Redesign of students’ worksheet on basic physics experiment based on students’ scientific process skills analysis in Melde’s law

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Abstract. Scientific process skills (SPS) are an intellectual skill to build knowledge, solve problems scientifically, train thinking skills as well as a very important part of the inquiry process and contribute to scientific literacy. Therefore, SPS is very important to be developed. This study aims to develop Student Worksheets (SW) that can trace SPS through basic physics experiments (BPE) on Melde’s law. This research uses R&D method involving 18 physics education department students who take the BPE course as a sample. The research instrument uses an SW designed with a SPS approach that have been reviewed and judged by expert, which includes observing, communicating, classifying, measuring, inferring, predicting, identifying variable, constructing hypothesis, defining variable operationally, designing experiment, acquiring and processing data to conclusions. The result of the research shows that the student's SPS has not been trained optimally, the students' answers are not derived from the observations and experiments conducted but derived from the initial knowledge of the students, as well as in the determination of experimental variables, inferring and hypothesis. This result is also supported by a low increase of conceptual content on Melde’s law with n-gain of 0.40. The research findings are used as the basis for the redesign of SW.

1. Introduction
Physics as one of the cornerstones in technology development, must supported with learning activity that provided opportunities for people who study this subject to discover and apply the knowledge they obtain. These statements are in line with the nature of physics which require its students to obtain experience of discovering as well as the scientist discover theories, laws and concepts [1, 2]. Efforts to cultivate the skills of physics education students as future teacher can be done through experiment activities because experiment activities can train students’ way of thinking and way of working. In experiment activities, students are actively involved in the processes of observing object, analyzing, proofing and concluding by themselves about object or some processes [3]. With experiment activities, students are given more opportunities to train and develop some skills, such as Science Process Skills (SPS) which are basic skills in experiment activities.

Science Process Skills (SPS) are intellectual abilities which useful for construct any knowledges or solve problems scientifically. These skills considered as important skills because underlying students ability to train thinking skills such as construct hypothesis, manipulate and analyse of data. According to Anderson, SPS are essential parts of inquiry process and give significance to students’ scientific
literacy level [4]. Furthermore, SPS can be developed by individual as provision in learning science through scientific method experiences in discovery processes and develop new knowledge [5]. Other than that, SPS also viewed as skills to obtain, develop and apply concepts, laws and theories in science [6]. According to the preceding explanation, it is implied that SPS are essential basic skills for every person in performing some kind of activity in order to obtain and develop new knowledge.

Even though these skills are considered as important, result of researches show that these skills are not owned by most teacher. Study in Jambi show that 63.44% teachers have low knowledge of SPS [7]. Test of students’ ability to explain experiment variables to the students who take Basic Physics Experiments 1 (BPE 1) show that only 47.75% students are able to show the relation between variable and this become problem to students who later asked to construct experiment procedures [8]. Another study shows teachers difficulties in facilitate observation activity and developing inquiry question in scientific approach [9]. The skill of facilitating observation, variable identification, hypothetic question development, and experiment procedures development has been connected to SPS. This indicates that higher education institutions have not provided sufficient SPS training for physics teacher which caused by the insufficient of SPS knowledge that served by colleges. Therefore, in developing the prospective science teacher education curriculum programs it is suggested that prospective teachers should be prepared with SPS knowledge.

The preparation of SPS for prospective teachers has been shown to have a positive effect on the academic ability of prospective teachers, as it providing experience and enhancing scientific ability [10]. Other findings suggest that the use of the SPS approach can lead to more effective learning environment and give impact on student achievement in chemistry [11]. Moreover, it is also found that experimental use based on constructivism models can provide an increased understanding of the concept of science and SPS [12]. Furthermore, studies on teacher training programs illustrate that conceptual understanding can be established through SPS and has an impact on the ability to teach science [4].

As already known that the SPS training gives prospective teachers experimental experience as scientists, this research intends to develop ways to enhance SPS prospective teachers’ skills through the development of experimental instruction design in the BPE 1 course. Instructional in the form of student worksheets designed using Approach SPS as illustrated in Figure 1 [13].

![Figure 1. Diagram of Science Proses Skills](image)

Experiments are constructed begin with observation to predict the relation between variables, make prediction question, explain experiment variables, classify dependent, independent and control variables, developing hypothetic question from the relation between dependent and independent variables, variable measurement and then do the data retrieval. This method is considered very...
appropriate to provide teachers’ skills in mastering the physics concepts and preparing the prospective teacher to be able to use the scientific approach in learning sciences and it is expected to be able to train SPS for prospective teachers.

2. Methods
This study uses research and development (R & D) with the aim to redesign Student Worksheet (SW) in BPE course which can train students’ SPS appropriately based on analysis result of students’ SPS profile. This study was conducted to 18 physics education department students who took BPE 1 course as research sample. Student Worksheet which designed with SPS approach after going through a review process and expert judgment is used as research instrument. This instrument meant to measure skills of observing, communicating, classifying, measuring, inferring, predicting, identifying variable, constructing hypothesis, defining variable operationally, experiment, acquiring and processing data, analyzing and concluding. SPS profiles are measured through portfolio assessment of performance and experiment products in form of students’ responses to a given worksheets. In addition to worksheets, there is support data for this research that is the conceptual mastery as measured by the normalized gain value \( g \) of the instrument developed based on the standard Force Concept Inventory (FCI) test. The supporting data is used as additional information on the achievement of the student SPS profile.

Profile of every aspect in SPS is measured, processed and made a percentage by interpretation as shown in the Table 1 [14].

\[
P(\%) = \frac{\sum \text{student's correct answer}}{\sum \text{Students}} \times 100 \%
\]

| Percentage | Interpretation |
|------------|----------------|
| 81-100     | Very Good      |
| 71-80      | Good           |
| 61-70      | Fair           |
| 51-60      | Poor           |
| 0-50       | Very Poor      |

Students in groups (2-3 students) have conducted experiments on standing waves with the aim of discovering the factors that influenced the wave velocity on the string as found by Melde who was guided using a SPS-based worksheet. Melde’s experimental setting is shown in Figure 2.

![Figure 2. Standing wave experiment apparatus (Melde’s Law)](image)

3. Results and Discussion
Based on the result of the analysis of answers written by students on the SPS-based worksheet, it is obtained the profile of student SPS achievement as shown in Table 2.
| No | Observed SPS aspect | Findings                                                                                                                                                                                                 | Recommendation in redesigning the worksheet                                                                 |
|----|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 1  | observing           | Finding 1: 16.67% Students are able to tell what is observed, patterns appear to form node and antinode when experiments are turned on. Students generally tell the results of their observations based on the knowledge they already have, not on the observations of the tools being observed. This can be seen from the direct appearance of the term vibration, frequency and wave. Finding 2: All students have been able to describe the pattern that formed on the string, which is in the form of antinodes and nodes (standing wave pattern) | Questions on observing aspects are made more specific involving all the senses, rather than open-ended questions |
| 2  | communicating       | 27.78% of students are able to communicate the characteristics of stationary waves. Other students that is 72.22% have not been able to explain that the standing wave is a combination of the coming wave (from the vibrator) and the reflected wave (from the end of the string on the pulley) with its characteristics. It is necessary to first raise the phenomenon of the standing wave and then one end is tied to indicate a stationary wave phenomenon. So that students are expected to explain the characteristics of stationary waves. |                                                                                                              |
| 3  | classifying         | All students have been able to group standing waves correctly from the given images                                                                                                                    |                                                                                                              |
| 4  | measuring           | Most students (77.78%) can measure wave parameters and their changes when other parameters are altered, including wavelength, frequency, and wave velocity on the string. However, there are still students who answered incorrectly about the measurement of wavelengths because of difficulty finding the position of the antinode or node. To obtain clear waveform parameters (frequency and wavelength), it is necessary to raise a demonstration with a large parameter change value so that the effects of changing those parameters on other parameters are more clearly visible and more easily observable. For example, the if frequency changes are large enough so that the wavelength changes are more observable. |                                                                                                              |
| 5  | inferring           | Over than half of the students (55.56%) can make pstringr inferences. Other students may find a change in the string waves when the load mass and the type of string is changed, but the inferring that the student raises is very diverse and even many of them makes erroneous inferences, such as writing the relationship of wavelength to mass, whereas what is expected is not the mass of string but the length density of the string. To obtain clear waveform parameters (frequency and wavelength), it is necessary to raise a demonstration with a large parameter change value so that the effects of changing those parameters on other parameters are more clearly visible and more easily observable. For example, the frequency changes are large enough so that the wavelength changes are more observable. |                                                                                                              |
| No | Observed SPS aspect | Findings | Recommendation in redesigning the worksheet |
|----|---------------------|----------|------------------------------------------|
| 6  | predicting          | Most of the students (72.22%) have been able to make correct predictions, predicting the change of wave velocity on the string when the tension and density are changed, but there are still wrong predictions (in accordance with the previously written inference), there are even two students who did not write down his predictive answers. | To emphasize, the prediction can be displayed again or ask students to reflect on inference answers. |
| 7  | identifying variable| Almost half of the students (44.44%) can correctly identify the experiment variables, while more than half of the students have been able to find out what quantities to measure, but some students fail in determining the types of variables (dependent, control, and independent), students who answer erroneously, especially on the part of the dependent variable that writes the dependent variable is the wave velocity, whereas this magnitude will then be sought later. The dependent variable should be the wavelength formed on the string when the tension and the string density parameter is altered. | It should be re-emphasized the difference between the independent variable, the dependent variable and the control variable in the experiment. |
| 8  | constructing hypothesis | Nearly half of the students (44.44%) can answer the hypothesis correctly. This is very closely related to the determination of experimental variables. Because more than half of students mistakenly write experiment variable, between independent variable and dependent variable, hence relation between these variables have become mistaken. | It should be re-emphasized the difference between the independent variable, the dependent variable and the control variable in the experiment. |
| 9  | defining variable operationally | The answer to this section is very much in line with the answer when the student identifies the variable as they have mistakenly defining the variable, this section also as many as 44.44% of students still mistakenly defining the variables, especially on the part of the dependent variable even though the students have been able to explain how the measurement of experimental variables. | It should be re-emphasized, related to independent variables, dependent variables and control variables, so that students are not wrong in determining how to measure and measuring tools needed in the experiment. |
| 10 | designing experiment | Nearly half of the students (44.44%) were able to design experiments clearly include the variables which need to be measured and how they were measured, but there were still students who wrote single measurement, whereas experiments could be repeated to obtain more accurate data. | It is need to be informed about repeated measurements to get more accurate data. |
| No | Observed SPS aspect | Findings | Recommendation in redesigning the worksheet |
|----|---------------------|----------|-------------------------------------------|
| 11 | acquiring and processing data | Students are able to display data adequately and perform data processing with statistical tests and adequate uncertainty, but almost all students (77.78%) did not write uncertainty in the measurement results of experimental variables. | It is need to be informed that the uncertainty in the experiment not only in the results of data processing but also appear in the process of measurement, so that in the table data measurement results should be raised uncertainty measurement in accordance with the measuring instruments used. |
| 12 | Analyzing | Almost all students (83.33%) analyzed the experimental results without the support of the literature, the students only explain the data and the results of data processing obtained. In addition, their analysis carried out generally in the form of mention of normative errors in experiments such as data retrieval errors, parallax and rounding errors in data processing. | It is need to be informed and affirmed about the importance of reference support and other supporting data to strengthen their arguments or correct the results of the experiments produced. |
| 13 | Conclusion | All students have been able to express the experimental conclusions of the regularity of the relationships of the experimental variables. | - |

Based on the findings shown in Table 2 it can be seen that there are still many achievements of student SPS that are low. Achievement of the lowest student occurs in the initial process of experiment, the observation activity with a percentage of 16.67%. The findings of worksheets indicate that in observation activities, students tend to answer worksheets not based on what they observe with the five senses but rather in the process of recalling the knowledge they have obtained, so that the observation process is not optimal. Students immediately bring up the terms, concepts, and theories that they understand as shown in Figure 3.

![Figure 3. Example of student answers on observation activities](image-url)

Another aspect of SPS that has very low achievement is the aspect of identifying the variable with the percentage of 44.44%. This indicates that the student has not been trained to distinguish variables in the experiment, especially the dependent variable such as the example of the answer shown in Figure 4.
Figure 4. Example of students answer on variables identification

The lack of trained aspects of SPS as shown in Table 2, also impact on students' conceptualization on experiment of standing waves (Melde’s Law). Based on the data processing of the concept mastery instrument which is developed based on the standard test of Force Concept Inventories (FCI), it is obtained a normalized gain value as shown in Table 3.

Table 3. Achievement of mastery of the concept of standing wave matter

| Test                | Pretest Average (100 scale) | Posttest Average (100 scale) | Gain Average | N-gain Average |
|---------------------|----------------------------|-----------------------------|--------------|----------------|
| Mastery of the concept | 25.93                       | 55.56                       | 29.63        | 0.40           |

Based on Table 3, the achievement of student conceptualization on standing wave material is low including the post-test score of 55.56 and the improvement of concept mastery of 0.40. This is of course not spared from the less optimal learning and debriefing of SPS as shown in Table 2. This is consistent with the findings of Hasbon which suggests that the use of the SPS approach can build a more effective learning atmosphere, and have an impact on student achievement [11], so if the approach of SPS is done less than optimal then academic achievement in this case the achievement of student concept mastery becomes less optimal. Furthermore, Necati reveals that the use of experiments based on the constructivism model can provide an increased understanding of the concept of science and SPS [12]. Therefore, the redesign process based on the recommendations presented in Table 2 is very important to achieve the process of learning and debriefing of good SPS for prospective teachers.

4. Conclusion

The result of the research shows that students’ SPS has not been trained optimally, students’ answers generally are not derived from observations and experiments conducted but derived from the initial knowledge of students, as well as in the identification of experimental variables, inferring, predictions, operational definitions and experimental hypotheses. This result is supported also by the improvement of low concept conception on standing wave material (Melde’s law) with n-gain value 0.40. The research findings are used as the basis for the redesign of worksheets, so that worksheets can be more revised and provide SPS for prospective teachers.
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Acknowledgments

The author would like to thanks the Ministry of Higher Education, Research and Technology (KEMRISTEK DIKTI), republic of Indonesia, which has funded this through the publication of the research (Penelitian produk terapan research-grand).