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INVESTIGATION OF STUDENTS' SCIENTIFIC CONSISTENCY AND LEARNING DIFFICULTIES IN THE FIRST LAW OF THERMODYNAMICS

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ABSTRACT

As part of ongoing research to develop an appropriate instructional method for teaching thermodynamics in introductory course, we have investigated the scientific consistency and learning difficulties of students enrolled in advanced course. This work focused on the concept of the first law of thermodynamics and its applications in the thermal processes. Regardless of the amount and details of prior instruction, a representational conceptual evaluation in the first law of thermodynamics (RCE-T) was given to 67 second-year students enrolled in thermodynamics course at the end of semester. RCE-T items were designed as an isomorphic multiple-choice test with three different representations which covered 10 themes. The findings show that none of students answered scientifically consistently and learning difficulties encountered by students are consistent with those reported in the previous research. Many students were unable to apply the concept of the first law of thermodynamics in various thermal processes. Through this investigation we may provide useful information to develop appropriate methods which overcome the pedagogical issues in learning the first law of thermodynamics at introductory course and advanced course.

Keywords: physics education research, scientific consistency, learning difficulties, the first law of thermodynamics

INTRODUCTION

Previous research has reported that students in introductory physics course experiencing significant difficulties in the fundamental concepts of thermodynamics, such as the first law of thermodynamics (Meltzer, 2004; Loverude et al. 2002). But unfortunately, the current research related to students learning of thermodynamics to overcome the difficulties faced by students, there are still few in number (Leinonen et al., 2013; Leinonen et al., 2012; Meltzer, 2004; Loverude, 1999). This makes the study of students learning of thermodynamics should be the focus of physics education research that require intensive attention.

Related to the efforts to design appropriate learning of thermodynamics, it seems multiple representations have great potential and benefit for the learning of thermodynamics (Meltzer, 2004). The use of multiple representations help students to practice in creating, interpreting and manipulating various representations, such as *P*-*V* diagram of the various thermodynamic process. Learning by utilizing multiple representations also should be supported with students' ability to use multiple representations in order to obtain the maximum learning (Meltzer, 2005). It means that students' ability in using multiple representations is important to be known before designing a learning. Unfortunately, in some previous studies, researchers reported only about conceptual difficulties faced by students, but did not provide a systematic evaluation of students' ability to use multiple representations in learning of thermodynamics. This has led us to further investigate students' ability in using multiple representations in learning and simultaneously get more in-depth information about the conceptual difficulties faced by students from different populations with previous research.

Students' representational ability which are considered in this study refers to students' ability to use different representations consistently and correct scientifically in solving isomorphics items with the context and content as similar as possible (Nieminen *et al*., 2010). Students' scientific consistency is important to be investigated because different representational formats can lead to different responses from a given students, even if the underlying physics is identical (Steinberg and Sabella, 1997) and also affect students' performance in solving problems (Meltzer, 2005).

In addition, students' scientific consistency will provide more in-depth information about the student's understanding and conceptual difficulties encountered by students in the fundamental concepts of thermodynamics because a good indicator of understanding of the concept is characterized by the ability to recognize and manipulate the concepts in various representations (Hestenes, 1997). Therefore, this study was conducted to describe students' scientific consistency and conceptual difficulties encountered by students in the first law of thermodynamics and its application in various thermodynamic processes.

The information presented in this paper is expected to be an evaluation in the learning of thermodynamics dan simultaneously as a reference to develop an appropriate instructional methods and curricular materials in learning of thermodynamics at the university level.

METHODS

Participant of this descriptive study was 67 second-year students 2015 who enrolled thermodynamics course in advanced course at Indonesia University of Education, Bandung. Data were documented by using a Representational Conceptual Evaluation in The First Law of Thermodynamics (RCE-T) that was given at the end of the semester, after students get all the learning of thermodynamics. RCE-T is a instrument test that was designed in the form of isomorphic test, which the context and concept are identical, but it was presented in different representations. RCE-T items was adapted from previous physics education research findings (Meltzer, 2004; Loverude et al., 2002; Rozier and Viennot, 1991) and designed to follow the instrument developed by Nieminen et al. (2010) and Meltzer (2005).

RCE-T consists of 30 items divided into ten themes, i.e. system internal energy (T1), work as a process-dependent function (T2), internal energy as a state function (T3), heat as a process-dependent function (T4), adiabatic compression (T5), adiabatic free-expansion (T6), isochoric process (T7), isothermal process (T8), cyclic process (T9), and specific heats of gases (T10). Each theme was presented in three items with different representations (verbal, diagram/pictorial and mathematics). The issue of the construction of tests, the validity and reliability of RCE-T has been presented in the previous paper (Sriyansyah and Suhandi, 2015). Here we provide a sample of the alternatives for theme 3 with three representations that used in Fig.1.

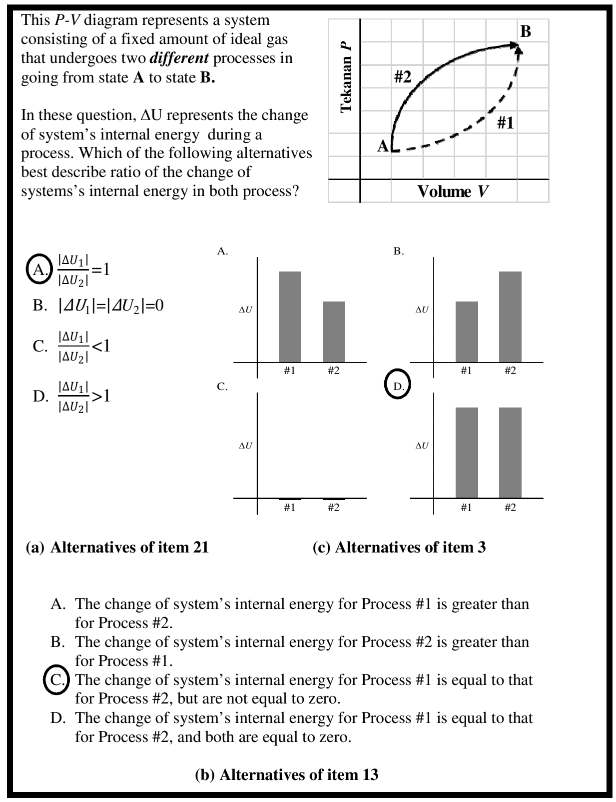

Figure 1. Sampel of the items and alternatives in theme 3 (T3) using three representations, (a) mathematics, (b) verbal, and (c) diagram representations. Circle sign refers to three corresponding alternatives which consistently and scientifically correct.

Students demonstrated scientific consistency when all the answers in a given theme answered correctly in terms of physics and representations. Data analysis followed the rules defined by Nieminen et al. (2010), as follows: a) two points, when students had chosen corresponding alternatives in all three items of the theme scientifically; b) one point, when students had chosen corresponding alternatives in two of the three items of the theme scientifically; c) zero points, when students had not chosen corresponding alternatives in the items of the theme.

Students' scientific consistency was categorized from the average scores obtained for all themes. The average score will be in the interval of zero to two. Based on the average obtained scores, students' scientific consistency (SC) was divided into three categories, namely consistent (1.7 ≤ SC <2), moderately consistent (SC ≤ 1.2 <1.7) and inconsistent (0 <SC <1.2).

RESULTS AND DISCUSSION

In this section, it will be discussed a description of students' scientific consistency, both in general and for each theme, the effect of representational format used in isomorphic items, and analysis of students' conceptual difficulties.

Students' Scientific Consistency

Generally, the average score of students' scientific consistency is 0.44, included in an inconsistent level. It showed that none of the students were able to answer all given themes scientifically and consistently. However, it did not mean that there was not also students who were able to answer each theme consistently. Here the percentage of students who answered consistently and scientifically (who got two points) on each theme are presented in Fig. 2.

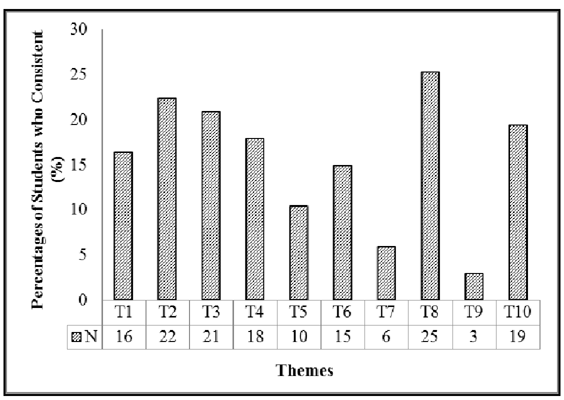

Figure 2. Percentage of students who answered consistently and scientifically on each theme.

Based on Figure 2, note that the percentage of students who were able to answer consistently each theme was varied in intervals of 3% - 25%. This amount was still less than half the samples size. It indicates two things, namely students encountered conceptual difficulties and with the representational format that used in the items. Two themes that showed a low percentage of students respectively from the lowest was theme 9 and theme 7, while the highest percentage of students lies in theme 8. The tendency of this data can also be seen in the average scores obtained in students' scientific consistency on each theme. Here the average score of students' scientific consistency on each theme, is presented in Fig. 3.

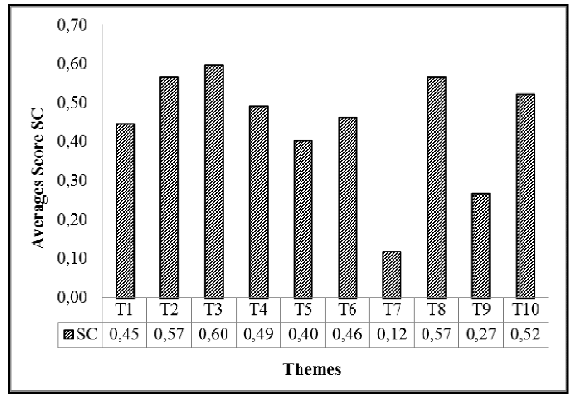

Figure 3. The average score of students' scientific consistency on each theme.

In Fig. 3, shows that the highest average lies in theme 3 about the concept of internal energy as a state function, while the lowest average lies in theme 7 about the concept of isochoric process. When compared with theme 9, it appears that the average scores of scientific consistency for theme 7 was lower than for theme 9. Even though the percentage of students who answered consistently (got two points) for theme 7 was higher than for theme 9, but the percentage of students who were not able to answer consistently (got zero points) for theme 7 (94%) was also greater than for theme 9 (76%). It indicates that the students appear to find it more difficult on the concept of isochoric process (T7) than the concept of cyclic process (T9).

In spite of that, students difficulty on the theme 7 in line with the study reported by Rozier and Viennot (1991), while the difficulty on the theme 9 was also in line with the study reported by Meltzer (2004). Analysis of students' responses will be described more fully in the students' conceptual difficulties section.

Furthermore in Fig. 2, the highest percentage of students who answered consistently lies in theme 8 (25%), but in Fig. 3, the average score of students' scientific consistency for theme 8 precisely at 0.57. It is below the average score of 0.60 which obtained by theme 3 as the highest averages score of scientific consistency among all given themes. Whereas, the percentage of students for theme 3 in Fig. 2 was only 21%. It can be explained because, although 25% of students got two points in theme 8, but many students who got one points only 6%, it was lower than 18% for theme 3. While students who got zero points 69% for theme 8 was higher than 61% for theme 3. It indicates that, overall students found it easier to answer theme 3 than theme 8.

However, generally an average score of students' scientific consistency was still inconsistent. It means that students still have difficulties in all the given themes. It also affirms that the advanced course was not necessarily improve students' understanding of the fundamental concepts of physics which is owned by the students, not even overcome certain conceptual difficulties.

Effect of Representational Format

In this section, it will be described the effect of representational format toward students' performance in each theme. Steinberg and Sabella (1997) states that the difference in the representations used in the problem can trigger different responses of the students, even if the underlying concept is identical. Analysis of the effect of representational format, will provide information about representation formats that is considered become the most difficult and most easily by students. Here the percentage of students who answered correctly in each representation within each theme is presented in Fig. 4.

The effect of representational format toward students' performance on each theme can be seen by looking at the trend of the difference between percentage of students who correctly answered three items isomorphic within each theme. On the theme 7, among the three representations used in this theme, it seems that representation diagram was the most difficult representations felt by student among others. While on the theme of 9, a mathematical representation which becomes most difficult. Then for theme 3, verbal representations was considered as the easiest, while the mathematical representation and the diagram representations showed the percentage of students were almost the same. These indicates that students experiencing difficulties related to the different representation formats used in each theme. However, in general, the average percentage of students who were able to answer correctly to each representation shows that mathematical representation (28%) felt to be more difficult than a diagram (35%) and verbal (33%) representations. It is seen from the average percentage of students who answered correctly in each representation within all given themes.

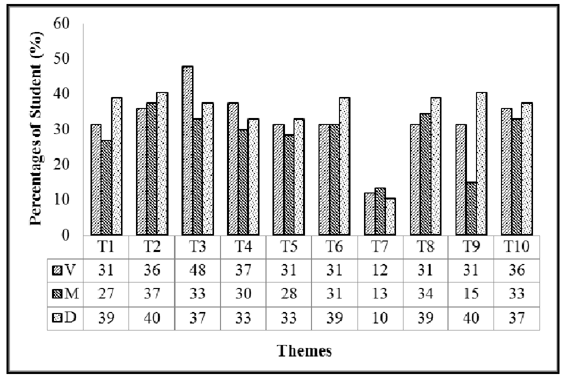

Figure 4. the percentage of students who answered correctly in each representation within each theme.

It is seen contrary to the statement of Lasry et al. (2009) which states that students usually tend to get the learning that is dominated by mathematical representation rather than qualitative representation. Students should find the mathematical representation easier than qualitative representation (verbal or graphs/ diagram). Moreover, the sample of this study are students who enrolled thermodynamics courses which give greater emphasis on calculus. Therefore, the findings of this study indicate that even after getting a dominant learning with mathematical representation, it turns out students still having trouble with mathematical representation in the given problem.

When the McNemar's test was conducted to determine the difference in students' correct response between representations on each theme, there were no significant differences in students' response between representations on each theme, except on the themes 3 and theme 9. The difference was statistically significant for theme 3 is only found between the verbal representation and mathematical representation (p <0.05), whereas on the theme 9, there were also statistically significant differences between verbal representation and mathematical representation (p <0.05) and between mathematical representation and pictorial representation (p <0.05). It shows that on themes 3 and theme 9, students' response was better on verbal representations rather than mathematical representation. Especially for theme 9, students' response was found better in verbal, mathematical, and pictorial item.

However, overall it can be said that there was no statistically significant difference in students' response between representations on each theme. It showed that students have difficulty in all representational formats that used in the items. It also proved that representational format affects students' response and performance.

The fact that students had difficulty at all representations indicates two possibilities, whether or not students had difficulty with representational formats or because they did not have an adequate understanding of the concept. To find out more about this, need further investigation and we are still conducting investigations related to representational and conceptual difficulties encountered by students in thermodynamics.

Students' Conceptual Difficulties

In this paper, only the difficulty on some specific themes that will be discussed. In particular the theme which shows the highest and lowest average scores of scientific consistency, i.e. theme 7 theme 9, and theme 3.

Theme 7 contains isochoric concept in the context of two rigid vessels which different in volume are filled with perfect gas. Large vessel has volume twice the volume of a small vessel and the initial temperature of the gas in both vessels are identical. The two vessels are heated up for the same time with identical heat sources, then one measure their respective final temperature. Students were asked to predict the final temperature of the gas in both vessel. This problem is adapted from Rozier and Viennot (1991).

Results of students' response analysis showed that on average 39% of students who answered all three items in the theme 7 states that the final temperature of the gas in the small vessel is twice greater than the final temperature of the gas in the large vessel. This suggests that there is a possibility of students experiencing misconceptions, because based on the study reported by Rozier and Viennot (1991), found that 22% of students (N = 255) and teachers (N = 28) in Paris gave a similar answer to 39% of students (N = 67) in this study. The reason that used by student refered to "the amount of heat is more diluted in the larger container, so the temperature does not increase as much as in the small container". However, to ensure that the students in this study had the same reason, it is necessary to further research to investigate the specifics. Nevertheless, the response of students in this study, at least have shown that students also seem to have a misconception. In addition, students were also unable to use the first law of thermodynamics to analyze these problems.

Theme 9 contains a cyclic process concepts presented in the form of a *P-V* diagram. Students were only asked to determine whether the *net* work done *by* or *on* the gas and whether the heat absorbed or released by the gas. This concept is expressed in mathematical and pictorial representations.

Based on the results of data analysis, students have more difficulty in the mathematical representation items than other representations. In addition, in mathematical representation item, the alternatives that most preferred by 29% students was the *net* work done *by* gas in the cyclic process is equal to the *net* heat absorbed *by* gas, both are equal to zero. It showed that students have a misconception, as reported by Meltzer (2004). However, it seems that students really do not understand the concept because the two items in the verbal and pictorial representations, the alternatives that were chosen by students is not consistent with their answer in mathematics item. Students have realized that the *net* work done by gas in the cyclic process is equal to the *net* heat absorbed by gas, but it seems the students had difficulty in determining the sign of the work and the heat. This is in line with the difficulties reported by Loverude et al. (2002) that students tend to be difficult to determine whether the work done *by* the system is positive or negative. Conceptual difficulties in a cyclic process has indeed been warned to be emphasized more intensive (Meltzer, 2004; Leinonen et al., 2013)

Finally, for theme 3 contains the concept of internal energy as a state function. This is the first report which examined the concept of internal energy as state function to find students' scientific consistency. Meltzer (2004) on previous research only focus on the concept of heat and work as a process-dependent function. The questions used to measure the theme 3 shown in Fig. 1. While on this theme, there was a lot of students answered these items correctly, but it still did not reach 50% (on average only 39% of students). Students' scientific consistency was also very low, i.e. at the inconsistent level with an average score of 0.44. It means that student conceptual understanding is still not well completely because a good understanding characterized by the ability to consistently and correctly answered scientifically, even though the context and representation changed (Hestenes, 1997; Steinberg and Sabella, 1997).

Based on the analysis of data, it is interesting to be reviewed is the students' answer which demonstrate the conception they have about the concept of energy as a state-function. The percentage of students who answered correctly in each item on theme 3 respectively 37% in item diagrams, 48% in verbal items, and 33% in mathematics items. These students realize that both processes that are presented in the *P-V* diagram on theme

3 have the same change of internal energy (see Fig. 1). While the percentage of students who did not realize that internal energy as a state-function, one of which states that the change of internal energy in the process #1 is smaller than for the process #2. The percentage of students who answered that alternative respectively 31% in diagram item, 39% in mathematics item, and 30% in verbal item. Students' responses indicated that students seem to have a misconception.

We are still conducting further investigations to know about students' reasoning related to the concept of internal energy as a state-function. The conception of energy as a function of time was not explicitly tested in previous studies. Meltzer (2004) focused on the concept of work and heat as a process-dependent function. In this study, we also investigates those concepts, but it will be discussed more fully in the next paper. Thus, the results obtained in this study are consistent with results of previous studies.

CONCLUSION

Generally, students' scientific consistency level was still inconsistent. Even none of the students who consistently answered all given themes. Analysis of each theme has provided information about the conceptual difficulties faced by students. Overall, students have difficulty at all given theme. Students were unable to apply the first law of thermodynamics in analyzing various thermodynamic processes, such as isochoric process and cyclic process.

The findings of this study are consistent with results of previous studies and also indicate the possibility of students experiencing misconceptions. Therefore, it still need continuous efforts to further investigate and overcome students' conceptual difficulties on thermodynamics. Information obtained from this study useful to design an appropriate instructional method and curricular materials by utilizing multiple representations in learning thermodynamics.

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