Measuring student mathematical representation abilities in physics on heat and temperature topic: Learning mode and gender

D. Fairuz Zulaikha
Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, 55281, Indonesia.

H. Putranta
Department of Physics Education, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Sunan Kalijaga Yogyakarta, Yogyakarta, 55281, Indonesia.
e-mail: himawan.putranta@uin-suka.ac.id

W. S. Brams Dwandaru
Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, 55281, Indonesia.

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This research examined an in-depth analysis of students' mathematical representation abilities in physics (MRAP): (1) the students' MRAP score in each sub-topic (temperature, expansion, heat, heat transfer); (2) the students' MRAP score in terms of learning mode (online and offline); (3) the students' MRAP level based on gender. The study used the survey method as a quantitative approach. The study sample consisted of 260 grade 11 students from three public senior high schools in Yogyakarta, Indonesia, with low, medium, and high ability levels. The Mann-Whitney U test was performed to determine if there was a statistically significant difference in the students' test results by learning mode and gender. The study's findings concluded that the students' scores in each sub-topic of temperature, expansion, heat, and heat transfer are 67.66; 63.67; 56.86; and 60.43; respectively. There are significant differences in students' mathematical representation abilities in physics between students learning modes (offline and online learning). At the same, time there are no significant differences in students' mathematical representation abilities in physics between males and females.

Keywords: Heat; high school students; mathematical representation abilities; physics; temperature.

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1. Introduction

Twenty-first-century learning requires students to solve problems related to the real world [1]. To have great problem-solving skills, the ability to represent information is required [2]. Representation plays an important role in explaining natural phenomena in physics learning and other science lessons [3]. Representation in physics means a way that acts as an intermediary to explain cognitive processes in solving physics problems [4]. Physics contains concepts in the form of verbal, vector, graphic, and mathematical representations [5]. Mathematical representation in physics acts as a bridge connecting abstract concepts with the everyday life context [6].

As a result, it is required to turn physics modeling into mathematical modeling and its interpretation in physics learning activities [7]. However, some students have difficulty interpreting mathematical equations in physics lessons [8]. Students view physics and mathematics as separate ways of thinking, which means that they have problems interpreting the physical meaning of an equation when expressed in mathematical form. Students also have difficulty making mathematical models of a physical phenomenon [9]. Mathematical representation is one of the strategies in the problem-solving process that helps students in the thinking process in studying physics [10]. Students' mathematical representations created when solving issues and studying physics are significant habits in aiding students' understanding and solving problems, as well as giving meaningful ways to express solutions and convey techniques to others [11].

The field of heat and temperature topic is one that students interact with almost daily from the very beginning of their lives [12]. Heat and temperature cover the most basic physical processes, leading to a complete understanding of science in general [13]. However, students find it hard to explain the phenomena scientifically, so their understanding overlaps [14]. For example, explaining the heat as energy moving from a certain object to another object results from temperature change and connecting two concepts, energy, and temperature [15].

The multiple-choice test format is the most utilized in assessment activities for a variety of reasons, including (1) test material is indicative of overall instructional material, (2) scoring can be done quickly, and (3) correct or wrong answers help the exam be objective [16]. On the other hand, the multiple-choice exam structure allows for guessing, which obscures the test taker's thought process [17]. As a result, a different test format is required to address these flaws. The multiple-choice test with reasons is one of the choices. In this form of test, the test taker selects the correct answer and justifies their selection. The test taker's reasons might be utilized to assess their abilities [18].

The coronavirus disease 2019 (COVID-19) pandemic that has hit all corners of the world, including Indonesia, has greatly impacted various activities, including education. The Government of the Republic of Indonesia, through the Ministry of Education and Culture, urges reducing the teaching and learning process in schools to prevent the transmission of the virus. Teachers and students can communicate indirectly (offline) or net (online) ways during the learning process [19]. Several studies comparing online and offline learning have been carried out. Some have shown that online learning is more effective than offline learning [20]. In comparison, other researchers showed that students with offline learning were better than students with online learning [21]. No research compares students' mathematical representation abilities in learning physics between offline and online learning modes.

Gender identity is often regarded as one of the most ubiquitous and long-lasting impacts on individual goals, ambitions, and behavior. A gender relationship is a social relationship between men and women that is beneficial to both parties and is marked by distinctions and disparities [22]. The link between gender identification and cognitive areas has long been a source of fascination for scientists [23]. Research on students' representational abilities in solving physics problems has been carried out. Furthermore, the profile of students' multi-representation abilities, including verbal representations, pictures, graphs, and diagrams [24]. The results showed that students had the lowest representational abilities in mathematical representations.

The study of students' mathematical representation abilities in physics (MRAP) by gender has not been carried out. The study of gender deserves more consideration in the education field [25]. Seeing MRAP by gender can help teachers to develop effective learning techniques. This research examined an in-depth analysis of students' MRAP (1) the students' MRAP score in temperature, expansion, heat, heat transfer; (2) the students' MRAP score in terms of learning mode (online and offline); (3) the students' MRAP level based on gender.

2. Method

2.1. General background

The study used the survey method as a quantitative approach to determine the difference of students' mathematical representation abilities in physics (MRAP) in heat and temperature topics based on learning mode and gender. The study sample consisted of 260 grade 11 students from three public senior high schools in Yogyakarta, Indonesia, with low, medium, and high ability levels. The students are between $15 - 17$ years old. The respondents are selected using a stratified random sampling technique. The distribution of the sample is shown in Table I.

TABLE I. Characteristics of the respondents.

No.	Characteristic	f	%
	Learning Mode		
1	Online	145	55.77
	Offline	115	44.23
	Gender		
2	Male	189	72.69
	Female	71	27.31

TABLE II. Aspects and sub-aspects of mathematical representation abilities in physics.

No.	Aspects	Sub-Aspects	Item
1	Mathematical Equation (ME)	a. Compile mathematical equations from other representations based on the available information (ME1)	1, 2 3, 4, 5
		b. Solve physics problems with mathematical equations (ME2)	6, 7, 8, 9, 10
2	Written Text (WT)	a. Write steps to solve mathematical problems with statements (WT1)	11, 12, 13, 14, 15
		b. Explaining the physical meaning of the problem based on numerical data in the given figure, table, diagram, graph, or equation (WT2)	16, 17, 18, 19, 20
		Total	20 Item

2.2. Research instrument and procedure

The research instrument consisted of 20 items of the MRAP test in the form of a two-tier test. The test item on the first tier has five options for answers: A, B, C, D, and E. The second tier contains five answers in the form of justifications for the first-tier answers. The physics topics tested were Heat and Temperature, with sub-topics consisting of temperature, expansion, heat, and heat transfer. The measured aspects and sub-aspects of MRAP can be shown in Table II.

TABLE III. The instrument validity results.

Number of Items	r_{count}	r_{table}	Interpretation
1	0.481	0.202	Valid
2	0.484	0.202	Valid
3	0.492	0.202	Valid
4	0.756	0.202	Valid
5	0.756	0.202	Valid
6	0.713	0.202	Valid
7	0.601	0.202	Valid
8	0.660	0.202	Valid
9	0.636	0.202	Valid
10	0.563	0.202	Valid
11	0.769	0.202	Valid
12	0.586	0.202	Valid
13	0.536	0.202	Valid
14	0.705	0.202	Valid
15	0.417	0.202	Valid
16	0.572	0.202	Valid
17	0.614	0.202	Valid
18	0.570	0.202	Valid
19	0.443	0.202	Valid
20	0.651	0.202	Valid

2.3. Validity and reliability of the instrument

Before being used, the instrument was put through a quality check employing a validity and reliability estimation test. The scores of six validators on the assessment results were then calculated using Aiken's formula. Aiken's index values ranged from 0.94 to 1.00. It is indicated that all items were valid. The study tested the instrument's validity and reliability using 93 students in addition to the primary data of the investigation. Table III shows the results of instrument validity using the Pearson correlation test.

Based on Table III, the Pearson correlation test result from 20 questions indicated the value of $r_{\text{count}} > r_{\text{table}}$. The result proved that the instrument is valid to collect data on students' MRAP. The reliability test result gave Cronbach's alpha value of 0.904. It means that the instrument is consistent in measuring students' MRAP.

2.4. Analyzing of data

The following were included in the data analysis: (1) computing the percentages of each aspect of MRAP, (2) comparing the students' MRAP scores in two different learning modes (offline and online learning), and (3) comparing the MRAP between male and female students. The percentage of MRAP scores by category is done by determining the levels using Table IV [26].

TABLE IV. Score interval of ability level.

No.	Interval of Ability	Level
1.	$M_i + 1.5SDi < \theta$	Very High
2.	$M_i + 0.5SD_i < \theta \leq M_i + 1.5SD_i$	High
3.	$M_i - 0.5SD_i < \theta \leq M_i + 0.5SD_i$	Medium
4.	$M_i - 1.5SD_i < \theta \leq M_i - 0.5SD_i$	Low
5.	$\theta < M_i - 1.5SD_i$	Very Low

The parameter M_i and SD_i are defined as ideal means and ideal standard deviation, respectively, mathematically formulated by Eq. (1) and Eq. (2).

$$M_i = \frac{1}{2}(\theta_{\max} + \theta_{\min}), \tag{1}$$

$$SD_i = \frac{1}{6}(\theta_{\max} - \theta_{\min}). \tag{2}$$

Descriptive and inferential statistics were performed to examine whether there is a significant relationship between MRAP scores in each aspect of learning mode and gender. Additionally, the acquired data were subjected to the Kolmogorov-Smirnov test. The premise of normality was violated, and the Sig. value was ($p < 0.05$). Thus, the data analysis was conducted using non-parametric tests to see whether there was a statistically significant difference in the students' learning mode and gender. The Mann-Whitney U test was performed to determine if there was a statistically significant difference in the pupils' test results by learning mode and gender.

3. Result

3.1. Students' scores in each sub-topic

The students' mathematical representation abilities in physics (MRAP) scores in each sub-topic can be seen in Table V.

Based on Table V, the highest score of students is in the sub-topic of temperature. The lowest score of students is in the sub-topic of heat. The results of the students' MRAP scores based on the category level in each sub-topic can be seen in Table VI.

Based on Table VI, in terms of temperature and expansion, students have MRAP scores at the high to a very high level. Meanwhile, in heat and heat transfer, students have

TABLE V. The descriptive statistic of students' MRAP scores in each sub-topic.

Sub-Topics	Average	Max	Min	Std. Deviation
Temperature	67.66	100.00	25.00	20.63
Expansion	63.67	100.00	25.00	19.13
Heat	56.86	100.00	25.00	22.25
Heat Transfer	60.43	100.00	25.00	19.26

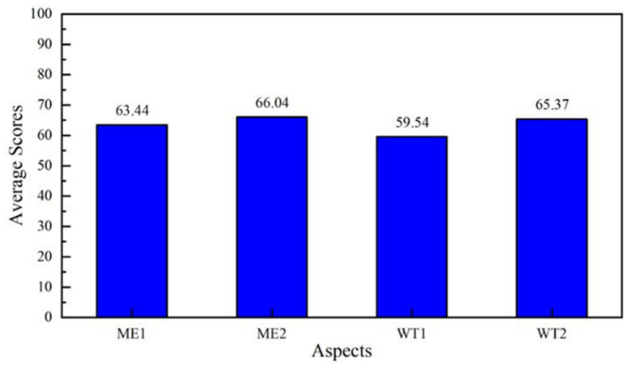

FIGURE 1. Students' MRAP score in each aspect.

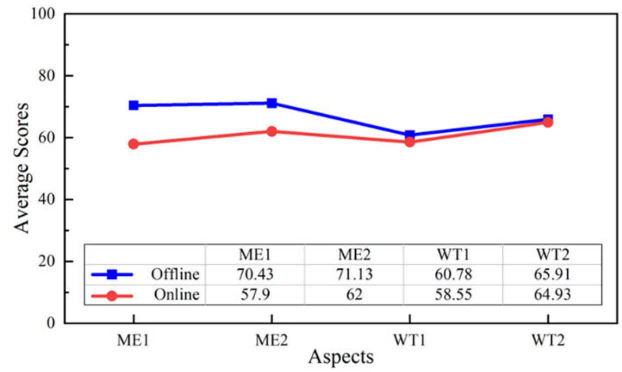

FIGURE 2. Students' MRAP scores in terms of learning mode in each aspect.

TABLE VI. The results of students' MRAP score based on category categories the number of students.

Categories	Temperature		Expansion		Heat		Heat Transfer	
	f	%	f	%	f	%	f	%
Very High	96	36.92	70	26.92	63	24.23	62	23.85
High	70	26.92	93	35.77	60	23.08	64	24.61
Medium	56	21.54	59	22.69	38	14.61	84	32.31
Low	37	14.23	31	11.92	65	25.00	44	16.92
Very Low	1	0.39	7	2.69	34	13.08	6	2.31

MRAP scores at the medium to a very high level. The result of the MRAP score based on aspect is explained in Fig. 1.

Based on Fig. 1, the highest score of students' MRAPS is in ME2 aspect, that is, solving physics problems with mathematical equations.

3.2. Comparison of MRAP scores of students in terms of learning mode

The results of the Mann-Whitney test in terms of learning mode overall and in each aspect of MRAP can be seen in Table VII.

Based on Table VII, the result of the Mann-Whitney test stated that there was difference in students' MRAP scores based on the learning mode in general. It is shown by the value of Asymp-Sig $= 0.004$ ($p < 0.05$). Two aspects of the mathematical equation (ME1 and ME2) showed a significant difference of students' MRAP scores. At the same time, two aspects of written text (WT1 and WT2) showed that there was no difference in students' MRAP scores. The comparison graph between students' MRAP scores in terms of learning mode is shown in Fig. 2.

Figure 2 shows that students who take offline learning mode have higher MRAP scores than students who follow online learning mode in every aspect. The highest MRAP aspect for students with offline learning mode is solving physics problems with mathematical equations (ME2). Meanwhile, the highest MRAP aspect for students with online learning model is explaining the physical meaning based on numerical data in the given figure, table, diagram, graph, or equation (WT2).

3.3. Comparison of MRAP scores of students in terms of gender

The results of the Mann-Whitney test in terms of gender in general and in each aspect of MRAP can be seen in Table VIII.

Based on Table VIII, the result of the Mann-Whitney test stated that there was no difference in students' MRAP scores based on gender in general and in each aspect. It is shown by the value of Asymp-Sig (p¿0.05). The comparison graph between students' MRAP scores in terms of learning mode is shown in Fig. 3.

Figure 3 shows that female students have higher MRAP scores than male students in every aspect. The highest MRAP score for male students is solving physics problems with mathematical equations (ME2). Meanwhile, the highest MRAP score for female students is explaining the physical meaning of the problem based on numerical data in the given figure, table, diagram, graph, or equation (WT2).

TABLE VII. Results of the mann-whitney test in terms of learning mode.

	All	ME1	ME2	WT1	WT2
U	6608.5	5334.0	6232.0	7599.0	8032.5
W	17193.5	15919.0	16817.0	18184.0	18617.5
Z	-2.87	-5.01	-3.51	-1.23	-.51
p	0.004	0.00	0.00	0.22	0.61

TABLE VIII. Results of the Mann-Whitney test in terms of gender.

	All	ME1	ME2	WT1	WT2
U	6107.0	5937.5	6619.5	5632.5	6363.5
W	8663.0	8493.5	24574.5	8288.5	8919.5
Z	-1.116	-1.434	-0.167	-2.006	-0.643
p	0.265	0.152	0.867	0.045	0.520

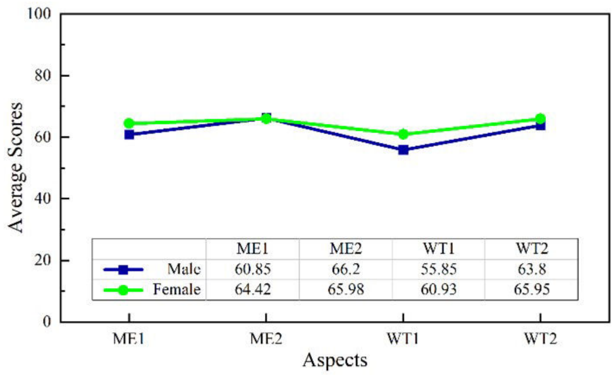

FIGURE 3. Students' MRAP scores in terms of learning mode in each aspect.

4. Discussion

According to the data obtained, the students' average mathematical representation abilities in physics (MRAP) scores on heat and temperature materials tended to be low (M = 63.60; SD = 17.54). The highest score of student achievement in the sub-topic of temperature. This can happen because students are familiar with temperature material. After all, students have studied it since elementary school and junior high school, especially about the concept of temperature and temperature conversion on each thermometer scale. The lowest score for students' MRAP achievement was on the sub-topic of heat. This is because, in the sub-topic of heat, many mathematical equations are used, which are a combination of several formulas [27]. In addition, the physics problems in the questions on the sub-topic of heat are very applicable and working on them also requires deep thinking skills [28]. The students' mastery of temperature and heat was the highest in the temperature sub-topic and the lowest in the heat sub-topic [29].

Research showed that the highest score of students' MRAP is solving physics problems with mathematical equations (ME2). This may be because students are accustomed to writing known physical variables first and then tackling the problem, making it easier for them to answer physics questions [30]. The lowest score is writing steps to solve mathematical problems with statements (WT1). This can happen because students still consider mathematical and verbal formulas as separate things [31]. However, physics can be explained by verbally combining sentences of mathematical equations and the relationship between variables [32].

Students can solve problems when using mathematical equations than when using verbal sentences from a mathematical formula. This is a unique problem. This can happen because most students only memorize formulas without understanding the physical meaning [33]. The form of sentences from mathematical equations makes students less familiar, so students need to recall previously acquired knowledge [34]. If students fail to activate their understanding, certainly they will not be able to solve the problem.

It can be underlined that there is a significant difference between the MRAP scores of students taking offline and online learning. Students who take offline learning have higher scores than students who take online learning in every aspect [35]. This can be caused because in online learning, students do not understand the material learned in class. Students lack concentration when learning, which causes an unsupportive learning environment and situation [36]. Furthermore, difference between learning effectiveness during the COVID-19 pandemic based on teaching methods both from and offline with offline learning being more effective than online [37].

Research results also showed no difference in MRAP scores between male and female students. Nevertheless, the research showed that the average MRAP score of female students was better than males. Gender variations in learning styles affect learning results. Males are less hard-working than girls in doing tasks and conducting mathematical calculations. This is also influenced by career interest. Female students want to have careers as doctors, work in a laboratory, be a science lecturer, an architect or similar. In contrast, male students aspire to be police officers, soldiers, soccer players, athletes, etc. This fact reveals that male students are more interested in physical activities than others [38]. In addition, MRAP tends to be theoretical physics knowledge, not practical [39-40].

5. Conclusion

The study's findings concluded that the students' scores in each sub-topic of temperature, expansion, heat, and heat transfer are 67.66; 63.67; 56.86; and 60.43, respectively. There is a significant difference in students' mathematical representation abilities in physics between students learning modes (offline and online learning). There is no significant difference in students' mathematical representation abilities in physics between males and females. The recommendation for further research is to analyze the differences in mathematical representation abilities in physics (MRAP) results by reviewing other student individual traits, such as learning patterns, cognitive style, or the type of instrument used (essay questions, multiple-choice questions, reasoned multiple choice questions, or others). Research participants are only limited to one area so, it is less representative to represent a larger number of students' mathematical representation abilities in physics.

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