The comprehensive physics laboratory work with model-based reasoning to improve 21st century competence

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Abstract. There are five types of physical laboratory work, namely deductive, inductive, science process skills, technical skills, and problem-solving where those have different goals. Currently, the laboratory work was more dominant on deductive, which does not optimally accommodate the students’ required competencies for the 21st century. Related to the issue, this research is important to find the best laboratory work with model-based reasoning by engaging laboratory work of deductive, problem solving and technical skills into comprehensive laboratory work. We explore model-based reasoning by undergraduate students and design a comprehensive laboratory work to the improvement of critical attitude and teamwork as a part of 21st-century competency. This study used a mixed method with a sequential exploratory design. Qualitative data were collected with theoretical studies. Quantitative data are collected with a scale scientific attitude. Increased critical attitude and teamwork are analyzed with n-gain. These research results were comprehensive laboratory work with reasoning components, such as theoretical guide, technical formulation, experimentation, problem description, problem analysis, repair and revision, and evaluation. The application of comprehensive laboratory work could improve critical attitude and teamwork with the high category. This study has succeeded in finding alternative concepts in laboratory work physics with reasoning based on models.

1. Introduction
Globalization and new technologies guide the improvement of students' skills and knowledge for success in the 21st century. All elements of education concern on achieving 21st-century competencies include personalization skills, collaboration, communication, initiative, resilience, responsibility, creativity, teamwork, networking, empathy, affection, management skills, and organizing skills [1]. The competencies and other skills, namely survival skills that must be prepared for life, work and citizenship, i.e.: critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurship, effective oral and written communication, accessing and
analyzing information, curiosity, and imagination [2]. The required skills in the 21st century include critical attitudes and teamwork and those a part of scientific attitude which is often applied in science.

Science as a group of knowledge concerned with the objects and the natural phenomena as the results from scientists thought or investigation through scientific experimenting methods. As a branch of science, physics deals with the physical knowledge of natural phenomena observation and it tries to find the patterns and principles that connect the phenomena through experimentation. The students could acquire the physical knowledge of an object by employing their senses where this physical information is derived from a direct abstraction of a certain object. Thus, in order to study physics and to form knowledge of physics, it requires direct contact with the object through laboratory work.

Laboratory work involves hands-on experience in which students can engage with science as a way of thinking and investigating to develop a decent understanding of concepts, principles, and scientific theories [3]. Laboratory activities can help students to acquire, to integrate and to build knowledge over a friendly way [4]. In laboratory activities, students will have a positive attitude, creative and critical thinking in order to obtain scientific results and to understand the scientific rules [5]. Laboratory work allows students to plan and to participate in investigations or in skills development activities. Many students will be delighted with laboratory work and they expect this method can be used as another way of learning.

The laboratory work cannot be separated from model and modeling. The model as a substitute object or a conceptual representation of the real thing [6]. It is needed because scientific ideas may not be easy to find by students through empirical practice only since it involves the process of initiation into ideas and scientific practices as well as make the ideas and the practices meaningful for every individual [7]. In the process of initiation, there will be some conceptual changes that can be also seen as a common reasoning process [7]. The models have been made static but it can be dynamic because of the thinking and reasoning process in laboratory work in the form of model-based reasoning. It is a generative representational change in science [8] Model-Based Reasoning has an important role in scientific discovery as it does in science learning [9].

The study of model-based reasoning has a fundamental contribution to the development of physics lab work. A new framework that describes model-based reasoning for physics laboratories. The student is more productive after applying to model on systems and physical measurement tools that include construction activities, prediction, data interpretation, model limitation identification, and revision [10]. Model-based reasoning and the ability to solve problems related to defective apparatus in physics lab classes [11]. Modeling gives students useful feedback for teaching decisions and increases professional practice [12]. Based on these studies, it can be inferred that the study of model-based reasoning in laboratory work is necessary as a basis to design effective laboratory work activities.

Laboratory work has five classifications based on their characteristics and objectives, namely (1) scientific process skill approach, (2) deductive or verification approach, (3) inductive approach, (4) technical skills, (5) problem-solving approaches [3]. Generally, frequent laboratory work employs a deductive pattern to prove the theories that have been studied previously. So far, the laboratory work does not pay attention on its purpose while each laboratory work has different purposes, for example, laboratory work on problem-solving aimed at attracting curiosity and train cognitive abilities and attitudes [3, 18]. The low performance in the laboratory work of students will affect their professionalism when becoming physics teachers, this is reflected from the lack of ability among the physics teachers in designing and organizing the activities for school physics lab.

The studies on the model-based reasoning for laboratory work has been widely reviewed [10, 13-16], however, most of them only reviewed on substantial laboratory work, particularly on measurement and troubleshooting activities. They did not examine the overall laboratory work activities. The model-based reasoning in the laboratory work only employ deductive approach and cannot accommodate the needs of 21st-century skills, therefore, this study completes the study of model-based reasoning on laboratory work with other approaches, i.e. problem-solving, inductive, technical skills and processing skills. This research combines deductive laboratory work, technical
skills and problem-solving into a comprehensive laboratory work and observed the model-based reasoning shown by the students. The result of this study can be the basis for the development of best laboratory work in order to improve the students’ critical attitude and teamwork.

2. Research Methodology
This study was conducted on the second semester of student’s undergraduate physics education program in West Borneo. The study was conducted on electrical concepts using Arduino and sensors as electrical measuring instruments. The qualitative research phase, we get a reasoning step which is an initiated reasoning in the problem-solving process. This component is used to define a diagnostic model as a reasoning trace incorporating all the individual reasoning steps that the learner must master to get the right solution. Hierarchy structure is then made with attention to the important thing and ignore the things that are considered less important. Hierarchy structure is the model-based reasoning. To test the validity of the model-based predictive pattern predictions to fit the actual lab work conditions it is followed by observation so that the design of comprehensive laboratory work based on the model-based reasoning can improve teamwork and critical attitude. In the quantitative research phase, a comprehensive laboratory application has been implemented previously for five lessons. During the implementation of comprehensive laboratory work, observation of students’ reasoning activities. Critical attitudes and teamwork are also observed through student behavior. Furthermore, at the end of the learning, students are given scientific attitude and calculated the increase of critical attitude and cooperation with the formula of gain as follows:

\[
\text{gain} = \frac{S_{\text{post}} - S_{\text{post}}}{100\% - S_{\text{pre}}} \times 100\%
\]

(1)

The criteria for gain index according to Hake [17], among others: \( g > 0.70 \) high category; \( 0.30 < g < 0.70 \) medium category; and \( g \leq 0.30 \) low category.

3. Findings
The alternative laboratory work that improves the critical attitude and teamwork was comprehensive laboratory work. It can be seen from each step of reasoning and the developed syntax of the laboratory work. The modified design of laboratory work refers to [10], shown in Figure 1.

The steps of the comprehensive laboratory work consisted of theoretical guidance presentation, technical formulation, measurement, problem description formulation, repair and revision, and evaluation. On repair and revision, the students show different reasoning that could be seen from the selection of problem-solving steps or selected different revision. Table 1 shows students’ reasoning in comprehensive laboratory work.

According to table 1, when learners got problems most of the students (25% of 30 students) have reasoned in repair measurement apparatus. 21% of students repair the measurement model. 20% of students rechecked the physical system model. 16% of students rechecked the physical system apparatus. 5% of students improved theoretical understanding by searched other literature. 23% of students rechecked the technical formulation. The results of the observations during repair of measurement apparatus activities showed in table 2.
Figure 1. Model-based reasoning of deductive, problem solving, and technical skills lab work

Table 1. Students’ reasoning on the comprehensive laboratory work

| Students’ reasoning based on a model                                      | Percentage |
|-------------------------------------------------------------------------|------------|
| Revisions of physical systems apparatus                                 | 16%        |
| Revisions of physical system models                                    | 20%        |
| Repairs of measurement apparatus                                       | 25%        |
| Repairs of the measurement model                                       | 21%        |
| Revisions of theory guidance                                            | 5%         |
| Revisions of technical formulation                                     | 23%        |

Table 2. Percentage of critical attitude and teamwork students shown during the reasoning process

| Reasoning                  | 21st Century Competence                                      | Indicator                                      | Percentage |
|----------------------------|-------------------------------------------------------------|-----------------------------------------------|------------|
| Measurement apparatus      | Critical attitude                                           | Checking on the truth of a concept (skeptic)  | 85%        |
| Teamwork                  |                                                             | Looking for more information to get the truth | 88%        |
|                            |                                                             | Repeating the activities carried out (carefully)| 66%        |
|                            |                                                             | Do not ignore small data                       | 71%        |
|                            |                                                             | Communication with friends and lecturers in learning | 89%    |
|                            |                                                             | Coordination in groups                         | 95%        |
|                            |                                                             | Contributions in groups                        | 96%        |

Table 2 indicating that the critical attitude and teamwork appear more dominant. Referring to the results of scientific attitude scale responses, the implementation of comprehensive laboratory work can improve the critical attitude and teamwork on each indicator as shown in Figure 2. Based on the results of gain calculations that indicate the improvement of scientific attitudes of each indicator as in Table 3.
Table 3. Improvement critical attitudes and teamwork in comprehensive lab work

| 21st Century Competence | Indicator                                      | \( S_{pre} \) | \( S_{post} \) | Gain | Category |
|------------------------|-----------------------------------------------|---------------|--------------|------|----------|
| Critical attitude      | Checking on the truth of a concept (skeptic)  | 75            | 88           | 0.5  | Medium   |
|                        | Looking for more information to get the truth | 79            | 91           | 0.6  | Medium   |
|                        | Repeating the activities carried out (carefully) | 61            | 64           | 0.1  | Low      |
|                        | Do not ignore small data                      | 68            | 79           | 0.3  | Medium   |
| Teamwork               | Communication with others in learning         | 71            | 83           | 0.4  | Medium   |
|                        | Coordination in groups                        | 84            | 98           | 0.9  | High     |
|                        | Contributions in groups                       | 83            | 96           | 0.8  | High     |
|                        | Average                                        | 74            | 85           | 0.4  | Medium   |

Figure 2. Students’ scores on each indicator of critical attitude and teamwork.

4. Discussions
Laboratory work enables students to plan and to participate in an investigation or to take part in activities that can enhance critical attitudes and teamwork. Laboratory work can be classified into five categories and each type of laboratory work has its own objectives and characteristics so that model-based reasoning in laboratory work will have distinctive features. Based on its objectives, the potential for improving 21st century skills is the modification of the laboratory work of deductive, problem solving, and technical skills.

This study explores in depth the characteristics of model-based reasoning in lab work based on qualitative studies supported by observations during learning. Based on the observations it is known the essence of the deductive laboratory work is at confirming the concepts, the principles, and the previous materials. At the beginning of learning, teachers present with the main idea through class discussion and reading, it will be followed by student activities in the laboratory work to illustrate the
concepts and relationships. Deductive laboratory work has positive benefits, which led the students to determine the advanced concept of abstract ideas. However, this laboratory work was considered traditional and it could not facilitate students to develop critical attitudes and teamwork so it must be modified with problem solving and technical skills.

Observations in the problem-solving laboratory work show that activity is dominated by activities that encourage students to experience an authentic investigation. The features of the model-based reasoning of laboratory work on problem-solving are the stage of the problem and the investigation design problem. This approach was highly recommended because students were involved in managing their own learning and they could have a better understanding of what they should do. Problem-solving activities required the connections among cognitive abilities, skills, and attitudes. This is supported by various previous research results that can stimulate critical attitudes, curiosity and train cooperation in groups [3, 19, 20].

Reviewing the intensity pattern of activities that appear on observations of laboratory work of technical skills, note that the characteristics of this laboratory work are the revision of measurement models and apparatus. Activities in the laboratory work of technical skills consist of problem-solving process related to the improvement of measurement device function so that scientific attitude is needed to support the success of laboratory work. Good laboratory techniques were important to obtain accurate data and reduce the probability of mistakes in experimenting [3, 21]. In this laboratory work, all students and teachers must master some basic laboratory techniques and incorporate manipulation skills. Based on the advantages of deductive, problem-solving, and engineering skills, the three models are combined to become a comprehensive lab work with steps consisting of theoretical guidance presentation, technical formulation, measurement, problem description formulation, repair and revision, and evaluation.

Referring to observations in laboratory work, critical attitude and teamwork were the required skills in the 21st century and those can be developed through comprehensive laboratory work. It can be seen from each step of reasoning and the developed syntax of the laboratory work. At the stage of theory, presentation guidance needed a critical attitude to understand the tools’ use and mechanisms. Based on the review of the theoretical guidance, the students needed a critical attitude and teamwork to formulate the set of tools and materials technology. In the process of measurement, it was required a good teamwork to obtain valid data and to make an efficient time for laboratory work based on the target. During the data collection, the students’ critical attitude will come up since they needed a critical attitude to obtain accurate experimental results. In the measurement process, the taken data, sometimes, shows a distorted pattern that required a critical attitude and good teamwork to analyze the problem description to reveal the source of the problem. The evaluation was done to check whether the tool was functioning properly to get accurate data to guarantee a valid conclusion. If there was a discrepancy between the conclusions and the objectives of the experiment, revisions and repair should be made including theory guidance revisions, technical formulation revisions, problem description revisions, measurement model repair, measurement tools repair, revisions of physical systems apparatus, revisions of physical system models, and revision of data analysis.

Each student has a different reasoning. Reasoning involves improvements in measurement devices by replacing suspected non-functional experimental devices. Revisions of physical system models are shown by improving Arduino program codes. Repairs of the measurement model are shown by improving the designed experimental circuit scheme. Revisions of the technical formulation are indicated by improving the experimental process. The revisions of physical systems apparatus and the Revisions of theory guidance are shown by revising theoretical understanding and reviewing the theory guides. Observations during the learning show that most students make improvements in measurement devices if they encounter problems in laboratory work. In contrast, few students revise their theoretical understanding. In the process of reasoning, comprehensive laboratory work spurs student cooperation and raises critical attitudes. The best teamwork showed by coordination, contribution, and communication with friends and lecturers in learning. The communicating during a discussion, students want to accept criticism and improve the statement if there is a mistake. Students
coordinate by dividing the roles/duties of each group member in doing the practicum. Students try to contribute to the group by helping to train a less intelligent friend in assembling experimental tools.

According to the calculation of gain, it is known that there is Improvement of scientific attitude after applying for the lab work comprehensive. The application of comprehensive lab work has improved both sides. However, it has not improved the critical attitude optimally. This is reflected in the lack of accuracy of the students in conducting the experiments indicated by the low increase of critical attitude on the aspect of thoroughness.

5. Conclusions
Five models of reasoning have been obtained in the laboratory work of physics. Three of them were in the form of modification, namely deductive laboratory work, problem-solving, and technical skills to become model-based reasoning in comprehensive laboratory work that can potentially increase students’ critical attitude and teamwork. The results of this study could be a basis for the development of laboratory work covering each stage/component of the students’ reasoning in order to prepare them to undertake the required competence in the 21st century.

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