Inquiry instructional model infused blended experiment: helping students enhance critical thinking skills

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Abstract. Critical thinking skills (CT) are pivotal elements in teaching and learning physics. Training CT skills can be carried out using diverse approaches in learning process. However, infusing blended experiment is rarely conducted to facilitate students to achieve CT skills. This study examined implementation of an inquiry instructional model infused blended experiment to enhance CT skills. The research method used in this study was quasi experiment with non-equivalent pretest-posttest design. The participants of this study were 81 students in one private senior high school in Indonesia. They were divided into three groups (27 students each group) to be given diverse treatments: an inquiry instructional model infused real, virtual, and blended experiment. The CT skills of students were photographed by an instrument test developed in specific topic in physics (i.e. electricity). In addition, normalized gain was used to analyse the enhancing of CT skills and analysis of variance (ANOVA) was expended to investigate the difference of normalized gain significance. Result of this study depicted that the infusing blended experiment through an inquiry instructional model was the most significant treatment among all treatments. This was portrayed by average of normalized gain achieved namely blended (0.44), virtual (0.32), and real experiment (0.31).

1. Introduction
Inquiry instructional model plays prominent role in shaping students’ skills in working in the laboratory independently. Enacting students to investigate a certain concept in science (e.g. physics) is a characteristic of inquiry instructional model. In this case, students act like a little scientist trying to find some concepts. There are several benefits when learning process was conducted in inquiry instructional models such as engaging students to be active in learning process, giving great opportunities to students to investigate the learning problems independently, and training higher thinking order skills (e.g. critical thinking, and problem solving skills) [1].

The implementation of inquiry instructional model would always connect to the types of experiments carried out by students. Most of inquiry instructional model supported by real lab or experiment which students can discover some concepts [2] and this affords direct experiences for students for connecting to real tools. The recent development in technology altered some forms of experiment and provided them in virtual environment. From time to time, the existing of virtual experiment extended widely in
science learning, for example, in physics, chemistry, biology, and engineering [2,3,4]. The reasons why virtual lab is to be popular to be carried out are because some abstract concepts in science can be depicted easily by virtual lab [5]. The second reason is that some experiments need huge cost to be conducted in real experiment and others are not possible to be carried out in real environment [5]. For instance, all concepts of special relativity topics in physics have all abstract concepts that are beyond the real experiment. The third, the time in conducting experiment is to be main aspect because by using virtual experiment, students can re-conduct the same experiment in several times [4, 5]. The last but not least, despite virtual lab no to train hand on aspects of students, this can train students higher thinking orders such as critical thinking and problem solving skills. Thus portrayed that virtual experiment could provide concise time in conducting the experiment for students.

The difference of benefits presented by real and virtual experiment urges researcher to blend these experiments in science learning process. Some research dealing with the implementation of combination between real and virtual lab increased the learning outcomes and conceptual understanding of students [4,6]. These evidences portrayed that blended experiment has great potency when implemented in learning process especially in science that contains a lot abstract concepts. Supporting of virtual lab to real lab was to be the best way in strengthening conceptual understanding of students in specific topic in science (i.e. physics). Some concepts that could not describe by real experiment could be clear by virtual experiment. This situation, indeed, would affect the conceptual understanding of students.

Departing from the benefits of blended experiment, this study tried to infuse blended experiment to inquiry instructional model as a way in enhancing students’ critical thinking. Refer to the syntax of inquiry instructional model used in this study was to use the 5E (engage, explore, explain, elaborate, and evaluate) model [7]. This model was chosen because of the familiarity used in Indonesia context. In every phase of syntax, the indicators of critical thinking skills would be trained by 5E inquiry model infused blended experiments. Infusing blended experiment conducted in two stages such as explore and elaborate which students carried out real experiment second phase (explore) and they conducted again the same topic with virtual experiment in fourth phase. By these situations, students could feel two different experiences using real and virtual experiment in inquiring some concepts of special topic in physics namely electricity. All in all, because these experiences lead to contextual environment, these would stimulate the critical thinking of students [8].

As argued in above, this study took topic the electricity that was focus in several contents namely series and parallel circuits, and Kirchhoff laws. The rationale for these topics is because they could be made in two different environments when students conducted the experiment that was real and virtual lab. Some abstract concepts, for instance, the drift velocity of positive charges as a current can be easily described in virtual lab. Students, indeed, could acquire the new experience dealing with the situations which they never saw before. This model environment hoped to urge students think critically toward what they saw.

There are seven indicators of critical thinking skills used in this study: analyzing affirmations and differences (I1), creating hypothesis (I2), considering an alternative (I3), stating the reasons (I4), making conclusion (I5), and applying concepts (I6). All indicators refer to the indicators of critical thinking skills by Ennis [9] and Fisher [10]. All activities of learning process of inquiry instructional model infused blended experiment could be conduit to train critical thinking skills. For example, to train analyzing affirmations and differences, students created the electric circuit in their worksheet that came from the real circuit that they carried out by real experiment. This process happened in the second phase (explore) when students conducted real experiment. In addition, the indicator of critical thinking such as creating hypothesis was trained in the first phase of inquiry instructional model infused blended experiment (engage). Teacher enacted students with giving real world problem related to electricity concepts. This situation stimulated students proposing hypothesis dealing with question given. Like two indicators explained, other five indicators also were trained by using the phase in inquiry instructional model syntax infused blended experiment. These two samples provided the rationale that inquiry instructional model infused blended experiment could be link students in enhancing both conceptual understanding and critical thinking skills [1]. In other words, students were insisted to
enhance critical thinking skills through series inquiry activities in the classroom both in real and virtual experiment.

2. Method
This study used quasi experiment with non-equivalent pre-test post-test design [11] in order to take data of critical thinking skills. There were 81 participants who came from the first year students in one senior high school in West Java Province, Indonesia. They were divided to three different groups: one control groups (real experiments) and two experiment groups (virtual and blended experiment). Inquiry instructional model infused real experiment was the treatment that was given to control group while infusing virtual and blended experiment to inquiry instructional model were the treatments that were received by experiment groups.

To garden the data of critical thinking skills, an instrument was developed based on seven indicators: analyzing affirmations and differences, creating hypothesis, considering an alternative, generalizing data, stating the reasons, making conclusion, and applying concepts. An instrument developed provided 25 items: 8 items in the first Kirchhoff law, 8 items in the second Kirchhoff law, and 9 items in series and parallel circuit. All items of critical thinking instrument were in multiple choice form, which the right answer was given one and wrong answer was given zero.

The analysis of enhancing critical thinking skills data was investigated using the normalized gain [12] that was acquired from the pre-test and post-test score. This value, then, also tested using analysis of variance (ANOVA) for determining the significance of normalized gain. Further analysis also carried out used post hoc analysis (HSD Tuckey) to determine which group had the most significant improvement of critical thinking skills among all groups. Both ANOVA and HSD Tuckey were tested by using Minitab 16.

3. Result and discussion
The result findings of this research depicted two main aspects namely students’ critical thinking skills comprehensively, and students’ critical thinking skills of each indicator. The analysis of which used normalized gain for enhancing students’ critical thinking skills, and ANOVA for the significance of normalized gain all groups.

3.1. Enhancement of students’ critical thinking skills
The average of normalized gain (\(\bar{g}\)) for all groups (i.e. control group and experimental group) can be seen in table-1. The p-value of ANOVA (p<0.05) depicted that the average of each normalized gain were different and lied in medium category. HSD Tuckey, then, portrayed that BE was the most significantly different among all other groups. On the other hand, VE and RE were not significantly different although the average of normalized gain was distinct.

| Group                  | N  | (\(\bar{g}\)) | HSD Tuckey | ANOVA (p)  |
|------------------------|----|--------------|------------|------------|
| Blended Experiment (BE)| 27 | 0.44         | A          |            |
| Virtual Experiment (VE)| 27 | 0.32         | B          | 6.69 (0.02) |
| Real Experiment (RE)   | 27 | 0.31         |            |            |

There are several factors that cause why inquiry instructional model infused BE was most significant among other groups: learning experiences, the learning activities suitable with topic, and accommodating students’ deliberation. Firstly, learning experiences which students conducted in inquiry instructional model infused BE were rich compare with other treatment (VE and RE). The combination RE and VE was to be unity of experiment gave students better learning experiences in training critical thinking skills. Students would experience two different experiences from real experiment to virtual experiment in creating their critical thinking skills. This was happened because every different learning experience contributed to strengthen critical thinking skills [13]. For instance,
in the second phase (elaborate), students collected data from two experiment, these cases urged students were trained by several skills more than one time or at least two times such as analyzing affirmations and differences ($I_1$), considering an alternative ($I_2$), generalizing data ($I_3$), stating the reasons ($I_4$), and making conclusion ($I_6$). The value of different experiences made meaningful learning for students because they carried out in different context of experiment [4]. This situation, indeed, stimulated critical thinking skills that was embarked from observation process that refer to what students saw and felt and then they used them as facts to be communicated and decided [10].

The second factor deals with learning activities related to learned topic in supporting critical thinking skills. This is essential because both real and virtual experiment have different advantages. When BE infused to inquiry instructional model, every advantage of learning activities provided by RE and VE would fill the drawback effect of each experiment in training critical thinking skills. RE enacted students to be active in hand on [14] that was the basis to search proper information. The acquired information, indeed, would be transferred in other situations, in this case VE. The benefits of VE and RE would be best way to train critical thinking when they were combined and infused to inquiry instructional model. Gelder [15] argued that critical thinking skills could not be learned in one context of learning provided. This case depicted that students had to transfer the initial information to different condition. In the BE, that situation was provided by VE that stipulated rich representation such verbal, numeric, concept, and graph [4].

The factor that we propose is accommodating the deliberation process. The core of deliberation process portrayed the belief retention [15]. Inquiry instructional model infused BE stipulated the initial condition in conflict cognitive form. This would stimulate students proposing hypothesis to answer the problem. The confirmation to the problems would be stipulated by RE in the first time. The first belief grew in mind of students, and VE would strengthen the deliberation process. Students, in this context, would communicate the reason why the phenomenon was happened. This process, indeed, also occurred in RE and VE but the BE provided more than others.

3.2. Enhancement of students’ critical thinking skills of each indicator

To consider how students’ critical thinking skills in each indicator, we elaborated with considering the normalized gain for every indicator. Table 2 depicted the average of normalized gain for seven indicators of critical thinking skills that were investigated in this study.

| Group                  | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
|------------------------|-------|-------|-------|-------|-------|-------|-------|
| Blended Experiment (BE)| 0.44  | 0.43  | 0.47  | 0.39  | 0.19  | 0.38  | 0.48  | 0.62  |
| Virtual Experiment (VE)| 0.32  | 0.28  | 0.41  | 0.36  | 0.11  | 0.28  | 0.24  | 0.56  |
| Real Experiment (RE)  | 0.31  | 0.27  | 0.27  | 0.25  | 0.17  | 0.20  | 0.43  | 0.51  |

Based on data (see table 2), inquiry instructional model infused BE gave positive effect in enhancing students’ critical thinking skills for each indicator. The average of normalized gain of each indicator in BE group had the highest value among those other groups. Six seventh of indicators were in medium category and one seventh in low category [12] for BE group. In addition, VE achieved the higher average of normalized gain in five indicators than those RE while two seventh of average of normalized gain (i.e. RE) were higher than those VE.

The first indicator, analyzing affirmations and differences, was trained well by Inquiry instructional model infused BE. The main factor is meaningful learning experiences. Students conducted RE in the second phase of inquiry (explore) and then they also carried out the same experiment using VE in the fourth phase (elaborate). The effect of this combination would advocate the deep understand that indirectly deals with critical thinking skills. For instance, students could make the real circuit in RE and they could also see the diagram of circuit in VE. From learning experiences, students had rich experiences in analyzing affirmations and differences [4]. The same situation occurred in training of
fourth indicator (generalizing data). Inquiry instructional model infused BE gave students the prior experience in generalizing data from RE. Students, then, re-conducted the same thing in VE. In VE situation, indeed, students were given better data because the data from VE had good characteristic that was non-error data [4] easily generalized.

The indicator of creating hypothesis was trained by inquiry infused BE in problems given to students in the prior learning process and BE. For students who was given the BE treatment in inquiry context acquired three opportunities in creating hypothesis: prior learning process, RE process, and VE process. The different chance was felt by RE and VE which students only created hypothesis in two opportunities. On the other hand, BE in inquiry context gave students the deliberation process [15]. If the result of BE was the highest among other treatments, the result was very logic because the more opportunities for students in creating hypothesis, the better skill of creating hypothesis would be mastered by students.

How did the indicator of analyzing data associated by inquiry infused BE? The process of analyzing data was carried out by students in second phase of inquiry (explore). They analyzed data along with the other students in the same group which mean that BE in inquiry context provided two opportunities to students in discussing with other students in the same group. This rationale showed that BE in inquiry context could enhance this indicator better than the others.

Two indicators of critical thinking skills, making conclusion and applying concepts, were also similar to four indicators explained before. Applying concepts in different situation of physics problems was linked by BE with considering what students did in RE and VE. In the end of RE, students tried to solve the problem related to experiment and they did again the different problem in the end of VE. The more they did with different problems, the higher their skills in applying concept in different situation. In addition, the indicator of making conclusion was spanned by BE in inquiry context by three opportunities that were in the end phase inquiry (evaluate), and two third of these trained in BE through RE and VE. Different from BE, RE and VE were just only to stipulate students in two chances: in the end of experiment and in the end of learning process (evaluate phase).

The six out of seven indicators, BE, VE, and RE was good enough in enhancing students’ critical thinking skills (medium category). One indicator, considering an alternative, had the least enhancing students’ critical thinking skills (low category). This indicator was worked out in learning process through arranging the systematic procedure of experiment. Because the experiment was carried out in context inquiry experiment, students did not familiarize with this situation because they conducted more experiment in cookbook experiment [16]. Thus situation affected directly to the skill of students in arranging the systematic procedure and indirectly affected to students’ critical thinking skills especially in considering an alternative.

4. Conclusion
Inquiry instructional model infused blended experiment was the treatment conducted in this this study. The benefits of real experiment that was combined with the advantages of virtual experiment in inquiry context were to be one of solutions in enhancing students’ critical thinking skills. This treatment, however, was to be evidence how the design of learning process, inquiry instructional model (i.e. 5E model) infused blended experiment, was to be link in facilitating several skills of critical thinking: analyzing affirmations and differences, creating hypothesis, considering an alternative, generalizing data, stating the reasons, making conclusion, and applying concepts. Six out of seven indicators had increase in medium but one indicator rose in low category. By considering the good characteristic owned by inquiry and BE is to be potential to be used in learning process regularly. Although the RE always takes much time, this condition stipulates students in first experience in inquiring new concept. The different supporting is donated to students by VE that present the interesting environment for students in inquiring new concept by take less time than RE. For any researcher who want conducting the study dealing with BE in inquiry context has to be careful in training students in inquiry experiment context. They have to familiarize with inquiry experiment because when they have lack knowledge and experiences; the result of the study is to be bias because of this situation.
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