Revista Portuguesa de Educação

Analysis of students' visual representation ability in physics based on empirical test results on the topic of rotational dynamics in the context of the traditional game of gasing

Rio Sebastian [i]
Universitas Negeri Yogyakarta, Indonesia.

Heru Kuswanto [ii]
Universitas Negeri Yogyakarta, Indonesia.

ABSTRACT

Visual representation ability plays a crucial role in physics learning, as it helps students develop a comprehensive and conceptual understanding of physical phenomena. However, this competence remains challenging for many learners. Therefore, this study aims to examine students' visual representation abilities through empirical written tests on the topic of rotational dynamics, using the traditional spinning-top game gasing as a case study. This research adopts a quantitative descriptive approach to assess students' visual representation skills through essay-type questions developed based on specific visual representation indicators. The results show that the majority of students demonstrate a very low level of visual representation ability, with 52% classified in this category. Furthermore, the average scores across all indicators were consistently low. The indicator related to analyzing images, diagrams, tables, or graphs in order to draw conclusions obtained the lowest mean score. Thus, it can be concluded that students' visual representation ability in physics learning, particularly in the context of rotational dynamics and the traditional gasing game, remains limited. Consequently, efforts are required to enhance this competence through innovative and appropriate physics learning activities.

Keywords: Visual representation; Rotational dynamics; Traditional game of gasing.

1. INTRODUCTION

Physics education plays a vital role in the development and advancement of technology. Physics significantly contributes to the development of science and technology within society (Bao & Koenig, 2019). Furthermore, physics education is a process aimed at enhancing students' understanding of physics concepts, principles, and laws, requiring effective and efficient teaching methods (Maknun, 2020; Riyan Rizaldi et al., 2021). This is supported by Beck and Barbato (2022), who stated that physics is a multifaceted branch of science that encompasses fundamental research driven by curiosity and applied research aimed at developing new technologies and insights for society. It also involves various ways of thinking and investigative methods, incorporating a scientific process approach (Etkina, 2023). In learning physics, students encounter context-based content, requiring critical thinking skills and physics representation, such as practical experiments and demonstrations (Dolgopolovas et al., 2022; Nazhifah et al., 2023; Ramadhan et al., 2023). However, most physics education in schools has not yet implemented contextual learning (Sherinnova et al., 2023). Additionally, students often only memorize physics material without developing representation and analytical ability (Ho et al., 2023; Maries & Singh, 2023). This leads to some physics topics, including rotational dynamics, being perceived as difficult by students.

Rotational dynamics is a complex subject, requiring the abstraction and consideration of various factors in the motion of objects. Many students struggle to understand rotational dynamics, especially subtopics like torque and the application of moment of inertia (Kladivová & Mucha, 2014; Mashood & Singh, 2012). Moreover, students often lack understanding of how torque influences angular speed and acceleration (Rimoldini & Singh, 2005). Bostan Sarıoğlan & Küçüközer (2013) concluded that students' understanding of torque and angular momentum often does not align with scientific concepts, leading to misconceptions. Students frequently face confusion when combining the relationships between torque, force, and angular acceleration, mistakenly assuming that constant torque results in constant angular speed and struggling to consider the line of action of force (Olazabal et al., 2021). Consequently, physics education on rotational dynamics in schools remains suboptimal, with conceptual errors present.

In school physics education, presenting rotational dynamics is crucial due to its relevance to everyday life. One application of rotational dynamics principles close to students is the traditional game of gasing (spinning top). Gasing is a game where the top spins on its axis to maintain balance (Syamsi & Tahar, 2021). The traditional game of gasing demonstrates to students the concepts of torque and moment of inertia. Widyaparamita et al. (2020) noted that gasing is related to physics topics such as the equilibrium of rigid bodies and rotational dynamics. The game of gasing generates a gyroscopic effect, keeping the top upright until the angular momentum and gyroscopic effect gradually diminish, causing the top to fall and stop spinning (Febriyanti et al., 2018; Matsyshyn, 2023). This game requires dexterity, strength, and strategy to defeat opponents by controlling the radius and shape of the top and the force applied through the tension of the string (Saprima et al., 2020). However, understanding the concepts of the traditional game of gasing within the context of rotational dynamics requires strategic representation to avoid misconceptions and difficulties. This is supported by De Cock (2012), who stated that the chosen solution strategies depend on the form of representation with which the problem is introduced. Therefore, it is important to incorporate physics education that develops students' representational abilities.

Representation is a crucial aspect of physics education. Presenting physics material involves various representations that must be interpreted according to accurate physics concepts. Representation refers to a form or depiction that conveys meaning through different methods. Teaching using representations accustoms students to communicate in the language of science, including physics, to solve problems (Dewi et al., 2019; Pulgar et al., 2021). Representation ability in physics education includes several types. According to Nasrun et al. (2023), representations are categorized into four types: verbal, diagrammatic, visual, and mathematical. This study focuses on students' visual representation ability.

Visual representation is a type of representational ability used to understand physics through images, diagrams, or graphs presented in physics problems (Kress & van Leeuwen, 2020). Physics education acknowledges that developing visual representation is an essential science process skill for the scientific method, especially in formulating hypotheses, designing experiments, analyzing and presenting data, and communicating results (Ioannidou & Erduran, 2021; Kaya et al., 2019; Volkwyn et al., 2020). Visual representation makes physics principles and laws more accessible and stimulates higher cognitive processes in students (Anam et al., 2024). It allows students to illustrate relationships between different concepts and enhances the optimal development of understanding scientific phenomena (Akerson et al., 2019; Tytler et al., 2020). Indicators of students' visual representation ability are shown in Table 1.

Table 1
Synthesis of visual representation ability indicators

(Mayer, 2009)	(Glazer, 2011)	(Elia et al., 2007)
1. Understanding visual information 2. Processing information into cognitive structures 3. Externalizing information as visual models such as visual representations	1. Representing data with graphs 2. Communicating data to make it easy to interpret	1. Drawing diagrams or pictures to solve problems 2. Understanding diagram to solve problems
Results of synthesis of visual representation ability indicators: 1. Identifying information (images, diagrams, tables, or graphs) to solve problems. 2. Describing problem-solving diagrams, graphs, or tables in a text through visual representation. 3. Analyzing images, diagrams, tables, or graphs to draw conclusions.		

Note. Authors' own elaboration.

The complex and structured scientific ability of visual representation involves various components at different levels through both implicit and explicit interactions (Abdurrahman et al., 2019; Park et al., 2020), often resulting in students experiencing difficulties in developing abstract concepts using visual representation (Ainsworth & Scheiter, 2021; Ye et al., 2020). Some indicators of visual representation ability in physics education are challenging to apply due to various factors, such as media, methods, and learning models. Based on Sebastian et al. (2023) using flip-book problem-based learning media, it was stated that indicators of processing visual information into cognitive structures had the lowest N-Gain value compared to other visual representation indicators. Therefore, based on the significance and challenges of visual representation in physics education, this study aims to empirically reveal students' visual representation abilities through essay tests on the topic of rotational dynamics using the traditional game of gasing as a case study.

2. METHOD

This research employs a quantitative descriptive method to examine students' visual representation ability through an empirical test using essay questions. The test assesses their ability based on visual representation indicators in the context of rotational dynamics with the traditional game of gasing as a case study. The subjects of this study consist of 254 students from 11th- and 12th-grade natural science majors taken from three high schools in the city of Yogyakarta, namely State High School 2, State High School 7, and State High School 11. The sampling technique used in this study is cluster sampling. Cluster sampling is a sampling technique taken from the entire population divided into several groups, or clusters, and random samples are then selected randomly (Singh & Masuku, 2014). Cluster sampling is more efficient and appropriate when dealing with a large population to avoid reducing variation (Berndt, 2020). Therefore, this research utilizes the cluster sampling technique.

The research instrument consists of two sets of questions, namely package A and package B. This is intended to prevent students from copying when sitting next to each other, thus allowing them to work independently. Each set of questions consists of three questions representing each visual representation indicator to be measured in students. The indicator of the question instrument can be shown in Table 2.

Table 2

Indicator of visual representation ability question instrument

Indicator of visual representation ability	Test items	Question indicators
Identifying information (images, diagrams, tables, or graphs) to solve problems	1A, 1B	Stating the moment of inertia value of the spinning top to solve the problem.
Describing problem-solving diagrams, graphs, or tables in a text through visual representation.	2A, 2B	Describing the moment of force (torque) diagram and moment of inertia graph of the spinning top case through the narrative presented.
Analyzing images, diagrams, tables, or graphs to draw conclusions.	3A, 3B	Comparing the moment of inertia and the moment of force among spinning tops to draw conclusions.

Note. Authors' own elaboration.

The visual representation ability test instrument underwent content validity testing and empirical validity testing. Content validity of the test instrument was conducted by five physics education expert lecturers and two high school physics teachers. The data analysis of content validity by validators used the Aiken's V test (Aiken, 1985). The following are the steps in analyzing the validation of the assessment instrument according to Aiken's V. Calculating Aiken's V index for each item based on the validator's assessment using Equation 1:

$$V = \frac{\sum s}{[n(c-1)]} \quad (1)$$

Description: V: Coefficient of content validity; s: r - l_0; l_0: Lowest validity rating; c: Highest validity rating; r: Rating given by the validator; n: Number of validators.

Meanwhile, in the empirical validity test, the questions were administered to 254 high school students in grades 11 and 12 majoring in natural sciences. The analysis of the empirical validity test used the partial credit model in the Quest program. A test item is considered valid based on the analysis if the INFIT MNSQ value is 0.77 ≤ X ≤ 1.33 (Adams & Khoo, 1996; Boone et al., 2014). In the partial credit model, the reliability value of the questions is also obtained from the output data ending in "sh" based on the summary of the case estimate reliability value. This reliability value can be categorized based on Table 3.

Table 3
Reliability categories

Reliability coefficient	Categories
$r_{11} < 0.2$	Very low
$0.2 \leq r_{11} < 0.4$	Low
$0.4 \leq r_{11} < 0.6$	Moderate
$0.6 \leq r_{11} < 0.8$	High
$0.8 \leq r_{11} < 1.0$	Very high

Note. Adapted from B. Subali and P. Suyata (2012)

Furthermore, in the data output ending with "it", the level of difficulty for each test item can be determined through the DIFFCLTY column, which indicates the delta value of the item difficulty (b). The categories of item difficulty levels are interpreted based on the delta (b) values as shown in Table 4.

Table 4
Categories of item difficulty level

Delta Value	Categories
$b > 2$	Very difficult
$1 < b \leq 2$	Difficult
$-1 < b \leq 1$	Moderate
$-1 > b \geq -2$	Easy
> -2	Very easy

Note. Adapted from W.J. Boone, J.R. Staver, & M.S. Yale (2014)

The level of students' visual representation ability is determined based on the assessment of the test instrument on the topic of rotational dynamics in the traditional spinning top game case, which includes subtopics of moment of force and moment of inertia in the spinning top game, through an assessment rubric. The assessment rubric for students' visual representation ability based on the test instrument can be shown in Table 5.

Table 5

Assessment rubric for visual representation ability test instrument

Number items	Assessment criteria	Rubric
1A	1. Identifying images in the spinning top case 2. Explaining statements and concepts of moment of force and inertia in the spinning top 3. Analyzing and applying concepts of moment of force and inertia 4. Drawing conclusions	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)
2A	1. Identifying statements in the spinning top case 2. Explaining and visualizing statements and concepts of moment of force in the spinning top 3. Analyzing and applying concepts of moment of inertia 4. Drawing conclusions from diagrams or graphs of moment of inertia concepts	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)
3A	1. Identifying statements in the spinning top case 2. Explaining statements of moment of inertia and angular acceleration in the spinning top 3. Analyzing and applying concepts of moment of inertia and angular acceleration of the spinning top 4. Drawing conclusions from the obtained values of moment of inertia and angular acceleration of the spinning top	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)
1B	1. Identifying images in the spinning top case 2. Explaining statements and concepts of moment of force and inertia in the spinning top 3. Analyzing and applying concepts of moment of force and inertia 4. Drawing conclusions	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)
2B	1. Identifying statements in the spinning top case 2. Explaining and visualizing statements and concepts of moment of force in the spinning top 3. Analyzing and applying concepts of moment of inertia 4. Drawing conclusions from diagrams or graphs of moment of inertia concepts	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)
3B	1. Identifying statements in the spinning top case 2. Explaining statements regarding the concept of moment of inertia and angular acceleration in the spinning top 3. Analyzing and applying the concepts of moment of inertia and angular acceleration of the spinning top 4. Drawing conclusions from the obtained values of moment of inertia and angular acceleration of the spinning top	• If the assessment criteria are not met (0) • If 1 assessment criterion is met (1) • If 2 assessment criteria are met (2) • If 3 assessment criteria are met (3) • If 4 assessment criteria are met (4)

Note. Authors' own elaboration.

In analyzing students’ visual representation ability, they can be categorized into rating categories based on the standard deviation range according to the assessment rubric, where each item has a highest score of 4 and a lowest score of 0. The range of rating categories for students’ visual representation ability can be shown in Table 6.

Table 6

Range of categories for visual representation ability assessment

Formula for score range	Score range	Categories
$\bar{X} > X_i + 1.8\, Sb_i$	$\bar{X} > 3.21$	Very high
$X_i + 0.6\, Sb_i < \bar{X} \leq X_i + 1.8\, Sb_i$	$2.40 < \bar{X} \leq 3.21$	High
$X_i - 0.6\, Sb_i < \bar{X} \leq X_i + 0.6\, Sb_i$	$1.60 < \bar{X} \leq 2.40$	Fair
$X_i - 1.8\, Sb_i < \bar{X} \leq X_i - 0.6\, Sb_i$	$0.79 < \bar{X} \leq 1.60$	Low
$\bar{X} \leq X_i - 1.8\, Sb_i$	$\bar{X} \leq 0.79$	Very low

Note. Adapted from S. E. P. Widoyoko (2012)

Description:

X_i	:	Average ideal score
$\bar{X}$	:	Average score
Sb_i	:	Ideal standard deviation

Which is

X_i	=	$\frac{1}{2} \times (\text{highest score} + \text{lowest score}) = \frac{1}{2} \times (4.00 + 0.00) = 2.00$
Sb_i	=	$\frac{1}{6} \times (\text{highest score} - \text{lowest score}) = \frac{1}{6} \times (4{,}00 - 0{,}00) = 0.67$

Note. Authors’ own elaboration.

3. FINDINGS AND DISCUSSION

3.1. CONTENT VALIDITY OF VISUAL REPRESENTATION ABILITY INSTRUMENT

Content validity ensures the appropriateness of test items in terms of construct and content, based on validation questionnaires and expert revisions. Five lecturers and two physics teachers assess the items using a Likert-scale questionnaire (1–4) and provide improvement suggestions. Aiken’s V analysis evaluates validity across four item categories with seven raters. According to the validity criteria, an item is considered valid if the value of V ≥ 0.76 (Aiken, 1985). The results of the content validity of the visual representation ability test instrument can be shown in Table 7.

Table 7

Results of content validity for the essay test on visual representation ability

Package	Question item number	Aiken's V	Explanation
A	1	0.86	Valid
	2	0.81	Valid
	3	0.76	Valid
B	1	0.76	Valid
	2	0.81	Valid
	3	0.81	Valid

Note. Authors' own elaboration.

Based on Table 7, it is shown that all items in the visual representation ability test in this study have Aiken's V values ranging from 0.76 to 0.86, indicating that all items are valid and suitable for measuring students' visual representation ability. However, each item has improvement suggestions from the validator, such as ineffective sentences, incorrect punctuation usage, a mismatch between question indicators and learning objectives (Bloom's Taxonomy Operational Verbs), a mismatch between questions and visual representation indicators, and the absence of suitable Bloom's Taxonomy Operational Verbs corresponding to the indicators in the presented questions. This is supported by Brookhart (2010), stating that the mismatch in the selection of Bloom's Taxonomy Operational Verbs based on question indicators will result in less accurate competency assessment and unclear student learning objectives. Therefore, all items are declared valid for measuring students' visual representation ability in the case of traditional game rotation dynamics material, but there should be improvements based on suggestions and feedback from the validator.

3.2. EMPIRICAL VALIDITY AND RELIABILITY OF VISUAL REPRESENTATION ABILITY INSTRUMENT

The suitability of items with the Partial Credit Model (PCM) is assessed using the INFIT MNSQ value from the Quest program analysis, specifically from the output file section ending in "sh". Items are considered valid if their INFIT MNSQ values fall within the range of 0.77 to 1.33. The analysis confirms that the visual representation items align with PCM criteria. The analysis results of the suitability of visual representation items are shown in Figure 1.

Figure 1

Results of analysis of suitability of visual representation ability question items

```
Item Fit                                                              26/11/23 15:25
all on all (N = 254 L = 6 Probability Level= .50)
------------------------------------------------------------------------------------
INFIT
 MNSQ          .56       .63       .71       .83      1.00      1.20      1.40      1.60      1.80
----------------+---------+---------+---------+---------+---------+---------+---------+---------
  1 item 1                          .              *              .
  2 item 2                          .             *|              .
  3 item 3                          .             *|              .
  4 item 4                          .              |  *           .
  5 item 5                          .              | *            .
  6 item 6                          .              |  *           .
```

Note. Authors' own elaboration.

Based on Figure 1, it can be seen that all items of visual representation ability show INFIT MNSQ values in the range of 0.77 to 1.33, so it can be stated that all items are valid and in accordance with the PCM through empirical testing of instruments carried out by students. The reliability of the visual representation ability instrument is presented in the output file ending in "sh", specifically in the summary of case estimates under the reliability of estimate section, as shown in Figure 2.

Figure 2

Results of reliability value of visual representation ability question instrument

```
Summary of case Estimates
=========================

Mean                         -.76
SD                           1.55
SD (adjusted)                1.32
Reliability of estimate       .73
```

Note. Authors' own elaboration.

Based on Figure 2, it can be seen that the reliability value of the visual representation ability question instrument is 0.73, which, based on Table 3, shows the category of high reliability level. So, it can be concluded that the instrument of visual representation ability is valid and reliable empirically to measure students' visual representation ability in the case of traditional spinning top game of the rotational dynamics material.

3.3. ITEM DIFFICULTY LEVEL OF VISUAL REPRESENTATION ABILITY INSTRUMENT

The level of item difficulty analyzed through the Quest program can be seen in the data output ending in "it". The level of difficulty of each item can be seen through the DIFFCLTY column, which shows the delta value of item difficulty (b). The category of item difficulty is interpreted through Table 4, which ranges from -2 to +2. Items with values close to +2.00 are classified as difficult, whereas those near -2.00 are considered easy. The characteristics of the difficulty level of visual representation ability items can be shown in Table 8.

Table 8

Level of difficulty of visual representation ability question items

Package	Item number	Delta Value (b)	Categories
A	1	-0.43	Moderate
	2	+0.09	Moderate
	3	+0.73	Moderate
B	1	-0.31	Moderate
	2	-0.44	Moderate
	3	+0.36	Moderate

Note. Authors' own elaboration.

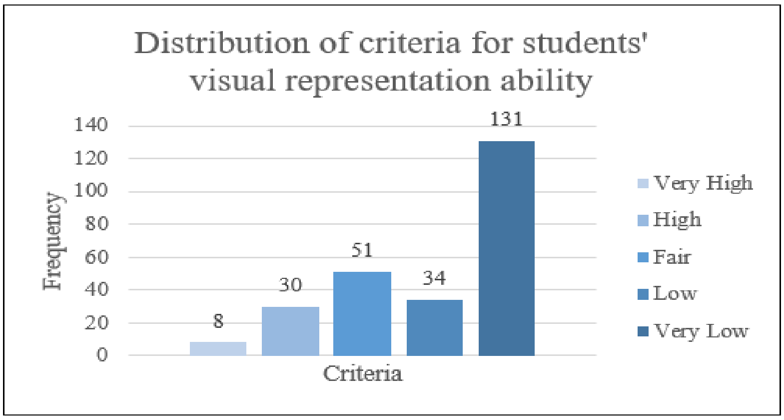
Based on Table 8, the difficulty level of all visual representation ability questions falls into the "Medium" category. Of the 6 items analyzed, item number 2 of package B has the smallest delta (b) value, -0.44, which indicates that this item is the easiest. Conversely, item number 3 of package A had the largest delta (b) value of +0.73, indicating that it was the most difficult.

3.4. ANALYSIS RESULTS OF STUDENTS' VISUAL REPRESENTATION ABILITY

The visual representation ability of students is obtained from the empirical test results with the score of each item in the range of 0 to 4 based on the assessment rubric shown in Table 5. While the criteria for students' visual representation ability are interpreted in Table 6. The distribution of data on the criteria for the visual representation ability of all students can be shown in Figure 3.

Figure 3

Data distribution of student visual representation ability criteria

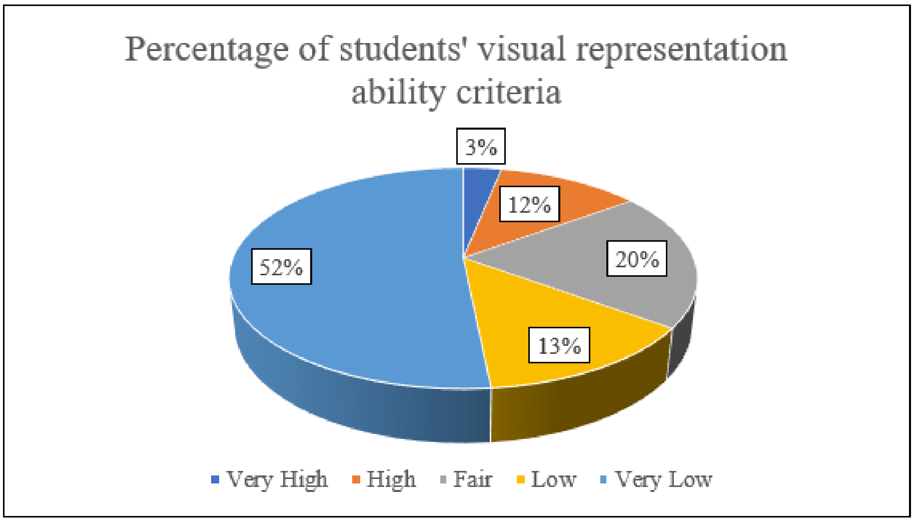


Note. Authors' own elaboration.

Based on Figure 3, it can be shown that students with "Very low" visual representation ability criteria have the highest number (131 students), while students with "Very high" visual representation ability criteria have the least number (eight students). This shows that the majority of students' visual representation ability is still classified as "Very low" criteria. Then, to clarify the description of the proportion of each criterion, the percentage of visual representation ability criteria shown in Figure 4 is presented.

Figure 4

Percentage of student visual representation ability criteria



Note. Authors' own elaboration.

Based on Figure 4, it can be seen that the "Very low" visual representation ability criterion has the highest percentage, of 52%, while the "Very high" criterion has the lowest percentage, of 3%. This indicates that the "Very low" visual representation ability criterion includes more than half of the students who participated in the empirical test. Therefore, it can be concluded that, based on the overall data, most students' visual representation abilities fall into the "Very low" category. This is consistent with the research by Utami et al. (2019), which stated that the visual representation ability of students is predominantly low, with 39.40% of students falling into the low category.

In this study, the indicators of visual representation ability were synthesized from three reference sources, as shown in Table 1. Based on the synthesis results, the indicators of visual representation ability in this study are formulated as follows: (1) identifying information (images, diagrams, tables, or graphs) to solve problems; (2) describing problem-solving diagrams, graphs, or tables in a text through visual representation; and (3) analyzing images, diagrams, tables, or graphs to draw conclusions. These indicators serve as the basis for determining the students' abilities related to visual representation in physics learning. Based on these indicators, the average scores for each visual representation ability indicator are presented in Table 9.

Table 9

Average assessment of students' visual representation ability for each indicator

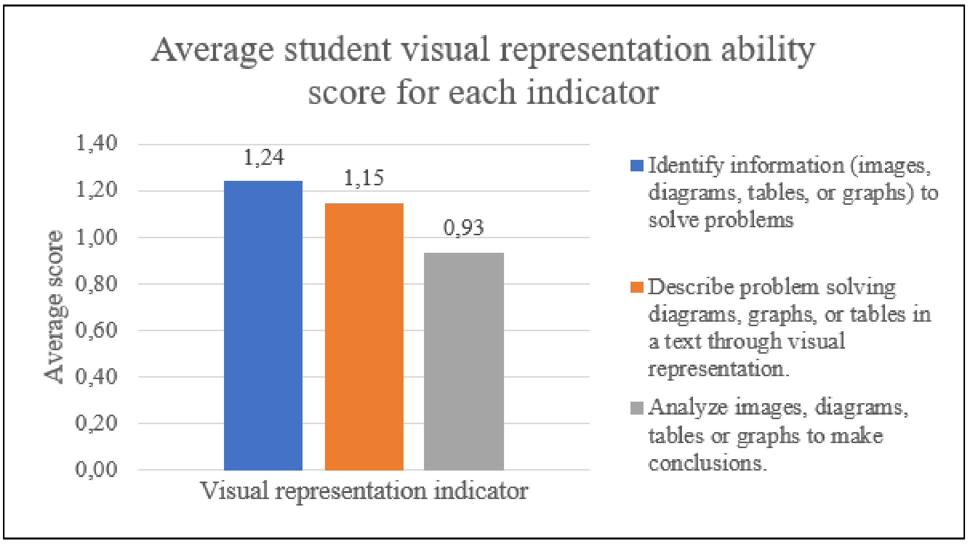
Nº.	Visual representation indicator	Average score	Criteria
1.	Identifying information (images, diagrams, tables, or graphs) to solve problems	1.24	Low
2.	Describing problem-solving diagrams, graphs, or tables in a text through visual representation.	1.15	Low
3.	Analyzing images, diagrams, tables, or graphs to draw conclusions.	0.93	Low

Note. Authors' own elaboration.

Based on Table 9, it can be seen that the average assessment of students' visual representation ability of all indicators is included in the "Low" criteria. Then, to make it easier to know the difference in the average assessment of each indicator, a bar graph is presented in Figure 5.

Figure 5

Average assessment of students' visual representation ability for each indicator



Note. Authors' own elaboration.

Figure 5 shows that the indicator for identifying information (images, diagrams, tables, or graphs) to solve problems has the highest average score, at 1.24. This indicates that most students find it easier to identify information from images, tables, and graphs to solve problems compared to other visual representation indicators. This finding is supported by Novitasari et al. (2021), who stated that students have good visual representation ability in presenting information in the form of images. Conversely, the indicator for analyzing images, diagrams, tables, or graphs to draw conclusions has the lowest average score, at 0.93. This indicates that most students find it more challenging to analyze images, diagrams, or tables to draw conclusions compared to meeting other visual representation indicators. This statement aligns with the research by Bollen et al. (2017), which noted that students face several difficulties in interpreting, constructing, and translating representations as part of analyzing images or diagrams in vector fields.

4. CONCLUSION

Based on the findings and discussion of this study, it can be stated that students' visual representation abilities in the physics learning context of traditional spinning top games, specifically on the topic of rotational dynamics, are still very low. This is evident from the data distribution, where more than half of the students in the implementation test fall under the "Very low" category, and only 15% have high visual representation abilities. Additionally, the overall average scores for each visual representation ability indicator are categorized as "Low". The indicator with the lowest average score is analyzing images, diagrams, tables, or graphs to draw conclusions. Therefore, there is a need for methods or media that can enhance students' visual analysis ability in physics learning in the future.

5. RECOMMENDATION

This research is expected to serve as a supportive resource or reference for researchers, lecturers, and physics teachers who need to address issues in physics education, particularly in students' visual representation abilities. However, this study is limited to high schools in the Yogyakarta region of Indonesia. Future research should include other regions to make the analysis of visual representation issues more general and credible. Additionally, with a large number of students, it is more challenging to control factors that affect them, such as the timing and conditions during the empirical test. Therefore, future research should take these factors into account to ensure accurate results and problem analysis.

AUTHORSHIP

Authors' contributions: Conceptualization, RS, HK; Methodology, RS; Validation, HK; Formal analysis, RS; Research, RS; Data curation, RS; Writing of original draft, RS; Writing of revisions and corrections, RS, HK; Supervision, HK; Project administration, RS, HK; Acquisition of funding, RS. All authors have read and agree to the publication of this manuscript.

CONFLICT OF INTEREST

The authors declare that there are no external conflicts of interest, direct or indirect, personal or financial interests related to this article.

REFERENCES

Abdurrahman, A., Setyaningsih, C. A., & Jalmo, T. (2019). Implementing multiple representation-based worksheet to develop critical thinking skills. *Journal of Turkish Science Educatio*n, *16*(1), 138–155. https://www.tused.org/index.php/tused/article/view/235

Adams, R. J., & Khoo, S.-T. (1996). *ACER Quest: The interactive test analysis syste*m (Version 2.1) [Computer software]. Australian Council for Educational Research. https://research.acer.edu.au/measurement/3/

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142. https://doi.org/10.1177/0013164485451012

Ainsworth, S. E., & Scheiter, K. (2021). Learning by drawing visual representations: Potential, purposes, and practical implications. *Current Directions in Psychological Science*, *30*(1), 61–67. https://doi.org/10.1177/0963721420979582

Akerson, V. L., Carter, I., Pongsanon, K., & Nargund-Joshi, V. (2019). Teaching and learning nature of science in elementary classrooms. *Science & Education*, *28*(3–5), 391–411. https://doi.org/10.1007/s11191-019-00045-1

Anam, R. S., Gumilar, S., & Widodo, A. (2024). The use of the Constructivist Teaching Sequence (CTS) to facilitate changes in the visual representations of fifth-grade elementary school students: A case study on teaching heat convection concepts. *International Journal of Science and Mathematics Education*, *22*(1), 73–99. https://doi.org/10.1007/s10763-023-10358-x

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*, Article e2. https://doi.org/10.1186/s43031-019-0007-8

Beck, C., & Barbato, F. (2022). Physics for secure and efficient societies. *Europhysics News*, *53*(5), 36–39. https://doi.org/10.1051/epn/2022506

Berndt, A. E. (2020). Sampling methods. *Journal of Human Lactation*, *36*(2), 224–226. https://doi.org/10.1177/0890334420906850

Bollen, L., van Kampen, P., Baily, C., Kelly, M., & De Cock, M. (2017). Student difficulties regarding symbolic and graphical representations of vector fields. *Physical Review Physics Education Research*, *13*(2), Article e020109. https://doi.org/10.1103/PhysRevPhysEducRes.13.020109

Boone, W. J., Staver, J. R., & Yale, M. S. (2014). *Rasch analysis in the human sciences*. Springer. https://doi.org/10.1007/978-94-007-6857-4

Bostan Sarıoğlan, A., & Küçüközer, H. (2013). Determination of conceptions of secondary 10th grade students about torque, angular momentum and Kepler's 2nd Law. *Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi*, *7*(1), 121–141. https://search.trdizin.gov.tr/tr/yayin/detay/154911/determination-of-conceptions-of-secondary-10th-grade-students-about-torque-angular-momentum-and-keplers-2nd-law

Brookhart, S. M. (2010). *How to assess higher-order thinking skills in your classroom*. ASCD.

De Cock, M. (2012). Representation use and strategy choice in physics problem solving. *Physical Review Special Topics Physics Education Research*, *8*(2), Article e020117. https://doi.org/10.1103/PhysRevSTPER.8.020117

Dewi, I. N., Ibrahim, M., Poedjiastoeti, S., Prahani, B. K., Setiawan, D., & Sumarjan, S. (2019). Effectiveness of Local Wisdom Integrated (LWI) learning model to improve scientific communication skills of junior high school students in science learning. *Journal of Physics: Conference Series*, *1157*(2), Article e022014. https://doi.org/10.1088/1742-6596/1157/2/022014

Dolgopolovas, V., Dagiene, V., Pozdniakov, S., & Liaptsev, A. (2022). Developing computational thinking skills to foster student research: Contemporary scientific education through modeling and simulations. In N. Rezaei (Ed.), *Integrated education and learning* (pp. 417–443). Springer. https://doi.org/10.1007/978-3-031-15963-3_23

Elia, I., Gagatsis, A., & Demetriou, A. (2007). The effects of different modes of representation on the solution of one-step additive problems. *Learning and Instruction*, *17*(6), 658–672. https://doi.org/10.1016/j.learninstruc.2007.09.011

Etkina, E. (2023). When learning physics mirrors doing physics. *Physics Today*, *76*(10), 26–32. https://doi.org/10.1063/PT.3.5324

Febriyanti, C., Prasetya, R., & Irawan, A. (2018). Etnomatematika pada permainan tradisional engklek dan gasing khas kebudayaan Sunda. Barekeng: *Jurnal Ilmu Matematika Dan Terapan*, *12*(1), 1–16. https://doi.org/10.30598/vol12iss1pp1-6ar358

Glazer, N. (2011). Challenges with graph interpretation: A review of the literature. *Studies in Science Education*, *47*(2), 183–210. https://doi.org/10.1080/03057267.2011.605307

Ho, Y.-R., Chen, B.-Y., Li, C.-M., & Chai, E. G.-Y. (2023). The distance between the humanities and medicine: Building a critical thinking mindset by interdisciplinary dialogue through mind mapping. *Thinking Skills and Creativity*, *50*, Article e101420. https://doi.org/10.1016/j.tsc.2023.101420

Ioannidou, O., & Erduran, S. (2021). Beyond hypothesis testing: Investigating the diversity of scientific methods in science teachers' understanding. *Science & Education*, *30*(2), 345–364. https://doi.org/10.1007/s11191-020-00185-9

Kaya, E., Erduran, S., Aksoz, B., & Akgun, S. (2019). Reconceptualised family resemblance approach to nature of science in pre-service science teacher education. *International Journal of Science Education*, *41*(1), 21–47. https://doi.org/10.1080/09500693.2018.1529447

Kladivová, M., & Mucha, L. (2014). Physical pendulum: A simple experiment can give comprehensive information about a rigid body. *European Journal of Physics*, *35*(2), Article e025018. https://doi.org/10.1088/0143-0807/35/2/0255018

Kress, G., & van Leeuwen, T. (2020). *Reading images: The grammar of visual design* (3rd ed.). Routledge. https://doi.org/10.4324/9781003099857

Maknun, J. (2020). Implementation of guided inquiry learning model to improve understanding physics concepts and critical thinking skill of vocational high school students. *International Education Studies*, *13*(6), 117–130. https://doi.org/10.5539/ies.v13n6p117

Maries, A., & Singh, C. (2023). Helping students become proficient problem solvers Part I: A brief review. *Education Sciences*, *13*(2), Article e156. https://www.mdpi.com/2227-7102/13/2/156

Mashood, K. K., & Singh, V. A. (2012). An inventory on rotational kinematics of a particle: Unravelling misconceptions and pitfalls in reasoning. *European Journal of Physics*, *33*(5), Article e1301. https://doi.org/10.1088/0143-0807/33/5/1301

Matsyshyn, O. (2023). *Toys or physics? Explaining physics through toys*. WS Education. https://doi.org/10.1142/13547

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press. https://eric.ed.gov/?id=ED530802

Nasrun, Prahmana, R. C. I., & Akib, I. (2023). The students' representative processes in solving mathematical word problems. *Knowledge*, *3*(1), 70–79. https://doi.org/10.3390/knowledge3010006

Nazhifah, N., Wiyono, K., & Ismet, I. (2023). Development of STEM-based e-learning on renewable energy topic to improve the students creative thinking skills. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9575–9585. https://doi.org/10.29303/jppipa.v9i11.5206

Novitasari, P., Usodo, B., & Fitriana, L. (2021). Visual, symbolic, and verbal mathematics representation abilities in junior high school's students. *Journal of Physics: Conference Series*, *1808*(1), Article e012046. https://doi.org/10.1088/1742-6596/1808/1/012046

Olazabal, L., Sarriugarte, P., Zuza, K., & Guisasola, J. (2021). Analyzing the upper secondary school students' difficulties in the rotation of rigid body. *Journal of Physics: Conference Series*, *1929*(1), Article e012008. https://doi.org/10.1088/1742-6596/1929/1/012008

Park, J., Chang, J., Tang, K.-S., Treagust, D. F., & Won, M. (2020). Sequential patterns of students' drawing in constructing scientific explanations: Focusing on the interplay among three levels of pictorial representation. *International Journal of Science Education*, *42*(5), 677–702. https://doi.org/10.1080/09500693.2020.1724351

Pulgar, J., Fahler, V., & Spina, A. (2021). Investigating how university students collaborate to compose physics problems through structured tasks. *Physical Review Physics Education Research*, *17*(1), Article e010120. https://doi.org/10.1103/PhysRevPhysEducRes.17.010120

Ramadhan, M. F., Mundilarto, M., Ariswan, A., Irwanto, I., Bahtiar, B., & Gummah, S. (2023). The effect of interface instrumentation experiments-supported blended learning on students' critical thinking skills and academic achievement. *International Journal of Interactive Mobile Technologies*, *17*(14), 101–125. https://doi.org/10.3991/ijim.v17i14.38611

Rimoldini, L. G., & Singh, C. (2005). Student understanding of rotational and rolling motion concepts. *Physical Review Physics Education Research*, *1*(1), Article e010102. https://doi.org/10.1103/PhysRevSTPER.1.010102

Riyan Rizaldi, D., Doyan, A., Makhrus, M., Fatimah, Z., & Nurhayati, E. (2021). Adaptation to new normal conditions: Students physics learning outcomes using the blended learning model. *International Journal of Asian Education*, *2*(3), 369–376. https://doi.org/10.46966/ijae.v2i3.171

Saprima, T., Etriadi, & Nasrullah. (2020). Permainan gasing di Sambas. *Jurnal Sambas (Studi Agama, Masyarakat, Budaya, Adat, Sejarah)*, *3*(1), 13–27. http://journal.iaisambas.ac.id/index.php/SAMBAS/article/download/194/153

Sebastian, R., Kuswanto, H., Jumadi, J., & Putri-Haspari, N. P. (2023). Effectiveness of flip-book optic devices based on problem based learning assisted with virtual laboratory simulation to improve high school students' visual representation. *Revista Cubana de Física*, *40*(2), 90–97.

Sherinnova, Hijriyah, U., Irwandani, Rahmayanti, H., Ichsan, I. Z., Nurfadhilah, & Sison, M. H. (2023). Contextual teaching and learning in natural science and environmental topic of elementary school, secondary school, and university: A meta-analysis study. *AIP Conference Proceedings*, *2595*(1), Article e040014. https://doi.org/10.1063/5.0124176

Singh, A. S., & Masuku, M. B. (2014). Sampling techniques & determination of sample size in applied statistics research: An overview. *International Journal of Economics, Commerce and Management*, *2*(11), 1–22. http://ijecm.co.uk/wp-content/uploads/2014/11/21131.pdf

Subali, B., & Suyata, P. (2012). *Pengembangan item tes konvergen dan divergen dan penyelidikan validitasnya secara empiris*. Diandra Pustaka Indonesia.

Syamsi, I., & Tahar, M. M. (2021). Local wisdom-based character education for special needs students in inclusive elementary schools. *Cypriot Journal of Educational Sciences*, *16*(6), 3329–3342. https://doi.org/10.18844/cjes.v16i6.6567

Tytler, R., Prain, V., Aranda, G., Ferguson, J., & Gorur, R. (2020). Drawing to reason and learn in science. *Journal of Research in Science Teaching*, *57*(2), 209–231. https://doi.org/10.1002/tea.21590

Utami, C. T. P., Mardiyana, & Triyanto. (2019). The identification of visual representation ability of junior high school students in solving geometry problems. *Journal of Physics: Conference Series*, *1180*(1), Article e012014. https://doi.org/10.1088/1742-6596/1180/1/012014

Volkwyn, T. S., Airey, J., Gregorcic, B., & Linder, C. (2020). Developing representational competence: Linking real-world motion to physics concepts through graphs. *Learning: Research and Practice*, *6*(1), 88–107. https://doi.org/10.1080/23735082.2020.1750670

Widoyoko, S. E. P. (2012). *Teknik penyusunan instrumen penelitian*. Pustaka Pelajar.

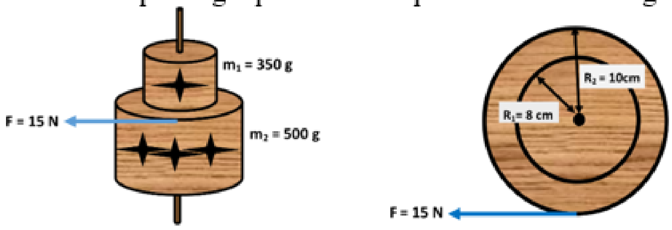
Widyaparamita, Saehana, S., & Darmadi, I. W. (2020). Pengaruh Pembelajaran Fisika dengan Media Permainan Gasing dan Permainan Perahu terhadap Hasil Belajar Siswa SMP Negeri 2 Sigi. *Jurnal Pendidikan Fisika Tadulako*, *8*(2), 45–48. https://garuda.kemdikbud.go.id/documents/detail/1774044

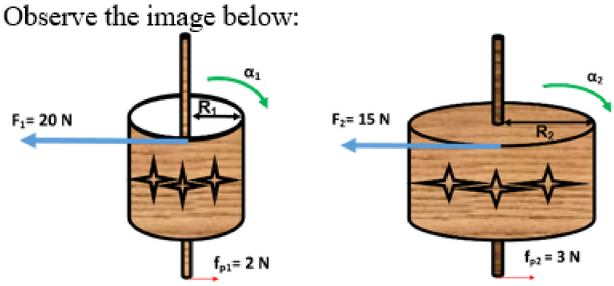
Ye, K., Ni, W., Krieger, M., Ma'ayan, D., Wise, J., Aldrich, J., Sunshine, J., & Crane, K. (2020). Penrose: From mathematical notation to beautiful diagrams. *ACM Transactions on Graphics*, *39*(4), Article e144. https://doi.org/10.1145/3386569.3392375

APPENDIX

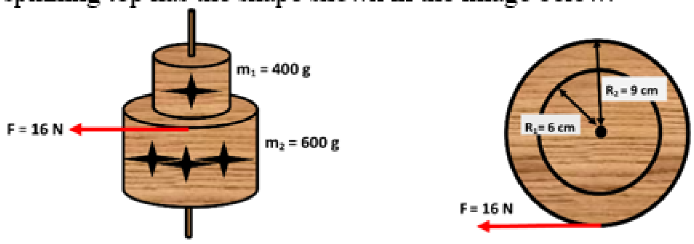
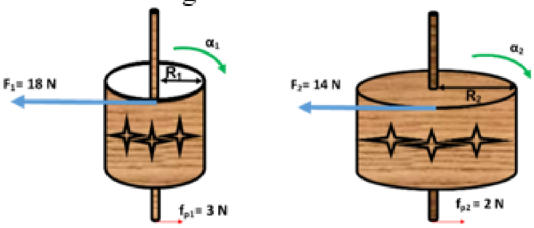
Appendix A

Visual Representation Ability Test Instrument

<table>
<tr><th>Package</th><th>Item number</th><th>Question</th></tr>
<tr><td rowspan="3">A</td><td>1</td><td>Budi is participating in a spinning top competition in his village. The competition is judged based on the top that spins the longest. Budi has a spinning top with the shape shown in the image below.


(side view) (top view)
With the mass distribution of the solid cylindrical spinning top covering both Part 1 and Part 2, Budi spun his top with a constant force F during the competition. However, his top lost to Rino's top, which has a moment of inertia of $4{,}20 \times 10^{-3}$ kgm^2.
a. If Budi wants to adjust the radius of the spinning top in Cylinder Part 2, what range of values should the radius be to surpass Rino?
b. If Budi wants to adjust the mass of the spinning top in Cylinder Part 1, what range of values should the mass be to surpass Rino?</td></tr>
<tr><td>2</td><td>Three spinning tops, 1, 2, and 3, are solid cylinders with radii of 8 cm, 10 cm, and 12 cm, respectively, each having a mass of 600 g. These tops are spun using a string perpendicular to their radii with a tension of 30 N in a clockwise direction. There is a frictional force of 2 N on the axle of each top, which has a diameter of 1 cm, causing the tops to eventually stop over time.
a. Draw the Free-Body Diagram (FBD) for the spinning top in this case!
b. Determine the moment of inertia for each spinning top?
c. Create a graph showing the relationship between the radius of the spinning top and its moment of inertia. Explain!</td></tr>
<tr><td>3</td><td>Observe the image below:


(1) (2)
Spinning top 1, with a radius of R_1 = 8 cm is a hollow cylinder, while spinning top 2, with a radius of R_2 = 16 cm is a solid cylinder. Both tops have the same mass of 1 kg. The image shows that a rotational force is applied, and there is friction at the axle, which has a diameter of 1 cm. Determine:
a. The ratio of the moments of inertia of the two spinning tops! And, provide a conclusion on which spinning top will stop spinning first!
b. The magnitude and direction of the total torque for each spinning top! And, provide a conclusion on which spinning top has the fastest angular acceleration!</td></tr>
</table>

	1	Roni is participating in a spinning top competition in his village. The competition evaluates the top that spins the longest. Roni's spinning top has the shape shown in the image below:  (side view) (top view) The mass distribution of the spinning top consists of a hollow cylinder, covering both Part 1 and Part 2. During the competition, Roni spins the top with a constant force *F*. However, his spinning top loses to Gibran's, which has a moment of inertia of $6{,}84 \times 10^{-3}$ kgm^2. a. If Roni wants to adjust the radius of the spinning top in Cylinder Part 2, what range of radius values would allow him to surpass Gibran? b. If Roni wants to adjust the mass of the spinning top in Cylinder Part 1, what range of mass values would allow him to surpass Gibran?
B	**2**	Three spinning tops, labeled 1, 2, and 3, are hollow cylinders with radii of 7 cm, 9 cm, and 11 cm, respectively, each having a mass of 800 g. These tops are spun using a string perpendicular to their radii with a tension of 32 N in a clockwise direction. There is a frictional force of 2 N on the axle of each top, which has a diameter of 1 cm, causing the tops to eventually stop over time. a. Draw the FBD for the spinning tops in this case! b. Determine the moment of inertia for each spinning top? c. Create a graph showing the relationship between the radius of the spinning top and its moment of inertia! Explain!
	3	Observe the image below:  (1) (2) Spinning top 1, with a radius of R_1 = 9 cm is a hollow cylinder, while spinning top 2, with a radius of R_2 = 18 cm is a solid cylinder. Both tops have the same mass of 800 g. The image illustrates that a rotational force is applied to each top, and there is friction at their axles, which have a diameter of 1 cm. Determine: a. The ratio of the moments of inertia of the two spinning tops! And, provide a conclusion on which spinning top will stop spinning first! b. The magnitude and direction of the total torque for each spinning top! And, provide a conclusion on which spinning top has the fastest angular acceleration!

Note. Authors' own elaboration.

i Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Colombo St. No. 1, Sleman Yogyakarta, 55281, Indonesia; Department of Physics Education, Faculty of Teacher Training and Education, Universitas Sarjanawiyata Tamansiswa, Batikan St. UH III, Yogyakarta, Indonesia.
https://orcid.org/0000-0003-4041-1325
riosebastian.2022@student.uny.ac.id

ii Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Colombo St. No. 1, Sleman Yogyakarta, 55281, Indonesia.
https://orcid.org/0000-0002-2693-8078
herukus61@uny.ac.id

All correspondence relating to this article should be sent to:

Rio Sebastian
riosebastian.2022@student.uny.ac.id

Recebido em 07 de junho de 2024
Aceite para publicação em 29 de abril de 2025
Publicado em 05 de março de 2026

Análise da capacidade de representação visual dos estudantes em física com base nos resultados de testes empíricos sobre a dinâmica rotacional no contexto do jogo tradicional do pião

RESUMO

A capacidade de representação visual desempenha um papel fundamental no processo de aprendizagem da Física, pois auxilia os estudantes na compreensão abrangente e conceptual dos fenómenos físicos. No entanto, essa competência ainda representa um desafio significativo para muitos alunos. Assim, este estudo tem como objetivo investigar as habilidades de representação visual dos estudantes por meio de testes empíricos, na forma de respostas escritas, sobre o tema da dinâmica rotacional, utilizando como contexto o jogo tradicional do pião. A pesquisa adota uma abordagem quantitativa descritiva, procurando avaliar a capacidade de representação visual a partir de questões discursivas elaboradas com base em indicadores específicos dessa competência. Os resultados revelam que a maioria dos estudantes apresenta um nível muito baixo de representação visual, sendo que 52% se enquadram nessa categoria. Além disso, com base nas pontuações médias obtidas nos diferentes indicadores, todos foram classificados como baixos. O indicador relacionado com a análise de imagens, diagramas, tabelas ou gráficos para a elaboração de conclusões apresentou a menor média. Dessa forma, conclui-se que a capacidade de representação visual dos estudantes na aprendizagem da Física, especialmente no contexto da dinâmica rotacional associada ao jogo tradicional do pião, ainda é limitada. Portanto, tornam-se necessários esforços para aprimorar essa competência por meio de atividades inovadoras e adequadas ao ensino de Física.

Palavras-chave: Representação visual, Dinâmica rotacional, Jogo tradicional do pião.

Análisis de la capacidad de representación visual de los estudiantes en física basada en los resultados de pruebas empíricas sobre el tema de la dinámica rotacional en el contexto del juego tradicional del trompo

RESUMEN

La capacidad de representación visual desempeña un papel fundamental en el aprendizaje de la Física, ya que permite a los estudiantes desarrollar una comprensión integral y conceptual de los fenómenos físicos. Sin embargo, esta competencia continúa siendo un desafío significativo para muchos alumnos. Por ello, el presente estudio tiene como objetivo examinar las habilidades de representación visual de los estudiantes mediante pruebas empíricas de respuesta escrita sobre el tema de la dinámica rotacional, utilizando como caso de estudio el juego tradicional del trompo (gasing). La investigación adopta un enfoque cuantitativo descriptivo para evaluar dicha capacidad a través de preguntas discursivas elaboradas con base en indicadores específicos de representación visual. Los resultados muestran que la mayoría de los estudiantes presenta un nivel muy bajo de representación visual, con un 52% clasificado en esta categoría. Asimismo, los puntajes promedio obtenidos en todos los indicadores se situaron en niveles bajos. El indicador relacionado con el análisis de imágenes, diagramas, tablas o gráficos para extraer conclusiones registró la media más baja. En consecuencia, se concluye que la capacidad de representación visual de los estudiantes en el aprendizaje de la Física, particularmente en el contexto de la dinámica rotacional y el juego tradicional del trompo, sigue siendo limitada. Por lo tanto, se requieren esfuerzos para fortalecer esta competencia mediante actividades innovadoras y adecuadas en la enseñanza de la Física.

Palabras clave: Representación visual, Dinámica rotacional, Juego tradicional del trompo.