Meta-Analysis of The Effectiveness of Problem-Based Learning Towards Critical Thinking Skills in Science Learning

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Abstract. In 21st century learning, students are required to be able to face the world of work that requires the ability, one of them is critical thinking. The objective of this meta-analysis is to estimate the effectiveness of problem-based learning on critical thinking skills. This meta-analysis research method consists of some steps, they are research problem, data collection (study), data coding, data analysis, and interpretation. Based on the journal research, it is found 17 critical thinking skills journals, 17 articles that fulfill the criteria: an empirical study on problem-based learning in college and secondary education conducted in classrooms. This explanation revealed that there is a strong positive effect of Problem-based Learning on critical thinking skills. The findings of the research revealed that the results of the meta-analysis were obtained an effect size of the influence of Problem-based Learning on the dependent variable of critical thinking skills of 3.1 which is classified as high where the influence of Problem-based Learning on the dependent variable of critical thinking skills is 99.9%.

1. Introduction
One of the skills that concern in 21st century learning is critical thinking [1]. Critical thinking was conceptualized to include cognitive skills and affective dispositions by the American Philosophical Association (APA) [2]. Critical thinking is the use of skills and strategies to improve outcomes according to individual goals and values [3], evaluating our own and others' ideas without prejudice [4]. Critical thinking involves scientific thinking, formal and informal logic, probabilistic thinking, evaluating the quality of information, generating and selecting alternatives and objectives, and analyzing arguments for conclusions [3]. According to Ennis, critical thinking also involves the ability to assess the credibility of sources, identify conclusions, reasons, and assumptions, assess the quality of arguments, develop and defend positions on an issue, ask appropriate clarifying questions, plan experiments and assess experimental designs, properly define terms, appropriate for the context, being open [5]. Critical thinking skills are very important to apply in students, one of the benefits is to prepare individuals to become independent lifelong learners as one of the long-term goals of education [6].

The implementation of various learning strategies that improve critical thinking skills in Indonesia has been implemented in college through practicum-based learning [7]; scientific approach [8].
secondary schools, especially in science learning including chemistry, physics and biology, several literatures have reported learning strategies used by problem solving and mind mapping [9], a cooperative learning model [10]; [11], inquiry [12]; [13], problem-based learning model [14]; [15]; [16]; [17]; [18]. Among several strategies, problem-based learning has become more prominent in promoting critical thinking skills.

Problem-based Learning has been recognized as a progressive active learning approach and learner-centered which unstructured problems (real-world or simulated complex problems) are used as starting points for the learning process [19]. In the Problem-based Learning model, students work in small collaborative groups and learn what they need to know to solve problems [20]. Problem-based Learning objectives include content learning, acquisition of process skills and problem-solving skills, and lifelong learning. The term of lifelong learning to emphasize skills such as independent learning, independent information mining, collaborative learning, and reflective thinking [20]; [19]. Problem-based Learning steps consist of introducing Problem-based Learning, identifying problems, brainstorming and generating ideas, identifying learning problems from hypotheses, independent learning, peer tutoring and the role of "expert", synthesis and application, reflection and feedback [21].

Research have examined the use of Problem-based Learning as a teaching method to improve critical thinking skills [22], but in addition to critical thinking skills Problem-based Learning also improves scientific and information literacy [23], oral communication [24]. However some research results have reported that Problem-based Learning when compared to conventional classroom learning does not improve critical thinking skills [25]; [26]. However, many researchers have found Problem-based Learning to be more effective in cultivating students' critical thinking skills [27]; [28]; [29]; [30].

A meta-analysis conducted in 2012 [31], a study conducted in the nursing field between 1965 and December 2012 showed that Problem-based Learning had an effect on developing critical thinking skills of nursing students compared to other teaching methods, with keywords guided in the quest is problem-based learning, critical thinking, nursing, and effects. Based on research that has been done before, it is necessary to study the effectiveness of problem-based learning or problem-based learning on critical thinking skills in science learning which includes chemistry, physics, and biology both in colleges and in secondary schools in Indonesia. So that the purpose of reviewing this article with a meta-analysis is to see the effectiveness of PBL on critical thinking skills in science learning. This meta-analysis research combines various kinds of research results that have been there before, focuses on accumulating the impact of previous research results, and can answer questions about the gap in results that occur from the dependent variable critical thinking.

1.1. Research Problem and Research Hypotheses

The problem of this meta-analysis is how effective is Problem-based Learning on critical thinking skills in science learning?

The hypothesis is that Problem-based Learning is effective in improving critical thinking skills in science learning.

2. Method

This meta-analysis research method consists of some steps, they are problem formulation, data collection (study), data coding, and data analysis and interpretation [32]. The procedure for this meta-analysis method is as follows:

2.1. Literature search procedure

The studies analyzed in this research were conducted with several approaches. The search was conducted on an electronic database using the keywords problem-based learning, critical thinking, Indonesia, problem-based learning, critical thinking. The first search was done using electronic databases, including google scholar, ERIC, DOAJ, Sciencedirect, and Researchgate, both in the form of national and international journals. Overall the database from the literature comes from secondary schools and several colleges in Indonesia.
2.2. Inclusion Criteria

Inclusion criteria are done by synthesizing research that investigates the effectiveness of problem-based learning in the fields of physics, chemistry, biology in secondary schools, and colleges. The studies included in this analysis are experimental and quasi-experimental research that compares students taught with problem-based learning models and students taught conventionally. The study that was synthesized was limited to research conducted in Indonesia. Designs that did not have a comparison group were not used in the analysis. Studies that do not report the effect sizes and statistics required for transformation are also excluded. The statistics required for this transformation are the mean, standard deviation, or various parametric statistics such as the results of the t-test and the F test.

2.3. Data Coding

Code sheets were prepared to translate the information into coded form. By using this sheet, variable information and effect sizes are coded for each study by taking into account the variables, they are lessons (biology, physics, chemistry), learning strategies (models or approaches or problem-based learning methods), dependent variables (critical thinking), duration of treatment (less than or equal to four weeks, more than four weeks), school level (college, secondary school), year of publication (2009-2019), sample size (more or equal to 30 people), publication sources (journal articles, ERIC documents), measurement tools (tests).

2.4. Metric for Expressing Effect size

The metric that is used to estimate and describe the effects of small groups is the standard difference effect size (d-index) standard [33]. For a two-sample analysis, the effect size was calculated by subtracting the mean score of the control group from the mean score of the experimental group and dividing it by the mean difference of the two standard deviations. For a single sample, it is calculated by subtracting the mean score at the pretest from the mean score at the posttest and dividing by the mean difference of the two standard deviations. Other formulas that can be used can be seen in table 1.

| No | Statistic Data Given | Formulas |
|----|----------------------|----------|
| 1. | Mean and standard deviation in one group | ES = \( \frac{X_{post} - X_{pre}}{SD_{pre}} \) |
| 2. | Mean and standard deviation in each group (two groups were only done by posttest) | ES = \( \frac{X_{experiment} - X_{control}}{SD_{control}} \) |
| 3. | Mean and standard deviation in each group (two groups performed pre-posttest) | ES = \( \frac{\left( \frac{X_{Post} - X_{Pre}}{SD_{Post}} \right)_{experiment} - \left( \frac{X_{Post} - X_{Pre}}{SD_{Post}} \right)_{control}}{\frac{1}{SD_{pre control}} + \frac{1}{SD_{pre experiment}} + \frac{1}{SD_{post control}}} \) |
| 4. | Chi-square | ES = \( \frac{2r}{\sqrt{1-r^2}} \); \( r = \frac{X^2}{n} \) |
| 5. | t count | ES = \( t \sqrt{\frac{1}{n_{experiment}} + \frac{1}{n_{control}}} \) |

After obtaining the effect size value, the results are interpreted into high, medium, and low categories, the criteria are in Table 2 [33].

| Effect Size (ES) | Cohen’s Standard Category |
|-----------------|--------------------------|
| 0 ≤ ES ≤ 0.2    | Low                      |
| 0.2 ≤ ES ≤ 0.8  | Medium                   |
| ES ≥ 0.8        | High                     |
After obtaining the ES values, the next step is interpreted to determine how much influence the independent variable has on the dependent variable with the conditions shown in Table 3 [34].

Table 3. ES interpretation affects the independent variables

| ES       | Effect (%) |
|----------|------------|
| 0.0      | 50         |
| 0.1      | 54         |
| 0.2      | 58         |
| 0.3      | 62         |
| 0.4      | 66         |
| 0.5      | 69         |
| 0.6      | 73         |
| 0.7      | 76         |
| 0.8      | 79         |
| 0.9      | 82         |
| 1.0      | 84         |
| 1.2      | 88         |
| 1.4      | 92         |
| 1.6      | 95         |
| 1.8      | 96         |
| 2.0      | 98         |
| 2.5      | 99         |
| 3.0      | 99.9       |

3. Results and Discussion

In this study, the number of journals that match with the research objectives is 10 journals. According to the inclusion and exclusion standards, the complete relevant articles (n = 10) were assessed for eligibility. It was found that 8 came from high school and 2 from college, which as a whole were articles about the influence of Problem-based Learning on the dependent variable critical thinking skills. The data abstraction process is shown in Figure 1.

Figure 1. flow chart for the selection of included studies

The details can be seen in Table 4. Effect size calculations were done to determine the effect of Problem-based Learning on the dependent variable on students' critical thinking skills as shown in Table 4.

Table 4. Effect Size Category Effect of Problem-based Learning on Variables Bound to Students' Critical Thinking Skills

| No. | Writer | Dependent Variable | Research Design | SD Control | ES     | Category |
|-----|--------|---------------------|-----------------|------------|--------|----------|
| 1   | U. Setyorini, et al., (2010) [15] | Critical Thinking | Pretest Posttest control group | t count=17 nE=40 nK=40 | 3.7 | High |
| 2   | Redhana, 2012 [35] | Critical Thinking | Pretest Posttest control Group | 18.89 16.57 | 31.54 | 1.1 | High |
| 3   | Malahayati, et al, 2015 [36] | Critical Thinking | Pretest Posttest only 1 group | t count = 45.041 n1=30 n2=32 | 11 | High |
| 4   | Astuti, 2016 [37] | Critical Thinking | Pretest Posttest control Group | 76.55 50.42 | 51.29 | 0.5 | Medium |
| 5   | Buku, et al., (2016) [38] | Critical Thinking | Posttest 3 group | t count= 28.251 n1=28 n2=27 n3 = 28 | 9.3 | High |
| 6   | Erta Sri Wahyu, et al., (2017) [39] | Critical Thinking | Pretest Posttest control group | t count=10.229 nE=34 nK=36 | 2.3 | High |
| 7   | Saei, et al, 2017 [40] | Critical Thinking | Posttest 3 group | t count = 15.9 n1=31 n2=20 n3=31 | 4.7 | High |
| 8   | Meilani, et al, 2017 [41] | Critical Thinking | Pretest Posttest control Group | 16.93 13 | 2.45 | 1.6 | High |
| 9   | Mundilarto, et al., (2017) [42] | Critical Thinking | Pretest Posttest control group | 40.97 32.03 | 17.81 | 0.5 | Medium |
| 10  | R. D. Anazifa, et al., (2017) [43] | Critical Thinking | Pretest Posttest control Group | 54.31 47.43 | 15.77 | 0.4 | Medium |
From Table 4, it can be seen that the effect size calculation results obtained a total ES of $3.1$. It means that the application of Problem-based Learning can improve students’ critical thinking skills by 99.9% [34]. The effect size value is in the high category [33]. The effect size representation of students’ critical thinking skills based on education level is shown in Figure 1.

In Figure 2, it can be seen that the ES at the high school and college levels is respectively 3.4 (high category) and 1.9 (high category).

Problem-based Learning is used as a learning model used in high schools and colleges has been effective and has an effect on improving critical thinking skills. Learning using Problem-based Learning is related to non-routine problem scenarios related to the real world including the main Problem-based Learning factors such as group studies, motivation, facilitators, and the learning environment [51], [52] state that student-centered learning is more effective for developing thinking skills including critical thinking.

Measuring tools in the form of critical thinking skills tests such as the optical instrument critical thinking ability [48], WGTCA [40], The Socratic question [17]. Bloom’s taxonomy of the cognitive learning domain [53]. Based on the results of this research, it has limitations in the standardized test used to measure critical thinking, not all reported the validity and reliability of the instrument. Differences in instrument validity and reliability might influence outcome measures [54]. The results of
the meta-analysis currently only apply to certain studies that were selected and given the stated limitations, generalization, and interpretation of the results should be made with consideration [54]. The measurement of critical thinking skills for the disposition domain (affective) has not been seen in the article found.

4. Conclusion
Based on the results of meta analysis, Problem-based Learning was used as a learning model has been effective and has an effect on improving critical thinking skills.

5. Suggestions
Problem-based learning has a high positive effect in improving critical thinking skills in science learning than traditional educational methods so that science educators can use it for effective learning.

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