various modes of representation. The standard criteria used to interpret these N-Gain scores are outlined in Table 4.

**Table 4.** *N-Gain Criteria*

Interval N-Gain	Category
$g \geq 0,70$	High
$0.30 \leq g < 0.70$	Medium
$g < 0.30$	Low

## 4. Result

### 4.1. Descriptive Analysis

As shown in Table 5, the descriptive statistical analysis of the 20 participating students indicates a clear improvement following the intervention. The pre-test scores ranged from a minimum of 10 to a

maximum of 80, with a mean of 56.00. In contrast, the post-test results demonstrated notable gains, with the minimum score rising to 50, the maximum reaching 100, and the overall mean increasing to 81.00.

**Table 5.** *Results of the Descriptive Statistical Analysis*

Statistics	Pre-test	Post-test
Sample Size (N)	20	20
Minimum Value	10	50
Maximum Value	80	100
Mean	56.00	81.00
Median	55.00	80,00
Mode	70	70 and 80
Range	70	50

Further analysis reveals that the median score increased from 55.00 on the pre-test to 80.00 on the post-test. While the pre-test data featured a single mode of 70, the post-test data presented a bimodal distribution with modes at both 70 and 80. Additionally, the range of scores decreased from 70 on the pre-test to 50 on the post-test, suggesting that the students' scores became more concentrated and evenly distributed after the learning activity.

**Table 6.** *Frequency Distribution of Pre-Test and Post-Test Scores*

Interval Score	Pretest		Posttest	
	Frequency	Percentage (%)	Frequency	Percentage (%)
0-20	1	5	0	0
21-40	4	20	0	0
41-60	7	35	2	10
61-80	8	40	10	50
81-100	0	0	8	40
Total	20	100	20	100

The frequency distribution of the students' pre-test and post-test scores, detailed in Table 6, illustrates a substantial shift in academic performance following the intervention. During the pre-test, the majority of the students (60%) scored 60 or below, with the highest concentration falling in the 41–60 interval (35%). Notably, no students achieved a score in the highest bracket (81–100). However, the post-test results reveal a dramatic upward trend in student achievement. The lower-scoring intervals (0–40) were completely eliminated, and 90% of the students scored 61 or higher. The most significant improvement is seen in the top tier, with 40% of the students reaching the 81–100 interval—a category that was entirely empty prior to the learning activity.

This significant redistribution of scores towards higher intervals can be directly attributed to the structured implementation of the MRA. The pre-test results suggest that students initially struggled to grasp the multifaceted nature of rigid body equilibrium. However, navigating the five progressive phases of the MRA (see Table 1) provided the necessary scaffolding to bridge these cognitive gaps. During Phase 1 (Orientation & Verbal Representation), students grounded abstract concepts by observing real-life phenomena and providing initial verbal explanations. The instructional sequence then systematically guided them through Phase 2 (Visual Representation), where they learned to draw force vectors and free-body diagrams accurately, and Phase 3 (Mathematical Representation), where they derived critical equilibrium equations from their visual models. The most substantial driver of the post-test improvement, however, was likely Phase 4 (Translation and Synthesis). In this phase, students were explicitly trained to independently connect these different forms—translating verbal question text into visual diagrams, and subsequently into mathematical calculations. By integrating Phase 5 (Evaluation and Reflection) to evaluate these interrelationships, the cognitive load of complex problem-solving was

significantly reduced. This holistic, step-by-step training in representational translation empowered the majority of the class to accurately solve rigorous equilibrium problems, directly resulting in the surge of students entering the 81–100 scoring interval.

## 4.2. Prerequisite Test

### 4.2.1 Normality Test

To verify the assumptions for parametric testing, the Shapiro-Wilk normality test was applied to the pre-test and post-test data. The statistical results of this prerequisite test are presented in Table 7.

**Table 7.** Test of Normality

Measurement	Shapiro-Wilk Statistic	df	Sig.
Before multi-representation	.920	20	.100
After multi-representation	.929	20	.145

Based on the Shapiro-Wilk analysis presented in Table 7, the significance level (Sig.) for the pre-test data is 0.100, and the significance level for the post-test data is 0.145. Because both significance values are greater than the standard alpha level of 0.05 ( $p > 0.05$ ), it can be concluded that both the pre-test and post-test datasets are normally distributed. Consequently, the prerequisite assumptions for conducting parametric statistical analysis (paired-samples t-test) have been successfully fulfilled.

### 4.2.2 Hypothesis Test

A paired statistical analysis was conducted to evaluate the difference in students' scores before and after the treatment. The analysis of the pre-test and post-test variable pair yielded a  $t$ -value of -13.81. Furthermore, the two-tailed significance value (Sig.) was found to be .000. Because this significance value is well below the standard alpha level of 0.05 (typically reported as  $p < .001$ ), it indicates that there is a highly statistically significant difference between the pre-test and post-test scores following the treatment.

Based on calculations using SPSS, the calculated  $t$ -value was 13.81, and the critical  $t$ -value was 2.13, with a significance level of  $0.000 < 0.05$ . Therefore,  $t_{\text{calculated}} > t_{\text{table}}$ , so  $H_0$  is rejected. It can thus be concluded that there is an effect of using the MRA on student learning outcomes. To determine the category of this effect, a normalized N-gain test can be used.

## 4.3. Normalized Gain Analysis (N-Gain)

The results of the normalized gain (N-Gain) analysis demonstrate that the students achieved an average N-Gain score of 0.62. This score falls within the 'moderate' category according to the N-Gain interpretation criteria, specifically within the interval  $0.30 \leq g < 0.70$ . These results indicate that the teaching approach implemented was able to improve students' learning outcomes quite effectively. The improvement in learning outcomes is also evident from a comparison of the average pre-test and post-test scores. The average pre-test score of 56.00 increased to 81.00 in the post-test. Thus, the results of the N-Gain analysis show that the implemented teaching methods were effective in improving students' learning outcomes.

## 4.4. Summary of Results

The quantitative analyses conducted in this study collectively demonstrate the efficacy of the MRA in enhancing students' understanding of rigid body equilibrium. Following the confirmation of normal data distribution, the paired-samples t-test revealed a highly significant difference between the pre-test and post-test scores ( $p < .001$ ), leading to the rejection of the null hypothesis  $H_0$ . This statistical significance is further supported by the N-Gain analysis, which yielded an average score of 0.62, categorizing the overall improvement in learning outcomes as moderate.

Together, these results indicate that the intervention did not merely produce a nominal increase in scores but facilitated a meaningful enhancement in students' cognitive capacities. By systematically guiding students to translate between verbal, visual, and mathematical representations, the MRA framework effectively reduced cognitive load. This structured scaffolding equipped the students with the necessary problem-solving tools to analyze and synthesize complex physics concepts, resulting in a marked improvement in their post-test performance.

## 5. Discussion

### 5.1. Interpretation of findings

Based on the research data analysis, the implementation of the MRA had an impact on the learning outcomes in physics—specifically on the topic of the equilibrium of rigid bodies—among Class 11 students at Tomohon State Senior High School 2. This was evidenced by an improvement in students' learning outcomes, attributed to the variation in teaching methods using the multi-representational approach. The learning process using teaching aids is very enjoyable for students as it enhances their engagement with mathematics lessons, thereby making physics less of a challenge for them. Meanwhile, students who did not achieve the required standard did so due to a lack of engagement; they tended to be passive during the learning process.

In essence, the effectiveness of MRA in the context of the equilibrium of rigid bodies lies in its ability to complement (complementary) and constrain incorrect interpretations (constraining) (Wong et al., 2011). In physics, students often memorize formulas but fail to identify the moment arms or the direction of torque in complex systems (Newcomer & Steif, 2008; Ortiz et al., 2005). During the MRA phase, the use of visual representations, such as free-body diagrams, constrains interpretation; these diagrams force students to explicitly define each force vector before incorporating it into mathematical equations (Rosengrant, 2005; Rosengrant et al., 2009). This aligns with Cognitive Load Theory, which posits that dividing information into visual (diagrams) and auditory/verbal (the teacher's explanation) channels optimizes students' working memory capacity (Hahn & Klein, 2023; Hochberg et al., 2020).

The application of an MRA in physics teaching, particularly in the topic of rigid-body equilibrium, significantly improves students' conceptual understanding. This approach integrates various forms of representation—such as verbal, visual, mathematical, symbolic, and concrete representations—which synergistically reinforce the process of knowledge construction. Previous research has shown that the MRA consistently improves students' conceptual understanding across various physics topics, including work and energy, and helps students gain a more comprehensive understanding of physics concepts (Taqwa et al., 2020). Multi-representation serves three main functions in learning: as a complement to provide additional information or aid cognitive processes; as a safeguard to minimize misinterpretation; and as a means of fostering deeper understanding (Sahara et al., 2020; Siswanto et al., 2018).

Through visual representations such as force diagrams and physical-situation diagrams, students gain a spatial understanding of the distribution of forces and moments. Force diagrams (free-body diagrams) are one of the most important visual aids in the study of mechanics, as they help students visualize the forces acting on an object. Research shows that students who use force diagrams correctly have a higher success rate in solving physics problems than those who do not use them (Rosengrant, 2005; Rosengrant et al., 2009). Force diagrams serve as a conceptual bridge between visual and mathematical representations, helping students apply Newton's laws more effectively (Wong et al., 2011). This visual representation is crucial in the study of the equilibrium of rigid bodies, as it helps students to understand Newton's laws and the principle of torque intuitively before performing mathematical

calculations. However, research indicates that many students struggle to apply both equilibrium principles consistently, particularly when dealing with systems featuring a continuous mass distribution. Students often focus solely on one principle (e.g., force equilibrium) and neglect the other (torque equilibrium), even though both are necessary for a complete analysis (Newcomer & Steif, 2008; Ortiz et al., 2005). An MRA helps students link mathematical representations with conceptual understanding, so that they not only manipulate equations but also understand the physical meaning behind them (Taqwa et al., 2020).

Meanwhile, verbal and concrete representations—including conceptual discussions and the use of visual aids or simulations—enrich the learning experience by engaging various cognitive modalities. Research shows that learning that incorporates a variety of representations helps students develop a stronger and more flexible understanding of physics concepts (Sahara et al., 2020). Concrete representations, such as teaching aids or computer simulations, provide an unforgettable experience and facilitate long-term knowledge retention through multimodal representation, which effectively bridges the gap between physical reality and abstract physics concepts. Interactive simulations that offer a variety of dynamic representations have proven effective in enhancing conceptual understanding by supporting inquiry-based learning and providing immediate feedback on experimental manipulations.

Furthermore, by actively engaging in linking different representations, students find it easier to identify misconceptions and build a deeper, more meaningful understanding. Research shows that visualization helps students move beyond symbols and formulas towards true conceptual understanding, with visualization tools acting as a bridge between abstract equations and the underlying particle-level explanations. Visualization also helps correct misconceptions and improve conceptual clarity, with many students feeling it resolves confusion and replaces weak ideas with a clearer understanding. In the context of rigid-body equilibrium, this approach helps students overcome common difficulties, such as assuming that equilibrium depends solely on equal forces on either side of the fulcrum, without considering moments of force (Newcomer & Steif, 2008; Ortiz et al., 2005).

This study also documents the shift in students' abilities from the cognitive level of C2 to C4 according to Bloom's Revised Taxonomy (Bao & Koenig, 2019; Qadar et al., 2025). At the C4 level, students begin to deconstruct the force components acting on asymmetrical objects and logically relate them to the system's stability. The ability to translate between representations—that is, the ability to move precisely from visual to mathematical formats—has proven to be a key indicator of learning success. This finding reinforces the evidence that, in secondary school, MRA is highly effective for topics with high visual complexity, such as mechanics and static equilibrium. This finding is consistent with previous studies that have shown that MRA consistently enhances students' conceptual understanding and learning outcomes across various physics topics (Sahara et al., 2020; Siswanto et al., 2018; Taqwa et al., 2020).

## *5.2. Implications*

The findings of this study have implications for the future direction of physics education. Firstly, from a pedagogical perspective, teachers must recognize that students' mathematical proficiency does not always reflect their conceptual understanding (Munfaridah et al., 2021). Consequently, physics teaching should no longer be 'formula-centered'. Teachers are advised to use worksheets that require students to present at least three forms of representation (verbal, visual, and mathematical) for each problem (Astuti, 2014). This helps students develop representational flexibility, which is an essential skill for solving advanced physics problems at the university level (Niyomufasha et al., 2024; Salumita & Putranta, 2025). Secondly, for curriculum developers, these findings highlight the importance of integrating systematic problem-

solving strategies. MRA can be adopted as a standard operating procedure in the teaching of mechanics to reduce misconceptions regarding force and torque (Sarizan et al., 2022; Taqwa et al., 2020). The long-term implication is an improvement in students' scientific literacy, enabling them not only to answer exam questions but also to understand the principles of mechanics in everyday life, such as the stability of building structures and the operation of lifting equipment (Bao & Koenig, 2019; Siswanto et al., 2018).

### 5.3. *Research Limitations and Future Research*

We are fully aware of several limitations that may affect the objectivity of these findings. The sample size, comprising 20 students, and the use of a one-group pretest-posttest design without a control group make it difficult to generalize the findings to a national scale. Furthermore, the potential for Hawthorne Effect bias, in which students perform better simply because they are aware they are the subjects of a new study, cannot be entirely ruled out.

Previous research at the university level has shown that the effectiveness of MRA can be enhanced with the aid of technology. It is therefore recommended that future researchers integrate MRA with interactive simulations, such as PhET, or with video analysis applications, such as Tracker. This integration enables dynamic, concrete representations that help students visualize changes in force in real time. Furthermore, future research should examine how MRA influences students' motivation and self-efficacy, as mastery of various forms of representation often boosts students' confidence when tackling difficult physics problems.

## 6. Conclusion

Based on the research and data analysis, the multi-representation approach is effective in improving student learning outcomes in the subject of equilibrium of rigid bodies in Class 11 at Tomohon State Senior High School 2. This finding is supported by the results of the Paired Sample T-Test, which showed a significance value of 0.000 and an n-gain score of 0.62 (moderate), proving that the intervention had a real impact on improving students' cognitive competence.

The integration of various forms of representation, including verbal, visual, mathematical, and concrete, has proven capable of facilitating a more comprehensive process of knowledge construction than conventional methods. This approach successfully bridges the abstraction of physics concepts by using force diagrams and teaching aids, enabling students to internalize the principles of equilibrium not merely as mathematical formulas but as logical physical phenomena. From a pedagogical perspective, this success confirms that learning strategies that involve multiple modes of representation are highly relevant for addressing the complexity of physics content, minimizing misconceptions, and creating a more meaningful and measurable learning experience.

## Author Contributions

**Garry Andreas Ludong:** Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Aswin H. Mondolang:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Jeferson Polii:** Methodology, Writing – review & editing, Supervision. **Kenny Setiawan Lahope:** Conceptualization, Methodology, Writing – review & editing, Supervision.

## Ethical statement

This study was approved by the Institutional Ethics Committee of Universitas Negeri Manado. All procedures involving human participants were conducted in accordance with the ethical standards of the

institutional research committee and with the 1964 Declaration of Helsinki and its later amendments. Participation in the study was entirely voluntary. All participants were informed about the purpose of the research, the procedures involved, potential risks and benefits, and their right to withdraw at any time without penalty. Verbal informed consent was obtained from all participants.

## Declaration of AI use

The authors used DeepL to translate the manuscript from the original Indonesian draft into English. ChatGPT and Gemini were then used to check the formatting and improve the sentence structure and clarity of the text. All AI-assisted outputs were thoroughly reviewed and edited by the authors, who remain fully responsible for the accuracy, originality, and integrity of the final manuscript.

## Conflict of Interest

The authors declare that there is no conflict of interest, either financial or non-financial, that could be perceived as influencing the work reported in this manuscript. All authors have reviewed and approved this statement.

## Supplementary Materials and Data Availability

The research instruments and validation data supporting the findings of this study are included within the article's Appendices. The raw dataset containing individual student scores is not publicly available due to privacy and ethical restrictions. However, anonymized data summaries can be obtained from the corresponding author upon reasonable request.

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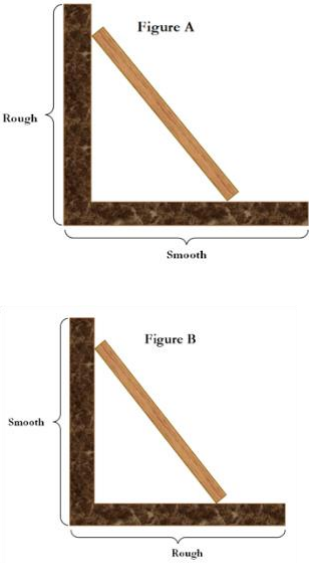
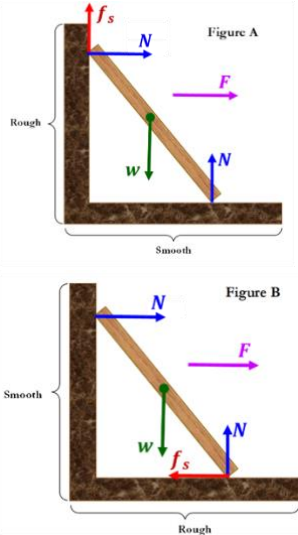

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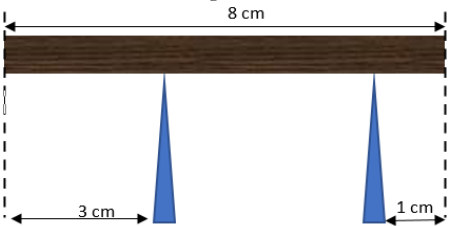
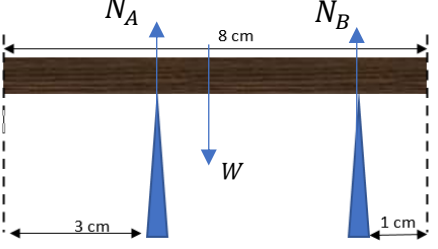
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## APPENDIX: A. RESEARCH INSTRUMENTS

**Table 8.** Test instrument for measuring students' physics proficiency

No	Question Indicators	Test	Answer
1	Students can explain the state of a rigid body at rest based on real-world phenomena	A wooden plank is placed horizontally on two supports, one at the left end and the other in the middle of the plank. A child is standing at the right end of the plank. If the plank remains stationary and does not move, what can you conclude about the state of the plank?	<p>The diagram shows that the object is in <b>equilibrium</b>, which means:</p> <ul style="list-style-type: none"> <li>• <b><math>\Sigma F</math> (total vertical force) = 0</b>: The total upward force (support reaction) is equal to the total downward force (the weight of the board and the child).</li> <li>• <b><math>\Sigma \tau</math> (total moment) = 0</b>: The moment of rotation produced by the weight of the board and the child at one support is balanced by the moment of rotation from the reaction force at the other support.</li> </ul> <p>In conclusion, the board is in equilibrium because all the forces and moments acting on it cancel each other out.</p>
2	Students can identify and analyse the concept of equilibrium in rigid bodies on a board resting on supports	<p>A wooden plank 4 metres long and weighing 200 N is placed horizontally on two supports, one at the left end (point A) and the other at the right end (point B). If a child weighing 300 N stands in the middle of the plank, then:</p> <p>(a). Is the board balanced?</p> <p>(b). Reaction forces at points A and B.</p>	<p><i>Is the board in balance?</i></p> <p>Yes, the board is in balance because:</p> <ul style="list-style-type: none"> <li>• The total downward force (the child's weight plus the weight of the board) is equal to the total upward force (the reactions from supports A and B).</li> </ul>

No	Question Indicators	Test	Answer
			<ul style="list-style-type: none"> <li>The child's centre of gravity is in the middle of the board, so there is no rotational force causing the board to tilt.</li> </ul> <p>The reaction forces at points A and B</p> <ul style="list-style-type: none"> <li>Because the child is standing in the middle of the board, the reaction forces at A and B are equal in magnitude.</li> <li>The total downward force is <math>200 + 300 = 500</math></li> </ul> <p>So, each support bears half the load:</p> $R_A = R_B = \frac{500}{2} = 250 \text{ N}$
3	Students can draw a force diagram for a homogeneous rod resting against a rough wall and a smooth floor using the concept of equilibrium of a rigid body	<p>Look at the following picture.</p>  <p>Draw a diagram showing what happens to the two homogeneous rods and explain what kind of force is involved?</p>	 <ul style="list-style-type: none"> <li>Normal force is the force acting on an object when it is in contact with a surface</li> <li>Gravitational force is the force of gravity acting on an object with mass</li> <li>Friction is a force that acts when two surfaces of objects come into contact and acts in the opposite direction to the motion of the objects</li> </ul>
4	Students can analyse cases of equilibrium in rigid bodies on a seesaw	<p>Two children named Excel and Savira are playing on the seesaw in the playground, as shown in the picture.</p> 	<p><b>Given:</b></p> <p>Excel mass (<math>m_E</math>) = 45 kg  Mass Savira (<math>m_S</math>) = 40 kg  Board length = 300 cm  Gravitational acceleration = <math>10 \text{ m/s}^2</math></p> <p><b>Asked:</b></p> <p>(a). Force diagram: when the distance between Savira and Excel, with the fulcrum at 150 cm, is = ?</p>

No	Question Indicators	Test	Answer
		<p>Excel and Savira weigh 45 kg and 40 kg respectively; the seesaw on which Excel and Savira are playing is 300 cm long, and the fulcrum is positioned in the middle of the board.</p> <p>(a). Draw a force diagram when the distance between Savira and Excel and the fulcrum is 150 cm</p> <p>(b). Draw a force diagram when the Excel moves 50 cm towards the support</p>	<p>(b). Force diagram: When the Excel sheet moves 50 cm towards the support = ?</p> <p><b>Solution:</b></p> <p><b>(a). When Excel and Savira are sitting 150 cm from the fulcrum</b></p> <p>Calculate the weight of each:</p> $W_E = m_E \times g = 45 \times 10 = 450N$ $W_S = m_S \times g = 40 \times 10 = 400N$ <p>Calculate the moment of force about the fulcrum:</p> $M_E = W_E \times r_E = 450 \times 150 = 67,500 N \cdot cm$ $M_S = W_S \times r_S = 400 \times 150 = 60,000 N \cdot cm$ <p><i>Conclusion:</i></p> <p>Since <math>M_E &gt; M_S</math>, the seesaw will tilt towards the Excel side (the left side is heavier).</p> <p><b>(b). When Excel moves 50 cm towards the support (Excel's distance = 100 cm, Savira remains at 150 cm)</b></p> <p>The gravitational force remains the same:</p> $W_E = 450N$ $W_S = 400N$ <p>Calculate the new moment of force:</p> $M_E = 450 \times 100 = 45.000 N \cdot cm$ $M_S = 400 \times 150 = 60.000 N \cdot cm$ <p><i>Conclusion:</i></p> <p>Now that <math>M_S &gt; M_E</math>, the seesaw will tilt towards Savira (the right side is heavier).</p>
5	Students can analyse and evaluate the forces acting on a rigid body in equilibrium	<p>Please look at the image below</p>  <p>The homogeneous wooden beam shown in the diagram is 8 cm long and weighs 200 N; it rests on two support columns, A and B. What is the load experienced by point A?</p>	 <p>Given. <math>L = 8 \text{ cm}</math>  <math>W = 200 \text{ N}</math></p> <p>Asked. <math>N_A = ?</math></p> <p>Solution.</p> $\sum \tau_B = 0$ $N_A \cdot r_A - W \cdot r_B = 0$ $N_A \cdot r_A = W \cdot r_B$ $N_A \cdot (4) = 200 \cdot 3$ $4N_A = 600$ $N_A = \frac{600}{4} = 150 \text{ N}$

## APPENDIX: B. VALIDATION OF RESEARCH INSTRUMENTS

The validation of the instrument was conducted on the test item instrument developed to measure students' understanding of the concept of equilibrium in rigid bodies; the content validity assessment was carried out by two experts in the fields of assessment and physics education through five aspects, namely

1. the alignment of the test items with the learning objectives,
2. the core or essence of a concept,
3. the suitability of test items for measuring indicators of conceptual understanding,
4. consistency in the use of representations (verbal, visual, and mathematical) within the test items, and
5. language and writing.

The content validation results were analyzed based on scores for the available assessment criteria using a five-point Likert scale, namely scores of 1 (invalid), 2 (somewhat invalid), 3 (moderately valid), 4 (valid), and 5 (highly valid).

The following are the results of the validation of the test instruments (pre-test and post-test) carried out by two validators.

**Table 9.** *Results of the test instrument validation*

Question Number	Assessment Criteria									
	Validator 1					Validator 2				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
1	5	5	4	4	5	5	5	4	4	4
2	4	5	4	4	5	4	5	5	4	5
3	5	4	4	5	4	5	4	5	5	4
4	4	5	4	5	4	4	4	5	5	4
5	4	4	5	5	4	5	5	4	5	4

The scores assigned by both validators for each aspect were then analyzed using Aiken's V coefficient to determine the content validity of each item in the test instrument. The results of the validity test are shown in Table 13.

**Table 10.** *Results of the Content Validity Test for the Test Instrument Using Aiken's V*

Question Number	Aiken's V	Category
1	0,73	Valid
2	0,73	Valid
3	0,73	Valid
4	0,71	Valid
5	0,73	Valid