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Experimental Demonstration for Enhancing Vocational Students' Comprehension on Heat Transfer through Conduction and Radiation of Light Bulb

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Abstract: This study aims to enhance the comprehension of vocational education students regarding heat transfer through conduction and radiation of light bulb using a conventional teaching supported by an experimental demonstration. The study was undertaken through several steps: (i) assessing students' knowledge (by a pretest), (ii) delivering a teaching about heat transfer using a conventional teaching method, and (iii) experimental demonstration supported by a recorded video with explanatory materials. Each step was carefully evaluated by direct observation and evaluation (by assessing test). The evaluation was done by a pretest-posttest technique, supported by questionnaire survey and interviews for the qualitative analysis. The experimental demonstration was done by observing the heating phenomenon of a 5-Watt bulb lamp inside a cube with varied wall materials, and students observed the heat transfer phenomenon from the measurement of temperature as a function of time. During the teaching process, especially in the experimental demonstration, the students were asked strictly to focus and clearly observe what phenomenon was happening. The teaching analysis results showed that the students' understanding improved significantly after the treatment using the experimental demonstration. The use of media also improved the students' understanding, and instilled more information through the media by stimulating the students' curiosity and interests in the subject. An analysis of the problems from the interviews and questionnaires was also conducted to reveal the main issues experienced because the delivered subject was not completely delivered in the curriculum. This study came up with new information on the need of additional experimental demonstrations and media (for repetition and clarification of the theoretical background for the happening phenomena) for improving students' comprehension.

Keywords: Conduction, heat transfer, radiation, vocational school, education

1. Introduction

Heat transfer is one of the various disciplines of thermal engineering that studies how to produce heat, use heat, convert heat, and exchange heat between physical systems(Wahyono & Rochani, 2019). In simple terms, the heat transfer is the movement of energy due to temperature differences. An example of the illustration of heat transfer is presented in Fig.

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1. Changes from heat to cold or vice versa are always related to heat transfer. Heat transfer is classified into conduction, convection, and radiation(Widodo, Hufad, Sunardi, & Nandiyanto, 2020).

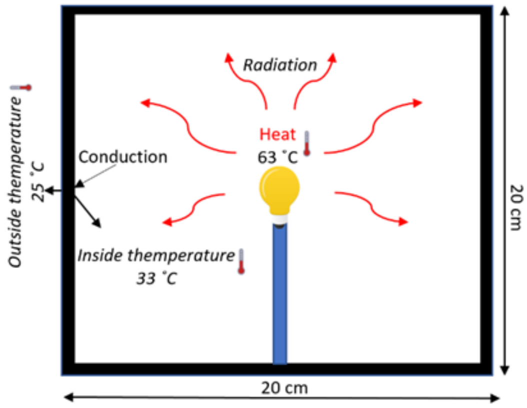

Figure 1 - Illustration of a cube used as a medium for heat transfer by heat conduction and radiation

Heat transfer phenomenon is one of the important subjects in vocational school (Pathare & Pradhan, 2010). The main reason why the heat transfer subject is important because this subject relates to the phenomena occurring regularly in nature, namely boiling water, burning, drying clothes, and cooking. The phenomenon of the heat transfer is usually observed by changes in temperature(Supu, Usman, Basri, & Sunarmi, 2017). Heat transfer phenomena have been well-implemented in various applications and industries. The concept of heat transfer is rich. Indeed, for some cases, when the concept is not delivered well to students, it rises a large number of misconceptions(Pathare & Pradhan, 2010). This will create problems when graduated vocational students face global competitiveness, relating to the skills and knowledge(Ana Ana, 2020; A Ana, Hurriyati, Rostika, & Nazeri, 2016). Global competition is inseparable from innovations in manufacturing techniques. Therefore, understanding heat transfer phenomena is very crucial for being well-taught in a vocational school.

To improve students' comprehension on heat transfer, many researchers have reported their ideas and strategies. To explain heat transfer, some researchers reported the use of direct observation in nature, designed specific equipment(Schnittka & Bell, 2011; Suresh, Chandrasekar, Selvakumar, & Page, 2012), and software(Ardiana, Akhsan, & Siahaan, 2018; Huizenga et al., 1999; Suryani & Ishafit, 2018) for explaining temperature, heat, and heat transfer for high school students. The strategies are good and possibly implemented. Indeed, media for teaching is important for improving students' comprehension.

The main issue especially in developing countries such as Indonesia is for the necessity of finding good strategies and media for teaching heat transfer. Teaching heat transfer needs sophisticated equipment, while these apparatuses are very limited. In fact, teaching based on nature or household goods can be an excellent problem solver to make students having scientific feeling in nature. Thus, they can apply and implement their knowledge to society(Al-Najar & El Hamarneh, 2019; Mulyadi, 2009). Unfortunately, until now, there is limited information on how to apply teaching strategies using household goods, while this is important, especially when teaching this heat transfer phenomenon in the rural area in Indonesia.

Here, the objective of this study was to enhance the knowledge and comprehension of vocational education students regarding heat transfer through conduction and radiation using conventional teaching supported by experimental demonstration. The experimental demonstration was done using a simple apparatus from household goods. We used the concept of heat transfer from the light bulb. This study demonstrates new information for the need of additional experimental demonstrations (in spite of using household goods) and recording media (for repetition and clarification of the theoretical background for the happening phenomena) for improving students' comprehension.

2. Methods

2.1 Research Subjects

The subject of this study was 31 vocational students at one of the general vocational schools in Cimahi, Indonesia.

2.2. Teaching Method

The study was done through three steps, and each step was carefully evaluated by direct observation.

i. Students were assessed by pretest to understand the knowledge of students gained until now.
ii. Students were delivered a teaching material about heat transfer through conduction, convection, and radiation using a conventional teaching method. Students listened what teacher delivered (using chalk and talk method).

iii. Students conducted experimental demonstration about the heat transfer, and all experimental procedures were recorded into video. The video was then added with theoretical explanation and completed with explanatory materials about heat transfer, types of heat transfer, examples of conductors and insulators, factors of affect heat transfer, and thermal diffusivity. Indeed, by sharing the video to students, the students could repeat by themselves and learn extensively about the delivered subject. During the teaching process, especially in the experimental demonstration, the students were asked strictly to focus and clearly observe what phenomenon was happening. In the end of the experimental demonstration, the students were given a posttest.

The experimental demonstration was done by observing the heating phenomenon of a 5-Watt bulb lamp inside the cube with varied wall materials with dimensions of 20 × 20 × 20 cm. This cube was designed so that the walls can be replaced with different materials but with the same thickness and same area. A 5 watt lamp is used to produce heat in the cube. A single switch was put to make it easy to turn off and turn on the light. The lamp was placed right in the middle of the cube.

To observe the heat transfer phenomena, several thermometers were put into several positions, and the temperatures were measured every 5 minute. The inside of the cube were placed four thermometers (T1, T2, T3, and T4), and one of them is attached to the inner wall (T4). T1, T2, and T3 were used to determine the heat transfer by radiation, and T4 was to determine the conduction heat transfer compared to the thermometer on the outer wall (T5). T5 was placed on the outside of the cube to detect outside temperature (T5). All thermometers have specifications (i.e. range temperature = between -50 and 110°C; Resolution = 0.1°C; Operating Voltage = 1.5 V, LR44 Buttoned Batteries, dimensions = 48 x 28.6 x 15.2 mm; and Screen Dimensions (LCD) of 46 x 27 mm). The vertical distance from T1 to the lamp was 2 cm, and was paralleled to the other thermometers. The distance between the thermometers was set with a distance of 5 cm each. Except T3 and T4, they were spaced according to wall thickness. The wall used was 5 mm thick. We used cloth tape to prevent air exchanges to the heating system.

To evaluate students' comprehension, several tests were done, including a pretest-posttest technique in each step of teaching, a questionnaire, survey, and interviews for the qualitative analysis. The basic student information including demographic information, IQ levels, and their basic abilities, namely mathematics, Indonesian, social science, science and religion, were also obtained from students to support research instruments.

3. Results and Discussion

3.1 Students' Demographics

Table 1 shows students' interest in subjects that are very important in vocational schools. There are five general subjects taken as an assessment to determine students' readiness in the heat transfer learning process. Each student shows different characteristics of interests. This result confirms that students' interests in subjects are based on curiosity and student satisfaction. These data were also used as a basis for determining intelligence and evaluating the best learning methods (Hidayat et al., 2020; Nandiyanto et al., 2018).

Table 1 - Students' demographic data for subjects.

No	Subject	Score (%)	Remark
1	Mathematics	66.70	Students' curiosity in science
2	Indonesian Language	73.33	Communication skills
3	Social Science	53.33	Society-related
4	Science	60.00	Science-related curiosity
5	Religion	66.70	Discipline

3.2 Experimental Apparatus

The experimental apparatus used in this study is presented in **Figure 2**. The experiments were done by observing the change of temperature as a function of time. The main heat source is 1 5-Watt bulb lamp inside the cube with varied wall materials with dimensions of 20 × 20 × 20 cm (**Figure 2(a)**). This cube was designed so that the walls can be replaced with different materials but with the same thickness and same area.

To evaluate the heat transfer phenomena, several thermometers were put into several positions, and the temperatures were measured every 5 minute. The inside of the cube placed four thermometers (T1, T2, T3, and T4), and the other thermometer (T5) attached on the outside wall. Detailed position of the thermometer is explained in the above method section and the illustration is in **Figure 2(a)**.

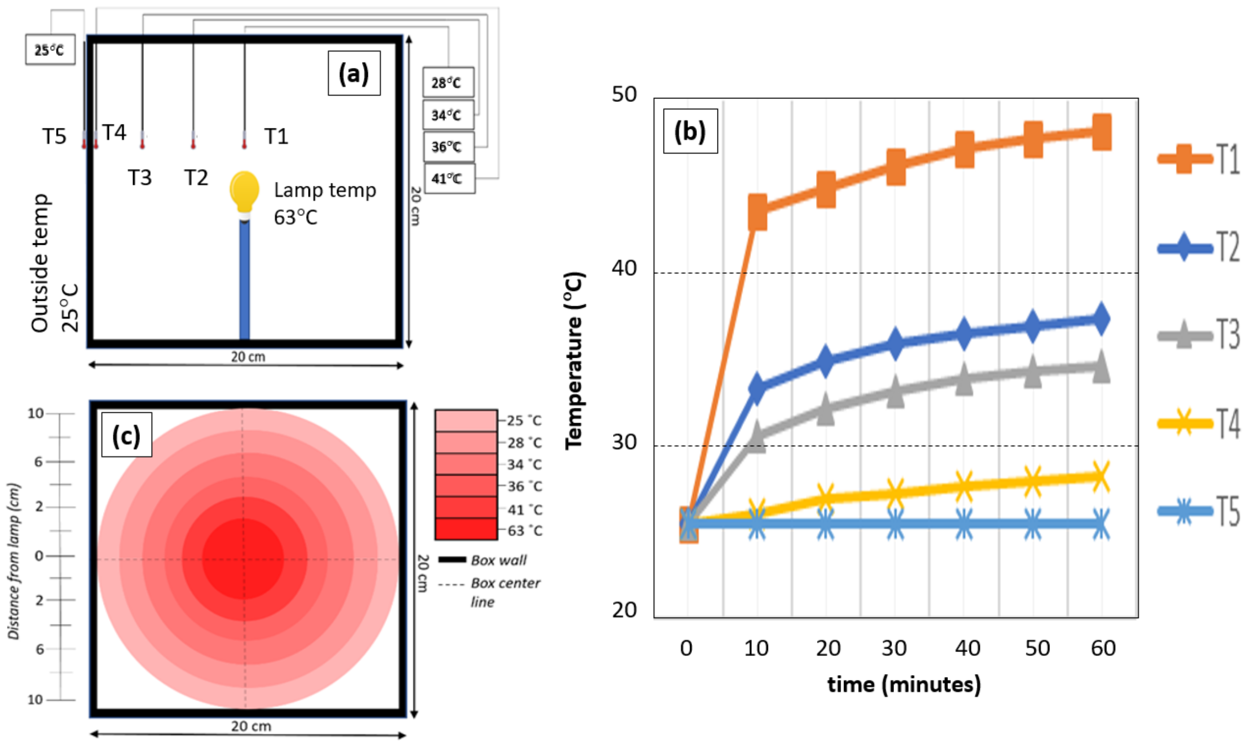

Fig. 2 - (a) cubes with acrylic walls used as a learning medium for heat transfer by conduction and radiation, (b) temperature profile as a function of irradiation time, and (c) temperature profile as a function of distance.

Figure 2(b) shows that relationship of temperature and heating time in different positions. The initial temperatures of all thermometers is 25°C. After 10-min process, the temperature increased in sequence of T1, T2, T3, T4, and T5, in which they were 43.6; 33.3; 30.6; 26.1; and 25.5°C, respectively. The highest temperature rise occurred at T1, this is because T1 distance is the closest to the heat source. The longer the heating process, the hotter the temperature inside the cube would get (thermal diffusivity) so that eventually the conditions inside the cube became stable (steady). This is confirmed by the relatively stagnant temperature profile in Figure 2 for all positions after processing of more than 30 minutes.

Figure 2(c) shows the heat distribution that occurs inside the cube. The lamp which acts as a heat source has a temperature of 63°C. The lamp releases heat by radiation. The heat was received by a thermometer sensor within 2 cm (T1) with a temperature of 48.3°C. T2, which was 5 cm from T1, received radiant heat, detecting a temperature of 37.3°C. T3, which was also 5 cm from T2 and attached to the wall, detected a temperature of 34.6°C. Finally, for T4 attached to the outer wall of the cube, it detected a temperature of 28.2°C. Based on these data, it is evident that the farther the thermometer is from the heat source, the less heat is obtained. These results were used as learning materials that had to be analyzed by students.

Figures 2(b) and 2(c) are important. The figures were used to inform what phenomena happening during the measurement test. The figures also were used as a standard result for comparing students' observation outcomes.

3.2 Teaching Results

Based on the demographic data in Table 1, we concluded that students' interest in the subject matter is very important because students who are less interests in a subject will complicate the learning process. This is one of the obstacles in getting good academic achievements. The experimental demonstration and experimental video learning media are expected to increase students' attractiveness towards heat transfer learning, which indeed, are utilized to enhance academic achievement.

Table 2 shows datasets of the pretest and posttest scores obtained from the students. These questions were given to ensure the level of student understanding during the learning process. These questions were consisted of topics about heat transfer by conduction, convection, and radiation. The results showed that in general students' scores increased significantly. Only several points have decreased, in which this will be explained in detail in the qualitative analysis.

By the t-test formula from Table 2, it was found that the t-count is 0.0270417. This number is smaller than t-critical which is 0.05 (t-count 0.0270417< t-critical 0.05). Thus, this test showed that the treatment using a combination of experimental demonstration and media significantly improved the students' understanding of the topic of heat transfer through conduction and radiation. This computation used a paired t-test and one-tailed t-test because we used the same subjects in the two sets of data and we also assumed it was one direction.

In the posttest session, we found that almost all students were able to answer the questions correctly, meaning increases in the students' understanding of heat transfer. In addition, students seemed more enthusiastic compared to during the initial pretest. That is due to the increases in the interest of students when watching experimental videos that use concrete media to help students become easier to understand the subject matter provided. The improvements of the students' comprehension due to the existence of experimental demonstration are in a good agreement with our previous studies (Hidayat et al., 2020; Nandiyanto et al., 2018).

3.3 Qualitative Analysis

Before presenting the experimental demonstration to the students, we administered a pretest. The pretest results showed that not all students understood about heat transfer. Some students cannot answer the questions given. Then, students were taught about heat transfer using conventional teaching as chalk and talk methods. To improve students' comprehension, an additional experimental demonstration was added after the conventional teaching since it can give a visual stimulus(Nandiyanto et al., 2018). Consequently, we presented an experimental demonstration learning and experimental video. The video itself contained some sentences and hints to enhance students' comprehension.

To analyze the results, we interviewed the students, and compared the results (as shown in Tables 1 and 2). In the pretest session, some students could not answer the questions given. This was caused by a lack of student understanding of the learning provided. When the learning process using an experimental demonstration was conducted, the teacher asked students, "is there anything you want to ask ...?", Then, no one answered, so it was assumed that all students understood the material presented. Then, the students were shown an experimental demonstration and video. The students became more interested to watch. Although there was still no response from students when teacher asked the students again after watching video "is there anyone who doesn't understand"?, we cannot guarantee that students understood about the subject. The posttest analysis showed the improvement in the student's comprehension and curiosity. However, to ensure the results, analysis of each question compared to the interview process was done.

The posttest can measure the understanding of each student. When asking the question "what is meant by thermal diffusivity?", Student A answered "Thermal diffusivity is the ratio of the time derivative to temperature in the second derivative", student B answered "Thermal diffusivity is conduction ...", and then student C answered "Thermal diffusivity is a measure of the material's response to temperature changes. ". Student B's interests are not like Student A and Student C. Then, the teacher gave the question again, "what is meant by heat transfer by conduction?", student A answered "conduction is heat transfer accompanied by the transfer of particles of the substance itself.", while student B replied "conduction is heat transfer ....". Student B looked confused, then continued to state "through intermediaries ...", while student C answered "conduction is heat transfer through intermediary media and is accompanied by the transfer of particles themselves.". The answers given by the students had their respective characteristics. The reason is that it depends on the students' interest in the heat transfer material.

The results in Table 2 showed that some improvements in the students' scores in most questions were found. However, the main important parameters are the question which the students' score getting worse (see Table 2 with Asterix (*)). Analysis of the misconception gained from the decrement scores are in the following:

i. Students did not understand the definition of heat energy release. They did not think about the reason for the release of heat (question number 2)
ii. The type of materials for transferring heat (question number 7, 12, and 21). However, the percentage of this type of students is not much. Comparing to the basic demography of students who did not get good scores in these questions, we can conclude that these students did not like science very much. However, this can be solved by additional teaching about conductor and insulator in heat transfer process, in which this will be done in our future work.
iii. Some students did not understand the meaning of radiation, convection, and conduction (question number 15 and 19). This inspired the teachers to give more examples and teaching for the definitions of these types of heat transfer. We found that students understood about the heat transfer but they were not familiar with the definition of these types of heat transfer.
iv. Regarding question number 24, we found that decreases in scores were found. However, we found that students just memorized the definition without deep understanding from this matter. This can be compared with the classification of heat transfers as explained in the above.

Table 2 - Scores (%) obtained from students by the experimental demonstration method.

No	Problems	Score (%)		
		Pretest	Posttest	Gain
1	Heat transfer is the transfer of heat energy (heat) from a higher temperature to a lower temperature.	74.20	84.31	10.11
2*	A substance / object that has a high temperature will not turn into a low temperature if it releases heat energy (heat).	59.57	50.00	-9.57
3	A substance / object that has a low temperature will turn into a higher temperature object if it receives heat energy (heat).	81.52	91.63	10.11
4	Conduction / Transfer Heat Transfer is heat transfer accompanied by the transfer of particles from the substance.	47.38	64.80	17.43
5	Motorcycle exhaust that gets hot when the engine is started is an example of convection heat transfer.	40.06	52.61	12.55
6	Butter heated in a pan that melts due to heat is one example of conduction heat transfer.	62.01	69.68	7.67
7*	The iron utilizes conduction / heat transfer types.	81.52	75.00	-6.52
8	Conductors are substances that have poor thermal conductivity.	71.77	86.75	14.99
9	Iron, copper and aluminum are some examples of conductors.	81.52	91.63	10.11
10	Isolators are substances that have good thermal conductivity.	69.33	81.87	12.55
11	Styrofoam and wood are examples of insulators.	76.64	81.87	5.23
12*	Iron is an example of an object that utilizes an insulator and a conductor together.	86.40	80.00	-6.40
13	Convection / Flow Heat Transfer is heat transfer that is not accompanied by the transfer of particles from the substance.	42.50	62.36	19.86
14	Convection / Flow heat transfer will occur due to changes in the density of substances.	54.69	74.56	19.86
15*	Boiling water is an example of conduction / heat transfer.	30.30	25.00	-5.30
16	Air Conditioning (AC) is an example of heat transfer by convection / flow.	74.20	79.43	5.23
17	Radiation / Radiant Heat Transfer is heat transfer without passing through intermediaries.	83.96	91.63	7.67
18	Feeling the warmth of a campfire when sitting around is an example of radiant heat transfer.	86.40	91.63	5.23
19*	Boiling hot water is an example of conduction / heat transfer.	40.06	35.00	-5.06
20*	The rate of heat transfer will be faster if the distance is closer to the heat source.	83.96	84.31	0.35
21*	Aluminum is often used as a material for making pans because it is a good conductor.	86.40	79.00	-7.40
22	In heat transfer analysis, thermal diffusivity is thermal conductivity divided by density and density at constant pressure.	71.77	81.87	10.11
23	Thermal diffusivity is measuring the ability of a material to conduct heat energy relative to its ability to store heat energy.	71.77	86.75	14.99
24*	Thermal diffusivity is the ratio of time to temperature in the second derivative.	71.77	60.00	-11.77
25	A substance with high thermal diffusivity, heat will move quickly because it conducts heat relative to its volumetric heat capacity.	71.77	84.31	12.55
	Average	68.06	73.84	5.67

Note: *There is a negative gain value

4. Conclusion

Strategies for improving students' comprehension on heat transfer have been demonstrated. Different from other teaching methods, we combined conventional teaching and experimental demonstration. The analysis results showed that the students' understanding improved significantly after the treatment using the experimental demonstration. The use of media also improved the students' understanding, and instilled more information through the media by stimulating the students' curiosity and interests in the subject. In addition, the experimental data involve only one group of students, informing the need of further studies, in which this will be done in our future work. This study came up with new information on the need of additional experimental demonstrations and media (for repetition and clarification of the theoretical background for the happening phenomena) for improving students' comprehension.

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