Project-based learning through STEM approach: Is it effective to improve students’ creative problem-solving ability and metacognitive skills in physics learning?

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Abstract. This study was aimed to determine the effect size of the PjBL learning model with the STEM approach in improving students’ creative problem-solving ability and metacognitive skills in physics learning. The results of the data analysis showed that there was an influence of the application of the PjBL learning model with the STEM approach toward students’ creative problem-solving ability and metacognitive skills. The creative problem-solving ability score obtained by the experimental class was 0.39 while the control class obtained a score of 0.30. In terms of metacognitive skills, the experimental class obtained a value of 0.30 while the control class obtained a value of 0.20. The PjBL learning model with the STEM approach was more effective in increasing the students’ creative problem-solving ability and metacognitive skills indicated by obtained effect size value of 0.72 and the effect size of the metacognitive skill of 0.64 in the medium category. Based on the results of the MANOVA test, the creative problem-solving ability and metacognitive skills were less than 0.05 (sig <0.05). It can be concluded that there was an effect of the application of the PjBL learning model with the STEM approach toward students’ creative problem-solving ability and metacognitive skills in physics learning.

Keywords: PjBL learning model, STEM approach, creative problem-solving ability, metacognitive skills, physics learning.

1. Introduction

The creative problem-solving ability or CPS is a process, method, or system to approach problems imaginatively and with ideas to look for various possible actions at each step of the problem-solving process [2, 3]. Creative problem-solving ability combines two abilities in a balanced manner, namely the analytical and imaginative abilities [3]. The thinking processes contained in the creative problem-solving ability are divergent thinking and convergent thinking [1-6]. The indicators of creative problem-solving ability are objective finding, fact-finding, problem finding, idea finding, solution finding, and acceptance finding [5,7].

The creative problem-solving ability is necessary and very important to master. They should become one of the teachers’ concerns when teaching at schools. Through creative problem-solving ability, issues
are solved in a new way [4, 8]. Brown defines metacognitive skills as regulatory activities related to problem-solving. These activities involve planning, monitoring, and evaluation components of metacognition [9, 10]. Metacognitive skills are part of metacognition in the form of a regulatory process carried out by individuals to control their cognition [11].

The metacognitive skills take place in the learning process [11] which indicators include planning skills, monitoring skills, and evaluation skills [12]. Metacognitive skills are included in higher-order thinking skills [13] which need to be developed and are very important to be empowered in the learning system because they help students in learning independently, activating self-development, determining the learning goals [10], and increasing academic success [14–18].

Metacognitive skills are closely related to creative problem-solving ability because they are an important factor in problem-solving activities [19]. They help to organize and supervise the learning. Also, they can be predictors of success in choosing an effective action plan to solve problems [10, 20].

Based on the pre-research data obtained from the eleventh-grade students of SMA N 1 Sendang Agung, the students’ average creative problem-solving ability and metacognitive skills were low. They could not solve problems into important points as the basis of choosing problem-solving strategies. The students answered incorrectly because they did not double-check their answers. This was caused by the uninteresting learning process. Students tend to be passive [21] and are less involved during the learning process [22]. The teachers did not pay attention to the creative problem-solving ability when teaching in the class [8]. Therefore, a learning model was needed to deal with the situation, conditions, and needs of students [23].

Students’ metacognitive skills can be improved by using the PjBL learning model [24]. The PjBL learning model can be used in physics learning [25, 26]. The PjBL can guide students to solve given problems and emphasize contextual learning through complex activities, such as giving students the freedom to explore learning activities, carry out projects collaboratively, and ultimately, produce a product [25–26]. Students also have the opportunity to investigate a topic based on a real-life problem in groups and seek knowledge from various sources [29]. Therefore, the PjBL learning can increase students’ creative problem-solving ability.

In line with the development of information and technology [30][31], an effective learning model and learning approaches are needed [32]. The PjBL model can be integrated with the STEM approach. STEM approach is a learning approach that integrates the concept of science, technology, engineering, and mathematics [33].

Through the STEM approach, students do not just memorize concepts, but rather understand the concepts of science and its relation in everyday life so that physics learning will be more meaningful for students [34–36]. This helps students improve their creative problem-solving ability. The application of the STEM approach in learning encourages students to design, develop, utilize technology, hone their cognitive and affective, and apply knowledge [37]. Those factors increase metacognitive skills

Several other studies had been conducted to improve creative problem-solving skills. One of them is the search, Solve, Create, and Share (SSCS) learning model which is effective in improving the creative problem-solving ability. It can also improve mathematical creative problem-solving ability [2]. The creative problem-solving ability can also be improved by a situation-Based Learning approach [5, 7]. Several other studies had also been done to improve metacognitive skills, namely; Remap Teams Games Tournament (Remap TGT) [15] Remap Think-Pair-Share (Remap TPS), and Remap Numbered Heads Together (Remap NHT) [38]. Another study also states that metacognitive skills can be improved by PBL and guided inquiry learning models [39]. The reading concept maps reciprocal teaching (REMAP RT) model can also improve metacognitive skills [40].

The difference between this study and previous studies is that this study used the project-based learning model with a STEM approach to determine its effectiveness on the creative problem-solving ability and metacognitive skills of students in physics learning.
2. Methods and Materials

This research was quasi-experimental. The control group variable is not fully controlled [41]. The experimental group and the control group were not chosen randomly. The design employed in this study was a non-equivalent control group design [41] because this study aimed to determine the effectiveness of the thePjBL with the STEM approach which requires an experimental class and a control class as well as a pretest and posttest in both classes to determine the increase of the creative problem-solving ability and metacognitive skills.

| Experimental class | O₁ | X | O₂ |
|--------------------|----|---|----|
| Control class      | O₃ | 0 | O₄ |

**Figure 1. The Non-Equivalent Control Group Design**

Figure 1 displays that X is the treatment, O₁ is the protest in the experimental class, O₂ is the posttest in the experimental class, O₃ is the pretest in the control class, and O₄ is the posttest in the control class.

The sampling technique used was purposive sampling based on certain objectives or certain criteria, not based on random and strata [42]. Researchers used a purposive sampling technique due to the characteristics of the population and the sample criteria required in the study. The criteria included the level of creative problem-solving ability, the similarity of materials learned, and the same teacher taught the population. Thus, it was decided that the experimental class was class XI IPA 3 and the control class was class XI IPA 2. The material taught during the treatment had basic competence that required students to do a project.

The research instruments used were test instruments to measure the creative problem-solving ability, a non-test instrument in the form of a questionnaire to measure students' metacognitive skills, and observation sheets. The test instrument had been checked for its feasibility through the validity test, difficulty level test, discrimination index, and reliability test.

The validity was tested using the product-moment correlation formula [43].

\[ r_{\text{observed}} = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{n(\Sigma X^2) - (\Sigma X)^2})(n(\Sigma Y^2) - (\Sigma Y)^2)} \]  

(1)

X is the variable scores (respondent's answer), n is the number of respondents, \( r_{\text{observed}} \) is the correlation coefficient between the variable x and the variable y, and Y is the total score of the variable (respondent's answer). The significance of the researcher's validity was calculated using the t-test:

\[ T_{\text{observed}} = \frac{r}{\sqrt{1 - r^2}} \]  

(2)

The value of the correlation coefficient N is the number of questions if \( t_{\text{observed}} \geq t_{\text{critical}} \), the questions are said to be invalid, and if \( t_{\text{observed}} \leq t_{\text{critical}} \), then the questions are said to be valid. Before the data were analyzed, a prerequisite test was carried out in the form of a normality test, namely the Kolmogorov-Smirnov Z (K-SZ) [44]. The variance homogeneity was tested using the variance-covariance matrix homogeneity test [45]. The hypothesis was tested using the MANOVA test assisted by the IBMSPSS Statistics 22 software. The n-gain and the effect size were also tested.

N-gain test had been carried out to see the increase of the creative problem-solving ability and metacognitive skills. The n-gain was tested using the Meltzer formula [46],

\[ g = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum score} - \text{pretest score}} \]  

(3)

The gain value was classified based on Richard R. (1999).
Table 1. Gain Classification

| Gain Value | Interpretation |
|------------|----------------|
| g≥0.7      | High           |
| 0.7>g≥ 0.3 | Moderate       |
| g<0.3      | Low            |

The effect size test had been performed to see the magnitude of the effect of other variables. The calculation was based on Hakke [47].

\[
d = \frac{m_A - m_B}{\sqrt{\frac{sd_A^2 + sd_B^2}{2}}} \tag{4}
\]

Based on the formula, \(d\) is the effect size, \(m_A\) is the average gain value of the experimental class, \(m_B\) is the average gain value of the control class, \(sd_A\) is the standard deviation of the experimental class, and \(sd_B\) is the standard deviation of the control class. The following is the category of effect size according to Erpina [48]

Table 2. Effect Size Category

| Effect size | Category |
|-------------|----------|
| \(d < 0.2\) | Low      |
| \(0.2 \leq \frac{d}{d} \leq 0.8\) | Moderate |
| \(d > 0.8\) | High     |

Analysis of the implementation of the PjBL learning model with the STEM approach. The criteria for assessing the implementation of learning [49] that have been carried out by the researcher are calculated by the following formula:

\[
\text{Percentage} = \frac{n}{N} \times 100 \tag{5}
\]

\(n\) is the score obtained and \(N\) is the maximum score.

Table 3. Evaluation Criteria for Learning Implementation

| Score Range | Criteria     |
|-------------|--------------|
| 90% \(\leq X\) | Very Good   |
| 80% \(\leq X < 90\%\) | Good       |
| 70% \(\leq X < 80\%\) | Enough     |
| 60% \(\leq X < 70\%\) | Less        |
| \(X < 60\%\) | Very Poor   |
3. Results

Figure 2 displays the results of the test to determine the creative problem-solving ability and questionnaires to determine the metacognitive skills. The experimental class's average value of the creative problem-solving ability (Objective finding, Fact-finding, Problem finding, Idea finding, Solution finding, Acceptance finding) was higher than the control class.

Figure 3. The Average Posttest Score of metacognitive Skills Indicator
Figure 3 displays the average score of metacognitive skills. The planning skills and evaluating skills of the control class were higher than the experimental class while the monitoring skills of the control class were smaller than the experimental class.

The greater creative problem-solving ability average pretest score was obtained by the experimental class (34.8) than the control class (33.2) while the greater metacognitive average pretest score was obtained by the control class (49.1) than the experimental class (43.2). It can be seen from the results of the posttest that both classes increased their creative problem-solving ability and metacognitive skills. In the creative problem-solving ability, the experimental class scored 60.6 while the control class scored 48.4. In the metacognitive skills, the experimental class scored 60.9 while the control class scored 59.9. The experimental class had a greater increase than the control class.

Table 4. The Results of Normality Test

| Kolmogorov-Smirnov | Creative Problem-Solving Ability | Metacognitive | Results | Interpretation |
|--------------------|---------------------------------|---------------|---------|----------------|
| Experimental       | Sig. 0.200                      | 0.059         | 0.074   | Sig>α Normal Distribution |
| Control            | 0.090                           | 0.05          | 0.05    |                |

Table 4 shows the sig value of the experimental class in the creative problem-solving ability was 0.200 (0.200> 0.05) while for the control class was 0.090 (0.090> 0.05). The sig value of metacognitive skill in the experimental class was 0.059 (0.059>0.05) while the control class was 0.074 (0.074>0.05). This shows that all data were normally distributed. The results of the homogeneity test can be seen in table 9.
Table 5. Levene’s Test of Equality of Error Variances

|                          | F    | DF1 | SigDF2 |
|--------------------------|------|-----|--------|
| Creative problem-solving | 2.783| 1   | .102   |
| Metacognitive            | .460 | 1   | .501   |

The significant value of the creative problem-solving ability was 0.102 > 0.05 and the metacognitive skills were 0.501 > 0.05. The creative problem-solving ability value was $F_{\text{observed}} = 2.7834$ which was smaller than $F_{\text{critical}} = 0.03431$ so that $F_{\text{observed}} < F_{\text{critical}}$. The metacognitive skill value was $F_{\text{observed}} = 0.460$ which was smaller than $F_{\text{critical}} = 0.03431$ so that $F_{\text{observed}} < F_{\text{critical}}$. The results indicated that the variance between groups was homogeneous.

The Box’s M was performed to see the homogeneity of the variance-covariance matrices. The results can be seen in Table 6.

Table 6. Box’s Test of Equality of Covariance Matrices

|               | Box’s M | F    | df1 | df2 | Sig. |
|---------------|---------|------|-----|-----|------|
|               | 5.108   | 1,628| 3   | 2378017,235 | .180 |

The obtained Box’s M value was 5.108 with a significant value of 0.180. The criteria states if the significance value is greater than $\alpha$, $H_0$ is accepted. It can be concluded that $H_0$ was accepted where the 2 Y variables (creative problem-solving ability and metacognitive skills) had the same variance-covariance matrices with variable X (PjBL learning model with STEM approach).

3.1. The Analysis of Creative problem-solving ability

Table 7. The Recapitulation of N-Gain on Creative Problem-Solving Ability

| Class         | N    | N-Gain         | Category |
|---------------|------|----------------|----------|
| Experimental  | 28   | 0.396562604    | Moderate |
| Control       | 24   | 0.300483339    | Moderate |

The n-gain value of the creative problem-solving ability obtained by the experimental class was 0.396562604 and the control class was 0.300483339, this indicated that the experimental class and the control class increased to the moderate category.

Table 8. The result of Effect Size on the Creative Problem-Solving Ability

| Standard Deviation | Standard Deviation | Effect Size | Category |
|--------------------|--------------------|-------------|----------|
| Experiment Class   | Control Class      |             |          |
| 0.139              | 0.12               | 0.72        | Medium   |

The effect size test showed that the independent variable (PjBL learning model with the STEM approach) affected the dependent variable (creative problem-solving ability). The standard deviation of the experimental class was 0.139 while the standard deviation of the control class was 0.12 and the value of the effect size was 0.72 included in the moderate category.
3.2. The Analysis of the Metacognitive Skill

Table 9. Recapitulation of N-Gain on Metacognitive Skills

| Class         | N    | N-Gain          | Category |
|---------------|------|-----------------|----------|
| Experimental  | 28   | 0.305256003     | Moderate |
| Control       | 24   | 0.204245289     | Low      |

The N-Gain value of metacognitive skills in the experimental class was 0.305256003 and for the control class was 0.204245289. This shows that the metacognitive skill in the experimental class has increased in the moderate category, while the control class has increased in the low category.

Table 10. Results of the EFFECT Size Metacognitive Skill

| Standard deviation Experiment class | Standard deviation Control class | Effect Size | Category |
|-------------------------------------|----------------------------------|-------------|----------|
| 0.15                                | 0.14                             | 0.64        | Medium   |

The results of the effect size test show that the PjBL learning model with the STEM approach affected the dependent variable (metacognitive skills). The standard deviation of the experimental class was 0.15 while the standard deviation of the control class was 0.14 and the effect size value of the metacognitive skill was 0.64 included in the moderate category.

3.3. Hypothetical Test

3.3.1. Multivariate Test

Table 11. Multivariate Test

| Effect             | Sig  |
|--------------------|------|
| Pillai’s Trace     | .000 |
| Wilks’ Lambda      | .000 |
| Hotelling’s Trace  | .000 |
| Roy’s Largest Root | .000 |

Table 11 shows that the significance value of the Pillai’s Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root was 0000 which is smaller than 0.05. It can be concluded that Ho was rejected and H1 was accepted. This means that the PjBL learning model with the STEM approach was effective in increasing creative problem-solving ability and metacognitive skills.

3.3.2. Between Subjects Effect Test

Table 12. Between-Subjects Effects Test

| Source  | Dependent Variable          | F     | Sig  |
|---------|----------------------------|-------|------|
| Intercept | Creative problem-solving ability | 1751  | .364, |
|          | Ability                     |       | 000, |
| Source  | Skill metacognitive         | 2651.735 | 000  |

Table 12 shows that the significance value of the between-Subjects Effects Test was effective in increasing creative problem-solving ability and metacognitive skills.
The obtained significant value of the creative problem-solving ability was 0.000 which is smaller than 0.05. It can be concluded that $H_0$ was rejected and $H_1$ was accepted. The obtained significant value of the metacognitive skills was 0.00 which is smaller than 0.05. It can be concluded that $H_0$ was rejected and $H_1$ was accepted. In short, the application of the PbJL model with the STEM approach was effective in increasing students’ creative problem-solving ability and metacognitive skills. The PbJL model with the STEM approach showed greater effectiveness on the creative problem-solving ability than metacognitive skills.

Table 13. Observation Results

| Meeting | Total Observer Score | Percentage | Category |
|---------|----------------------|------------|----------|
| 1st     | 69                   | 92%        | Excellent|
| 2nd     | 70                   | 93.3%      | Excellent|
| 3rd     | 72                   | 96%        | Excellent|
| Total   | 211                  | 93.7%      | Excellent|

The results of the observation showed that the learning model implementation at each meeting was in the excellent category.

4. Discussion

Based on the N-gain test results, the experimental class and control class’s creative problem-solving ability and metacognitive skills increased. However, the experimental class experienced a greater improvement compared to the control class. The experimental class was more effective than the control class because of the differences in the treatment given by the research to the students.

The experimental class applied the PbJL model with a STEM approach while the control class applied direct instruction with a scientific approach. The PbJl learning model with the STEM approach runs well in the experimental class based on the lesson plan.

The PbJL model can increase learning motivation, activeness, and the ability to solve complex problems. It is also able to improve students’ skills in managing learning resources [50]. The STEM approach also can cultivate the understanding of the relationships between principles, concepts, and skills of a particular discipline domain; help students to understand the process of scientific inquiry; encourage collaborative problem solving and interdependence in group work; expand the mathematical and scientific knowledge; build active knowledge and memory through independent learning; increase students’ interest, participation, and attendance; and develop the ability to apply the knowledge [51].

The PbJL learning model with the STEM approach consists of five steps to achieve a specific process [27]. It is suitable to increase the creative problem-solving ability and metacognitive skills.

In the first step (Reflection), the researchers gave ill-defined questions in the form of problems related to everyday life through videos and images. This step stage-trained the creative problem-solving ability indicator which is an objective finding because the video media and subsequent images required learners to know the problems presented [7]. The problems obtained were then searched for their relationship with the material. This trained the metacognitive skills in the planning skills aspects [10, 12].

In the second step (Research), the students were guided and directed to find information related to the (Science) problem from student worksheets and various sources of information, both from books and the internet (Technology). At this stage, the researchers guided students’ to develop conceptual understanding through discussion [27]. The students conducted an investigation and selected important information that could train their planning skills in the creative problem-solving ability in the form of fact-finding, namely finding information related to facts according to the given problem situation [7].

In the third step (Discovery), students were directed to create a design that can solve the problems in the form of a mini proposal based on the worksheet. This step empowered the problem of finding, idea finding, and solution-finding. The problem finding, idea finding, and solution finding are included in
the creative problem-solving ability indicator, namely identifying data obtained then selecting ideas that can determine solutions [7].

In the fourth step (Application), the teachers asked students to do a project task in the form of making simple binoculars; here is one of the simple binoculars that the students made:

![Figure 5. The Product of Project Assignments](image)

The project assignments were carried out in groups to improve their monitoring skills. The monitoring skills activities had been carried out in various stages and by working on project assignments. In group works, peers corrected wrong or inaccurate methods [12,14]. It also increased acceptance finding by developing a mini proposal containing a plan of action to be carried out so that it can be checked.

Students presented the product of the optical material (mathematics). Here, the students held a question and answer session and each student identified errors [12]. The relationship between metacognitive skills and creative problem-solving ability was directly proportional. The higher the increase of the metacognitive skills, the higher the increase of the problem-solving ability [15]. In his research, metacognitive skills showed a positive relationship with students’ cognitive learning outcomes [14].

This research is in line with other research, namely the integration of the PjBL model with the STEM approach can improve technical skills and project design [52]. The PjBL learning model with the STEM approach provided students the opportunity to design solutions to implement problem-solving [53]. The application of project-based learning integrated with STEM on air pollution material can improve students’ scientific literacy [54]. Besides, other studies showed that the use of the PjBL learning model with the STEM approach can improve students’ creative thinking skills [55]. This is also supported by the result of the implementation of the PbJL model and the STEM approach on the basic competence of milk processing technology which can improve students’ creativity and learning outcomes [56].

5. Conclusion and Recommendation

The PjBL learning model with the STEM approach was more effective in increasing students’ creative problem-solving ability and metacognitive skills indicated by the obtained effect size value of creative problem-solving ability of 0.72 and the effect size value of the metacognitive skills of 0.64 in the moderate category. Based on the results of the MANOVA test, the significance value of creative problem-solving ability and metacognitive skills was less than 0.05 (sig <0.05). It can be concluded that the PjBL learning model with the STEM approach was effective in improving students’ creative problem-solving ability and metacognitive skills in physics learning.

Based on the data analysis and conclusions, the researchers suggest the other researchers examine the effect of the PjBL learning model with the STEM approach on other physics materials. Further researchers should first re-analyze and adjust the application, especially in terms of time allocation, supporting facilities, and students’ characteristics.
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