Recitation program to improve students’ conceptual understanding of Thermodynamics

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Abstract. The purpose of this research was to analyze the improvement of students' mastery of thermodynamics concepts after they learn three packages of recitation program that cover state equation of ideal gas, The First Law of Thermodynamic, and The Second Law of Thermodynamic. The subjects consisted of 21 undergraduate students enrolling in the fundamental physics course. The results showed that the recitation program improved students’ conceptual understanding of thermodynamic with the d-effect size of 2.51 and N-gain of 0.365. The program effectively helps the students in constructing P-V diagrams and understanding the relationship between the average particle's kinetic energy and temperature of the gas. However, some contents need to be improved to help the students more fluent in determining total work and heat involved in any cyclic process.

1. Introduction
Mastery of fundamental concepts is the main focus of physics education. An indicator that a student has already mastered a concept is he/she able to apply the concept in various types of problems [1]. However, researches show that most students have difficulty to apply some concept to solve problems [1, 2]. One fundamental concept that is difficult for students is the thermodynamic concept [3].

Several studies have identified student difficulties in mastering thermodynamic concepts. Monteyne et al [4] reported that some students find it difficult to apply the gas state equation if there are three variable changes. Incorrect understanding when identifying pressures in containers that have different temperatures [5], identifying isobaric phenomena [6] and identifying temperatures in the adiabatic compression process are still experienced by students [7]. Students also have not mastered the concepts of work, heat and internal energy presented by PV diagrams [8]. Difficulties in mastering the Second Law of Thermodynamics, especially about the engines, are also often experienced by students. Some students find it difficult to use the Second Law of Thermodynamics to identify engines that can work based on the engines' diagram presented [9]. Besides, students still need to practice to manipulate mathematical equations about heat efficiency and refrigerator engines [10].

One of the ways to improve students' understanding is to provide better learning. The learning must provide some opportunity to construct the concepts broadly and intact because each student has a different speed to understand the concepts. Previous studies have developed various ways to improve students' concepts by using some learning strategies [11, 12, 13] Also, several studies developed some
learning that can be done outside of lecture hours [3, 14]. The learning outside of the lecture hours can be done by giving some exercises. So, the previous researchers have developed some exercises about thermodynamic concepts. Erceg et al [7] develop some questions that related to the microscopic gas model or the kinetic gas theory. Sujito et al [15] developed Socratic Dialog Media, including temperature and heat. [3] also developed the question of the First Law of Thermodynamic. Cochran and Heron [9] developed a matter of the Second Law of Thermodynamics about identifying 3 machine diagrams (heat engines, refrigerator engines, and strange devices) that can be realized.

Exercises can improve students’ understanding. The exercises must immediately provide feedback so it will be more effective. Feedbacks were used to help the student knows whether his/her answer is correct or not. It also is used to guide students to correct their concepts. Several studies have provided feedback on their development instrument of kinematic problems [16] and magnetism problems [17]. However, there has been no development of thermodynamic problems with feedback.

University in America always gave some exercises and the feedback outside of the lecture hour. They provide a deepening of topics in the form of additional lectures which are often called recitation [2]. Their recitation is often accompanied by a teaching assistant. Whereas in Indonesia there were not teaching assistants to give some additional lectures.

Technology can help lecturers in Indonesia to give recitation more efficiently because it can provide immediate feedback. Previous studies also used computer technology so that students immediately get feedback on their answers [18, 16, 15, 17]. Giving recitation by utilizing technology is suitable to be applied to thermodynamic because of the broad and complex scope of the topic. The focus of this study is to checked whether the recitation program can improve students’ conceptual understanding or not. There were three sub-topics in the recitation program. There were gas state equations, the First Law of Thermodynamics, and the Second Law of Thermodynamic.

2. Methods
This study uses a quantitative approach to see whether recitation programs can improve students' conceptual understanding. The recitation program in this study was a group of conceptual problems about thermodynamics with different feedback in every choice. The sequence of this study was pre-test, intervention (the usage of recitation program), and post-test. The intervention was conducted for 2 weeks with 3 meetings which take 90 minutes each. Subtopic for every meeting was different. In the first meeting, students learned about gas state equations, thermodynamic processes, and average kinetic energy of particles. In the second meeting, students learned about work, heat and internal energy in thermodynamic processes. In the third meeting, students learned about the heat engines and refrigerator engines’ principle. The sum of the problems was 30 problems.

Quantitative data was obtained from pre-test and post-test scores. Then, we tested the normality and paired sample t-tested to finding d-effect size [19]. Besides, we would discuss students’ understanding of thermodynamics before and after the intervention. The subject of this study consisted of 21 undergraduate students of Physics Education at the State University of Malang who had just finished discussing thermodynamic concepts in the Second of Fundamental Physics Course.

The instrument was 17 multiple choice problems. This instrument had the same scope of the topic as the coverage of the recitation program topic. The pre-test instrument was the same as a post-test instrument. This instrument has also been tested for reliability with the Cronbach Alpha coefficient of 0.68.

3. Results and Discussion
The results of the normality test show that the pre-test and post-test are normally distributed because the skewness value is between -1 and 1 [20]. The results of the paired sample t-test showed that there were significant differences in the average score between the pre-test and post-test ($t(20) = 9.4$, $p = 0.000$, $d = 2.51$). It meant the recitation program could improve students' conceptual understanding of thermodynamic concepts. In addition, the improvement could be seen from the N-gain. The N-gain value
is 3.65. This value indicated the improvement in the lower medium category. Even though it was in the lower medium category but overall there was an improvement of students’ conceptual understanding.

Out of the 17 problems were tested, two problems experienced significant increases to answer the correct choices (questions number 2 and 7) and there was one question that none of the students answered correctly (question number 13).

3.1 The Strenght of Recitation Program

Item number 2 shows that students already understand about the isobaric process based on phenomena and constructing $PV$ diagrams based on phenomena (Figure 1). The correct answer has increased from 1 to 14. The purpose of this problem was to construct a $PV$ diagram based on phenomena. The phenomenon of balloon deflating was due to a decreasing temperature which causes the volume to decrease. While the pressure in the balloon when the balloon deflates was still the same as the atmospheric pressure. So the diagram could be described as an isobaric diagram. With directions from A to B (the decreasing of volume and temperature) (d).

A bottle with a balloon has a condition that show in the picture. If the variation of balloon’ surface tension can be ignored then the $PV$ diagram that fits the process of volume deflating is …. 

![Figure 1. Problem number 2](image)

The pre-test results showed that only one student answered correctly. While the other students did not answer correctly. There were 10 students chose the answer b for various reasons. The first reason was to consider this phenomenon as an isothermal process even though the problem had been implicitly explained the temperature would decrease. The second reason was when in state B the volume decreases so that the pressure would increase $P \approx \frac{V}{V}$. The third reason was to assume that the process occurs as a process of constant volume so that the variables that change are only P and T. From those reasons, we concluded that students have not fully understood the gas state equation. Nine students choose answer c with unclear reason. There was a student who did not answer question number 2.
### Table 1. Cross-tabulation of problem number 2.

|       | Post-test | Total |
|-------|-----------|-------|
|       | a  b  c  d |       |
| Pre-test |         |       |
| b      | 0  3  0  7 | 10    |
| c      | 1  0  1  7 |  9    |
| d      | 0  0  1  0 |  1    |
| -      | 0  1  0  0 |  1    |
| Total  | 1  4  2 14 | 21    |

*a correct answer

The post-test result showed that 14 students answered correctly for various reasons. Two students understood if the process that occurs is the isobaric process. However, 12 students had not realized that the process was the isobaric process.

R : Why did you choose d?
S1 : The temperature of the system was decreasing. So, the volume would be decreased.
R : Okay. And then?
S1 : I analyze the diagram’s choices. The initial and final temperature diagrams a, b and c are equal. While the final temperature diagram d is less than the initial temperature.
R : From the problem, did you realize if the process is the isobaric process?
S1 : No. I chose d because it is the only choice with decreasing temperature.

Based on the interview, students could analyze the $PV$ diagram very well. However, they have not realized that the process was the isobaric process. Whereas, the problem has been stated that we could ignore the balloon surface tension (the air pressure in the balloon was always the same as the air pressure outside the balloon). Nevertheless, the students have been proficient in analyzing diagrams using gas state equations to find temperatures. They knew that the temperature of the initial state was greater than the temperature of the final state (d). There was a student who chose answer (a) with reason $P_1 > P_2$ and $V_1 > V_2$. There were 4 students chose answer b. They thought the pressure in state A greater than state B and the volume in state B greater than state A. From those statements we knew that students did not understand if the volume of the balloon will shrink. Two students chose to answer c. They thought the process was an isothermal process.

There were two reasons for the increase in the correct answer. First, students had understood how to read and analyze $PV$ diagrams. Second, they also had already used the ideal gas state equation ($PV = nRT$) to identify the $PV$ diagrams. There were 7 problems that they learned in the recitation program. Problem number 1.2 - 1.5 trains students to identify T-V diagrams in isochoric, isothermal, isobaric and unfamiliar processes by using $PV = nRT$. Problem number 1.6 - 1.8 trained students to identify temperatures in four conditions in unfamiliar processes represented by the P-V diagram. Also, all feedbacks were used to train students to use $PV = nRT$ for diagram identification. According to records during the intervention, students faced some difficulty. It was analyzing the diagram, especially the $TV$ diagrams and unfamiliar processes. Students were often fooled when answering problems number 1.6 - 1.8. It also happened in previous research [21]. Whereas those problems use the same diagram and ask the same thing, the only difference was the representation. Those problems were designed to make students always careful in analyzing diagrams. As a consequence, they became experts in analyzing diagrams by using $PV = nRT$. 

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Item number 7 (Figure 2) had a large increase of correct answer. This shows that students understood the concept after the intervention.

Two containers A and B are filled with helium gas. The number of gas particles in container A is double compare to container B and the volume of container B is doubled compare to container A. The temperature of the two containers is the same as the environment temperature. The average kinetic energy of gas particles \( (E_K) \) in containers A and B is...

- a. \( E_{K_A} = E_{K_B} \) because of the temperature of containers A and B are the same
- b. \( E_{K_A} = E_{K_B} \) because of the volume of the container is equal
- c. \( E_{K_A} > E_{K_B} \) because of the number of particles A greater than the number of particles B
- d. \( E_{K_A} < E_{K_B} \) because it is tighter so that the average distance between particles is shorter

**Figure 2.** Problem number 7.

Students need to understand the relationship between temperature and \( E_K \). Based on the equation, the temperature is the macroscopic representation of \( E_K \). So the number of gas particles and container volume does not affect \( E_K \) (a). At the pre-test, three students chose answers a. But at the pre-test, ten students chose answer c because they did not understand the difference between the average kinetic energy of gas particles \( (E_K = -k_B T) \) and the internal energy of gas \( (E_{int} = -\frac{3}{2}Nk_B T) \). So they think that the number of gas particles affects \( E_K \). Besides, three students were mistaken between \( E_K \) and Boltzman's constant \( (k_B) \) \( (PV = Nk_B T) \). Three students who choose the answer d have a reason. If the gas particles are denser then it will affect \( E_K \). Some of them have miscalculated \( E_{K_A} \) and \( E_{K_B} \).

|         | Post-test | Total |
|---------|-----------|-------|
|         | a \(^a\) | c | d |       |
| Pre-test| 3 | 0 | 0 | 3       |
|         | 1 | 0 | 0 | 1       |
|         | 9 | 3 | 1 | 13      |
|         | 3 | 0 | 0 | 3       |
|         | 1 | 0 | 0 | 1       |
| Total   | 17 | 3 | 1 | 21      |

\(^a\) correct answer

The post-test results showed that 17 students chose the answer because of \( E_K \) depending on temperature. There is even one student who explains that \( E_K \) influenced by temperature not the number of particles. Three students chose to answer b without writing down any reason. One student chooses the answer d \( E_K = \sqrt{\frac{1}{2}mv^2} \). Based on these reasons, it can be seen that he still does not understand if \( E_K = \sqrt{\frac{1}{2}mv^2} \) it is used in particle objects (solid objects). The increase in the number of students who answered correctly was due to the use of the first package of recitation program. Students learned about the relation of average kinetic energy with temperature in a different context.

The number of correct answers was raised from 3 to 17. It due to the recitation program provides appropriate problems and feedbacks. The problem is problem number 1.12. Students were trained to identify the relationship between temperature and the average kinetic energy of particles. In addition, the recitation program provided feedback to guide students to recognize the differences between \( E_K \) and \( E_{int} \). While students who are still wrong to answer question number 7 still have the same thoughts with previous research [7].

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3.2 The Weakness of Recitation Program

Item number 13 (Figure 3) shows the difficulties to analyze cyclic processes. No one answered it correctly either at the pre-test or post-test. This problem aims to determine the total of work and heat in the cyclic process.

The $PV$ diagram shows the gas pressure and volume values, starting at state A, continuing to states B, C, and D and returning to state A. The correct statement in one cycle $A \rightarrow B \rightarrow C \rightarrow D \rightarrow A$ is....

a. the magnitude of the work total is zero because the initial and final state of the system are same
b. the total heat transferred to the system is zero because the initial and final state of the system are same
c. as a whole, the work is done on the environment
d. as a whole, the heat release to the environment

![Figure 3. Problem number 13.](image)

To solve problems number 13, we must understand about work and heat concept. Work and heat are process function. Work is a process of energy exchange through mechanical interactions while heat is a process of energy exchange through thermal interactions. The way to find out heat total is to know the work total in the cyclic process. Process $A \rightarrow B \rightarrow C \rightarrow D \rightarrow A$ shows the work done on the system. When the gas is compressed, the heat in the system will come out. So that overall gas releases the heat to the environment (d).

At the pre-test, there were ten students chose answers a. The reason is the initial and final state is the same so the work total is zero. Meanwhile, five students choose the answer b because $Q_{DA}$ has negative value, $Q_{AB}$ has a positive value, $Q_{BC}$ has a positive value, and $Q_{CD}$ has a positive value. There were three students chose the answer c with unclear reason. And, there were three students who did not answer the problem.

### Table 3. Cross-tabulation of problem number 13

|       | Post-test | Total |
|-------|-----------|-------|
|       | a  | b  | c  | d* |       |
| Pre-test | A  | 4  | 0  | 6  | 0     | 10   |
|         | B  | 2  | 1  | 2  | 0     | 5    |
|         | C  | 2  | 0  | 1  | 0     | 3    |
|         | d*| 0  | 0  | 0  | 0     | 0    |
|         | -  | 1  | 1  | 1  | 0     | 3    |
| Total   | 9  | 2  | 10 | 0  | 21    |

* correct answer

The post-test results show that no one has chosen the correct answer (d). There were nine students who chose answers a. Some students still have an understanding that if the work total is zero because it returns to its original state.

R : What is the work total in the cyclic process?
S2 : The work total is zero
R : Why?
S2 : Because the initial and final conditions are the same, so the work total is zero
R : Did you calculate the area under the $DA$ and $BC$ path?
S2 : No
There were two students answer b. They thought heat as a state function. So, the total heat which transferred in the system was zero. Ten students chose to answer c. They thought the work done on the system and the heat enters the system. But, they were not writing the work and heat in each process. However, ten students have understood that in the cyclic process the change in internal energy is zero. In addition, students also know that work can be calculated from the area below the path.

R : Why the work total of the cyclic process is zero?
S3 : Because the area under the path DA is greater than the area under the path BC so that the work total cannot be zero
R : Overall gas does mechanical work into the environment or does gas receive mechanical work from the environment?
S3 : Maybe gas does mechanical work into the environment
R : Are you sure?
S3 : Yes, because of the answer in recitation program similar to these problems states
R : How about the previous recitation problem? Didn't the previous question guide you to understand the work done on the system or work done on the environment?
S3 : Yes it's already there, but I still confused about it

Almost all students chose answers a and c. Students who choose to answer a thought work as a state function. Even though, the recitation program already trained students to determine the work and heat in cyclic processes (questions number 2.6 and 3.1). Students' thought about work and heat similar to the previous research [22] [23]. The reason for the answers given by students who answer c is more or less the same as the feedback in the recitation program. It indicated that students still not understand about work and heat concepts. To answer this problem, students must understand the concept of work done on system or environment and heat entering the system or heat out of the system first. While answering question number 13 in pre-test and post-test, there were no students who used work and heat concept correctly. So when we gave a problem with the opposite process directly with the exercises, they still consider the process presented in the pre-test-post-test as the same as the problem in recitation program.

4. Conclusion
Three packages of conceptual problems along with the feedbacks (recitation program) could improve students' conceptual understanding in thermodynamics. This is evidenced by the results of d-effect size of 2.51 and N-gain of 0.365. However, students still need to improve their understanding because there were problems that they cannot answer correctly and there were some concepts that they did not fully understand yet. So, we suggest in future research to adding some problems with analyzing phenomena which need thermodynamics process, analyzing work total and heat total in various processes which represented by PV diagrams.

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