Identifying students’ difficulty in the basic of thermodynamics

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Abstract. Conceptual understanding is one of the main topics in physics educational research. It is important as the basic of other ability in education, such as argumentation, making scientific explanation and problem solving. This survey study aims to identify students’ difficulty to understand the basic of thermodynamics. There are 128 first year undergraduate students as the participants of the study. The data collection method is test. Result of the study shows that isobaric process of ideal gas and mechanical equilibrium state concept are the most difficult concepts. Some difficulties are found in understanding the basic of thermodynamics: (1) because of the presence of higher cognitive load while solving conceptual problems, (2) when the question demands other ability, especially mathematical ability, to solve the conceptual problem, (3) because of students’ disability to integrate the knowledge. This study could be used to develop learning instruction or media in basic physics or introduction of thermodynamics course.

1. Introduction
Students’ conceptual understanding is one of the important topics in physics educational research. It is one of the main goals in physics learning. Understanding the concepts is important as the basic of other ability in learning, such as argumentation [1], making scientific explanation [2], and problem solving [3]. Describing students’ understanding in physics is important to identify their difficulty then design learning to overcome it.

Some standardized tests have been developed to identify students’ conceptual understanding and reveal students’ difficulty, such as TCS [4], STPFaSL [5], TCE [6], and HTCE [7]. Many of them are designed in daily live context. Many studies used those instruments to describe students’ conceptual understanding.

Thermodynamics is one of physics branch deals with heat, work, temperature, and energy. Students’ understanding in this physics branch has been identified. Some of them focus on heat and temperature concepts and some other are on thermodynamics law [8][9][10][11]. Some of them reveal students’ difficulty and some others reveal students’ disability to think as the way of scientists think about the concepts (students were confused between their naïve understanding and scientific concept). Most students were in low level of conceptual understanding in thermodynamics, although they have been studied thermodynamics since their primary school [12]. They were low in some concepts such as relation between energy and enthalpy reactions, heat and temperature [9][11], first law of thermodynamics [13], and mechanical equilibrium principle [8]. The study about students’ conceptual understanding continues, students’ difficulty in understanding the concepts have been identified, and many interventions have been implemented to overcome many obstacles in education [3][14][15]. However, the data show that study to identify students’ difficulty is still needed, because students’ understanding differs based on their background and experience [16], especially during COVID-19 pandemic.
During COVID-19 pandemic, students face different learning atmosphere experience. This study held to identify students’ difficulty in understanding the basic of thermodynamics concepts, especially during COVID-19 pandemic. The result of this study could be the base to design learning effectively or develop media to learn about the basic of thermodynamics.

2. Method
This was a survey study. There were 128 undergraduate science education students of first year as the participants of the study. The students have not studied the basic of thermodynamics in basic physics or thermodynamics course. Students have to answer questions in the survey study at the beginning of the course, before learning about the basic of thermodynamics. As undergraduate students, they have learned the basic of thermodynamics in high school.

Due to COVID-19 Pandemic, this study held online. The questions were presented in google form platform. The answer acceptance was limited based on the set time. There were 12 questions in bahasa (Indonesian language) as a test instrument. The instrument consisted of 3 topics is presented in Table 1. Eleven questions were taken from TCS [4], while 1 question was arranged to compare with one of the topics in the study. The instrument was statistically valid and reliable, with the number of reliabilities 0.69, analyzed using KR 20. The results of the test are analyzed descriptively.

Table 1. Categories of Questions

| Topic of Questions                      | Sub-topic of Questions            | Question Number in TCS | Question Number in study instrument |
|----------------------------------------|-----------------------------------|------------------------|-------------------------------------|
| Heat and temperature                   | Thermal equilibrium               | 1 and 7                | Q, Q6, Q5                           |
|                                        | Heat transfer                     | 5 and 6                | Q2, Q3                             |
| Isobaric process of ideal gas          | Isobaric process of ideal gas     | 9, 12, and 13          | Q, Q2, Q8                          |
| Adiabatic                              | Adiabatic                         | 14, 15, 16, and 17    | Q9, Q10, Q11, Q12                  |

3. Results and Discussion
Students’ correct answer percentage are presented in Figure 1. Figure 1 shows that the most difficult topic is isobaric process of ideal gas, among topics asked in survey study. Only 29.69% of students answered the question in isobaric process of ideal gas correctly. Students’ answer distributions are presented in Table 2, 3, and 4.

Table 1. Percentage of students’ correct answer in every topics

| Topic                  | Percentage (%) |
|------------------------|----------------|
| Thermal equilibrium    | 42.45          |
| Heat transfer          | 70.70          |
| Isobaric Process       | 29.69          |
| Adiabatic Process      | 42.77          |

Figure 1. Percentage of students’ correct answer in every topics

Thermal equilibrium topic was asked in the first, fourth, and fifth questions. Most students answer correctly in the fourth question, but less in the first and fifth questions. In the first question, the students were asked about the range of final temperature; in the fourth question, the students were
asked to compare the heat transfer of the different volume objects; and in the fifth question, the students were asked about the exact number of final temperatures in thermal equilibrium state.

In the first and fifth questions, students needed mathematical ability to answer those two questions. Students answer distribution is presented in Table 2. The number of students’ correct answer in both questions are similar, 46 and 48, although the first question asked only about the range of final temperature, in contrast to the first question that asked the students to state the exact number of final temperatures. Due to the low number of students’ correct answer, it indicates that students were getting trouble in the questions asking about the final temperature in thermal equilibrium state, needed mathematical ability to solve it.

Students were asked about the same topic (rate of heat transfer between objects with different material) in the second and third questions, but the number of students answered correctly is quite different. 113 students answered correctly in the second question, but only 68 students in the third question, as presented in Table 2. The second and third questions are presented in Figure 2.

Figure 2. The second and third questions [4]

Table 2. Students’ answer distribution of Thermal equilibrium and Heat transfer topics

| Choice | Q₁ | Q₂ | Q₃ | Q₄ | Q₅ |
|--------|----|----|----|----|----|
| A      | 25 | 11 | 68 | 19 | 48 |
| B      | 20 | 7  | 69 | 23 |    |
| C      | 46 | 3  | 47 | 40 | 32 |
| D      | 33 | 113| 6  | -  | 25 |
| E      | 4  |    |    |    | -  |

The correct answer

The fourth and fifth questions asked about heat transfer of objects with different materials. In the fourth question, students were asked to compare the rate of heat transfer between plastics and metal, while in the fifth question, between wood and metal. There were 113 students answer correctly in the fourth question, but only 68 students answer the fifth question correctly, as presented in Table 2. In the fifth question, most students choose C option as the answer. They chose the answer, failed in identification of heat transfer in metal. Choosing that option indicates that students don’t have a good
knowledge about heat transfer process. The fifth question is more complex than the fourth question, because the students need to have more and better knowledge to answer it.

The sixth, seventh, and eighth questions asked about isobaric process of ideal gas, as shown in Figure 3. Most students answer correctly in the sixth but less in the eighth question, as presented in Table 3. The sixth question asked about the change of ideal gas temperature in a syringe covered by frictionless movable piston with mass M. The syringe is moved from the vessel with cold water to the vessel with hot water.

**Table 3.** Students’ answer distribution of isobaric process of ideal gas

| Choice | Q6 | Q7 | Q8 |
|--------|----|----|----|
| A      | 68 | 49 | 39 |
| B      | 43 | 51 | 71 |
| C      | 17 | 28 | 18 |

The seventh and eighth questions show three identical cylinders contain ideal gas. All of them are covered with frictionless movable piston with mass M. Cylinder A and B are in thermal equilibrium with 20°C of room temperature, while cylinder C is kept to have 80°C of temperature. All pistons are in mechanical equilibrium with the environment. The seventh question asked about the pressure of cylinder A compare to cylinder B, while the eighth question comparing B and C. The sixth, seventh, and eighth question are presented in Figure 3.

**Figure 3.** The sixth, seventh, and eighth questions [4]

In both questions (the seventh and eighth questions) only a little number of students answer the questions correctly. The students couldn’t think that the frictionless identical piston covering the cylinder can move freely due to the volume expansion of gas, to keep the gas in cylinder to have the same pressure (isobaric).
The case mentioned indicates that most students also fail to recall the concept of mechanical equilibrium state to answer those two questions. The pressure of ideal gas in cylinder is controlled by the pressure of environment outside the cylinder [17]. Instead of using this concept, students preferred to recall the concept ‘higher temperature increase the pressure of ideal gas in cylinder’ (based on 71 students choose ‘smaller’ when they were asked the gas pressure in cylinder B compare to cylinder C). This finding is also found in the previous study, that most students were getting trouble answering the question that involve mechanical equilibrium state and isobaric concept [8].

Mechanical equilibrium is a concept learned in the previous course. Students have studied this concept in basic physics course I. Students’ disability to recall this concept while answering conceptual question about isobaric process of ideal gas indicates their disability to integrate one concept to another concept in physics, such as finding in previous study of momentum concept [18]. Their conceptual understanding was fragmented. When they learned about isobaric process of ideal gas, they left their understanding in a previous course. It happened because they think physics as fragmented, not as one body knowledge.

Due to the characteristics of those three questions, the seventh and eighth questions are more complex than the sixth question. These two questions also become the questions with smallest number of correct answers in this study. It shows that isobaric topic is the most difficult topics among thermal equilibrium, heat and transfer, isobaric, and adiabatic topics. Students’ ability to answer the question degrade while solving the more complex question. It happened due to the presence of higher cognitive load [19]. This is the same as the finding in the second and third questions, when students fail to answer the question correctly due to the complexity of the question (more knowledge was needed to find the right answer).

The ninth, tenth and eleventh questions asked about the temperature (Q9), pressure (Q10), and volume (Q11) change of ideal gas in isolation state when some objects are placed on the piston covering the syringe of this ideal gas, in Figure 4. The twelveth question asked about the change of 1 mole ideal gas temperature when the gas pushed with frictionless piston. Most students answer correctly in those three questions (the ninth, tenth and eleventh questions), as presented in Table 4.

The largest number of students answer correctly in the tenth question. The students could predict that the temperature and pressure are going to be higher when some objects are placed on the frictionless piston. Some of them, as the second largest number of students answer correctly in this topic, predict correctly that the volume is going to decrease when some objects are placed on the frictionless piston.

![Figure 4](image.png)

**Figure 4.** The Figure in the eighth-eleventh (left) and twelfth (right) questions [4]

| Choice | Q9 | Q10 | Q11 | Q12 |
|--------|----|-----|-----|-----|
| A      | 46 | 66  | 29  | 61  |
| B      | 37 | 30  | 46  | 38  |
| C      | 45 | 32  | 53  | 29  |

Table 4. Students’ answer distribution of adiabatic topic

The correct answer
4. Conclusions

Based on the result of this study, Isobaric of ideal gas is the most difficult topics among heat and temperature, isobaric process of ideal gas, and adiabatic process of ideal gas topics. The students’ fail in recalling frictionless movable piston concept while answering the questions. This fail refers to the presence of higher cognitive load, in more complex question, such as more variables involve in a question that need to be solved. The students also fail in answering question correctly while it need mathematical ability to solve it. The result of this study also reveals students’ disability to integrate one concept to another concepts. It indicates that students see physics as fragmented knowledge, not as one body knowledge.

The study was limited to identify students’ difficulty in basic of thermodynamics. It didn’t explain why students experienced this difficulty, especially during this COVID-19 pandemic. This result of study should be used to develop learning instruction or media in thermodynamics, to overcome students’ difficulties in thermodynamics.

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