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Analysis of the multirepresentation ability of physics education students in problem-solving related to physics

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Abstract
Students frequently struggle to comprehend and solve challenges during learning, especially when dealing with physics-related problems. This study examines how well physics education students can perform multiple representations when solving physics-related problems. This survey was conducted on 48 samples selected using purposive sampling techniques and data collection methods using questionnaires. The data collection instrument in this study used a Likert scale questionnaire packaged in Google Forms. The data that had been collected through the questionnaire was then analyzed descriptively. The findings of this study indicate that the multirepresentation skills possessed by physics students can improve their understanding and help them solve physics problems that they face both textually and contextually. Multirepresentation abilities are also in line with encouraging strengthening the curriculum and teaching methods of students in physics education study programs to be more meaningful and comprehensive. Students who have studied physics materials will be able to illustrate the material in figures, tables, or mathematical equations. For students and lecturers to engage in meaningful and comprehensive learning in the future, the findings of this study will serve as the foundation for improving the quality of instruction in the physics education study program.

Keywords: ability analysis, mathematical representation, multirepresentation, problem solving, visual representation.

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I. Introduction

The creation of information and communication technology, which has drastically altered human life, is rooted in physics. Physics is a science that studies the character and interaction of symptoms, energy, phenomena, and causal relationships of subatomic particles (microcosmos) and large systems (macro cosmos) [1]. The science of physics is a field that studies natural phenomena and symptoms logically, rationally, and systematically, which includes scientific processes and attitudes [2]. The scientific method includes observation, evaluation, hypothesis generation, planning and conducting experiments, evaluating measurement data, and making conclusions [3]. Physics is a process that grapples with conjecture, observation, and investigation [4]. Ariani said that physics does not only revolve around theories and equations. However, many concepts must be understood deeply and holistically so that students can build their knowledge based on their direct experience and active role in the learning process [5].

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In the 21st century, development and change move quickly in all fields, including economy, information, politics, and education. Therefore, each individual is required to keep up with the rapid developments. One of them is the ability to interpret data in various forms. This ability is the ability of multirepresentation [6]. Multirepresentation is the presentation of the same concept in different forms, including descriptive, experimental, mathematical, figurative, kinesthetic, and visual modes of representation [7],[8]. Zachria stated that the functional relationship of physical quantities could be expressed as a simple mathematical formulation and then represented as a graph. The advancement of puts technology has been found in the representation of the interaction of physical quantities into a phenomenon so that the output of the representation can be in the form of animation or simulation. The representation has the format and content of information so that it can be used to solve physical problems with various types of representations [9].

Multirepresentation is a combination of representations in verbal, mathematical, image, and graphic formats [10]. Verbal representation is a representation in the form of an explanation or description in words and sentences [11]. Graphic representation is a form of representation in sketches or drawings based on the description that has been given. The form of graphic representation is a representation that describes the relationship between a variable and another variable based on verbal and mathematical explanations [12],[13]. According to Setyawati, mathematical representation is a form of representation that is presented in the form of symbols, equations, formulas, and data processing [6]. Mathematical representation ability assists in mathematical thinking and communicating ideas, especially in the ability of external representation in images, symbols, graphs, or physical objects [14].

Ainsworth mentions [7] that, in general, in the presentation of multirepresentations, there are three main functions in learning activities. The first function uses representations containing complementary information or as a knowledge function. The second function is that using one representation can limit the possibility of errors in interpreting other representations. Third, multirepresentation aims to encourage learners to strengthen their understanding of a phenomenon or situation deeply and thoroughly. In other words, multirepresentation will make learning more profound [15],[16]. Multirepresentation-based learning models can improve student understanding [6],[17]. Multirepresentation can provide holistic knowledge benefits if learners connect information available in various forms of representation. The capability to connect multiple representations for each learner must be different and is influenced by the initial ability of an individual. Suppose the abilities of a learner are initially low. In that case, they will tend to have difficulty making interconnections, causing the learner to be unable to construct concepts like students with higher initial abilities [18]. Problem-solving ability is a component that must be owned and developed by each learner. This ability will increase sensitivity to a problem [19]. The relation between Multirepresentation ability and problem-solving is that physics learning is more emphasized in improving higher-level thinking skills [20].

Several students had difficulty in making physical representations. In addition, several students could not verbally represent physics concepts. The students successfully solved problems preceded by visual representations with a combination of mathematical representations [21]. These findings show that students who successfully solve physics problems require assistance with a thorough understanding and use of multirepresentation [7]. In addition, several researchers have researched Multirepresentation skills related to understanding physics students in physics-related problem-solving. The study explained that the multirepresentation approach improved students' understanding of the physics material of effort and energy [22]. Students can solve physics problems in various representations. In 2018, Marpaung and Simanjutak examined the learning design with its basis as a problem and Multirepresentation of learning outcomes and critical thinking skills of new students in higher education. The results showed that students' ability to represent various forms of representation is still low [23]. Based on the problem description, this study examines how well physics education students can be multi-represented when tackling physics-related challenges.

II. Methods

General Background

The research method used in this study is a quantitative descriptive research method that aims to provide an overview or explanation and validate the phenomenon being studied. In its use, the problem formulated for research must be feasible to raise, of scientific value, and small in scope [24]. The descriptive method is the search for facts with the proper interpretation and studies of societal problems [25]. As well as procedures that apply to community greetings and specific situations, including the relationship between activities, attitudes, views, as well as ongoing processes, and the influence of a phenomenon, descriptive research is a research method that tries to describe the object or subject under study according to what it is. Data collection techniques are the most essential step in research because the main purpose is to get data [26]. Researchers cannot obtain data that meets the specified standards without understanding data collection techniques.

Researchers cannot get data that satisfies the set data standards if they do not comprehend data collection strategies. A flow chart was made to describe the phases of the research process, from planning to data analysis. An eyebrow diagram was created to illustrate the steps taken in the research process, from planning to data analysis. This diagram aims to provide a clear visual description of the research flow and facilitate understanding of the process. The following are the steps shown in the flow chart:

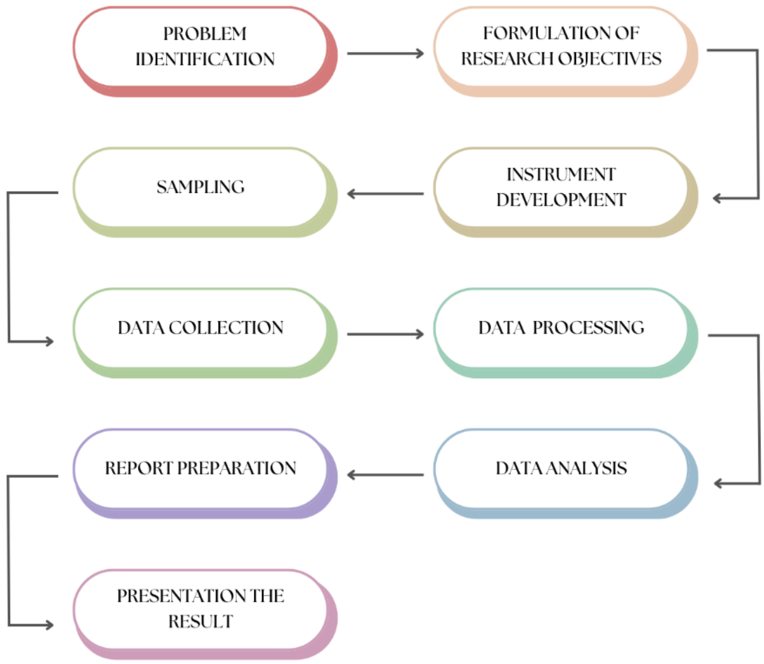

Figure 1. Flow chart

Participant

The participants used in this study were students of the Physics Education Study Program class of 2022, 2023, and 2024, with 48 respondents. Sample selection was carried out using a simple random sampling technique. Simple random sampling is applied to populations with homogeneous characteristics. This method is used to register the entire population with a lottery system and obtain a sample of the desired size [27]. In the context of this study, the intended characteristics include educational background, experience in conducting physics experiments, and perceptions of the obstacles faced during the learning process. Using a representative sample, the study's results are expected to provide an accurate picture of the Multirepresentation abilities of physics education students in solving physics-related problems.

Sampling was done by circulating questionnaires to students enrolled in the Physics Education Study Program batch 2022, 2023, and 2024. The instrument was designed to collect data on various aspects, including attitudes, experiences, and challenges they faced in experimenting. As such, the study focused on the number of respondents and the quality of their data. Through this approach, the research can provide a deeper insight into the factors that influence the conduct of physics experiments and recommendations that can be used to improve student's learning experience in the future.

Instrument

This research collected data using a Google form-based Likert scale survey. This questionnaire consists of 15 statements designed to measure students' perceptions of the obstacles they face while implementing physics experiments. The type of questionnaire used is closed, where the respondent is asked to assess each statement presented. The survey questionnaire instrument used in collecting data on physics education students' perceptions of Multirepresentation skills was in the form of statements about *I know what Multirepresentation skills are, I know the forms of Multirepresentation ability, I see the application of Multirepresentation skills in courses related to physics, I can apply Multirepresentation skills in courses related to physics, I often use Multirepresentation skills in physics-related classes*, and *I often use Multirepresentation skills in physics-related courses*.

However, the survey questionnaire of physics education students' opinions regarding understanding physics courses through various forms of Multirepresentation skills was in the form of statements. *I can use multiple media in courses related to physics. I'm able to analyze an image to solve problems in physics, I'm able to analyze a graph to solve problems in physics, I'm able to interpret verbal descriptions to solve problems in physics*, and *I can analyze images, diagrams, and verbal descriptions to understand physics concepts*. Meanwhile, the survey questionnaire of physics education students' opinions regarding improving various student abilities related to physics problems includes the statements that *Multirepresentation ability can improve the ability to solve physics-related problems, Multirepresentation ability can improve the ability to argue about solving issues related to physics, multi representation ability can build meaning behind the mathematics of a physics equation, and multi representation ability is useful in describing symbols in physics*. The assessment is carried out using a Likert scale that has five answer options (Table 1).

Table 1. Likert scale description

Likert - Scale	Likert-Scale Description
5	Strongly Agree (SA)
4	Agree (A)
3	Neither Agree or Disagree (NAD)
2	Disagree (D)
1	Strongly Disagree (SD)

College students were given 10 minutes to answer the questionnaire. This specified time is sufficient for respondents to consider each statement and provide answers matching their experience. Using a Likert scale, the data obtained is expected to give a clearer picture of student perceptions of obstacles. The data was collected by distributing questionnaires through the Google form platform. Using Google Forms allows respondents to fill out questionnaires online easily and quickly and provides data collection and processing convenience. The questionnaire link was distributed to students through the WhatsApp group of the Physics Education Study Program, making it easy for all respondents to access. After the questionnaire is filled in, the collected data will be analyzed using descriptive analysis techniques. The score of each statement will be calculated to get the average and frequency distribution of respondents' answers. This analysis aims to identify the main obstacles faced by students during the experiment and provide a deeper insight into their perceptions of the learning process.

Data Analysis

After the survey data collection, the next step is calculating the score to analyze the results. The data collected from the questionnaire will be automatically integrated and analyzed using the data analysis feature available on Google Forms. This feature allows researchers to get summary statistics that include the percentage of respondents for each statement quickly and efficiently. The results of this automatic analysis provide an overview of the proportion of students who agree or disagree with each statement. Thus, researchers can easily identify patterns and trends in students' perceptions of the obstacles they face during physics experiments. Manual calculations can also be performed if necessary to ensure the accuracy and validity of the data.

$$P = \frac{\Sigma F}{\Sigma N} \times 100\% \quad (1)$$

P is the percentage, F is the respondent's answer score, and N is the total maximum score.

III. Results and discussion

Result of perception of the Multirepresentation ability of physics education students in solving physics problems

A survey was conducted to gather related information to ascertain students' multirepresentational abilities in problem-solving. The purpose was as a guide to investigate students' perspectives and experiences on the capacity of diverse physics education students to solve physics-related challenges. The data collected became the basis for understanding students' capacity in Multirepresentation. Table 2 shows the results of the student multirepresentation skills survey.

Table 2. Survey results of physics education students' opinions regarding Multirepresentation skills

Aspect	Statement	SD	D	NAD	A	SA
Regarding Multirepresentation skills	I know what Multirepresentation skills are	0.0%	8.2%	24.5%	61.2%	6.1%
	I know the forms of Multirepresentation ability	0.0%	6.1%	38.8%	55.1%	0.0%
	I know the application of Multirepresentation skills in courses related to physics	0.0%	4.1%	36.7%	55.1%	4.1%
	I can apply Multirepresentation skills in courses related to physics	0.0%	6.1%	34.7%	55.1%	4.1%
	I often use Multirepresentation skills in physics-related courses	0.0%	12.2%	49.0%	36.7%	2.0%
	I often use Multirepresentation skills in physics-related courses	0.0%	4.1%	36.7%	49.0%	10.2%

The survey results in Table 2 show that most physics education students know about multirepresentation ability, and the positive response received by 67.3% agreed. In addition to knowing descriptively about multirepresentation ability, students must also understand its forms; 55.1% agreed that they knew the forms of multirepresentation ability. However, the rest were undecided and did not even know the forms of these abilities. In applying multirepresentation skills, students showed that they could analyze the application and apply multirepresentation skills in physics; the data collected is the same, namely 55.1% for both. In using multirepresentation skills, 49.5% of physics education students still doubt that they have often applied it to solve problems related to physics. For understanding courses related to physics, with a percentage above 49%, multirepresentation ability can improve understanding.

Table 3 shows the survey results of physics education students' opinions regarding understanding physics courses through various forms of multirepresentation skills.

Table 3. Survey results of physics education students' opinions regarding understanding of physics courses through various forms of Multirepresentation skills

Aspect	Statement	SD	D	NAD	A	SA
Understanding of physics courses through various forms of Multirepresentation skills	I'm able to use multiple media in courses related to physics	0.0%	8.2%	22.4%	67.3%	2.0%
	I’m able to analyze an image to solve problems in physics.	0.0%	4.1%	38.8%	53.1%	4.1%
	I’m able to analyze a graph to solve problems in physics.	0.0%	2.0%	51.0%	42.9%	4.1%
	I’m able to analyze verbal descriptions to solve problems in physics	0.0%	0.0%	53.1%	44.9%	2.0%
	I can analyze images, graphs, and verbal descriptions to understand physics concepts.	0.0%	2.0%	42.9%	53.1%	2.0%

Through the survey that has been distributed, the opinions of physics education students are very diverse regarding the use of their multirepresentation skills. As many as 67.3% of students agree they can use various media in physics-related courses. The press here includes multiple options such as props, tools, etc. When broken down into Multirepresentation skills, as many as 53.1% of students can analyze a picture to solve problems in physics, and 38.8% still doubt that the ability to interpret questions and pictorial material can improve their understanding of physics. Other than images, analysis of graphs is one form of Multirepresentation skills used to understand physics concepts and solve physics-related problems; the survey results show that 51.2% of students still doubt the ability to analyze graphs, and 42.9% agree that they can analyze graphs. In addition to charts and graphs, there are verbal descriptions as a means of solving physics problems, where 53.1% of students doubt their ability and 44.9% feel able to analyze verbal descriptions related to problem-solving. In addition to using it in problem-solving, Multirepresentation skills are also used in understanding physics concepts; in this section, 53.1% of physics education students feel that they can use their abilities, while 42.9% still doubt their abilities.

Table 4 show survey results of physics education students' opinions regarding improving various student abilities related to physics problems.

Table 4. Survey results of physics education students' opinions regarding improving various student abilities related to physics problems.

Aspect	Statement	SD	D	NAD	A	SA
The improvement of various student abilities related to physics problems.	Multirepresentation ability can improve the ability to solve physics-related problems	0.0%	2.0%	22.4%	61.2%	14.3%
	Multirepresentation ability can improve the ability to argue about solving problems related to physics	0.0%	6.1%	10.2%	71.4%	12.2%
	Multirepresentation ability can build meaning behind the mathematics of a physics equation	0.0%	6.2%	22.4%	55.1%	16.3%
	Multirepresentation ability is useful in describing symbols in physics	0.0%	6.1%	10.2%	71.4%	12.2%

After understanding the ability and forms of Multirepresentation, several questions were asked about the benefits of Multirepresentation ability for students in physics. 61.2% of students agreed that their multirepresentation skills could improve problem-solving related to physics. In addition to problem-solving, about the ability to argue in problem-solving related to physics problems, 71.4% of students feel confident that their Multirepresentation skills are qualified and continue to improve, with an additional 12.2% strongly agreeing with the survey statement. It cannot be separated from a mathematical equation that describes a material or concept from physics. 55.1% of students agreed, and 16.3% strongly agreed that multirepresentation skills can build the meaning behind a mathematical physics equation. In addition to the meaning behind mathematical equations, Multirepresentation skills are also useful in describing symbols in physics; 71.4% agreed that Multirepresentation skills are useful in this field. The survey was carried out by providing statements that respondents could agree or disagree with.

Where according to Patriot in [1], the Multirepresentation approach in the context of physics learning is a view in repeating concepts and perceptions of physics concepts that are equalized by using a choice of presentation or representation models such as images, graphs, diagrams, symbols, mathematical equations, and information technology assistance. In line with previous research that shows various representations can affect cognitive abilities in concept understanding and problem-solving [1], students were asked how much they knew about Multirepresentation skills in the first section. In this section, 61.4% of students knew multirepresentation ability, while the other 24.5% did not understand multirepresentation ability. In addition to understanding descriptive multirepresentation ability, students were also confronted with their knowledge of the forms of multirepresentation ability. 55.1% of students stated that they knew the forms of multirepresentation ability. In addition, 38.8% of students were doubtful about their knowledge of the forms of multirepresentation ability. The application of Multirepresentation skills was also measured in this study, where students were given statements about their ability to analyze and use their skills to solve problems. Problems can be represented in three forms: 1) verbal representation, which appears in spoken and written language; 2) pictorial representation, which appears in pictures, tables, and graphs.; 3) symbolic representation, which appears in numbers, operations, and connection signs [28]. Representation in mathematics can take the form of visual, verbal, and symbolic representations. Furthermore, visualization or visual representation creates illustrations that help clarify the problem and facilitate its solution [29].

In contrast, verbal representation refers to conveying mathematical concepts, writing the steps of solving mathematical problems, and interpreting a representation. 55.1% of students know the application and can apply multirepresentation physics-related skills. In contrast, as many as 36.7% feel hesitant about using these abilities, and 34.7% of students are hesitant about applying the Multirepresentation skills they have in courses related to physics. The last statement in the first section is that their understanding increases using Multirepresentation skills, and 49% agree. However, 36.7% are still hesitant about this matter. In a [1], Rizky stated that multirepresentation has several purposes and plays a role in physics education. The three purposes of multirepresentation are to deepen insight, solve problems, and as a complement. Its ability to solve problems is one of its roles. The features of multirepresentation can be used as a tool to overcome physics difficulties.

For example, graphical depictions can conclude the relationship between two variables and connect two physics ideas. Measuring students' ability to use media in physics-related courses, 67.3% of students feel capable, while 22.4% doubt their ability. In analyzing an image to solve physics-related problems, 51.3% of students can analyze images to solve physics problems, whereas 38.8% of students feel doubtful in measuring their ability to analyze images. In addition to images, graph analysis helps solve physics-related problems. Where 42.9% of students feel capable of analyzing graphs. The negative trend is that 51% of students doubt their abilities. Graph analysis is one of the things that is difficult to do for physics education students who have filled out the survey. These findings show that students who successfully solve physics problems require assistance with a thorough understanding and use of multirepresentation [7]. Problem-solving in physics is also done in verbal descriptions, where 44.9% of students agree that verbal descriptions can facilitate their analysis of physics problems.

Through Multirepresentation learning, it has been discovered that the learning process may support students with varying ability levels and successfully enhance students' comprehension of concepts, critical thinking, and problem-solving abilities [30]. It is well established that Multirepresentation learning can help students of all ability levels and effectively enhance their comprehension of concepts, critical thinking, and problem-solving abilities[1]. Waldrip defines Multirepresentation as the same idea conveyed in various representation modes, such as verbal, graphic, pictorial, and mathematical. Mathematical structure that can provide a quantitative description of the concept. Graphic format, capable of using a graph to illustrate abstract ideas. A notion might be illustrated and described using a picture format. Verbal formats can provide concept definitions. Multirepresentation abilities play a significant influence on the cognitive process of learning.
However, as many as 51.3% doubted their descriptive analysis skills, which can be categorized as a weakness in their understanding of problem-solving in physics. Not only in its use in problem-solving, but multirepresentation skills are also used in understanding physics concepts where 53.1% of students can analyze images, graphs, and verbal descriptions to understand concepts, but 42.9% feel their doubts in analyzing a physics concept using multirepresentation skills. The ability to multirepresentation can improve problem-solving skills related to physics, which is a statement that 61.2% agree with, with an additional 14.3% strongly agreeing. However, 22.4% of students still doubt that multirepresentation can improve problem-solving skills regarding physics problems. Multirepresentation skills are also used to strengthen argumentation skills in solving physics-related problems, where 83.6% agree, with 12.2% strongly agreeing. In addition, Multirepresentation skills are useful for building meaning behind the mathematics of an equation. A total of 55.1% of students agreed with the statement.

IV. Conclusions

Research that has been conducted on analyzing the ability of representation of physics education students in solving problems related to physics reveals that most of the students have known what is meant and the form of Multirepresentation ability; students have also applied and been able to analyze the application of these abilities about physics. In the application of these skills, 67.3% of students have been able to explore various media that improve their ability to understand physics concepts and solve problems regarding physics, including 53.1% felt the positive impact of using image representation; 42.9% felt the improvement of problem-solving ability using graphic representation analysis. In addition, many students benefited from multirepresentation skills, including problem-solving skills at 61.2%, arguing about physics problem-solving at 71.4%, and constructing meaning from equations and symbols related to physics at 71.4%. This positive trend shows that Multirepresentation skills can improve the ability to solve physics-related problems.

This research, however, has various limitations that need to be considered. The data collection results cannot be generalized to students from other study programs. In addition, the method of data collection used was a survey based on a Likert scale, as this scale only provides a general description and is not in-depth when explaining an analysis of student abilities. Another restriction faced in the study is that this research has not taken into account external factors that can be an inhibiting factor for students' multirepresentation skills. For that reason, if further research is conducted, it is recommended that the limitations be overcome by expanding the scope of participants, using more varied methods, and considering external factors that affect children's multirepresentation skills. With these steps, further research is likely to provide a more complete and effective picture and information on the knowledge of students' multirepresentation skills in solving physics-related problems.

References

[1] L. Avraamidou, "Identities in/out of physics and the politics of recognition," *Journal of Research in Science Teaching*, vol. 59, no. 1, pp. 58-94, 2022, doi: https://doi.org/10.1002/tea.21721

[2] F. Lafifa, D. Rosana, S. Suyanta, S. Nurohman, and S. R. D. Astuti, "Integrated STEM approach to improving 21st-century skills in Indonesia: A systematic review," *International Journal of STEM Education for Sustainability*, vol. 3, no. 2, pp. 252-267, 2023, doi: https://doi.org/10.53889/ijses.v3i2.219

[3] H. K. Mohajan, "Qualitative research methodology in social sciences and related subjects," *Journal of Economic Development, Environment, and People*, vol. 7, no. 1, pp. 23-48, 2018, doi: https://doi.org/10.26458/jedep.v7i1.571

[4] E. Manz, R. Lehrer, and L. Schauble, "Rethinking the classroom science investigation," *Journal of Research in Science Teaching*, vol. 57, no. 7, pp. 1148-1174, 2020, doi: https://doi.org/10.1002/tea.21625

[5] P. Y. A. Dewi and K. H. Primayana, "Effect of learning module with setting contextual teaching and learning to increase the understanding of concepts," *International Journal of Education and Learning*, vol. 1, no. 1, pp. 19-26, 2019, doi: https://doi.org/10.31763/ijele.v1i1.26

[6] S. Fathonah, E. Cahyono, S. Haryani, S. Sarwi, and N. H. Lestari, "Application of Multirepresentation-based creative problem-solving learning models to improve students' critical and creative thinking skills," *International Journal of Cognitive Research in Science, Engineering, and Education*, vol. 12, no. 1, pp. 185-200, 2024, doi: https://doi.org/10.23947/2334-8496-2024-12-1-185-200

[7] D. Adelia, R. Linda, and M. Erna, "Development of e-module based on multiple representations to improve the competence of chemical literacy and learning independence of students on the material reaction rate," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 12, pp. 11101-11110, 2023, doi: https://doi.org/10.29303/jppipa.v9i12.5541

[8] M. L. Tomkelski, M. Baptista, and A. Richit, "Physics teachers' learning on using multiple representations in lesson study about Ohm's law," *European Journal of Science and Mathematics Education*, vol. 11, no. 3, pp. 427-444, 2023, doi: https://doi.org/10.30935/scimath/12906

[9] B. Mainali, "Representation in teaching and learning mathematics," *International Journal of Education in Mathematics, Science, and Technology*, vol. 9, no. 1, pp. 1-21, 2021, doi: https://doi.org/10.46328/ijemst.1111

[10] P. G. W. Adnyana, I. M. Suarsana, and I. G. P. Suharta, "Multirepresentation discourse model and math problem-solving skills of high school students," *Journal of Learning Improvement and Lesson Study*, vol. 1, no. 1, pp. 40-48, 2021, doi: https://doi.org/10.24036/jlils.v1i1.8

[11] N. Munfaridah, L. Avraamidou, and M. Goedhart, "The use of multiple representations in undergraduate physics education: what do we know and where do we go from here?" *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 17, no. 1, pp. 1934-1943, 2021, doi: https://doi.org/10.29333/ejmste/9577

[12] C. Sa'dijah and M. Muksar, "Assessing students' errors in mathematical translation: From symbolic to verbal and graphic representations," *International Journal of Evaluation and Research in Education*, vol. 10, no. 1, pp. 115-125, 2021, doi: https://doi.org/10.11591/ijere.v10i1.20819

[13] Z. E. Ünal, A. M. Ala, G. Kartal, S. Özel, and D. C. Geary, "Visual and symbolic representations as components of algebraic reasoning," *Journal of Numerical Cognition*, vol. 9, no. 2, pp. 327-345, 2023, doi: https://doi.org/10.5964/jnc.11151

[14] V. Hatisaru, "Exploring evidence of mathematical tasks and representations in the drawings of middle school students," *International Electronic Journal of Mathematics Education*, vol. 15, no. 3, pp. 609-617, 2020, doi: https://doi.org/10.29333/iejme/8482

[15] C. Zhang, Z. Yang, X. He, and L. Deng, "Multimodal intelligence: Representation learning, information fusion, and applications," *IEEE Journal of Selected Topics in Signal Processing*, vol. 14, no. 3, pp. 478-493, 2020, doi: https://doi.org/10.1109/JSTSP.2020.2987728

[16] F. Musil, A. Grisafi, A. P. Bartók, C. Ortner, G. Csányi, and M. Ceriotti, "Physics-inspired structural representations for molecules and materials," *Chemical Reviews*, vol. 121, no. 16, pp. 9759-9815, 2021, doi: https://doi.org/10.1021/acs.chemrev.1c00021

[17] L. Sahara, N. Nafarudin, S. Fayanto, and B. A. Tairjanovna, "Analysis of improving students' physics conceptual understanding through discovery learning models supported by Multirepresentation: Measurement topic," *Indonesian Review of Physics*, vol. 3, no. 2, pp. 57-65, 2020, doi: https://doi.org/10.12928/irip.v3i2.3064

[18] D. S. Pambudi, I. K. Budayasa, and A. Lukito, "The role of mathematical connections in mathematical problem solving," *Jurnal Pendidikan Matematika*, vol. 14, no. 2, pp. 129-144, 2020, doi: https://doi.org/10.22342/jpm.14.2.10985.129-144

[19] R. Çakır, Ö. Korkmaz, Ö. İdil, and F. U. Erdoğmuş, “The effect of robotic coding education on preschoolers' problem solving and creative thinking skills,” *Thinking Skills and Creativity*, vol. 40, no. 1, pp. 1008-1016, 2021, doi: https://doi.org/10.1016/j.tsc.2021.100812

[20] P. G. W. Adnyana, I. M. Suarsana, and I. G. P. Suharta, “Multirepresentation discourse model and math problem-solving skills of high school students,” *Journal of Learning Improvement and Lesson Study*, vol. 1, no. 1, pp. 40-48, 2021, doi: https://doi.org/10.24036/jlils.v1i1.8

[21] A. A. Nugroho, N. Nizaruddin, I. Dwijayanti, and A. Tristianti, “Exploring students' creative thinking in the use of representations in solving mathematical problems based on cognitive style,” *Journal of Research and Advances in Mathematics Education*, vol. 5, no. 2, pp. 202-217, 2020, doi: https://doi.org/10.23917/jramathedu.v5i2.9983

[22] T. Sunarti, “Research analysis on Multirepresentation in physical materials in the year 2014 to 2021,” *IJORER: International Journal of Recent Educational Research*, vol. 3, no. 3, pp. 259-268, 2022, doi: https://doi.org/10.46245/ijorer.v3i3.218

[23] C. Coman, L. G. Țîru, L. Meseșan-Schmitz, C. Stanciu, and M. C. Bularca, “Online teaching and learning in higher education during the coronavirus pandemic: Students' perspective,” *Sustainability*, vol. 12, no. 24, pp. 10367-10378, 2020, doi: https://doi.org/10.3390/su122410367

[24] P. P. Ray, “ChatGPT: A comprehensive review on background, applications, key challenges, bias, ethics, limitations, and future scope,” *Internet of Things and Cyber-Physical Systems*, vol. 3, no. 1, pp. 121-154, 2023, doi: https://doi.org/10.1016/j.iotcps.2023.04.003

[25] C. F. J. Pols, P. J. J. M. Dekkers, and m. J. De Vries, “What do they know? Investigating students' ability to analyze experimental data in secondary physics education,” *International Journal of Science Education*, vol. 43, no. 2, pp. 274-297, 2021, doi: https://doi.org/10.1080/09500693.2020.1865588

[26] S. Dawadi, S. Shrestha, and R. A. Giri, “Mixed-methods research: A discussion on its types, challenges, and criticisms,” *Journal of Practical Studies in Education*, vol. 2, no. 2, pp. 25-36, 2021, doi: https://doi.org/10.46809/jpse.v2i2.20

[27] A. Håkansson and V. Henzel, “Who chooses to enroll in a new national gambling self-exclusion system? A general population survey in Sweden,” *Harm Reduction Journal*, vol. 17, no. 1, pp. 1-12, 2020, doi: https://doi.org/10.1186/s12954-020-00423-x

[28] S. R. Manurung, “improving students thinking ability in physics using interactive multimedia based problem solving,” *Jurnal Cakrawala Pendidikan*, vol. 39, no. 2, pp. 460-470, 2020, doi: https://doi.org/10.21831/cp.v39i2.28205

[29] C. Buckley and C. Nerantzi, “Effective use of visual representation in research and teaching within higher education,” *International Journal of Management and Applied Research*, vol. 7, no. 3, pp. 196-214, 2020, doi: https://doi.org/10.18646/2056.73.20-014

[30] E. Krisnaningsih and E. Hariyono, “Implementation of Multirepresentation learning on climate change integrated dynamic fluid to improve student's problem-solving skills,” *Berkala Ilmiah Pendidikan Fisika*, vol. 10, no. 1, pp. 44-56, 2022, doi: https://doi.org/10.20527/bipf.v10i1.12465