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Original Research

Improving Understanding of 1-Dimensional Kinematics Concepts through Motion Diagram Approach

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ABSTRACT

Students' understanding of kinematics concepts still tends to be low because they have difficulty understanding concepts in various representations. This quantitative study investigates the effectiveness of the motion diagram approach in teaching one-dimensional kinematics through a pretest-posttest control group design. The experimental class utilized motion diagrams, while the control class was taught using conventional methods over a five-week period. The research was conducted at one of the public high schools in Makassar City. The experimental and control classes consisted of 36 students. Students' understanding was assessed using a validated set of 12 multiple-choice questions, with data analyzed through descriptive statistics and independent sample t-tests to evaluate differences in learning outcomes. Results indicated that the experimental class exhibited significantly more improvement in conceptual understanding than the control class, suggesting that motion diagrams enhance students' grasp of kinematic principles. The findings support integrating multi-representational learning strategies, facilitating students' active engagement and knowledge construction. The motion diagram approach effectively reduces cognitive load and promotes deeper understanding by visually representing motion and encouraging students to translate this information into tables, graphs, and equations. Additionally, the study highlights the importance of combining visual and verbal representations, which aligns with Dual Coding theory, enhancing retention and motivation. Overall, the research underscores the potential of innovative teaching methods, such as motion diagrams, to improve educational outcomes in physics, thereby enriching the learning experience and fostering a more profound comprehension of scientific concepts among students. In the future, similar experiments could be applied in broader contexts or in other subjects of physics, as well as the potential integration of this approach with modern technology.

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1. INTRODUCTION

Science education, especially physics, is important in developing students' critical and analytical thinking skills. Having many applications in daily life, physics concepts are also closely related to the concepts of other sciences. Many everyday phenomena can be explained using physics concepts (Arokoyu & Aderonmu, 2018; Kikas, 2003; Körhasan & Kaltakci-Gurel, 2019; Mualem & Eylon, 2007; Ogundeji et al., 2019; Taqwa et al., 2019a; Taqwa et al., 2019b). In addition, many everyday problems require physics concepts to solve them (Adams & Wieman, 2015; Firmansyah et al., 2023). Straight motion is one of the fundamental topics in physics that plays a crucial role (Halloun & Hestenes, 1985). Straight motion is a fundamental concept in kinematics that students must understand because it is needed to explain other movements, such as circular motion, parabolic motion, and oscillation. Understanding the concept of straight motion is not only the basis for learning advanced physics concepts but also helps students understand natural phenomena that occur in everyday life. However, in practice, many students experience difficulties understanding this concept, mainly due to limited mathematical understanding and visualization of motion in the abstract.

Concept understanding is one of the important goals that all students in physics classes must achieve (Rivaldo et al., 2019; Taqwa & Rivaldo, 2019; Taqwa et al., 2019c; Susanti et al., 2020). With a good understanding of the concept, students can explain various physical phenomena and solve problems relevant to their knowledge (Sajadi et al., 2013; Hegde et al., 2012; Docktor & Mestre, 2014; Ryan et al., 2016). In addition, using concepts is also important in building knowledge of higher-order thinking skills such as critical thinking skills, problem-solving skills, divergent thinking skills, creative thinking skills, and so on. Understanding concepts is not limited to remembering factual knowledge that students get when learning in class (Schank & Abelson, 1995); with a good understanding of concepts, students are expected to link interrelated knowledge with the awareness they build themselves. Without a good understanding of concepts, students' knowledge tends to be fragmented (Harlow & Bianchini, 2025), so students have difficulty when faced with complex problems.

Many research results show that students' understanding of kinematics concepts still tends to be low. Shodiqin and Taqwa (2021) found that students have difficulty in understanding the concept of acceleration, where the score obtained by 159 students on the topic only reached 30.47. Many students have difficulty interpreting positive or negative signs on vector quantities in kinematics, such as displacement, velocity, and acceleration. Many students assume that the negative sign on acceleration means that the object is moving at a decreasing speed, and the positive sign means that the object is moving at an increasing speed (Taqwa & Rivaldo, 2018). In addition, students also have many difficulties in understanding kinematics presented in different representations, such as graphs, mathematics, and tables.

Many things cause difficulties for students in understanding the topic of straight motion. One of the things that causes students difficulties is that their understanding is still fragmented. They find it difficult to link their knowledge with the new knowledge they gain in the learning process. In addition, students find it difficult to change their understanding from one representation to another. This is because, in the learning process, students are not trained to represent a concept in various diverse representation formats (Ainsworth, 1999). Learning still uses conventional methods emphasizing knowledge transfer from teachers to students (Cashman & O'Mahony, 2022; Rosenquist & McDermott, 1987). For this reason, a new approach is needed to make students more active in constructing their understanding so that the knowledge they get can be more comprehensive and in-depth. By constructing their own knowledge, it is hoped that students can store their knowledge in long-term memory. So that when students need the knowledge they have gained to solve problems, they can immediately call on the knowledge they already have.

The motion diagram analysis approach has been proposed as one effective method to help students develop a deep understanding of the concept of straight motion (Sutopo, 2012). Motion diagrams allow for the visual representation of motion data, such as position, velocity, and acceleration, in the form of graphs or vector diagrams. By utilizing this approach, students can more easily connect the conceptual and mathematical aspects of straight motion. This study aims to examine the effect of the motion diagram analysis approach on students' concept understanding of straight-motion material. This research is expected to contribute to the development of more effective physics learning methods and help improve the quality of students' understanding of basic concepts in physics.

2. METHOD

This research is a quantitative study with an experimental research design. The experimental research design used in this study was the pretest-posttest control group design. In this study, the experimental class was taught using the motion diagram approach. The control class in this study was taught using conventional methods (see Fig. 1), where E is the experiment class, C is the control class, O_{1E} is the pretest in the experiment class, O_{1C} is the pretest in the control class, I_E is intervention in experimental class, I_C is intervention in control class, O_{2E} is the post-test in the experiment class, and O_{2C} is post-test in the control class. Conventional methods in this study are learning carried out by emphasizing the transfer of information from instructors to students. The study was conducted over 5 weeks. The first week was conducted as a pretest, the second to the fourth week were conducted as learning, and the fifth week was conducted as post-test activities. The research was conducted at one of the public high schools in Makassar City, and control and experimental classes were randomly selected. The experimental and control classes consisted of 36 students.

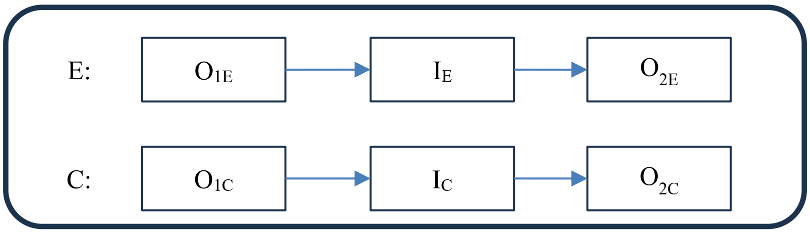

Figure 1. Research Design

The motion diagram approach referred to in this study is a learning approach that begins by presenting the problem of object motion by providing position information as a function of time in a visual representation. Based on the position information as a function of time used in the visual representation, students are asked to re-represent the position as a function of time in the format of tables, graphs, and mathematical equations. This starts by building knowledge about position, displacement, and distance traveled, speed and velocity, and acceleration.

The instrument used to measure students' understanding of one-dimensional kinematics consisted of 12 multiple-choice questions. The questions used in the pretest and post-test are the same. Four experts validated all questions used in this study, and then we conducted empirical tests. The 12 questions are valid and reliable. The scoring used in this study is 1 for correct answers and 0 for wrong answers.

Data analysis in this study was carried out by calculating descriptive statistics consisting of measures of Central tendency (mean and median), data distribution (standard deviation), and skewness values to see whether the data were normally distributed. If the skewness value is between -1 to + 1, then the data is close to a normal distribution. An independent sample t-test was conducted to see the difference between the experimental and control classes. The improvement from the pretest to the post-test for both classes was measured by calculating the n-gain value. The impact of the application of learning in both classes is measured by calculating the d-effect size.

3. RESULTS AND DISCUSSION

3.1. Students' score of conceptual understanding

Students' understanding of the concept of one-dimensional kinematics is based on the pretest and post-test scores they have obtained. Table 1 shows the descriptive statistics of the pretest and post-test scores for the control and experimental classes. The control and experimental classes show that the post-test results are higher than the pre-test results. In the control class, the average score increased from 41.44 to 58.80; in the experimental class, the average score increased from 40.51 to 83.79. These results indicate that, based on the scores obtained by students, the increase in understanding of the concept of 1-dimensional kinematics is better in the experimental class than in the control class. When viewed from the average score, the pretest for both classes, between the control class and the experimental class, does not show a significant difference in understanding the concept. Even the experimental class has a slightly lower average pretest score compared to the average pretest score of the control class. When viewed from the standard deviation score, the control class pre-test, control class post-test, experimental class pre-test, and experimental class post-test have a relatively similar score distribution. This shows that the four classes have almost the same characteristics. Skewness scores for all four classes are between -1 and -1, indicating that all data groups have a near-normal distribution. However, we still conducted the Kolmogorov-Smirnov statistical test, showing that all data groups were normally distributed. In addition, the homogeneity test also shows that the experimental and control groups have a similar level of uniformity (homogeneity).

The pretest and posttest scores for both classes can be compared by looking at Figure 2. We have sorted the student scores from lowest to highest for each class. Both control and experimental classes have almost the same scores. However, there are some differences in scores between the control and experimental groups at the pretest. In the experimental class, the lowest pretest score was 8.33, while in the control class, the lowest pre-test score was 16.67. It can also be seen that all students in both experimental and control classes experienced an increase in scores from the pre-test to the post-test. However, there is one student with the same pretest and posttest scores, namely the 35th student with a fixed score of 66.67. Based on the graph, it can be seen that the change in post-test scores in the experimental class is higher than the change in scores in the control class.

These statistical results show that students taught using motion diagrams have a better understanding than those taught with conventional methods. In the next section, we will further discuss the statistical test related to the significance of this difference in understanding using the t-test and describe how understanding the concept of 1-dimensional kinematics improved for the control and experimental classes.

Table 1. Descriptive statistic of students' conceptual understanding in pretest and posttest for experiment and control class

Group		N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
		Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
Control	Pretest	36	16.67	66.67	41.44	12.68	0.049	0.393
	Posttest	36	33.33	91.67	58.80	13.65	0.237	0.393
Experiment	Pretest	36	8.33	66.67	40.51	12.62	-0.169	0.393
	Posttest	36	66.67	100.00	83.79	10.15	-0.011	0.393
Valid N (listwise)		36						

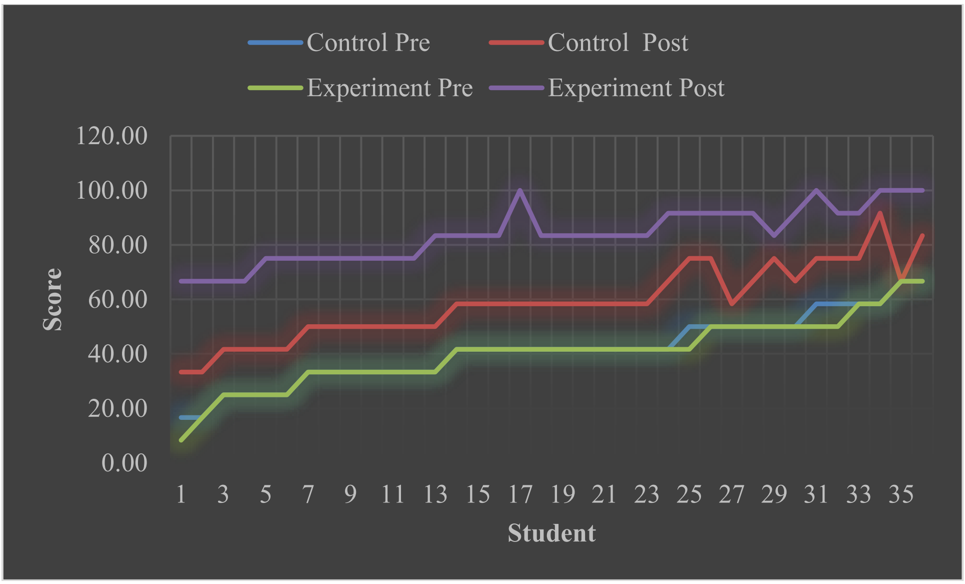

Figure 2. Change in student scores from pretest to posttest

3.2. The impact of using motion diagrams in learning 1-dimensional kinematics

Based on the difference test results using the Independent Samples Test presented in Table 2, information was obtained that the Levene test showed a value of F = 0.16 with Sig. = 0.70 in the control class and F = 0.62 with Sig. = 0.44 in the experimental class. Both Sig. values are greater than 0.05, which means that the assumption of homogeneity of variances is met. Therefore, the results of the t-test analysis using the assumption of Equal variances can be used for further interpretation.

In the control class, the t-test produced a value of t = -5.59 with degrees of freedom (df) = 70 and a value of Sig. (2-tailed) = 0.00 ($p < 0.05$). The mean difference in scores between the experimental and control groups was -17.36, with a Standard Error Difference of 3.10. The 95% confidence interval for the mean difference was -23.55 to -11.17, which did not include a zero value. This indicates a significant difference between the control group using conventional methods and the experimental group. Meanwhile, in the experimental class, the t value = -16.02 with df = 70 and Sig. (2-tailed) = 0.00 ($p < 0.05$). The mean difference in scores between the experimental and control groups was -43.29, with a Standard Error Difference of 2.69. The 95% confidence interval for the mean difference is in the range of -48.67 to -37.90. These results indicate a highly significant difference between learning with motion diagrams and conventional methods. By considering both test results, it can be concluded that learning using motion diagrams is significantly more effective than conventional methods in improving student learning outcomes. The effectiveness of the motion diagram method is shown by the higher average score as well as the statistical test results that support the difference.

The results of the N-gain and d-effect size analysis presented in Table 3 show the difference in the improvement of learning outcomes between the control class and the experimental class. In the control class, the N-gain value of 0.296 indicates that the improvement in learning outcomes is in the low category. The d-effect size value of 1.318 is included in the large effect size category, which indicates that the conventional method has a significant effect on improving learning outcomes, although the improvement is relatively limited. In contrast, in the experimental class, the N-gain value of 0.728 is in the high category, which indicates that learning with motion diagrams significantly improves student learning outcomes. The d-effect size value of 3.780 is in the very large effect size category, which indicates that this method has a tremendous impact on the achievement of learning outcomes. Overall, the N-gain and d-effect size analysis confirm that learning using motion diagrams is more effective in improving learning outcomes than conventional methods and has a much greater impact on improving student learning outcomes. This reinforces the conclusion that innovative approaches, such as the use of motion diagrams, are very feasible to implement in the learning process to improve the quality of education.

Learning 1-dimensional kinematics using motion diagrams has proven more effective than conventional methods, especially when analyzed from the perspective of multi-representation theory. This result is also supported by previous research, which shows that the use of learning modules that integrate motion diagrams can significantly improve understanding of kinematics concepts (Taqwa et al., 2022). Multi-representation emphasizes that understanding of physics concepts can be strengthened by connecting various forms of representation, such as visual, numerical, graphical, and mathematical (Aminuddin, 2024). Motion diagrams become a bridge that integrates tabular, graphical, and mathematical representations. In motion diagrams, students can visually understand the relationship between position, velocity, and time through the movement patterns of objects. This information can be translated into data tables to organize observations in a structured manner. Furthermore, these tables are converted into graphs of position against time, velocity against time, or acceleration against time, which provide an understanding of the pattern of change in motion. Furthermore, motion diagrams also allow students to understand mathematical relationships, such as using kinematics equations to explain quantitative relationships between variables. On the other hand, the advantage of students who are required to construct their knowledge is that they can store their knowledge in long-term memory. This is expected to help them activate the knowledge they have acquired when needed to solve relevant cases.

This multi-representation approach supports constructivist theory, which states that students build understanding through direct experience and active engagement in learning. Using multiple representations to support students' understanding is one of the essentials in learning built on constructivist theory (Baviskar et al., 2009). By analyzing and visualizing motion diagrams, students are more active in building concepts independently, in contrast to conventional methods that tend to be teacher-centered and focus on solving mathematical problems without conceptual exploration. Active student involvement in learning is important so that learning is not just one-way, but also the transfer of knowledge from teacher to student. In addition, Cognitive Load theory shows that presenting information in visual form (Cao et al., 2009; Cook, 2006; Leahy & Sweller, 2011; Mousavi et al, 1995; Klingner et al., 2011), such as motion diagrams, can reduce students' cognitive load in understanding complex concepts. Visualization helps the brain process information more efficiently by simplifying kinematics abstractions into a more intuitive form.

Furthermore, the Dual Coding theory also reinforces the effectiveness of motion diagrams. Dual Coding theory, introduced by Allan Paivio (Clark & Paivio, 1987; Paivio & Clark, 2006; Paivio, 1991; Sadoski & Paivio, 2004; Paivio, 2014), offers a powerful framework for enhancing kinematics learning through the integration of verbal and visual representations. In the context of kinematics, which often involves abstract concepts such as velocity, acceleration, and displacement, the use of motion diagrams, graphs, and animations can provide concrete visual representations. When this information is presented alongside verbal or text explanations, students can utilize both channels of information processing, verbal and non-verbal, to build a deeper understanding. Visual representations help students visualize and internalize concepts that may be difficult to understand through text or numbers alone. Thus, the Dual Coding theory supports a multimodal learning approach (Chen & Fu, 2003), which can improve students' retention and understanding of kinematics material, allowing them to relate and integrate different forms of information more effectively. This learning is expected to increase students' consistency in using their knowledge. This integration enriches the learning experience and facilitates the transfer of knowledge to new situations, which is a key goal in science education. By combining visual and verbal representations, motion diagrams allow students to process information through two cognitive pathways: the verbal pathway (teacher explanation) and the visual pathway (diagram image). This combination improves students' understanding and recall of kinematics concepts (Taqwa et al., 2017; Romansyah & Taqwa, 2021; Tebabal & Kahssay, 2011; Waldrip et al., 2013). In addition, the relevance of motion diagrams to real phenomena in daily life increases students' learning motivation, which contributes significantly to learning success according to intrinsic motivation theory.

By referring to these theories, it can be concluded that motion diagrams not only support the understanding of kinematics concepts through the integration of multi-representations but also facilitate student engagement, reduce cognitive load, and improve retention and learning motivation. This makes learning using motion diagrams an innovative approach and more effective than conventional methods in improving student learning outcomes.

Table 2. Independent samples t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Control	Equal variances assumed	0.16	0.70	-5.59	70	0.00	-17.36	3.10	-23.55	-11.17
	Equal variances not assumed			-5.59	69.62	0.00	-17.36	3.10	-23.55	-11.17
Exp.	Equal variances assumed	0.62	0.44	-16.02	70	0.00	-43.29	2.69	-48.67	-37.90
	Equal variances not assumed			-16.02	66.91	0.00	-43.29	2.69	-48.68	-37.89

Table 3. N-gain and d-effect size results

Class	N-gain	d-effect size
Control	0.296	1.318
Experiment	0.728	3.780

4. CONCLUSION

The research highlights the significant advantages of using motion diagrams in teaching one-dimensional kinematics, demonstrating that this innovative approach improves students' conceptual understanding compared to conventional teaching methods. The findings indicate that while the control and experimental groups experienced an increase in their understanding, the experimental group, which utilized motion diagrams, showed a markedly higher enhancement in their post-test scores. This improvement can be attributed to the multi-representational nature of motion diagrams, which effectively integrate visual, numerical, and graphical representations. Such integration not only aids in clarifying complex kinematic concepts but also aligns with constructivist theories that advocate for active student engagement and the construction of knowledge through hands-on experiences.

Furthermore, the study emphasizes the role of motion diagrams in reducing cognitive load, allowing students to process and internalize information more efficiently. By presenting information visually, students can better grasp the relationships between position, velocity, and time, often abstract concepts in kinematics. Combining visual and verbal representations enhances retention and motivation, as students can relate theoretical concepts to real-world phenomena. Overall, the research supports the implementation of motion diagrams as a powerful pedagogical tool in physics education, reinforcing that innovative teaching strategies can significantly improve learning outcomes and foster a deeper understanding of scientific principles among students.

REFERENCES

Adams, W. K., & Wieman, C. E. (2015). Analyzing the many skills involved in solving complex physics problems. *American Journal of Physics*, *83*(5), 459-467. https://doi.org/10.1119/1.4913923

Ainsworth, S. (1999). The functions of multiple representations. *Computers & education*, *33*(2-3), 131-152. https://doi.org/10.1016/S0360-1315(99)00029-9

Aminuddin, M., Salman, Z., & Irawati, A. (2024). Multi-representation approach in improving 1-dimensional kinematics conceptual understanding. *Universal Education Journal of Teaching and Learning, 1*(2), 41-45. https://doi.org/10.63081/uejtl.v1i2.34

Arokoyu, A. A., & Aderonmu, T. S. (2018). Conceptual formation, attainment and retention of Chemistry and Physics students in real-life phenomena. *International Journal of Scientific Research and Innovative Technology*, *5*(5), 18-34.

Baviskar, S. N., Sandhya, N., Hartle, R. T., & Whitney, T. (2009). Essential criteria to characterize constructivist teaching: Derived from a review of the literature and applied to five constructivist-teaching method articles. *International Journal of Science Education, 31*(4), 541-550. https://doi.org/10.1080/09500690802349251

Cao, Y., Theune, M., & Nijholt, A. (2009). Modality effects on cognitive load and performance in high-load information presentation. In *Proceedings of the 14th International Conference on Intelligent User Interfaces* (pp. 335-344). https://doi.org/10.1145/1502650.1502693

Cashman, A., & O'Mahony, T. (2022). Student understanding of kinematics: a qualitative assessment. *European Journal of Engineering Education, 47*(6), 886-909. https://doi.org/10.1080/03043797.2022.2073200

Chen, G., & Fu, X. (2003). Effects of multimodal information on learning performance and judgment of learning. *Journal of Educational Computing Research, 29*(3), 349-362. https://doi.org/10.2190/1R3H-HM0K-0V62-0V43

Clark, J. M., & Paivio, A. (1987). *A dual coding perspective on encoding processes.* In Imagery and Related Mnemonic Processes: Theories, Individual Differences, and Applications (pp. 5-33). Springer New York. https://doi.org/10.1007/978-1-4612-4631-7_1

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education, 90*(6), 1073-1091. https://doi.org/10.1002/sce.20199

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics-Physics Education Research, 10*(2), 020119. https://doi.org/10.1103/PhysRevSTPER.10.020119

Firmansyah, D., Taqwa, M. R. A., Setiyani, A., & Ramadani, C. I. (2023). Analysis of College Students' Conceptual Understanding on Work and Energy Topic in Various Representations. *Jurnal Pendidikan Fisika dan Teknologi*, *9*(2), 306-314. https://doi.org/10.29303/jpft.v9i2.4760

Halloun, I. A., & Hestenes, D. (1985). Common sense concepts about motion. *American journal of physics, 53*(11), 1056-1065. https://doi.org/10.1119/1.14031

Harlow, D.B., & Bianchini, J.A. (2025). *Knowledge-in-Pieces—Andrea A. diSessa, David Hammer*. In: Akpan, B., Kennedy, T.J. (eds) Science Education in Theory and Practice. Springer Texts in Education. Springer, Cham. https://doi.org/10.1007/978-3-031-81351-1_22

Hegde, B., & Meera, B. N. (2012). How do they solve it? An insight into the learner's approach to the mechanism of physics problem solving. *Physical Review Special Topics—Physics Education Research, 8*(1), 010109. https://doi.org/10.1103/PhysRevSTPER.8.010109

Kikas, E. (2003). University students' conceptions of different physical phenomena. *Journal of adult development*, *10*, 139-150. https://doi.org/10.1023/A:1023410212892

Klingner, J., Tversky, B., & Hanrahan, P. (2011). Effects of visual and verbal presentation on cognitive load in vigilance, memory, and arithmetic tasks. *Psychophysiology, 48*(3), 323-332. https://doi.org/10.1111/j.1469-8986.2010.01113.x

Körhasan, N. D., & Kaltakci-Gurel, D. (2019). Student teachers' physics knowledge and sources of knowledge to explain everyday phenomena. *Science Education International*, *30*(4), 298-309. https://doi.org/10.33828/sei.v30.i4.7

Leahy, W., & Sweller, J. (2011). Cognitive load theory, modality of presentation and the transient information effect. *Applied Cognitive Psychology, 25*(6), 943-951. https://doi.org/10.1002/acp.1779

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87*(2), 319-334. https://doi.org/10.1037/0022-0663.87.2.319

Mualem, R., & Eylon, B. S. (2007). "Physics with a smile"—Explaining phenomena with a qualitative problem-solving strategy. *The Physics Teacher*, *45*(3), 158-163. https://doi.org/10.1119/1.2709674

Ogundeji, O. M., Madu, B. C., & Onuya, C. C. (2019). Scientific Explanation of Phenomena and Concept Formation as Correlates of Students' Understanding of Physics Concepts. *European Journal of Physics Education*, *10*(3), 10-19. https://eric.ed.gov/?id=EJ1299975

Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology/Revue Canadienne de Psychologie, 45*(3), 255-287. https://doi.org/10.1037/h0084391

Paivio, A. (2014). Intelligence, dual coding theory, and the brain. *Intelligence, 47*, 141-158. https://doi.org/10.1016/j.intell.2014.04.006

Paivio, A., & Clark, J. M. (2006). *Dual coding theory and education.* Pathways to Literacy Achievement for High Poverty Children, 1, 149-210.

Rivaldo, L., Taqwa, M. R. A., & Faizah, R. (2019). Identifikasi Pemahaman Konsep Usaha dan Energi Calon Guru Fisika. *Jurnal Pendidikan Sains Universitas Muhammadiyah Semarang, 7*(2), 157-163. https://doi.org/10.26714/jps.7.2.2019.157-163

Romansyah, T. A., & Taqwa, M. R. A. (2021). Konsistensi representasi dalam menyelesaikan kasus jarak tempuh. *Radiasi: Jurnal Berkala Pendidikan Fisika, 14*(2), 87-98. https://doi.org/10.37729/radiasi.v14i2.1143

Rosenquist, M. L., & McDermott, L. C. (1987). A conceptual approach to teaching kinematics. *American Journal of Physics, 55*(5), 407-415. https://doi.org/10.1119/1.15122

Ryan, Q. X., Frodermann, E., Heller, K., Hsu, L., & Mason, A. (2016). Computer problem-solving coaches for introductory physics: Design and usability studies. *Physical Review Physics Education Research*, *12*(1), 010105. https://doi.org/10.1103/PhysRevPhysEducRes.12.010105

Sadoski, M., & Paivio, A. (2004). *A dual coding theoretical model of reading.* In Theoretical Models and Processes of Reading (5th ed., pp. 1329-1362). International Reading Association.

Sajadi, M., Amiripour, P., & Rostamy-Malkhalifeh, M. (2013). The examining mathematical word problems solving ability under efficient representation aspect. *Mathematics Education Trends and Research, 2013*(1), 1-11. https://doi.org/10.5899/2013/metr-00007

Schank, R. C., & Abelson, R. (1995). *Knowledge and memory: The real story*. In Knowledge and Memory: The Real Story, ed Wyer RS.

Shodiqin, M. I., & Taqwa, M. R. A. (2021, June). Identification of student difficulties in understanding kinematics: focus of study on the topic of acceleration. *In Journal of Physics: Conference Series* (Vol. 1918, No. 2, p. 022016). IOP Publishing. https://doi.org/10.1088/1742-6596/1918/2/022016

Susanti, S. D., Taqwa, M. R. A., & Sulur, S. (2020). Pengembangan e-module berbasis discovery learning berbantuan PhET pada materi teori kinetik gas untuk mahasiswa. *Jurnal Pendidikan Fisika dan Teknologi, 6*(2), 287-296. https://doi.org/10.29303/jpft.v6i2.2234

Sutopo, S. (2012). Pembelajaran kinematika berbasis diagram gerak: Cara baru dalam pengajaran kinematika. In *Seminar Nasional Penelitian Universitas Negeri Yogyakarta*. Yogyakarta: Universitas Negeri Yogyakarta (p. 11).

Taqwa, M. R. A., & Rivaldo, L. (2018). Kinematics Conceptual Understanding: Interpretation of Position Equations as A Function of Time. *Jurnal Pendidikan Sains Universitas Negeri Malang*, 6(4), 478018. https://doi.org/10.17977/jps.v6i4.11274

Taqwa, M. R. A., & Rivaldo, L. (2019). Pembelajaran problem solving terintegrasi phet: membangun pemahaman konsep listrik dinamis. *Kwangsan: Jurnal Teknologi Pendidikan, 7*(1), 45-56. http://dx.doi.org/10.31800/jtp.kw.v7n1.p45--56

Taqwa, M. R. A., Faizah, R., & Rivaldo, L. (2019a). Pengembangan lembar kerja mahasiswa berbasis POE dan kemampuan berpikir kritis mahasiswa pada topik fluida statis. *Edufisika: Jurnal Pendidikan Fisika*, *4*(01), 6-13. Retrieved from https://mail.online-journal.unja.ac.id/EDP/article/view/6284

Taqwa, M. R. A., Rivaldo, L., & Faizah, R. (2019b). Problem based learning implementation to increase the students' conceptual understanding of elasticity. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, *9*(2). http://dx.doi.org/10.30998/formatif.v9i2.3339

Taqwa, M. R. A., Priyadi, R., & Rivaldo, L. (2019c). Pemahaman konsep suhu dan kalor mahasiswa calon guru. *JPF (Jurnal Pendidikan Fisika) FKIP UM Metro, 7*(1), 56-67. http://dx.doi.org/10.24127/jpf.v7i1.1547

Taqwa, M. R. A., Hidayat, A., & Sutopo, S. (2017). Konsistensi pemahaman konsep kecepatan dalam berbagai representasi. *Jurnal Riset dan Kajian Pendidikan Fisika, 4*(1), 31-40. https://doi.org/10.12928/jrkpf.v4i1.6469

Taqwa, M. R. A., Suyudi, A., & Faizah, R. (2022). Integration of motion diagram-based module to improve students' conceptual understanding of 1-dimensional kinematics. *Journal of Physics: Conference Series*, 2309(1), 012062. https://doi.org/10.1088/1742-6596/2309/1/012062

Tebabal, A., & Kahssay, G. (2011). The effects of student-centered approach in improving students' graphical interpretation skills and conceptual understanding of kinematical motion. *Latin-American Journal of Physics Education, 5*(2), 9. Retrieved from http://www.lajpe.org/june11/9_LAJPE_509_Ambelu_Tebabal_preprint_corr_f.pdf

Waldrip, B., Prain, V., & Sellings, P. (2013). Explaining Newton's laws of motion: Using student reasoning through representations to develop conceptual understanding. *Instructional Science, 41*, 165-189. https://doi.org/10.1007/s11251-012-9223-8