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# Science process skills and critical thinking skills in inquiry-based learning model with project-based assessment

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## Abstract

The purpose of this research is to determine whether or not there are significant improvements in science process skills and critical thinking skills in connection with the use of the inquiry-based learning model with project-based assessment on the topic of heat and fluids. The current levels of students' science process skills and critical thinking skills are still low, and it is important to develop these skills as they influence the way students think and act in solving problems. The inquiry-based learning model with project-based assessment is used to enhance students' science process skills and critical thinking skills. This research employed a pretest-posttest Non-equivalent Control Group Design. The study involved a population of 10th-grade students at State Senior High Schools in Singaraja, with a sample size of 159 students. Data were collected using tests for science process skills and critical thinking skills. The data analysis techniques included descriptive analysis and multivariate covariance analysis. The analysis results yielded a significance value of $< 0.05$. In conclusion, there are differences in science process skills and critical thinking skills, both simultaneously and partially, between the experimental group and the control group. The findings have confirmed that the inquiry-based learning model with project-based assessment is effective in improving science process skills and critical thinking skills, making it an optimal choice for addressing challenges in physics education.

**Keywords:** Concept of heat, Critical thinking skills, Inquiry-based learning model, Project-based assessment, Science process skills.

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## 1. Introduction

The purpose of education is to develop students' potential to become capable, creative, critical, independent individuals who master science and technology. This potential can be realized if mathematics and science education can foster logical thinking, critical thinking, creativity, initiative, and adaptability to change and development. The skills required to face 21st-century challenges involve not only teaching literacy and numeracy but also how to use and develop thinking skills into higher-order thinking skills [1, 2]. Developing critical thinking skills is crucial because real-life problems are becoming increasingly complex and complicated [3, 4].

According to the Survey Programme for International Student Assessment (PISA) in 2018, Indonesia ranked 73rd out of 79 participating countries in mathematics. In the science category, Indonesia ranked 71st out of 79 countries [5]. This underperformance suggests that Indonesian students' critical thinking skills and science learning outcomes are still very low. Preliminary studies show that students' critical thinking skills have not been optimized [6-8].

21st-century learning aims at preparing learners to enter a workforce that requires them to possess high levels of curiosity, problem-solving skills, and critical thinking skills [9]. Critical thinking skills are among the indicators of quality human resources. The importance of developing critical thinking skills presents a challenge for educators to manage learning that can develop students' critical thinking skills [10-13].

The way physics has been taught so far has not aligned with the true nature of science. The learning has been more teacher-centered, where the teacher tends to use conventional teaching models. In essence, science encompasses processes, products, and attitudes [14-16]. As a process, science focuses on the process of acquiring knowledge. In this process, experts use process skills. Science process skills are essential in learning science. Based on the preliminary studies, it is shown that students' science process skills are still low [17-20]. As a product, science focuses on outcomes, specifically knowledge. On the other hand, as an attitude, it aims at equipping, training, and instilling positive values in students [21].

Learning is the interaction of ideas and processes; new knowledge is built upon prior knowledge; learning is enhanced when students find meaning [22]. It appears that a transformation in physics education is needed, shifting from rote memorization to reflective thinking. Additionally, the assessment system also needs improvement. New ideas to address the suboptimal development of students' science process skills and critical thinking skills are by implementing an inquiry-based learning model that allows students to construct their knowledge through assessments embedded within scientific discovery.

One assessment integrated with the inquiry-based learning model is project-based assessment. Project-based assessment can enhance students’ critical thinking skills and learning outcomes [23, 24]. The inquiry-based learning model in physics education can improve students' activity, critical thinking skills, and science process skills [25, 26]. Based on this background, the research aims at analyzing the differences in science process skills and critical thinking skills simultaneously and partially between students facilitated with an inquiry-based learning model with project-based assessment and those facilitated with a conventional learning model.

In the context of learning science, science process skills involve the development of cognitive, affective, and psychomotor skills. Specifically, cognitive skills are about student learning using the mind, psychomotor skills involve hands-on experiences of students using the tools and materials, measurement, preparation, or assembly tools, and affective skills focus on the interaction of students with each other. Science process skills are known as procedural skills and experimental and scientific inquiry abilities. Science process skills are the abilities utilized by scientists to acquire scientific products, which include: (1) observation, (2) classification, (3) measurement, (4) identification and control of variables, (5) hypothesis formulation, (6) experimentation, (7) drawing conclusions from experiments, and (8) communicating experimental results [27, 28].

Critical thinking means thinking correctly in the pursuit of relevant and reliable knowledge. Critical thinking is reasonable and reflective thinking focused on deciding what to believe or do. The dimensions and indicators of critical thinking skills are: (1) formulating problems, with the indicator of formulating questions that direct investigation; (2) providing arguments, with indicators such as offering arguments as needed, demonstrating similarities and differences, and presenting complete arguments; (3) making deductions, with indicators such as logically deducing, interpreting appropriately, conducting data collection investigations, analyzing data, making generalizations, and drawing conclusions; (4) conducting evaluations, with indicators such as evaluating based on facts and offering alternative solutions; (5) making decisions and taking actions, with indicators such as determining solutions and selecting feasible options for implementation [29, 30].

The teaching model implemented in this research is the inquiry-based learning model with project-based assessment. The steps used in presenting the material with the inquiry-based learning model are as follows: (a) the problem identification phase, (b) the data collection and testing phase, (c) the data collection through experimentation phase, (d) the explanation formulation phase, and (e) the inquiry process analysis phase, as well as the concept application phase [31]. Inquiry teaching is an approach where students study scientific events with the mindset and approach of scientists [32].

According to this approach, the teaching and learning process with an inquiry approach is characterized by the following characteristics: (1) the use of process skills, (2) the teaching and learning process centers around questions, (3) hypotheses are formulated by the students to guide the investigation, (4) the students propose methods for data collection, (5) students conduct experiments individually or in groups, and (6) the students process the data to arrive at tentative conclusions. The advantages of the inquiry approach include: (1) teaching becomes more student-centered, (2) the learning process through inquiry can develop and enhance students' self-efficacy, (3) expectations increase, and (4) the inquiry approach can prevent students from learning through rote memorization [21, 33]. The inquiry-based learning model is an instructional technique where, in the teaching and learning process, students are confronted with a problem [18, 34].

Previous research on physics learning during the data collection phase of experiments used virtual laboratories. Experiments with virtual laboratories had limitations, as the physics concepts learned were less tangible for students. In this study, the data collection phase in the experiment used a real laboratory. This approach was believed to challenge students to think and make greater use of science process skills. The application of an appropriate learning model and type of assessment will influence the learning process. One type of assessment that teachers can use is project-based assessment.

Project-based assessment is conducted on tasks that must be completed within a specified timeframe. A project task begins with planning, data collection, organization, processing, and presentation of data [35]. Project-based assessment requires students to solve various problems. The advantages of project-based assessment include: (1) providing opportunities for students to fully express the competencies they have mastered, (2) being more efficient and producing products with economic value, (3) yielding results in competency mastery that can be accounted for and are eligible for certification, (4) focusing on students' higher-order thinking and problem-solving skills, (5) enhancing students' skills in communication, collaboration, problem-solving, and engaging cognitive, affective, and psychomotor domains [36]. Previous research had a limited scope of material, which in turn restricted students' experience in creating projects. In this study, the scope of the material was broader, covering vibrations, heat, and hydrostatics. This is believed to foster greater development of students' critical thinking skills and science process skills as they complete projects. The previous research focused on the issues of science process skills and scientific attitudes. In this study, besides examining science process skills, critical thinking skills were also investigated.

## 2. Method

This research is a quasi-experimental study. This study uses the pre-test - post-test non-equivalent control group design, which can be described as follows.

| | | | | |
|---|---|---|---|---|
| Experimental Group | : | $O_1$ | $X_1$ | $O_3$ |
| Control Group | : | $O_2$ | $X_2$ | $O_4$ |

[37]

**Figure 1.**
Pre-test post-test non-equivalent control group design.

Figure 2. describes the treatment during the research in the experimental group and control group. At the beginning of the study, both groups were given a pretest ($O_1$) for the experimental group and ($O_2$) for the control group. The experimental group used an inquiry-based learning model with project-based assessment ($X_1$), while the control group used a conventional learning model ($X_2$). At the end of the study, a post-test was administered, ($O_3$) for the experimental group and ($O_4$) for the control group.

This study involved a population of 10th-grade students from state senior high schools (SMAN) in Singaraja. The research sample consisted of 159 students. The sampling technique used was cluster random sampling, which divides the sample into several separate groups (clusters).

The science process skills instrument was in the form of an objective multiple-choice test consisting of 25 questions. The item validity was calculated using the point-biserial correlation formula, and the results showed that the correlation values for all items were greater than the critical value ($r_{table}$), indicating that the items were valid. The reliability of the test was calculated using the KR-20 formula, and the instrument was considered reliable if the calculated reliability coefficient ($r_{count}$) was greater than 0.6. The reliability testing result showed a value greater than 0.6, specifically 0.71, indicating that the instrument was reliable.

The critical thinking skills instrument was in the form of an essay test consisting of 10 questions. The item validity was calculated using the Product Moment Correlation formula, and the results showed that all items were valid because the correlation values were greater than the critical value ($r_{table}$). The reliability of the test was calculated using the Alpha-Cronbach formula. The result of the reliability test was greater than 0.6, specifically 0.87, indicating that the instrument was reliable. Valid and reliable instruments provide accurate and dependable results in measuring attitudes, knowledge, and skills. Indicator in Table 1, the assessment of science process skills is a modification of the main aspects of Harlen [27]. Indicators for assessing critical thinking skills use indicators from Ennis [29] that have been presented in Table 2.

**Table 1.**
Science process skills indicators adapted from Harlen and the number of questions

| Indicators | Vibrations | Static fluids | Heat | Number of questions |
|---|---|---|---|---|
| Formulate a hypothesis | 2 | 1 | 1 | 4 |
| Observe | 2 | 2 | 1 | 5 |
| Investigate | 1 | 1 | 1 | 3 |
| Interpreting findings | 2 | 2 | 1 | 5 |
| Make conclusions | 2 | 1 | 1 | 4 |
| Communicate | 1 | 1 | 1 | 4 |

Based on Table 1, the number of questions for each indicator was as follows: formulating a hypothesis consisted of 4 items, observing consisted of 5 items, investigating consisted of 3 items, interpreting findings consisted of 5 items, making conclusions consisted of 4 items, and communicating consisted of 4 items. The material used covered vibrations, hydrostatics, and heat. Based on Table 2, there was 1 question item for each indicator.

**Table 2**.
Critical thinking skills indicators adapted from Ennis and a number of questions.

| Dimension | Indicator | Number of Questions |
|---|---|---|
| Formulating the problem | Formulate questions that guide the investigation | 1 |
| Provide arguments | Arguments as needed | 1 |
| | Complete argument | 1 |
| Make deductions | Deduct logically | 1 |
| | Interpret correctly | 1 |
| Carrying out induction | Analyze data | 1 |
| | Draw a conclusion | 1 |
| Conduct evaluation | Evaluate based on facts | 1 |
| Decide and implement | Determine the way out | 1 |
| | Choose which possibilities to implement | 1 |

The data were analyzed using descriptive statistics and multivariate analysis of covariance. Prior to hypothesis testing, prerequisite tests were conducted, including tests for normality of data distribution, homogeneity of variance, linearity of data, significance of the regression direction, and multicollinearity. The hypotheses formulated in this study are: 1) there is a simultaneous difference in process skills and critical thinking skills between the experimental group and the control group; 2) there is a difference in science process skills between the experimental group and the control group; and 3) there is a difference in critical thinking skills between the experimental group and the control group. The testing criteria in this study are as follows: H0 is rejected if $F_{count} > F_{table}$ and $p > 0.05$. The physics topics used in this study are heat, vibrations, and static fluids.

## 3. Results and Discussion

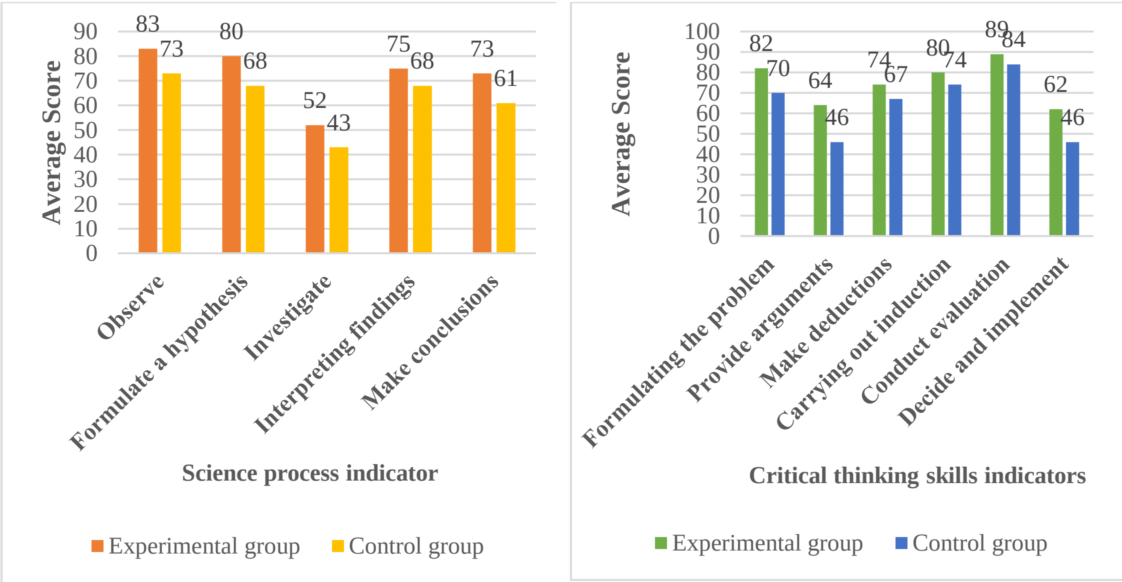
### *3.1. Descriptive of Analysis*

The description of the research data results is presented in Table 3. The results of the descriptive analysis showed that the average science process skills score in the experimental group was 72.4, categorized as high, with a standard deviation of 10.42, which was higher than the control group, which had an average score of 61.5, categorized as moderate, with a standard deviation of 9.02. The average critical thinking skills score in the experimental group was 73.1, categorized as high, with a standard deviation of 10.68. The average critical thinking skills score in the control group was 61.9, categorized as moderate, with a standard deviation of 8.97. This means that the average scores for both science process skills and critical thinking skills were higher in the group of students who were facilitated with the inquiry-based learning model with project-based assessment compared to the group of students who were facilitated with the conventional learning model.

**Table 3.**
Description of science process skills and critical thinking skills.

| Statistics | Experimental Group | | Control Group | |
|---|---|---|---|---|
| | Science Process Skills | Critical Thinking Skills | Science Process Skills | Critical Thinking Skills |
| Mean | 72.4 | 73.1 | 61.5 | 61.9 |
| Std. Deviation | 10.42 | 10.68 | 9.02 | 8.97 |
| Category | High | High | Moderate | Moderate |

Figure 2 shows the scores of the process skills indicator and critical thinking skills dimension. Figure 2(a) explains that the use of the inquiry-based learning model with project-based assessment is more effective in improving the scores of each science process skill indicator compared to the control group. Figure 2(b) explains that the use of the inquiry-based learning model with project-based assessment is also more effective in improving the scores of each critical thinking skill dimension compared to the control group. Students who use the inquiry-based learning model with project-based assessment tend to have a higher inclination toward truth-seeking. This suggests that students do not immediately accept the information provided but first verify its accuracy. Through experiments to complete projects, curiosity is fostered and students' science process skills are practiced. In addition, students are trained to analyze every phenomenon they encounter. In other words, students are trained to develop their thinking abilities. The results of the study show that the experimental group scores higher than the control group on all indicators or dimensions.




(a) (b)

**Figure 2.**
(a) Science process skills and (b) critical thinking skills.

### *3.2. Prerequisite Tests for Analysis*

The prerequisite tests for analysis include the test of normality of data distribution, the test of homogeneity of variance, the test of linearity, a test of significance of regression direction, and the test of data multicollinearity. Research hypothesis testing is conducted once all prerequisite tests are met. The results of the prerequisite tests are as follows.

#### *3.2.1. Normality Test*

A summary of the results of the normality test for science process skills and critical thinking skills is presented in Table 4. Based on the calculation results, the Kolmogorov-Smirnov[a] significance values for all variables are as follows: 0.08 for science process skills in the experimental group ($Y_1$); 0.11 for science process skills in the control group ($Y_2$); 0.06 for critical thinking skills in the experimental group ($Y_3$); and 0.07 for critical thinking skills in the control group ($Y_4$). Since these values are greater than 0.05, Ho is accepted, meaning the data were normally distributed. In conclusion, the distribution of data for all variables was normal.

**Table 4.**
Results of the normality test for science process skills and critical thinking skills.

| Variables | Shapiro-Wilk | | | Condition | Conclusion |
|---|---|---|---|---|---|
| | Statistic | df | Sig. | | |
| ($Y_1$) | 0.094 | 79 | 0.08 | 0.08 > 0.05 | Normal |
| ($Y_2$) | 0.116 | 80 | 0.11 | 0.11 > 0.05 | Normal |
| ($Y_3$) | 0.098 | 79 | 0.06 | 0.06 > 0.05 | Normal |
| ($Y_4$) | 0.94 | 80 | 0.07 | 0.07 > 0.05 | Normal |

#### *3.2.2 Homogeneity of Variance Test*

The results of the homogeneity of variance test are shown in Table 5. Referring to Table 5, the significance values generated for each data group were all greater than 0.05. This means that the data on science process skills, critical thinking skills, and data on science process skills and critical thinking skills had homogeneous variances.

**Table 5.**
Summary of homogeneity of variance test results

| Data | F | Sig. |
|---|---|---|
| Science Process Skills ($Y_1$) | 1.618 | 0.21 |
| Critical Thinking Skills ($Y_2$) | 3.661 | 0.06 |
| $\begin{pmatrix}Y_1\\Y_2\end{pmatrix}$ | 8.175 | 0.07 |

#### *3.2.3. Linearity Test and Significance of Regression Direction Test*

The results of the linearity test are shown in Table 6. Indicate that the significance values for deviations from linearity are greater than 0.05, specifically 0.52 for science process skills and 0.11 for critical thinking skills. These values indicate a linear relationship between the pre-test and post-test data.

**Table 6.**
Results of linearity test.

| Regression | N | F-*Deviation from linearity* | Sig. |
|---|---|---|---|
| $X_1 - Y_1$ | 159 | 0.95 | 0.52 |
| $X_2 - Y_2$ | 159 | 1.45 | 0.11 |

The results of the significance of the regression direction test are shown in Table 7. The results of the analysis showed a significance value for the F linearity of less than 0.05, which was 0.00; therefore, H0 is rejected. It can be concluded that the pre-test scores X1 had a significant linear relationship with science process skills (Y1), and the pre-test scores X2 had a significant linear relationship with critical thinking skills (Y2).

**Table 7.**
Results of the significance of the regression direction test

| Regression | N | F-*Linearity* | Sig. |
|---|---|---|---|
| $X_1 - Y_1$ | 159 | 8.655 | 0.00 |
| $X_2 - Y_2$ | 159 | 9.025 | 0.00 |

*3.2.4. Multicollinearity Test*

Multicollinearity testing is conducted if the tolerance value is less than 0.1 or the Variance Inflation Factor (VIF) is greater than 10, which indicates multicollinearity. Based on the analysis results, the VIF value = 1.00, or the tolerance value = 1.00, with a significance level of less than 0.001. Since the VIF is less than 10, the variables of science process skills and critical thinking skills did not experience multicollinearity and therefore could be used as dependent variables both individually and simultaneously.

*3.3. Results of Multivariate Covariance Test*

*3.3.1. The Effect of Inquiry-Based Learning Model with Project-Based Assessment on Science Process Skills and Critical Thinking Skills*

The results of the multivariate covariance test are presented in Table 8. The multivariate covariance analysis yielded an F-value of 66.593[b] with a significance level of 0.000 for Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. The research hypothesis H0: 'There is no simultaneous difference in science process skills and critical thinking skills between students facilitated with the inquiry-based learning model with project-based assessment and those facilitated with the conventional learning model' is rejected.

**Table 8.**
Multivariate tests[a]

| | Effect | F | Sig. |
|---|---|---|---|
| | Pillai's Trace | 66.593[b] | 0.000 |
| Z | Wilks' Lambda | 66.593[b] | 0.000 |
| | Hotelling's Trace | 66.593[b] | 0.000 |
| | Hotelling's Trace | 66.593[b] | 0.000 |

*3.3.2. The Effect of Inquiry-Based Learning Model with Project-Based Assessment on Science Process Skills*

The results of the Tests of Between-Subjects Effects are presented in Table 9. The test yielded an F-value of 82.168 with a significance level of 0.000 for the variable of science process skills. The research hypothesis H0: 'There is no difference in science process skills between students facilitated with the inquiry-based learning model with project-based assessment and those facilitated with the conventional learning model' is rejected because the significance value is less than 0.05, specifically 0.000. This indicates that there is a significant difference in science process skills between the experimental group and the control group.

**Table 9.**
Tests of between-subjects effects.

| Dependent Variable | F | Sig. |
|---|---|---|
| Science Process Skills | 82.168 | 0.000 |
| Critical Thinking Skills | 51.687 | 0.000 |

*3.3.3. The Effect of Inquiry-Based Learning Model with Project-Based Assessment on Critical Thinking Skills*

Table 9 shows the results of the Tests of Between-Subjects Effects, which yielded an F-value of 51.687 with a significance level of 0.000 for the critical thinking skills variable. The research hypothesis H0: 'There is no difference in critical thinking skills between students facilitated with the inquiry-based learning model with project-based assessment and those facilitated with the conventional learning model' is rejected because the significance value is less than 0.05. This indicates that there is a significant difference in critical thinking skills between the experimental group and the control group.

*3.4. Discussion*

Science process skills are intellectual activities commonly performed by scientists to solve problems and discover scientific products [27, 38]. Critical thinking is a systematic approach that allows students to examine the facts, assumptions, logic, and language underlying others' arguments. To enable students to compete and face future challenges, critical thinking is essential [39].

Currently, students' science process skills and critical thinking skills have not developed optimally in science learning. This is because the learning process has not been able to facilitate students in learning using a scientific approach [26, 40]. Therefore, it is necessary to direct students toward solving science problems by involving critical thinking skills and science process skills. The inquiry-based learning model is an approach that involves students in discovering or proving concepts, principles, and laws of physics [41]. This learning model integrates project-based assessment, which involves students designing, collecting data, and reporting their project results. In this model, the teacher acts as a facilitator and evaluates the results of students' work or discoveries presented through the completed projects. The hypothesis test results indicated that H0 was rejected, meaning there were simultaneous differences in science process skills and critical thinking skills between students facilitated by the inquiry-based learning model with project assessment and those facilitated by the conventional learning model. The differences arose because students were challenged to think and were trained to develop science process skills while working on projects. These research findings are consistent with the study by Erkacmaz, et al. [42]. The learning steps in this study differed from previous research. The difference in this study lies in the fact that, after students discovered the concept, they continued by creating a project applying the concept they had learned. Experts have previously conducted research showing that the elements of activities within the inquiry-based learning model have a positive impact on curiosity, self-efficacy, critical thinking, and learning outcomes. Although empirically, no research has specifically mentioned that the inquiry-based learning model with project-based assessment has a positive effect on science process skills and critical thinking skills. Therefore, further research on this matter is needed.

The hypothesis test indicated a significant difference in science process skills between students facilitated by the inquiry-based learning model with project-based assessment and those facilitated by the conventional learning model. The average science process skills score for the experimental group was higher than that of the control group. This difference was because, when students planned projects, created projects, and reported project results, they became accustomed to formulating hypotheses, performing measurements, analyzing data, interpreting data analysis results, and communicating project outcomes. Such learning experiences develop students' science process skills. These findings are consistent with the study by Puspito, et al. [43], which found that the Inquiry-based Laboratory Approach in science education can enhance science process skills. This study's findings also align with the research by Parmiti, et al. [36], which found a significant difference in science process skills between students learning with Project-based Assessment based on local culture and those with conventional assessment.

Critical thinking skills are essential in physics education. Students need critical thinking skills to succeed in the 5.0 society revolution [44, 45]. Higher levels of critical thinking lead to greater mastery of physics concepts. Critical thinking helps students build knowledge into great ideas. Hypothesis testing showed a significant difference in critical thinking skills between the experimental group and the control group. The average critical thinking skills of the experimental group were higher than those of the control group. This was due to the student's enthusiasm during experiments when working on projects, which supports curiosity, utilizes process skills, and demands critical thinking. Learning activities in the experimental group were oriented towards the stages involved in project-based assessment, integrated within the inquiry-based learning model. The treatment of classroom learning procedures had an impact on material presentation. The students worked systematically, starting with a problem, gathering information, planning the project, executing the project, drawing conclusions, and communicating the project results.

Inquiry-based learning with project-based assessment is student-centered. This approach challenges students to engage in critical thinking, such as providing arguments, inductive and deductive reasoning, and making decisions to solve problems. Project tasks encourage students to develop higher cognitive thinking [46, 47]. According to Rejeki [48], the inquiry-based learning model promotes the development of thinking skills, problem-solving, creativity, information access, information processing, questioning, drawing conclusions, and negotiating. The results of this study are consistent with research by Erkacmaz, et al. [42], which found that an inquiry-based laboratory approach effectively enhances science process skills and critical thinking skills. While working on the project, collaboration occurs among group members to produce a quality project. Collaboration motivates students to present innovative ideas based on their critical thinking. The research of Wilma et al. showed that collaborative learning positively impacts the improvement of concept mastery and critical thinking skills [49]. Furthermore, Nguyen's research findings indicated that project-based assessment has an effect on students' critical thinking [50].

## 4. Conclusion

Based on the research results and discussion, the following conclusions are made. There is a significant difference in science process skills and critical thinking skills, both simultaneously and partially, between the students facilitated by the inquiry-based learning model with project assessment and those facilitated by the conventional learning model. The inquiry-based learning model with project-based assessment is an innovative learning model grounded in constructivist theory. This model can serve as an alternative teaching model in physics education. This research can be further developed with other materials and by using virtual labs. Furthermore, for future researchers interested in investigating the same topic, it is suggested to consider including science process skills and critical thinking skills as additional factors. Additionally, enhancing the statistical significance by enlarging the sample size.

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