The multiple representations ability of students in linear motion

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This research aims to reveal students' ability to analyze the equation of position versus time, so students can describe quantities of motion with multiple representations in linear motion. Subjects included 54 students of XI grade from one of the high schools in Pasuruan and Sumenep Madura. Then three students were interviewed about the difficulties when making representations. The, research instrument was an open-ended test of linear motion with reability 0.707. The test instrument is a question in position versus time, and then students are asked to answer 5 questions by describing the quantities of motion in the representation of tables, mathematical equations, graphs, verbal, and motion diagrams. The results showed that students had difficulties describing the quantities of motion with multiple representations. The most common difficulty is drawing motion diagrams. The study recommended further research using learning-based multiple representations to improve conceptual understanding.

Keywords: Multiple representations; representation ability; linear motion.

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1. Introduction

The representation ability is one of the important abilities for students while studying physics. Representations in physics can be in the form of verbal descriptions, pictures, diagrams, graphs, computer simulations, and mathematical equations [1-5]. The use of multiple representations can increase students success in solving physics problems [3-9] and help students to understand concepts [9-12]. Therefore, knowledge of students difficulties in using multiple representations is important to identify in order to design appropriate learning [13].

Kinematics is a physics topic that students are required to have good representation ability. Some representations that students must have in kinematics include graphs, diagrams, and mathematical equations [14]. The ability of students to represent the main ideas of kinematics in various representation formats is also needed for further learning of physics. For example, to understand the concept of mechanics (the relationship of force and motion), first, students have to understand the kinematics concept [15]. Therefore, the ability to represent the kinematics is very necessary to make it easier for students to learn the next concept of physics.

Previous research has revealed various student difficulties in solving kinematics problems presented in various forms of representation. Several studies reveal students' difficulties in understanding kinematics graphs [16-21]. Ceuppens *et al.* (2019) [22] found that students had difficulty in determining the initial position of objects when solving problems in the form of mathematical equations. In other representations, students have more difficulty solving kinematics problems in symbolic than numeric representations [23-25]. Previous research also found that students had misconceptions and had difficulty describing the quantities of motion such as displacement, distance traveled, velocity, and acceleration, which were zero in various representations such as sentences, motion diagrams, graphs, and pictures [26]. Research about the students' ability to describe the quantities of motion with representations in kinematics has been carried out in Indonesia. The research result of Tamyiz, M. Yusup, *et al.* (2020) [27] shows that the students' ability to draw graphs position, velocity, and acceleration versus time is sufficient. However, research on students' ability to interpret the equation of position versus time using other representations has not been found. Therefore, this study aims to reveal students' ability to analyze the position-versus-time equation for an object moving with constant acceleration by using various representations, such as tables, mathematical equations, graphs, verbal descriptions, and motion diagrams. If students' multiple representation abilities are identified correctly, then teachers can find out the type of representation that needs to be improved during learning. In addition, interviews were conducted to find out the reasons why students had difficulty in making representations. The results of this study can be used as input for a physics teacher in an effort to improve students' representational abilities through learning physics. The purpose of this study was to analyze the ability of students to describe quantities of motion with multiple representations in linear motion. The research questions raised are followed. 1. How is the ability of students to describe the quantities of motion with multiple representations? 2. What representation is most difficult for students to describe?

2. Method

The study used a survey with a cross-sectional design approach. The research data were quantitative and qualitative data as supporting data. The research subjects included 54 students of class XI consisting of 31 students from one high school in Sumenep and 23 students from one high school in Pasuruan east java for the 2021/2022 academic year. Subjects consisted of 34 female and 20 male students. Respondents who were selected had received previous linear motion kinematics learning.

Data were collected by giving a representation ability test in the form of an open-ended test to the respondents. Respondents completed the test for 25 minutes, then the researcher gave a score using a previously designed rubric. The rubric consists of 4 categories, namely missing (0), inadequate (1), need some improvement (2), and adequate (3). Rubrics were used by two researchers when giving student scores to maintain consistency in the scoring. After scoring and grouping categories, 3 students from the missing category (0) with the highest percentage of students were interviewed open-ended to find out the reasons why students had difficulties when making representations.

The research instrument used was an open-ended test of linear motion with reability 0.707. The test given is in the form of a linear motion kinematics question with a representation of the equation of position versus time, and then students are asked to answer 5 questions using table representations, mathematical equations, graphs, verbal descriptions or sentences, and motion diagrams equipped with velocity vectors. The open-ended test instrument was used because the respondents had never been challenged to complete the task of making multiple representations. The items used are presented in the appendix.

Quantitative data were analyzed descriptively. Prior to quantitative analysis, the data collected were scored based on a rubric that had been adapted based on the research of Etkina *et al.* (2006) [28]. The rubric for assessing representational abilities is presented in the appendix. Answers from the student's representation ability test were corrected by two proofreaders to see the reliability of the rubric used. Student scores for each representation from the two correctors were entered into SPSS and then tested for reliability using Cohen's Kappa. If the reliability test results compared to the Kappa criteria are more than 0.70, it can be said that the measurement is reliable [29]. The results of the Cohen's Kappa calculation for the assessment rubric for each representation are 0.716-0.945, so it can be concluded that the rubric instrument used is reliable. While the qualitative data were analyzed using the constant comparative method [30]. The analysis steps are carried out as follows: 1) Coding the reasons that students make into a number of categories; 2) Reducing the variety of initial categories into a number of independent categories.

TABLE I. Percentage of categories for each question item.

Item	Representations	(0)	(1)	(2)	(3)
1	Table	4	7	59	30
2	Mathematics	39	11	50	0
3	Graph	4	69	28	0
4	Verbal	6	70	24	0
5	Motion Diagram	52	48	0	0

3. Result

Each representation that students have made is categorized into 4, namely missing (0), inadequate (1), needs some improvement (2), and adequate (3). The type of representation that is most difficult for students to make is characterized by the highest number of students falling into the missing category (0) and the lowest number of students falling into the adequate category (3). The ability of students' representation of linear motion kinematics can be seen from the percentage of students who fall into the category of each representation presented in Table I.

The research results showed that apart from the table representation, there were no students who succeeded in making a complete representation or were included in the adequate category (3). These results indicate that students have difficulty describing quantities in multiple representations. In the table representation, 59 percent of the student population was included in the need some improvement (2) category, but most students wrote wrong data. One of the table representations drawn by students in the need some improvement (2) category is presented in Fig. 1. In Fig. 1, students answer that the position of the car when $t = 5$ s is 22 meters. Meanwhile, the exact position of the car when $t = 5$ s is 27 meters.

In mathematical representation, 50 percent of the student population is in the need some improvement (2) category, but most students do not write vector signs and units of velocity. The mathematical representation of position versus time

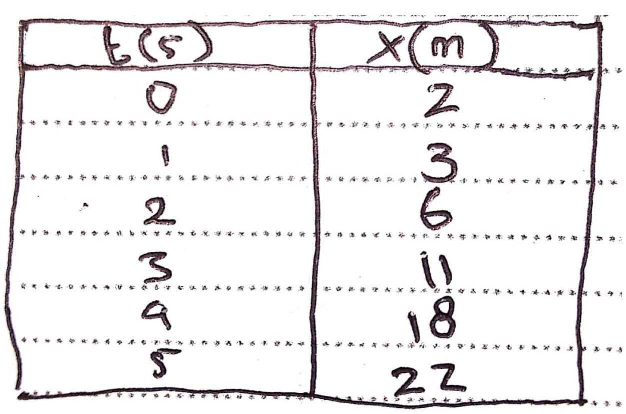

FIGURE 1. Table representation of position versus time.

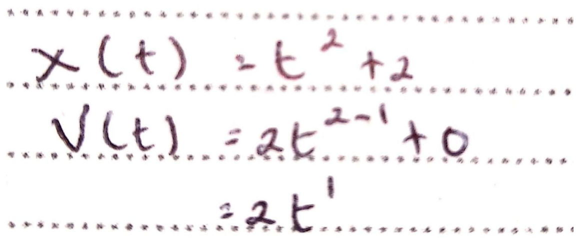

FIGURE 2. Equation representation of velocity versus time.

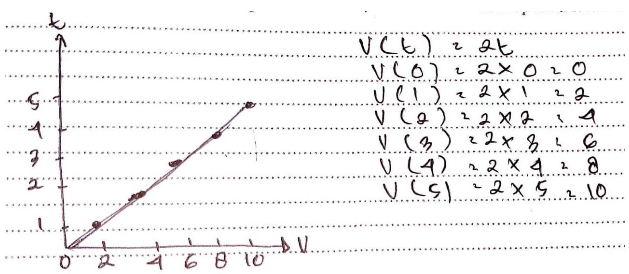

FIGURE 3. Graphical representation of velocity versus time.

described by students in the need some improvement (2) category is presented in Fig. 2.

In the graphic representation, 69 percent of the student population falls into the inadequate category (1). These results indicate that half of the student population has difficulty drawing velocity versus time graphs. Most students can describe each axis with a scale, but there are errors in the location of the quantities on the axes and the quantities are not equipped with units. Most students also draw arrows at the ends of each axis. The graphic representation depicted by students in the inadequate category (1) is presented in Fig. 3.

In verbal representation, as much as 70 percent of the student population is in the inadequate category (1). Most students only wrote down the car's movements for 5 seconds with positive velocity but did not write down the value and direction of the car's movement. A verbal representation of the movements described by students in the inadequate category (1) is presented in Fig. 4.

In the representation of motion diagrams, as many as 48 percent of the student population fell into the inadequate category (1), but the majority of students only drew position motion diagrams without labels and velocity vector diagrams. A diagram representation of the movements described by students in the inadequate category (1) is presented in Fig. 5.

The research results show that the highest percentage of missing categories (0) is the motion diagram representation at 52 percent. This shows that motion diagrams are the most difficult representation for students to draw. Interviews with 3 students from the missing (0) category of motion diagram representation were conducted to find out the reasons why students experienced difficulty when creating motion diagrams equipped with velocity vectors.

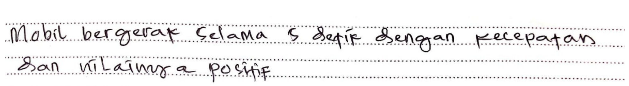

FIGURE 4. Verbal representation.

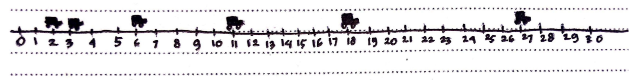

FIGURE 5. Motion diagram representation of position versus time.

4. Discussion

Based on the results of the interview, one of the difficulties encountered by students was difficulty interpreting the representation of motion diagrams. Suci stated that physics learning was carried out using the lecture method and motion diagrams had not been introduced when studying the kinematics of linear motion. However, Suci is of the opinion that the velocity versus time graph and the motion diagram are the same representation. Meanwhile, Ali and Nikmah also stated that they could not draw motion diagrams because motion diagrams had never been introduced in studying linear motion kinematics. The interviews resulted in the conclusion that students had difficulty creating representations of motion diagrams equipped with velocity vectors because motion diagrams had not been introduced by educators when studying kinematics of linear motion previously.

Based on the research results, students experience difficulty in describing quantities in multiple representations. Motion diagrams are the most difficult representations for students to draw. There are several reasons why students have difficulty creating motion diagram representations on the topic of linear motion kinematics. First, students have not been introduced to motion diagram representations in learning the kinematics of linear motion. This condition causes students to have difficulty interpreting motion diagrams. Students tend to guess the shape of a motion diagram equipped with a velocity vector, which is the same as a graph of velocity versus time. Even though, motion diagrams are different from velocity versus time graphs, motion diagrams can be formed by imagining a moving object being photographed with a camera light flashing at a constant velocity [31].

Confusion occurs because the use of the word "diagram" can cause students to interpret motion diagrams as being in the form of a bar chart. This research produced a finding that the reason why students had difficulty drawing motion diagrams was that students had never learned the representation of motion diagrams in learning.

Second, learning the kinematics of linear motion using the lecture method is often carried out in schools. This condition causes students to tend to be passive in learning. Based on the results of interviews, students have never been given a challenge to complete the task of making a representation of a motion diagram or other representations in learning. This causes students to have difficulty describing quantities in multiple representations. This finding is in accordance with the results of previous research, where students' fluency in making representations is influenced by students' experience of building and/or using representations in solving problems [32,33]. This research has been able to reveal the representational abilities and difficulties faced by students in analyzing the equation of position versus time and then expressing it in various other representations. However, this research still has several shortcomings. First, there are still few respondents. This is because data collection was carried out in the COVID-19 situation. Second, the question on the representation of kinematics of linear motion that is tested is only in the form of position versus time equations, then students are asked to describe quantities in various other representations. So the representation used in the questions is not yet varied. Therefore, researchers suggest that it is necessary to prepare questions in other forms of representation such as tables, graphs, verbal or motion diagrams, and then students are asked to describe quantities in other representations. This research has provided an illustration that to train students to be able to work with a variety of representations, more appropriate learning strategies are needed.

5. Conclusion and recommendation

Based on the results of data analysis and discussion, it can be concluded that students experience difficulty in creating multiple representations, but motion diagrams are the most difficult representation to depict in linear motion kinematics. Students have difficulty creating representations of motion diagrams accompanied by velocity vectors because motion diagrams have not been introduced in learning. In addition, learning carried out in schools uses the lecture method so that multiple representations have not been taught optimally. This research suggests further research using learning-based multiple representations to improve conceptual understanding, multiple representation abilities, and reduce the difficulties experienced by students.

Appendix

A. Instrument test

The car moves to the right along a straight line for 5 seconds. Its position as a function of time is given by the equation $x(t) = t^2 + 2$ where x is in meters and t is in seconds. Answer the following questions clearly and correctly!

1. Make a data table of the relationship between position and time for the first 5 seconds!
2. Find the mathematical equation for velocity as a function of time!
3. Graph the relationship between velocity and time for the first 5 seconds!
4. Describe the movement of the car during the first 5 seconds of movement using words or sentences!
5. Draw a motion diagram of the car's position over time during the first 5 seconds of moving along with its velocity vector!

B. Representation ability assessment rubric

Representation	*(0) Missing*	*(1) Inadequate*	*(2) Need Some Improvement*	*(3) Adequate*
Table	Does not create a Table	Make a table, write physical quantities correctly but the unit are wrong or there are no unit. Some data is incorrect or missed.	Make a table, write physical quantities and their unit correctly, but some of the data is wrong or not answered correctly. Or Write all the data correctly but do not write or there are errors in writing physical quantities and units	Create tables completely and without errors.
Mathematics	Does not create Mathematics Or write the wrong equation	Make representation mathematically, you can write equality used to complete problem, input data or concept physics is not quite right, or just write down data but not answer problems	Make representation mathematically, you can write equality used to complete problem, input data or concept physics properly, However, there are errors in writing vectors and units	Make mathematics completely and without errors.
Graph	Does not create a Graph	Make graph representation which contains it the axes, scales, and data are incorrect or can make it happen axes, scales, and labels on each axis but no in accordance with the variable that used	Make graphic representation which contains it axes and scales and contains labels on each axis but does not include data. Or creating axes and scales and entering data but not creating labels for each axis	Make graphs completely and without errors.
Verbal	Makes no verbal or sentence	Describes physical phenomena with words or sentences but lacks physical concepts or applies the wrong concepts	Describe physical phenomena with words or sentences but the physics concepts applied are incomplete	Describe physical phenomena with words or sentences with complete and correct physical concepts
Motion Diagram	Does not create a Motion Diagram Or Creating a faulty motion diagram	Create a motion diagram that contains correct point and scale However, there are data errors or it does not describe the vector direction, vector length, etc not accompanied by quantity physical	Create motion diagrams that contain points, scales, physical quantities, and representative vectors. However, there is a movement flow that is inaccurate or incomplete.	Create motion diagrams completely and without errors.

FIGURE 6. Representation ability assessment rubric.

1. L. Bollen *et al*., Student difficulties regarding symbolic and graphical representations of vector fields, *Phys. Rev. Phys. Educ. Res.* **13** (2017) 020109, https://doi.org/10.1103/PhysRevPhysEducRes.13.020109.
2. P. Klein, A. Müller, and J. Kuhn, Assessment of representational competence in kinematics, *Phys. Rev. Phys. Educ. Res.* **13** (2017) 010132, https://doi.org/10.1103/PhysRevPhysEducRes.13.010132.
3. M. De Cock, Representation use and strategy choice in physics problem solving, *Phys. Rev. ST Phys. Educ. Res.* **8** (2012) 020117, https://doi.org/10.1103/PhysRevSTPER.8.020117.
4. D. Rosengrant, E. Etkina, and A. Van Heuvelen, An overview of recent research on multiple representations, *AIP Conf. Proc.*, **883** (2007) 149, https://doi.org/10.1063/1.2508714.
5. T. Haratua and J. Sirait, Representations based physics instruction to enhance students' problem solving, *Am. J. Educ. Res.* **4** (2016) 1, https://doi.org/10.12691/education-4-1-1.
6. R. J. Dufresne, W. J. Gerace, and W. J. Leonard, Solving physics problems with multiple representations, *Phys. Teach.* **35** (1997) 270, https://doi.org/10.1119/1.2344681.
7. B. Ibrahim and N. S. Rebello, Representational task formats and problem solving strategies in kinematics and work, *Phys. Rev. ST Phys. Educ. Res.* **8** (2012) 1, https://doi.org/10.1103/PhysRevSTPER.8.010126.
8. E. Puspitaningtyas *et al*., Physics student' responses when asked to select and solve motion kinematics problems in various representations, *AIP Conf. Proc.*, **2330** (2021) 050002, https://doi.org/10.1063/5.0043437.
9. D. Rosengrant, A. Van Heuvelen, and E. Etkina, Do students use and understand free-body diagrams?, *Phys. Rev. ST Phys. Educ. Res.* **5** (2009) 010108, https://doi.org/10.1103/PhysRevSTPER.5.010108.
10. M. Masrifah *et al*., An investigation of physics teachers' multiple representation ability on newton's law concept, *Jurnal Penelitian & Pengembangan Pendidikan Fisika* **6** (2020) 105, https://doi.org/10.21009/1.06112.
11. D. F. Treagust, The importance of multiple representations for teaching and learning science, *Education research highlights in mathematics, science and technology* **2018** (2018) 215, https://doi.org/10.1007/978-981-10-3549-4.
12. A. Van Heuvelen and X. Zou, Multiple representations of work-energy processes, *Am. J. Phys.* **69** (2001) 184, https://doi.org/10.1119/1.1286662.
13. Y. Theasy *et al*., Multi-representation ability of students on the problem solving physics, *J. Phys.: Conf. Ser.*, **983** (2018) 012005, https://doi.org/10.1088/1742-6596/983/1/012005.
14. N. H. Dienyati, I. K. Werdhiana, and U. Wahyono, Analisis pemahaman konsep siswa berdasarkan multirepresentasi pada materi usaha dan energi kelas XI SMAN 1 banawa tengah, *Jurnal Kreatif Online* **8** (2020) 74.
15. A. Purwanti, S. Sutopo, and H. Wisodo, Penguasaan Konsep Materi Kinematika pada Siswa SMA Kelas X dengan Menggunakan Pembelajaran Multirepresentasi, Jurnal Pendidikan: Teori, *Penelitian, dan Pengembangan* **2** (2017) 575
16. R. J. Beichner, Testing student interpretation of kinematics graphs, *Am. J. Phys.* **62** (1994) 750, https://doi.org/10.1119/1.17449.
17. P. Hale, Connecting Research to Teaching: Kinematics and Graphs: Students' Difficulties and CBLs, *Math. Teach.* **93** (2000) 414, https://doi.org/10.5951/MT.93.5.0414.
18. M. Luedo, S. Supeno, and M. Maryani, Kemampuan Interpretasi Grafik Siswa Sekolah Swasta di Thailand Selatan pada *Materi Kinematika Gerak dalam Pembelajaran Fisika* **6** (2021) 132, https://dx.doi.org/10.36709/jipfi.v6i2.16409.
19. L. C. McDermott, M. L. Rosenquist, and E. H. Van Zee, Student difficulties in connecting graphs and physics: Examples from kinematics, *Am. J. Phys.* **55** (1987) 503, https://doi.org/10.1119/1.15104.
20. M. Planinic, et al., Comparison of student understanding of line graph slope in physics and mathematics, *Int. J. of Sci. Math. Educ.* **10** (2012) 1393, https://doi.org/10.1007/s10763-012-9344-1.
21. M. L. Rosenquist and L. C. McDermott, A conceptual approach to teaching kinematics, *Am. J. Phys.* **55** (1987) 407, https://doi.org/10.1119/1.15122.
22. S. Ceuppens *et al*., 9th grade students' understanding and strategies when solving x(t) problems in 1D kinematics and y (x) problems in mathematics, *Phys. Rev. Phys. Educ. Res.* **15** (2019) 010101, https://doi.org/10.1103/PhysRevPhysEducRes.15.010101.
23. C.-S. Hung and H.-K. Wu, Tenth graders' problem-solving performance, self-efficacy, and perceptions of physics problems with different representational formats, *Phys. Rev. Phys. Educ. Res.* **14** (2018) 020114, https://doi.org/10.1103/PhysRevPhysEducRes.14.020114.
24. E. Torigoe, How numbers help students solve physics problems, arXiv preprint arXiv:1112.3229 (2011), https://doi.org/10.48550/arXiv.1112.3229
25. E. Torigoe and G. Gladding, Same to us, different to them: Numeric computation versus symbolic representation, *AIP Conf. Proc.*, **883** (2007) 153, https://doi.org/10.1063/1.2508715.
26. A. Motlhabane *et al*., Learner's alternative and misconceptions in physics: A phenomenographic study, *J. Balt. Sci. Educ.* **15** (2016) 424, https://doi.org/10.33225/jbse/16.15.424.
27. M. Tamyiz *et al*., Analisis Kemampuan Siswa dalam Membuat Grafik Pada Pokok Bahasan Kinematika di SMA N 1 Indralaya, *Jurnal Literasi Pendidikan Fisika (JLPF)* **1** (2020) 145, https://doi.org/10.30872/jlpf.v1i2.263.
28. E. Etkina *et al*., Scientific abilities and their assessment, *Phys. Rev. ST Phys. Educ. Res.* **2** (2006) 020103, https://doi.org/10.1103/PhysRevSTPER.2.020103.
29. G. A. Morgan *et al*., SPSS for introductory statistics: Use and interpretation, 2nd ed. (Psychology Press, 2004).

30. A. L. Strauss, The discovery of grounded theory: Strategies for qualitative research (Routledge, 2017).

31. B. Glaser and A. Strauss, Discovery of Grounded Theory: Strategies for Qualitative Research (Routledge, New York, 2017), https://doi.org/10.4324/9780203793206.

32. M. Hill and M. D. Sharma, Students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the representational fluency survey, *EURASIA J. Math. Sci. Tech. Ed.* **11** (2015) 1633, https://doi.org/10.12973/eurasia.2015.1427a.

33. M. Wati, Studi Kemampuan Representasi Siswa pada Pokok Bahasan Hukum Newton, *Jurnal Inovasi Pembelajaran Fisika* **7** (2020) 010108, https://repo-dosen.ulm.ac.id//handle/123456789/17842.

34. P. B. Kohl, D. Rosengrant, and N. D. Finkelstein, Strongly and weakly directed approaches to teaching multiple representation use in physics, *Phys. Rev. Spec. Top. - Phys. Educ. Res.* **3** (2007) 1, https://doi.org/10.1103/PhysRevSTPER.3.010108.