Development of guided inquiry-based laboratory worksheet on topic of heat of combustion

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Abstract. Chemistry curriculum reform shows an explicit shift from traditional approach to scientific inquiry. This study aims to develop a guided inquiry-based laboratory worksheet on topic of heat of combustion. Implementation of this topic in high school laboratory is new because previously some teachers only focused the experiment on determining the heat of neutralization. The method used in this study was development research consisted of three stages: define, design, and develop. In the define stage, curriculum analysis and material analysis were performed. In the design stage, laboratory optimization and product preparation were conducted. In the development stage, the product was evaluated by the experts and tested to a total of 20 eleventh-grade students. The instruments used in this study were assessment sheet and students’ response questionnaire. The assessment results showed that the guided inquiry-based laboratory worksheet has very good quality based on the aspects of content, linguistic, and graphics. The students reacted positively to the use of this guided inquiry-based worksheet as demonstrated by the results from questionnaire. The implications of this study is the laboratory activity should be directed to development of scientific inquiry skills in order to enhance students’ competences as well as the quality of science education.

1. Introduction

At the beginning of the 21st century, chemistry curriculum entered a new reform in which inquiry has been suggested as a central style for learning activities [1]. Inquiry refers to the ways how scientists study the natural world [2,4]. In scientific process, scientists formulate question, hypothesize, identify and control variables, design experiments, collect and process data systematically, draw conclusions, and communicate experimental results both in oral and written presentations [6]. The attainment of these inquiry skills can be achieved through a guided inquiry-based laboratory. In guided-inquiry laboratory, students are only given the problems and they must plan the investigation, collect and organize their own data, and make evidence-based conclusions [7-11]. Some hints are also given in order to guide students’ activity [12]. This type of laboratory, that are contain less direction, allows the students to construct their knowledge [1]. Previous studies confirmed that guided-inquiry laboratory had much more effect on students’ academic achievement than the traditional teaching method [13-17]. In addition, other studies reported that students who engaged in guided-inquiry laboratory were able to...
ask more and better questions regarding chemical phenomena and showed higher level of critical thinking than students who received traditional instruction [1,12,18,19].

On the contrary with this ideal expectation, chemistry lab activity in Indonesia still organized in cookbook-style. In cookbook-type laboratory, students perform the experiments in small groups by following the instructions in the laboratory manual, like a recipe [7]. Students are not stimulated intellectually because they only have to recall the principle that have been taught in the classroom [12]. In addition, the laboratory worksheets used by teachers are generally taken from the textbooks that are still presented in cookbook-style instruction. Due to this problems, the present study aims to develop a guided inquiry-based laboratory worksheet in chemistry. This study is useful to support the implementation of inquiry-oriented learning.

2. Methods
The method implemented in this study was development research which was limited into three stages: define, design, and develop. In define stage, curriculum analysis and material analysis were performed. In design stage, the laboratory optimization and product preparation were conducted. In development stage, the quality of product was judged by the experts in the aspects of content, linguistic, and graphics. We also tested this worksheet to a total of 20 eleventh-grade students as the main user. The data was collected through assessment sheet and students' response questionnaire and further analyzed using the equation (1).

\[ P = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} B_i} \times 100\% \]  

where,
\( P \) = percentage of score  
\( A_i \) = score for item-\( i \)  
\( B_i \) = maximum score for item-\( i \)  
\( n \) = number of items  
\( i = 1,2,3,...n \)

In order to make conclusion, the percentage of score was interpreted according to the criteria used in related research [20]. Table 1 shows the criteria used to categorize the score.

| Percentage  | Category      |
|-------------|---------------|
| 0% - 20%    | Very bad      |
| 21% - 40%   | Bad           |
| 41% - 60%   | Medium        |
| 61% - 80%   | Good          |
| 81% - 100%  | Very good     |

3. Result and Discussion
3.1. Define Stage
In define stage, learning requirements were assigned and defined. This stage consisted of curriculum analysis and material analysis.

3.1.1. Curriculum Analysis. Curriculum is essential for learning process because it contains a set of plan, arrangement and ways to achieve the national goals of education. Therefore, before designing a lesson plan, teacher needs to analyze the curriculum. According to the chemistry syllabus, students
should have skills in formulating problems, developing hypotheses, defining variables, designing and conducting experiments, collecting and processing data systematically, drawing conclusions, and communicating experimental results both in oral and written presentation [6]. Therefore, a guided-inquiry laboratory should be designed.

3.1.2. Material Analysis. Calorimetry is an essential topic in secondary school chemistry. However, in fact, students have a lack understanding in the concepts of calorimetry. Previous studies found that students could not distinguish between heat and temperature, could not identify systems and environments, and didn’t understand the thermal equilibrium and heat capacity as well as the relationship between heat flow, heat capacity, and temperature changes [21]. In addition, some teachers only focused the calorimetry experiment on determining the heat of neutralization, whereas the energy changes of almost all chemical reactions can be determined, include combustion and dissolution reaction. Based on these facts, this study aims to develop laboratory worksheet on the topic of heat of combustion reaction.

3.2. Design Stage
The aim of this stage was to produce a laboratory worksheet. This stage consisted of two steps: laboratory optimization and product preparation.

3.2.1. Laboratory Optimization. Optimization aims to determine the optimal conditions of the experimental variables. The experimental variables were the characteristics of food sample and heat capacity of calorimeter. The optimization results of the determination of food sample are presented in Table 2.

| Food samples   | Characteristic | Ability to burn |
|----------------|----------------|-----------------|
| Rice           | Wet            | Not burnt       |
| Bean           | Slightly wet   | Slightly burnt  |
| Bread          | Slightly wet   | Slightly burnt  |
| Biscuit        | Slightly wet   | Slightly burnt  |
| Chips brand A  | Dry            | Burnt           |
| Chips brand B  | Dry            | Burnt           |
| Chips brand C  | Dry            | Burnt           |

Based on the data in Table 2, it was found that the best food samples used in the experiment were the various types of chips. It is due to its characteristic which is dry and easy to burn.

The next optimization is the determination of heat capacity of calorimeter. In this experiment, a soda can, which acts as a calorimeter, is a conductor that will absorb the heat during combustion process. Therefore it is necessary to determine its heat capacity ($C_k$). Certain amount of cold water at 24°C was mixed with the same amount of hot water at 40°C in soda can. The temperature changes were measured every three seconds and then plotted against time to obtain mixed temperature ($T_c$). The temperature of the mixture used in the calculation to obtain the value of $C_k$ using the equation (2) [22]:

$$C_k = \frac{m_1 \times c \times (T_1 - T_c) - m_2 \times c \times (T_2 - T_c)}{T_c - T_2}$$

where,

$C_k$ = heat capacity of calorimeter (kal/°C)

$m_1$ = mass of hot water (gram)

$m_2$ = mass of cold water (gram)
c = specific heat of water (1 kcal/g °C)
T_1 = temperature of hot water (°C)
T_2 = temperature of cold water (°C)
T_e = temperature of mixture (°C)

Determination of C_k was conducted as much as three times to obtain more accurate result. Observation of water temperature changes in the 1st, 2nd and 3rd experiments are presented in Table 3.

Table 3. Determination of heat capacity of soda cans calorimeter

| Experiment | Mass of hot water (gram) | Mass of cold water (gram) | Temperature of hot water (°C) | Temperature of cold water (°C) | Temperature of mixture (°C) | C_k (kal/°C) | Average C_k (kal/°C) |
|------------|--------------------------|---------------------------|-------------------------------|-------------------------------|----------------------------|-------------|---------------------|
| 1          | 50                       | 50                        | 40                            | 24                            | 31.5                       | 6.7         | 7.0                 |
| 2          | 50                       | 50                        | 40                            | 25                            | 32.0                       | 7.1         | 7.1                 |
| 3          | 50                       | 50                        | 40                            | 25                            | 32.0                       | 7.1         | 7.1                 |

Based on the Table 3, the average value of C_k was 7.0 kcal/°C, which means that the soda can calorimeter absorbs 7 calories of energy to raise the temperature by one degree Celsius. This value is used to calculate the calorie of food. Determination of calorie of food was conducted by burning certain amount of food sample below the soda can which contained certain amount of water. The heat released from the combustion reaction will flow and absorb by the calorimeter as well as the water. Changes in water temperature before and after the sample completely burnt were measured and mass of remaining sample was also weighed. These values were used to calculate the calorie value of food using the equation (3).

\[ Q = \frac{(m_w \times c \times \Delta T) + (C_k \times \Delta T)}{\Delta m} \]  

(3)

where,
Q = calorie of food (kcal/°C)
m_w = mass of water (gram)
c = specific heat of water (kcal/g °C)
C_k = heat capacity of calorimeter (kcal/°C)
\( \Delta T \) = water temperature changes (°C)
\( \Delta m \) = mass of sample burnt (gram)

3.2.2. **Worksheet preparation.** The laboratory worksheet was compiled by referring to the characteristics of guided-inquiry instruction. In guided-inquiry instruction, students are only given the problems and do not given the procedure. Students are also directed to determine the variables and how to measure them [7]. The components of guided-inquiry worksheet was according to the inquiry stages which include: orientation by providing the phenomena, formulating problems, formulating hypotheses, collecting data, designing experiments, analyzing data, hypotheses testing, and drawing conclusion.

3.3. **Development Stage**

This stage is an improvement to make the worksheet was feasible to be used in the laboratory activity. Development phase begins with a draft assessment by the experts and continued to limited testing.
3.3.1. Draft Assessment. Draft assessment covered aspects of content, language, and graphics. The experts consisted of 7 teachers who teach in eleventh grade and 3 lecturers from Chemistry Education Department. The results of the draft assessment are presented in Table 4.

**Table 4. Results of draft assessment on the aspects of content, language, and graphics**

| Aspect      | Indicator                              | Score (%) | Average (%) |
|-------------|----------------------------------------|-----------|-------------|
| Content     | Conformity with learning indicators    | 92.5      | 94.7        |
|             | Material accuracy                      | 95.0      |             |
|             | Knowledge and value content            | 96.7      |             |
| Language    | Unity of ideas                         | 90.0      | 85.8        |
|             | Logic                                  | 87.5      |             |
|             | Efficient                              | 82.5      |             |
|             | Emphasis                               | 90.0      |             |
|             | Use of spelling                        | 85.0      |             |
|             | Communicative                          | 80.0      |             |
| Graphic     | Proportion                             | 90.0      | 95.0        |
|             | Consistency                            | 92.5      |             |
|             | Center of attention                    | 97.5      |             |
|             | Font size                              | 95.0      |             |
|             | Font type                              | 97.5      |             |
|             | Space wide                             | 97.5      |             |

Based on the data in Table 4, the average score of the aspects of content, language, and graphic were 94.7%, 85.8%, and 95.0% respectively. Due to the criteria in Table 1, these values categorized as “very good”, which means that the guided inquiry-based laboratory worksheet has very good quality based on the aspects of content, linguistic, and graphics.

3.3.2. Limited testing. A limited testing was conducted to 20 eleventh-grade students to explore students’ responses on the use of laboratory worksheet. The students’ responses presented in Table 5.

**Table 5. Students’ responses on the use of guided inquiry laboratory worksheet**

| Statement                                      | Percentage of responses |
|------------------------------------------------|-------------------------|
| The guided-inquiry lab worksheet is easy to use | 78.4%                   |
| Satisfaction in using guided-inquiry lab worksheet | 76.3%                   |

According to the Table 1, the percentage of students’ responses in each statement was categorized as “good” (more than 61%). It indicates that students reacted positively to the use of this guided inquiry-based worksheet.

4. Conclusion
The development of guided-inquiry laboratory worksheet was conducted through three stages: define, design, and develop. Draft assessment results showed that the quality of this worksheet was very good in terms of content, language, and graphic. The questionnaire results also showed students’ positive responses to the use of guided-inquiry worksheet. The results of this study indicate that a guided-inquiry laboratory worksheet is possible to be implemented in secondary school laboratory.
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