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Enhancing Students' Concepts Mastery in Kinetic Theory of Gases through the STEM-Discovery Learning Model

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Abstract
Students' difficulties with gas kinetic theory material have led to low mastery of physics concepts. Improving mastery of the concept of the kinetic theory of gases can be supported by using learning models. There have been many studies that prove that discovery learning can influence physics learning outcomes. However, this study uses a STEM approach integrated into a discovery learning model that acts as part of the inquiry level in physics classes Merdeka curriculum. This research aims to improve students' mastery of concepts in the kinetic theory of gases material through the STEM-discovery learning model. This research used a one-group pretest and posttest design on 30 students of class XI Merdeka 4 at SMAN 1 Dolopo. The instruments used are the RPP and five questions describing the concept mastery test. The data obtained was then analyzed using the normality test, difference test, N-gain, and effect size, and categorizing the students' concept mastery level for each question. The results of this research reveal that STEM-discovery learning is able to increase students' mastery of concepts in kinetic gas theory material. Interestingly, this research also found that students' correct conceptions have not been able to be stored in memory very well, so it is necessary to link kinetic gas theory material to other physics material that is still relevant so that students are motivated to remember and retain concepts.

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1. Introduction

The kinetic theory of gas is material related to the ideal gas law, an abstract material consisting of small molecules that collide with each other [1]. The kinetic gas theory material teaches about the behavior of gas particles which are defined in macroscopic quantities, namely pressure, volume, temperature and microscopic quantities, collision frequency, speed and energy [2]. The difficulty that students find is connecting the concept of microscopic quantities of an ideal gas, such as collisions and kinetic energy, with macroscopic quantities such as temperature and volume [3]. Difficulties occur at a higher level, namely that there is often confusion between the speed of particle movement which is a microscopic quantity and macroscopic processes related to understanding thermodynamic quantities [4]. Meanwhile, students who study physics are directly related to mastering the concepts and principles of physics. This concept becomes the basis for the development of more complex thinking, allowing students to formulate various principles and make generalizations [5].

Physics needs to be studied as previous physicists acquired knowledge, therefore guidance to find out and act must be carried out because this can help to gain mastery of concepts [6]. The empirical evidence shows that high school students' mastery of physics concepts in Indonesia still shows an inadequate level, difficulties still experienced by students include determining internal energy by the number of changing gas particles and the average speed of an ideal gas [7]. Low mastery of concepts is due to the use of inappropriate learning models [8]. Another factor that causes low mastery of concepts is teaching and learning activities in the classroom which are still teacher-centered [9]. Students who participate in direct concept discovery will have physics concepts that last longer [10].

The discovery learning model is constructivism-based learning where this learning model applies a lot of student-centered learning and involves students' active role in building knowledge [11]. Compared to other learning models, discovery learning has several advantages, namely effectively improving students' mathematical understanding and learning outcomes [12]. This model focuses more on students' direct experience during learning [13]. The discovery learning model also emphasizes the discovery of previously unknown concepts or principles [14]. Previous research shows that the application of the discovery learning model has a significant impact on students' mastery of concepts [15], [16], [17]. The use of discovery learning models in the learning process has been proven to be able to improve students' concepts substantially [18]. This research combines the discovery learning model with a STEM approach which is expected to provide students with more opportunities to build mastery of concepts from the process of scientific observation, and application of technology, to problem-solving [19]. The results of the research [20], the STEM approach is suitable to be combined with the inquiry learning model. In this learning model, students are more directly involved in building knowledge concepts that are actively involved through direct observation and experimentation [21]. STEM can build good concept mastery through a scientific mindset and link it to the application of technology in everyday life [22], [23]. Aspects of the STEM approach integrate mastery and skills so that the knowledge built can become a unified whole that can be applied in the world of everyday life [19]. The STEM-discovery learning model can increase the effectiveness of meaningful learning and produce varied learning [24].

Previous research has combined the discovery learning model with a STEM approach. Research by Fadlina and Ritonga (2021) showed that STEM-discovery learning with stimulation, problem statement, data collection, data processing, verification, and generalization stages to improve learning outcomes of motion systems concept [25]. Khotimah et al., (2022) [26] showed the development of the STEM-discovery learning module which was developed consisting of Discovery I, Discovery II, and Discovery III, where each discovery has learning activities that students must carry out. Another research by Astryani et al (2022) showed that developing student worksheets using STEM in the discovery learning model with stimulation, problem statement, data collection, data processing, verification, and generalization stages in elementary school space figure material [27]. However, this study uses a STEM approach integrated into a discovery learning model that acts as part of the inquiry level by Wenning (2005) [28] with stages of observation, manipulation, generalization, verification, and application, then the integration of the STEM approach in Merdeka Curriculum. This research aims to improve students' mastery of concepts in the kinetic theory of gases material through the STEM-discovery learning model.

2. Methods

This research is quantitative research using one group pretest and posttest design. One group pretest and posttest design is the design chosen when researchers only use 1 group of research subjects and carry out test measurements before and after treatment [29], [30], [31]. Differences in measurement results are considered as the effect of treatment. This research was conducted on 30 students of class XI Merdeka 4 at SMAN 1 Dolopo with the research design scheme as follows Table 1.

Table 1. One Group Pre-test and Post-test Design Scheme [30]

Pretest	Treatment	Posttest
O_1	X	O_2

The data collection technique uses a concept mastery test which is carried out in the pretest (O_1) and posttest (O_2). The pretest was carried out to measure students' mastery of initial concepts which was carried out before learning gas kinetic theory through STEM-discovery learning (X), and the posttest was carried out to measure students' mastery of final concepts which was carried out after learning gas kinetic theory through STEM-discovery learning. The stages used to build mastery of concepts in discovery learning according to those proposed by [28] are known as levels of inquiry, then STEM-discovery learning is developed as in Table 2 below.

Table 2. STEM-Discovery Learning Syntax

Stages	Description of Learning Activities	STEM
Observation	Students observe problems given by the teacher that can give rise to responses in the investigation, describe in detail what they observe, then they communicate analogies and other examples related to the observed phenomena. Guiding questions are developed to guide the investigation process. (S)	Science (S): Knowledge of the concept of kinetic theory of gases
Manipulation	Delivering problem-solving, holding discussions about a number of ideas that can be investigated through worksheets, as well as designing approach methods to understand phenomena. (S, M)	Technology (T): Existing technology that is thought to be able to assist the investigation
Generalization	Students build various new principles or laws to explain problems including solutions to the use of technology in solving problems through worksheets. Students provide a reasonable explanation of the phenomenon. (S, T, E, M)	Engineering (E): Engineering techniques used to design the investigation design that will be implemented
Verification	Carry out testing using general laws derived from previous stages through working on questions/practice questions. (S, T, E, M)	
Application	Students design and realize the results of problem-solving. (S, T, E, M)	Mathematics (M) Mathematical calculations to solve problems

The research instrument consists of a learning implementation plan, as well as a concept mastery test instrument which consists of five descriptive questions and a trial of the instrument was carried out using 68 students and was declared valid and reliable at 0.513. Data analysis was carried out on data that was normally distributed [Sig. 0.153 > 0.05] and then a paired samples test was carried out between pre-test and post-test data. The criteria for students' concept mastery level [32] are presented as Table 3.

Table 3. Criteria for Students' Concepts Mastery Level

Level	Grading Criteria	Score
NR (no response)	The student did not answer	0
NU (no understanding)	The answer is wrong and the reasons given do not match the statement, the reasons given are irrelevant or unclear, and there is no explanation.	2
SM (specific misconception)	The student's answer is correct but it is a scientific method and there are misconceptions.	5
PUSM (partial understanding with a specific misconception)	Students' correct answers show mastery of the concept but there are still misconceptions.	8
SU (sound understanding	The student's answer correctly contains all parts of the scientific concept.	10

To see the increase in pre-test data to post-test, N-gain and effect size tests were carried out. The N-gain formula [33] is as follows.

$$\text{N-gain} = \frac{\text{post-test score} - \text{pre-test score}}{\text{maximum score} - \text{pre-test score}} \qquad (1)$$

Next, the results of the N-gain calculation are interpreted [34] using the following categories (Table 4).

Table 4. N-gain Categories

Range	Category
N-gain < 0,25	Low
0,25 ≤ N-gain ≤ 0,45	Lower medium
0,45 ≤ N-gain ≤ 0,65	Upper medium
N-gain ≥ 0,65	High

The strength of the difference in mean scores in the sample so that the learning influence is found to be in the low, medium and high categories. The effect size is calculated using the formula [35] as equation 2.

$$d = \frac{M_A - M_B}{(SD_{pre} + SD_{post})/2} \qquad (2)$$

information: M_A = average pre-test score, M_B = average post-test score, SD = standard deviation

The effect size value is interpreted according to the following categories (Table 5) [34].

Table 5. Effect Size Categories

Range	Category
d > 1,00	Much bigger than the standard
0,51 ≤ d ≤ 1,00	Bigger than standard
0,21 ≤ d ≤ 0,50	Standard
d ≤ 0,20	Smaller than standard

3. Results and Discussion

The application of the STEM-discovery learning model to the topic of kinetic theory of gases amounted to eight meetings with two meetings each for testing and six meetings for learning. Students' mastery of concepts in gas kinetic theory material was obtained from the results of the pre-test and posttest. There is a difference in the results of concept mastery in the pre-test and post-test during STEM-discovery learning based on the paired t-test value [Sig. 0.00 < 0.05]. In this case, there are many reasons why this could happen. One of them is the lack of practice in the material in physics lessons [36] and the lack of student's ability to use appropriate physics concepts to solve physics problems [37]. Based on this, it can be concluded that STEM-discovery learning influences the differences in pretest and posttest results in students' mastery of concepts.

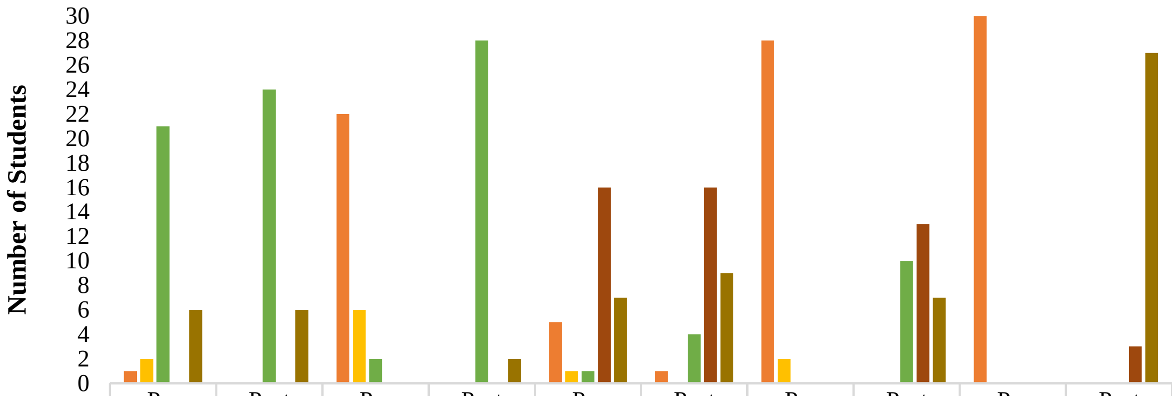
To see an increase in students' mastery of concepts, N-gain was used from the pre-test and post-test results through the STEM-discovery learning model. Based on the calculation results, the N-gain value was obtained at 0.64 in the upper medium category. In addition, it was found that the average score on the post-test was 73.5 while on the pre-test it was 26.6, which indicates an increase in the average understanding of students' concepts in the kinetic theory of gases. Next, the strength of the pre-test and post-test increase was measured using the d-effect size test. The results of the d-effect size test show a Figure 1 in a category that is much larger than the standard value, which indicates that the application of learning using the STEM-discovery learning model has an impact on concept mastery. The number of students at each level of student concept mastery is presented in Figure 1 below.

3.1. Students' Concept Mastery in Number 1

Student's question (1)

Zaldi conducted a fluid experiment which aimed to determine the effective speed of oxygen gas. At room temperature, oxygen gas particles move with an effective speed v. Then Zaldi heated the gas to four times the original temperature. The average speed of the gas after heating is ½ times the initial speed. Is the statement true? If it is correct, explain in detail, but if it is not correct then write down the correction.

During the pre-test, students' answers tended to lead to the level of mastery of SM concepts, and during the post-test, there was an increase in the number of students at the same level (see Figure 1). Often students still face difficulties in understanding the conceptual physics concepts taught to them students [38]. The students' answers showed that the reasons given and the explanations were wrong in concept or did not understand at all, and thought the value '*V*' was volume. Students also use the Boyle-Guy Lussac law equation to work on problems.



	Question Number 1		Question Number 2		Question Number 3		Question Number 4		Question Number 5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
NR	1	0	22	0	5	1	28	0	30	0
NU	2	0	6	0	1	0	2	0	0	0
SM	21	24	2	28	1	4	0	10	0	0
PUSM	0	0	0	0	16	16	0	13	0	3
SU	6	6	0	2	7	9	0	7	0	27

Level of Students' Concept Mastery

Figure 1. Students' Concept Mastery Levels

SM so conceptually but scientifically the reasons given are incorrect/there are misconceptions. One example is writing symbols, where students write 'V22' which should be V_2^2 and then write 'V12' which should be V_1^2. This is possible because students work without knowing what they are writing. Furthermore, there was an increase in concept mastery, although very little at the SU level, so students' answers correctly contained all parts of the concept scientifically according to what was asked in the question, considering that the question was a type of evaluation question that required improvement in working coherently and correctly. Discovery learning requires students to master concepts based on their experiences [28]. Students who make observations during learning will have the correct answers.

3.2. Students' Concept Mastery in Number 2

Student's question (2)

A piston in a motorcycle engine contains one mole of ideal gas. The piston is seated tightly so that no gas escapes and friction between the piston and the cylinder wall is negligible. The piston is quickly pressed inward so that the gas volume immediately decreases. What is the internal energy and temperature of the gas in the piston?

Students' answers in the pre-test lead to NR and in the post-test, there was a significant change, namely in the SM category, which means that the majority of students experienced misconceptions. The students' answers, both pre-test and post-test, showed that *"it is true that kinetic energy increases as the volume rises"* even though it is clear from the question that *"the piston is quickly pressed inward so that the volume of the gas immediately decreases"*.

3.3. Students' Concept Mastery in Number 3

Student's question (3)

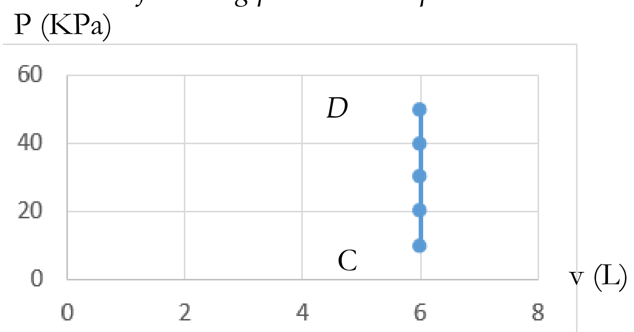
A number of ideal gases undergo a process (constant temperature), so that the pressure becomes 2 times the original pressure, so the volume (X) becomes...

Most of the students' answers on the pre-test led to PUSM and SU on the post-test there was no significant change. There was a shift in the level of mastery of concepts from 5 in the pre-test including the NU category in the post-test to only 1 student. Meanwhile, the SU category on the pre-test, there were originally 7 to 9 students'. The changes are supported by activities at the verification stage integrated STEM. Students in groups identify the relationship between the Ideal Gas equation of state and the problems in the apperception given at the beginning of the lesson (the phenomenon that motorbike tires deflate more easily if filled with oxygen compared to being filled with nitrogen). While student answers are in the SU category where the answers are complete and coherent. For students' answers in the PUSM category, it can be seen from the correct answer, but the meaning of the known components is not clear, it could be that the origin of writing is proven by writing 2P = 2PL. Mistakes made by students related to mathematical notation. From this, it is evident that one of the obstacles to mastering physics concepts is a weak mathematical ability [7], [39].

3.4. Students' Concept Mastery in Number 4

Student's question (4)

Look at the following picture to do question number 4!



If a number of moles of oxygen gas are in a closed tube with a pressure of 10 KPa (state C). Then the gas pressure is increased to 50 KPa (state D) at constant volume. Then the gas pressure is increased to 50 KPa.

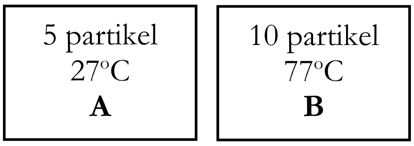
a. Determine the final temperature at state D

b. Determine the ratio of the average kinetic energy of the gas in states C and D

There were many changes in students' answers from the pretest which was originally NR then changed in the post-test leading to SM, PUSM, and SU. Mastery of concepts in the pre-test as many as 28 students' were in the NR category, which means that many students' did not answer. Then in the post-test, there were changes, namely in SM there were 10 students', in PUSM there were 13 students' and in SU 7 students'. This is because of learning activities use discovery at the application stage integrated STEM, students' prepare discussion results related to average kinetic energy, students' and teacher discuss in detail what they have formulated average kinetic energy of gas. Students' are given questions related to other conditions of kinetic energy that use general formulations, and students' are asked to connect the two equations into a new formulation of the average speed of gas. Then in the PUSM answer category where the students' answer is correct, it shows mastery of the concept but there are still some misconceptions, namely examples and it is known that there are none, suddenly the students' answer using a formula. In line with research which shows that students' often have misconceptions about the relationship between molecular attractive forces and the kinetic theory of gases [40].

3.5. Students' Concept Mastery in Number 5

Student's question (5)



The picture illustrates the research carried out by Nia in analyzing the energy in gas. The ratio of the internal energy of the gas in the two containers (A and B) is...

In the pre-test, all students' mastery abilities were still at the NR level, then in the post-test they were seen to shift to SU. A total of 30 students' had a mastery level of the concept of NR, which means that all students did not answer the question. Then in the post-test, the students' concept mastery abilities were at the PUSM level of 2 students and SU of 28 students, which means that the students' answers correctly contained all parts of the concept scientifically after receiving STEM-discovery learning. The use of the discovery learning model itself in the learning process has several advantages, including the concepts and principles learned through independent discovery by students will be more meaningful, and can help students' to strengthen their mastery of concepts [41]. Student answers on the PUSM level post-test is correct, but the method given is not correct/ there is a misconception. The misconception in question is that the calculation answer for the comparison made is inaccurate but the answer is correct.

The results of data analysis show that STEM-discovery learning can improve students' concept mastery, where the post-test is higher than the pre-test and it is proven that there have been many changes in the level of concept mastery. Furthermore, improvements were seen when students' presented work, both the results of discussions and work resulting from projects carried out at home. Success in learning can be measured through students' ability to master learning material and convey back the material they have learned [42]. In line with research which states that through experimental activities in the discovery learning model, students can be trained to learn to discover knowledge independently [43]. STEM implementation is also recommended for Merdeka curriculum students' [44]. There are interesting things seen in the level of students' mastery of concepts before and after learning. Before the treatment, students' had mastered the concepts, but after the treatment there were students' whose mastery of the concepts decreased and even had misconceptions. This could be because students' during the pre-test did not necessarily master the concept, but students only answered by guessing and coincidentally the student's answer was correct. Good mastery of concepts will ensure that what is learned is stored in memory well [45], but there are factors that memory power can decrease if it is not studied repeatedly. This finding is in line with research showing that information initially stored in long-term memory can move to short-term memory, causing forgetting [46].

4. Conclusion

The application of learning gas kinetic theory material through the STEM-discovery learning model influences students' concept mastery results. This is proven by the fact that there are differences in the results of the pre-test and post-test concept mastery. There was an increase in the average score of students' mastery of concepts in the kinetic theory of gases with an N-gain value of 0.61 which was in the upper medium category and the effect size test showed a figure of 4.19 in a category that was much greater than the standard value.

This research has implications for strengthening previous research regarding the use of the STEM-discovery learning model in learning to improve students' abilities, especially mastery of physics concepts. However, in practice, it is still necessary to review or study repeatedly so that the correct concepts are stored in students' long-term memory.

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