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Multiple Representation Ability of High School Students in Physics: A Study of Modern Response Theory

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Abstract

Physics education emphasizes students' ability to represent a problem and then choose alternative solutions from various perspectives. However, teachers still very rarely use this ability as the focus of assessment. The purpose of this study is to describe the results of an assessment of the ability to represent multiple physics in each of its components. This is survey research that takes a quantitative approach. This study's sample included 287 high school students from Yogyakartam using cluster sampling. The instrument used is a physics multiple representation ability test that has been tested for validity, reliability, and item quality using IRT 1 PL analysis. According to the measurement results, physics high school students' dual representation ability in all aspects, namely mathematical representation, graphic representation, image representation, and verbal representation, is in the low category. However, according to the four existing components, the mathematical component is the highest and the verbal component is the lowest. So this finding can be a reference for teachers in improving the quality of physics teaching.

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Introduction

Physics is a scientific knowledge that could be separated from other scientific fields, so it is essential that we study it. Physics, as fundamental science, has characteristics such as the scientific form consisting of facts, concepts, principles, postulates, and scientific theories and methodologies. Students in physics classes are expected to be able to explain the behavior of everyday objects and phenomena. As a matter of fact, physics knowledge adheres to constructivism, in which students construct their own knowledge and experience (Asriadi & Istiyono, 2020). Physics is also an important subject in the IT era. The contribution of physics in the IT era is very useful for every society (Asriadi & Hadi, 2021). Physics as a basic science has characteristics that include the form of science consisting of facts, concepts, principles, postulates, and theories as well as scientific methodologies (Crouch et al., 2018). Physics lessons also demand that students be able to solve complex problems by applying their knowledge and understanding of students to real situations (Nugroho et al., 2020). Learning physics requires students to develop multiple representation abilities. The use of multiple representations in the teaching and learning process can help students become better at solving problems, but some students master different representations (Lahope et al., 2020). So this ability is very necessary for learning physics.

Representation is a replacement for something that represents to explain a concept that is used to find solutions in various ways based on his mind's interpretation so that the concept becomes more meaningful. Multiple representation abilities are considered the key to learning physics so there is good enough motivation to learn how students use multiple representations when solving problems and learn how best to teach problem-solving using multiple abilities (Aisyah & S, 2021). Multi-representation ability is the ability to interpret and apply various representations in explaining physics concepts and problems in physics (Andromeda & Djudin, 2017). Multi-representation involves sequentially translating a given physics problem from one language symbol to another, starting with writing a verbal description of the problem, then moving it into the form of customized drawings and diagrammatic representations, and ending (usually) with a mathematical formula that can be used to determine an answer use numbers (Mahmudah & Kurniawati, 2021). Although using multiple representations in teaching has great potential benefits, it can also harm the learning process, as cognitive load increases (Irwandani, 2014). There are some cognitive tasks that learners must perform on multiple representations, they must learn the format and operator of each representation, underscore the relationship between the representation and the domain it represents, and understand how the representations relate to one another (Handayani & Rasyid, 2015).

The importance of multiple representations has also been reported in physics education research, Nieminen offers several reasons why multiple representations are useful in physics education: they encourage students to tackle physics problems, build bridges between oral and mathematical representations, and help students develop images that give symbols meaning mathematical symbols. This researcher also argues that one of the important goals of physics education is helping students to learn to construct multiple representations of physical processes, and to learn to move in all directions between these representations. In addition, it has been shown that to understand a physics concept, the ability to recognize and manipulate that concept in various representations is essential (Nieminen et al., 2010). Multiple representations as a practice of representing the same concept through various forms, which includes descriptive (verbal, graphic, table) representation modes, experimental, mathematical, figurative (pictorial, analogy, and metaphor), kinesthetic, visual, and action operational mode (Kn & Sudarti, 2021). Students will have a broad intellectual horizon if they understand that ability.

Multiple representation abilities are considered essential for learning physics, so there is sufficient motivation to learn how students use multiple representations when solving problems and how to best teach problem-solving using multiple abilities. Multi-representation is a representation of a concept that is carried out in more than one way, there are at least 3 representations in physics, namely (1) verbal representation; (2) physical representation; and (3) mathematical representation (Kurniasari & Wasis, 2021). In learning physics, the three representations must be applied by the physics teacher so that students understand physics concepts correctly and completely. Learning by using multiple representations will provide more benefits, especially in honing students' various intelligence abilities or better known as multiple intelligences (Maharani et al., 2015). Multiple representations have three main functions, namely as a complement, limiting interpretation, and building understanding. The first function is that multiple representations are used to provide representations that contain complementary information or help complete cognitive processes. Second, one representation is used to limit the possibility of misinterpretation in using another representation. Third, multiple representations can be used to encourage students to build an in-depth understanding of the situation (Rasmawan, 2020). In this regard, it is critical to understand students' ability to use multiple representations during the physics learning process. One approach is to go through the assessment process. Multiple representation abilities will be assessed in this study, including mathematical representation skills, graphic representations, verbal representations, and image representations. The fourth representation must be used by the physics teacher in order for students to understand physics concepts correctly and completely. Learning with multiple representations will provide more benefits, particularly in honing students' intelligence abilities in multiple ways, also known as multiple intelligences. Based on the description above, the purpose of this study is to assess multiple representation physics ability and describe the components of multiple representation ability in physics learning.

Method

This is survey research that takes a quantitative approach. The research design used is cross-selection, which is research by studying objects over a specific period. Information from a subset of the population is collected directly empirically to learn what some of the population thinks about the object being studied in the field (Creswell, 2012). This service was carried out to assess students' multiple physics representation skills by going through two major stages: instrument validation through content validation and construct validation using the FGD (Focus Group Discussion) method, and data analysis using the IRT (Item Response Theory) theory with 1PL (Logistics Parameters). The interpretation is then examined in light of the ability measurement results.

This study's population consists of Yogyakarta high school students. The test subjects were then determined using a cluster sampling technique based on the district in the Special Region of Yogyakarta. The sample size was 287 students from 5 high schools in Yogyakarta. The ability test of multiple representations of physics was used in this study. The following table contains a description of indicators of multiple representation capability.

Table 1. Component Representation Ability Variables Description

Variable	Indicator	Indicator Description
Multiple Representations	Math Representation	Mathematical ability is illustrated by the ability to express mathematical ideas (problems, statements, definitions, etc.) in a variety of ways. In this case, students express mathematical ideas and ideas displayed by students, as well as substitute forms of a problem that they are confronted with as a result of their interpretation of their thoughts.
	Graphic Representations	Ability to analyze the relationship of related variables, present data in the form of graphs or diagrams, and solve problems using graphical representations. In this case, students seek substitute forms of aspects of

Variable	Indicator	Indicator Description
		a problem situation that are used to find graphic solutions.
	Image Representations	The ability to comprehend a theory through the use of visual media. In this case, students are helped by media in the form of images to understand a theory and imagine how it occurred.
	Verbal Representations	The ability to comprehend a theory through the use of verbal sentences. Where students can only understand the theory through sentences that explain it and students can imagine the theory

The test instrument is in the form of a two-tier multiple choice consisting of 39 items with cognitive levels of C2-C4. The material being tested is straight motion and Newton's laws. Based on the assessment rubric, data on student responses were analyzed by assigning a score of 1-5. A score of 5 indicates that the answer is correct and that both the mathematical and verbal explanations or graphs are correct and complete. A score of 4 indicates that the answer is correct and that both the mathematical and verbal explanations or graphs are correct but incomplete. A score of 3 indicates that the answer is correct, the explanation is mathematically correct, but no verbal or graphic explanation is provided. A score of 2 indicates that the answer is incorrect, that the mathematical reasoning appears correct but is not quite correct, or that the answer is correct but there is no mathematical explanation. Score 1 indicates that you attempted to solve the problem.

The reliability coefficient and item difficulty level were calculated based on the results of the QUEST program analysis. If The instrument is said to be reliable if the reliability coefficient is greater than 0.7, and less reliable if the reliability coefficient is less than 0.7. While the difficulty of the items that can be measured by the instrument ranges from -3 to +3, 0.25 to 0.75 is a good difficulty level (AM & Hadi, 2021). A question with a difficulty level less than 0.25 is considered difficult; a question with a difficulty level greater than 0.75 is considered too easy.

Categories based on the ideal mean and standard deviation were used to determine the level of representation of multiple physics of high school students. This is applied under the assumption that higher-order thinking skills in physics are distributed normally. The highest and lowest scores of the research variables are used to calculate the ideal mean score (Mi) and ideal standard deviation score (SBi). The highest possible score for all answers is the highest ideal score. The lowest possible score for all answers is the ideal lowest score. The ability level has a range, as shown in the table below.

Table 2. The interval of Values at the Ability Level

Ability Interval	Category
$\theta \leq Mi - 1,5\ SBi$	Very low
$Mi - 1,5\ SBi < \theta \leq Mi - 0,5\ SBi$	Low
$Mi - 0,5\ SBi < \theta \leq Mi + 0,5\ SBi$	Medium
$Mi + 0,5\ SBi < \theta \leq Mi + 1,5\ SBi$	High
$Mi + 1,5\ SBi < \theta$	Very high

Results and Discussion

Quality of Physics Component Representation Ability Instruments

Math Ability

The ability to represent multiple physics on mathematical components was tested for empirical validity with 39 test items given to 287 students as test subjects QUEST output results are described as follows.

Table 3. Mathematical Component Empirical Validity Test Results

No	Parameter	Estimate Item	Estimate Case
1	Estimation of item reliability	0.46	0.57
2	Item difficulty level	0.00±0.57	
3	INFIT MNSQ	1.00±0.09	1.00±0.22
4	OUTFIT MNSQ	0.99±0.12	0.99±0.31
5	INFIT t	0.06±0.77	0.04±0.81
6	OUTFIT t	0.04±0.64	0.08±0.65

Based on Table 3, the reliability of the two types is based on the reliability of the items and subjects seen in the estimated case. The higher the reliability value, the more test items that fit or match the model being tested, and vice versa. The item reliability value is 0.46 and the subject reliability value is 0.57. This shows that the level of consistency of the subject/respondent in choosing the answer is still weak, but the quality of the items for measuring the ability of multiple representations on mathematical components is quite reliable (Subali et al., 2019). Apart from knowing the reliability of the test instrument, it is also possible to know the level of difficulty of the items. The level of difficulty of the items that can be measured by the instrument is in the range of -3 to +3 which is 0.00±0.57 so the instrument is suitable to be used to measure students' multiple representation abilities of physics.

Determination of the overall fit of each item with the model in the QUEST program is based on the magnitude of the INFIT MNSQ average value or the INFIT t average value of the item concerned. The amount of the unweighted mean square in the QUEST program is abbreviated as OUTFIT MNSQ and the expected Weighted Mean Square is 1 and the variance is 0. Items are considered to fit the Rasch model if the INFIT MNSQ value is in the range 0.77 – 1.33 and the OUTFIT t value is less than equal to 2.00. Based on Table 1, it can be seen that the INFIT MNSQ value is 0.91 - 1.09 which is in the range of 0.77 - 1.30 and the OUTFIT t value is -0.60 to 0.68 which is less than equal to 2. shows that overall the items fit the Rasch model.

Graphics Ability

The ability to represent multiple physics on the graph component was tested for empirical validity with 39 test items given to 287 students as test subjects QUEST output results are described as follows.

Table 4. Graph Component Empirical Validity Test Results

No	Parameter	Estimate Item	Estimate Case
1	Estimation of item reliability	0.47	0.69
2	Item difficulty level	0.00±0.56	
3	INFIT MNSQ	1.00±0.10	1.00±0.22
4	OUTFIT MNSQ	1.00±0.12	1.00±0.26
5	INFIT t	0.02±0.79	0.06±0.71
6	OUTFIT t	0.03±0.66	0.11±0.56

Based on Table 4, the reliability of the two types is based on the reliability of the items and subjects seen in the estimated case. The higher the reliability value, the more test items that fit or match the model being tested, and vice versa. The item reliability value is 0.47 and the subject reliability value is 0.69. This shows that the level of consistency of the subject/respondent in choosing the answer is still weak, but the quality of the items for measuring the ability of multiple representations on the graph component is quite reliable (Bashooir & Supahar, 2018). Apart from knowing the reliability of the test instrument, it is also possible to know the level of difficulty of the items. The level of difficulty of the items that can be measured by the instrument is in the range of -3 to +3 which is 0.00±0.56 so the instrument is suitable to be used to measure the ability of multiple representations of physics students on the graphic component.

Determination of the overall fit of each item with the model in the QUEST program is based on the magnitude of the INFIT MNSQ average value or the INFIT t average value of the item concerned. The amount of the unweighted mean square in the QUEST program is abbreviated as OUTFIT MNSQ and the expected weighted mean square is 1 and the variance is 0. Items are considered to fit the Rasch model if the INFIT MNSQ value is in the range 0.77 – 1.33 and the OUTFIT t value is less than equal to 2.00. Based on Table 1, it can be seen that the INFIT MNSQ value is 0.90 -. 1.10 which is still in the range of 0.77 - 1.30 and the OUTFIT t value is -0.63 to 0.69 which is less than equal to 2. This shows that overall the items fit the Rasch model.

Image Ability

The ability to represent multiple physics in the image component was tested for empirical validity with 39 test items given to 287 students as test subjects QUEST output results are described as follows.

Table 5. Empirical Validity Test Results of Image Components

No	Parameter	Estimate Item	Estimate Case
1	Estimation of item reliability	0.79	0.68
2	Item difficulty level	0.00±0.67	
3	INFIT MNSQ	0.98±0.11	1.00±0.30
4	OUTFIT MNSQ	1.06±0.31	1.07±0.77
5	INFIT t	-0.24±1.33	-0.05±1.07
6	OUTFIT t	0.08±1.40	0.09±0.92

Based on Table 5, the reliability of the two types is based on the reliability of items and subjects seen in the estimated case. The higher the reliability value, the more test items that fit or match the model being tested, and vice versa. The item reliability value is 0.79 and the subject reliability value is 0.68. This shows that the level of consistency of the subject/respondent in choosing the answer is high and the quality of the items to measure the ability of multiple representations on the image components is quite reliable (Larasati et al., 2020). Apart from knowing the reliability of the test instrument, it is also possible to know the level of difficulty of the items. The level of difficulty of the items that can be measured by the instrument is in the range of -3 to +3 which is 0.00±0.67 so the instrument is suitable to be used to measure the ability of students' multiple physics representations on the graphic component.

Determination of the overall fit of each item with the model in the QUEST program is based on the magnitude of the INFIT MNSQ average value or the INFIT t average value of the item concerned. The amount of the unweighted mean square in the QUEST program is abbreviated as OUTFIT MNSQ and the expected weighted mean square is 1 and the variance is 0. Items are considered to fit the Rasch model if the INFIT MNSQ value is in the range 0.77 – 1.33 and the OUTFIT t value is less than equal to 2.00. Based on Table 1, it can be seen that the INFIT MNSQ value is 0.87 - 1.09 which is still in the range of 0.77 - 1.30 and the OUTFIT t value is -1.32 to 1.48 which is less than equal to 2. This shows that the overall items in the image components match the Rasch model.

Verbal Ability

The ability to represent multiple physics on the verbal component was tested for empirical validity with 39 test items given to 287 students as test subjects QUEST output results are described as follows.

Table 6. Verbal Component Empirical Validity Test Results

No	Parameter	Estimate Item	Estimate Case
1	Estimation of item reliability	0.79	0.67
2	Item difficulty level	-0.00±0.80	
3	INFIT MNSQ	0.98±0.11	1.00±0.29
4	OUTFIT MNSQ	1.06±0.30	1.07±0.74
5	INFIT t	-0.23±1.28	-0.05±1.06
6	OUTFIT t	0.07±1.38	0.09±0.93

Based on Table 6, the reliability of the two types is based on the reliability of items and subjects seen in the estimated case. The higher the reliability value, the more test items that fit or match the model being tested, and vice versa. The item reliability value is 0.79 and the subject reliability value is 0.67. This shows that the level of consistency of the subject/respondent in choosing the answer is high and the quality of the items to measure the ability of multiple representations on the verbal component is quite reliable. Apart from knowing the reliability of the test instrument, it is also possible to know the level of difficulty of the items. The level of difficulty of the items that can be measured by the instrument is in the range of -3 to +3 which is -0.01±0.80 so the instrument is suitable to be used to measure the ability of multiple representations of students' physics on the verbal component.

Determination of the overall fit of each item with the model in the QUEST program is based on the magnitude of the INFIT MNSQ average value or the INFIT t average value of the item concerned. The amount of the unweighted mean square in the QUEST program is abbreviated as OUTFIT MNSQ and the expected weighted mean square is 1 and the variance is 0. Items are considered to fit the Rasch model if the INFIT MNSQ value is in the range 0.77 – 1.33 and the OUTFIT t value is less than equal to 2.00. Based on Table 1, it can be seen that the INFIT MNSQ value is 0.87 - 1.09 which is still in the range of 0.77 - 1.30 and the OUTFIT t value is -1.31 to 1.45 which is less than equal to 2. This shows that overall the items on the verbal component are by the Rasch model.

Results of Measurement of Physics Compound Representation Ability

Math Ability

Information about students' multiple representation abilities on mathematical components can be seen in Table 7 below.

Table 7. The Result of Compound Representation of Mathematical Components

Ability Estimation Interval (θ)	Number of Students	Category
$\theta < -1{,}995$	108	Very low
$-1{,}995 < \theta \leq -0{,}665$	103	Low
$-0{,}665 < \theta \leq 0{,}665$	43	Medium
$0{,}665 < \theta \leq 1{,}995$	11	High
$\theta > 1{,}995$	22	Very high

Based on Table 7, it can be seen that the students' ability to represent multiple mathematical aspects most dominates in the very high ability category as many as 123 students or as much as 42.85%. This means that the ability to represent multiple mathematical aspects is in the very high category.

Graphics Ability

The ability of multiple representations of students in the graph component obtained the output results as shown in Table 8 below.

Table 8. The Result of Compound Representation of Graphics Component

Ability Estimation Interval (θ)	Number of Students	Category
$\theta < -1{,}995$	107	Very low
$-1{,}995 < \theta \leq -0{,}665$	115	Low
$-0{,}665 < \theta \leq 0{,}665$	19	Medium
$0{,}665 < \theta \leq 1{,}995$	13	High
$\theta > 1{,}995$	21	Very high

As seen in Table 8, the students' ability to represent multiple graphic aspects predominates in the low ability category, with as many as 115 students (40.1 %) participating. This indicates that the ability to represent multiple mathematical aspects is very high.

Image Ability

In the ability of students to represent multiple physics in the image component, the output results are obtained as shown in Table 9 below.

Table 9. The Result of Compound Representation of Image Component

Ability Estimation Interval (θ)	Number of Students	Category
θ < -1,995	59	Very low
-1,995 < θ ≤ -0,665	130	Low
-0,665 < θ ≤ 0,665	79	Medium
0,665 < θ ≤ 1,995	13	High
θ > 1,995	6	Very high

According to Table 9, students in the low ability category own as many as 130 students or 45.29 % of the ability to represent multiple aspects of the image that dominates. This indicates that the ability to represent multiple mathematical aspects is low.

Verbal Ability

The ability of the verbal component of multiple representations of physics obtained the average output of the ability as shown in Table 10.

Table 10. The Result of Compound Representation of Verbal Component

Ability Estimation Interval (θ)	Number of Students	Category
θ < -1,995	58	Very low
-1,995 < θ ≤ -0,665	132	Low
-0,665 < θ ≤ 0,665	48	Medium
0,665 < θ ≤ 1,995	33	High
θ > 1,995	15	Very high

Table 10, students in the low ability category own as many as 132 students or 42.99 % of the verbal aspects of the multiple representation abilities that dominate. This indicates that the ability to represent multiple mathematical aspects is low.

Discussion

Based on the research data, it can be seen that the students' multiple physics abilities on average have low abilities in all components of ability. However, it can be seen that the students' multiple physics abilities of the four components are the highest in the mathematical component, then graphics, followed by verbal, and the lowest in the image component. This is supported by a statement that shows that the multiple representation abilities of students differ in solving a problem according to their respective representational abilities (Susilo, 2018).

The mathematics component is low because many students learn solely through memorization and observation. They have no idea that each question will be of a different type. Students should be able to study and comprehend what they are learning without hearing it. Furthermore, the findings show that students' mathematical abilities are extremely low. This can be seen in the students' inability to answer questions using simple mathematical operations (addition, subtraction, multiplication, and division). Furthermore, questions requiring calculation can only be answered with the correct answer, but the reason given is incorrect. This indicates that students only guess the answer but do not understand the mathematical concept of the answer. This discovery is undoubtedly alarming because physics is synonymous with numbers and calculations, as well as a thorough understanding of theoretical concepts. As a result, it is natural that the mathematical component of physics' dual representation ability is weak. This finding is also supported by theory (Loc & Phuong, 2019) which states that students are less careful in carrying out the mathematical calculation process, resulting in incorrect final results. So students faced many difficulties and had errors using visual and symbolic representations. This opinion is reinforced by the statement (Doruk, 2019) which states that the tendency of students who have mathematical abilities are people who can think cause and effect, use numbers, select and categorize, understand storylines, and read tables.

The graphic component is the second component of students in the low category's dual physics ability. The lack of student interviews in reading graphic information is the root cause. As a result, the information in the graph is misconstrued. In this study, it was discovered that students misinterpreted the graph of the relationship between distance and time that described speed. The incorrect graph interpretation is the discovery that students are unable to represent information in graphs, which are then converted into concepts or physics formulas. Graphs and diagrams, on the other hand, are more easily used in physics lessons to describe the relationship in an equation or theoretical concept. This finding is supported by the theory (Treagust et al., 2017) that students will understand questions in the form of graphs differently if they do not understand and have a broad understanding of the fundamental concepts of physics. According to research (Permadi, 2018), students have low graphic skills because they are less able to answer questions that include graphs, diagrams, and mathematical symbols.

Image components are rated as low. This low ability is because when learning physics, students are required to know not only the formula for the material's equation, but also the concept of the material, which is visualized in the form of images. According to the findings of this study, students did not understand the information presented in the images related to the concept of physics material. Students can only interpret images that are textually or visually interpretable, but they cannot find the meaning contained in the image, which is closely related to the concept of physics. Students only memorize the material they have obtained, so the image component falls to the bottom of the students' multiple abilities. This finding is supported by (Aisyah & S, 2021) research which found that students consider physics material to be something abstract where it is difficult to imagine events or events even though they have been given pictures.

The verbal component is the next multiple representation ability, which is also in the low category. Students do not easily understand physics material if it is just explained in words, which puts this component in the low category. This is supported by research findings that reveal pupils are unable to completely comprehend the narrative in the questions. The majority of questions containing stories or narratives containing information are incorrectly answered. This fact is corroborated by research, according to which linguistic representations contained in learning textbooks are still difficult to understand without the aid of other components such as pictures or visuals (Savinainen et al., 2013).

Based on the results of the study, it was shown that the ability of students to use all the ability of multiple representation skills was not maximized, which was indicated by low results. The role of multiple representation skills has not been maximized in training students. This is following the research conducted (Wela et al., 2020) which states that learning by applying the multiple representation abilities of students has not been maximally applied by the teacher so it is a triggering factor for the low ability of students' multiple representations. Students may be able to solve a problem because they follow the solutions in the book and cannot draw conclusions and generalize from one solution to another.

This research suggests that a program or teaching method that specifically trains multiple representation skills in physics learning, particularly in mathematics, graphics, pictures, and verbal aspects, is required. Because physics is an expression of a fact in the universe, teachers or preliminary physics teachers should be able to make physics material more recognizable to students. There are meanings, patterns, and explanations for a phenomenon, so representations, interpretations, connections, and logical inferences are required so that they can be used to find previously unknown answers and solutions.

Conclusion

Based on the results of research and discussion, it can be concluded that the students' ability to represent multiple physics is best in the mathematical component, then the graphic component, then the image component, and the lowest in the verbal component. The mathematical component was the best because the participants thought that physics depended on calculations and had often practiced math problems. So the results show that the multiple representation ability of students' physics lies in the mathematical component. The lowest component is the verbal component. This happens because physics subjects if only explained in words, students are not able to understand and understand the meaning of the questions given and do not understand the meaning of the questions.

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