# Learning Chemistry Through Project: The Impact of STEM – Based Project Learning on Students' Mastery of Natural Acid- base Indicators

**Hilka Yovi Selvirna[1],**
**Dedeh Kurniasih[2*]**
**Raudhatul Fadhilah[3]**
[1,2,3]Muhammadiyah University of Pontianak,
Jl. Jendral Ahmad Yani N0. 111

dedeh. kurniasih@unmuhpnk.ac.id

## ABSTRACT

The low student achievement in acid–base material at SMAN 9 Pontianak highlights the need for an innovative learning approach that promotes active student engagement and strengthens conceptual understanding. Previous studies have shown that the Project-Based Learning (PjBL) model can improve students' conceptual understanding when integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach. This study aims to analyze the effect of the STEM-based PjBL model on improving student learning outcomes. A quantitative approach was used with a quasi-experimental design of the Nonequivalent Control Group Design type. The sample was selected using purposive sampling, resulting in 74 eleventh-grade students out of 246, divided into a control group (demonstration method) and an experimental group (PjBL-STEM), each consisting of 37 students. The research instruments included validated pretest and posttest questions. Data were analyzed using normality tests, homogeneity of variance tests, independent sample t-tests, and effect size calculations. The results showed a significant difference between the two groups, with an effect size of 2.085, which falls into the high category. These findings indicate that the implementation of the STEM-based PjBL model significantly improves student learning outcomes and is effective in developing critical thinking skills and understanding of chemistry concepts. Therefore, the STEM-based PjBL model can be considered a strategic alternative in chemistry education.

**Keywords:** Acid–Base, Student Learning Outcomes, STEM Approach, Project-Based Learning.

## INTRODUCTION

Chemistry, as part of the natural sciences, plays a vital role in equipping students with scientific thinking abilities and problem-solving skills. Chemistry learning in the Merdeka Curriculum is expected to transform into a more meaningful and transformative experience by providing space for students to explore, innovate, and create in understanding scientific phenomena around them (Taruklimbong & Murniarti, 2024; Desrianti & Yuliana Nelisma, 2022). The characteristics of this curriculum encourage the development of 21st-century competencies, including critical thinking, creativity, collaboration, and communication (Jufriadi et al., 2022). However, the reality of chemistry learning in the field still shows many challenges, particularly in mastering abstract concepts such as acid–base material. Students often struggle to understand the content, especially in calculations and applying concepts to real-life contexts (Uthami et al., 2023). This condition contributes to the low learning outcomes, as reflected in Indonesia's science literacy score in PISA 2022, ranking 74th out of 79 countries, with a score of 396—far below the international average (OECD, 2022).

A similar issue was found at SMAN 9 Pontianak. Observations and interviews revealed that many students remained passive during chemistry lessons. Teachers' efforts to use various learning media, such as PowerPoint presentations and educational videos, have not significantly improved learning outcomes. Among the 37 students in class XI Chemistry 3, 40.54% had not met the minimum mastery criteria (KKM), indicating that conventional teaching strategies have not sufficiently supported deep conceptual understanding.

Based on these facts, the problem lies in the use of learning approaches and models that have not effectively increased student activity and learning outcomes. Therefore, innovation in learning is needed to enhance both student achievement and engagement. One possible solution is to implement active, innovative, and enjoyable learning experiences that are expected to produce high-quality students—such as by applying the Project-Based Learning (PjBL) model integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach (Salame & Nazir, 2019). The implementation of appropriate learning models and approaches, such as STEM-based PjBL, is expected to be a solution to the low learning outcomes observed at SMAN 9 Pontianak.

Project Based Learning focuses on developing students' independence in learning through problem-solving, as well as providing opportunities for students to produce a project or product as part of their learning process, which emphasizes contextual learning (Sholahuddin et al., 2023; Astra et al., 2019). This learning model involves several stages: formulating essential questions, designing the project, creating a schedule, monitoring project progress, testing the outcomes, and evaluating the completed project (Eriza & Hadi, 2023). PjBL has several advantages, such as enhancing students' conceptual understanding and creativity through project activities (Cahyaningsih et al., 2020). encouraging active student engagement (Krismawati, 2019. and improving students' learning outcomes (Mangangantung et al., 2023). Meanwhile, STEM is an innovative learning approach that integrates science, technology, engineering, and mathematics to provide meaningful learning experiences for students (Fajrina et al., 2020). The advantages of the STEM approach include enhancing students' understanding of principles and concepts, and fostering curiosity (Saleh et al., 2020).

The STEM approach and Project-Based Learning (PjBL) model have been proven effective in improving students' learning outcomes and critical thinking skills, as supported by various studies. (Baihaqie et al., 2024) showed that the implementation significantly enhanced students' critical thinking skills, with the average pretest score increasing from 35.53 to 82.89 on the posttest. In the topic of global warming, (Oktaviyanti et al., 2024) also reported similar findings, where the application of the PjBL model improved students' pretest scores from 48.7 to 84.65 on the posttest. Overall, these findings reinforce the conclusion that project-based learning integrated with the STEM approach not only impacts cognitive aspects but also strengthens scientific literacy, problem-solving abilities, and students' readiness to face real-world challenges. It also encourages students to think across disciplines and produce authentic, project-based solutions (Amarlita, 2023).

However, at SMAN 9 Pontianak, the implementation of PjBL has not yet systematically integrated the STEM approach. The PjBL model is still used conventionally, even though integrating STEM into learning projects not only strengthens theoretical aspects but also facilitates 21st-century skills. Therefore, this study was conducted to evaluate the effect of implementing the STEM-based PjBL model on students' mastery of natural acid–base indicators, as well as to provide empirical contributions to the development of more innovative and applicable chemistry learning strategies.

## METHOD

This study used a quantitative approach with an experimental method. The population consisted of 246 eleventh-grade students in the second semester at SMAN 9 Pontianak. Using purposive sampling, 37 students from class XI Chemistry 2 were selected as the control group and 37 students from class XI Chemistry 3 as the experimental group. The research design used was the Nonequivalent Control Group Design, with the research layout presented in Table 1.

Table 1: Nonequivalent Control Group Design layout

| Class | Pretest | Treatment | Posttest |
|---|---|---|---|
| E | $O_1$ | $X_1$ | $O_2$ |
| K | $O_3$ | $X_2$ | $O_4$ |

Information:

| | | |
|---|---|---|
| E and K | : | Experimental class and control class |
| $O_1$ and $O_3$ | : | Pretest for experimental and control classes |
| $X_1$ | : | Treatment given to the experimental class using the STEM-based PjBL learning model |
| $X_2$ | : | Treatment given to the control class using the demonstration method |
| $O_2$ and $O_4$ | : | Posttest for experimental and control classes |

Calibration of Research Instruments

**Validation**

Validation testing is a process used to evaluate the feasibility of a measurement tool, namely the learning tools (chemistry teaching modules, student worksheets, and project assessment rubrics) and research instruments (pretest and posttest questions), for use in learning activities. In this study, there were two validators: a lecturer and a chemistry teacher. The validation scores from the validators were calculated using a percentage formula. The criteria for the validation results are presented in Table 2.

Table 2: Classification of Validation Results

| Percentage% | Validation criteria |
|---|---|
| 76-100 | Valid |
| 56-75 | Fairly Valid |
| 40-55 | Less Valid |
| 0-39 | Not Valid |

(Sukmadinata, 2012).

**Reliability**

Reliability testing is conducted to determine the extent to which the test used can be trusted. Therefore, the validated pretest and posttest questions need to be trialed first. The tests in this study are in the form of essay questions, and their reliability level is calculated using the Alpha formula, as shown in Equation (1) below.

$$r_{11} = (\frac{n}{n-1})(1 - \frac{\sum ó_i^2}{ó_i^2} \qquad \text{(equation 1)}$$

Table 3: Reliability Test Criteria

| Coefficient Interval | Criteria |
|---|---|
| 0,800-1,000 | Very High |
| 0,600-0,899 | High |
| 0,400-0,599 | Moderet |
| 0,200-0,399 | Low |
| 0,000-0,199 | Very Low |

### Data Analysis

Data analysis was conducted using SPSS version 25.0 for Windows to determine whether there were significant differences in students' learning outcomes between the experimental class implementing the STEM-based Project-Based Learning (PjBL) model and the control class using conventional learning. The testing stages included the Normality test (Shapiro-Wilk), Variance Homogeneity test, Independent Sample t-Test, n-gain analysis, and Effect Size calculation.

## FINDINGS AND DISCUSSION

### Findings

### Validation of learning tools

The validation process was carried out using validation sheets referring to the criteria of content feasibility, language, and presentation, in accordance with the standards of learning tools in the Merdeka Curriculum. After all assessment instruments were completed, the scores from each validator were collected and analyzed to determine the validity level of the tools. The validation test results by the validators are shown in Figure 1.

Figure 1: Diagram of Learning Tools Validation Results

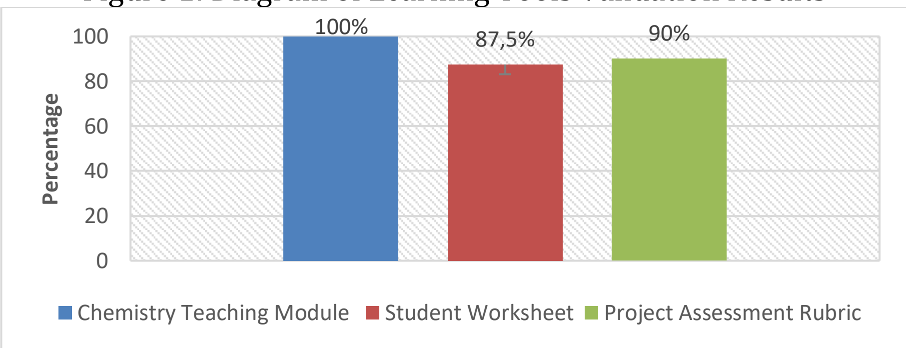


Figure 1 shows that the teaching module received the highest validation score, with an average of 100%, indicating that the module meets the validity standards for use in learning. The project assessment rubric was validated at 90%, while the student worksheet received the lowest validation score of 87.5%. Overall, the learning tools demonstrate a very high level of validity and are deemed suitable for use in the learning process.

### Validation Test of Research Instruments

The research instruments that were validated consisted of the pretest and posttest questions. The validation results showed that both the pretest and posttest instruments received the same validation score of 87.5%. This percentage falls into the 'good' category, while 12.5% was categorized as 'fairly good'. The instruments met the feasibility criteria and were declared suitable for use in the research.

### Reliability Test

The reliability test was conducted in Grade XII Science at SMAN 9

Pontianak, where students had previously studied acid-base material. The results of the reliability test showed that the research instrument obtained a reliability coefficient of 0.79. Therefore, it can be concluded that the instrument is suitable for measuring students' learning comprehension.

**Normality Test**

The students' pretest and posttest data were analyzed using the Shapiro-Wilk normality test. This test was conducted to determine whether the students' learning outcomes data, both before and after the treatment, were normally distributed. The analysis results showed that the significance value in the experimental class was 0.196 for the pretest and 0.497 for the posttest. Meanwhile, in the control class, the significance values were 0.460 for the pretest and 0.108 for the posttest. All significance values are greater than 0.05 (Sig. > 0.05), indicating that the data in both classes are normally distributed.

**Homogeneity of Variance Test**

The homogeneity test aims to determine whether two groups of data have equal variances. The result of the homogeneity test showed a significance value of 0.268 > 0.05, indicating that the variances of the two groups are homogeneous. This means there is no significant variance difference between the control and experimental groups in the pretest data. With the assumptions of normality and homogeneity met, the data analysis can proceed using the Independent Samples Test with the assumption of Equal Variances Assumed.

**Independent Samples t-test**

Based on the analysis using the assumption of Equal Variances Assumed, the significance value (2-tailed) obtained was 0.046 for both classes. Since this significance value is less than ($p < 0.05$), the null hypothesis ($H_0$) is rejected. Therefore, it can be concluded that there is a significant difference in the students' initial abilities between the experimental and control classes. Consequently, the subsequent data analysis focuses on the gain scores to examine the improvement in learning outcomes.

**N-gain Calculation**

The n-gain analysis showed that the average increase in student learning outcomes in the experimental class was 79.90 (high category), while in the control class it was only 37.22 (medium category). These results indicate that students in the experimental class experienced a significantly higher improvement in learning outcomes. Thus, the implementation of the STEM-based Project-Based Learning (PjBL) model proved to be more effective than conventional learning in the control class.

## Effect Size Calculation

The result of the effect size calculation yielded an ES of 2.085 > 0.8, which falls into the high category. This indicates that the implementation of the STEM-based Project-Based Learning (PjBL) model is significantly more effective in improving students' learning outcomes compared to conventional methods. This is because the approach is more aligned with the learning needs of the 21st century.

Instruction in the experimental and control classes

The implementation of the PjBL-STEM learning model in Grade 11 Chemistry 3 at SMAN 9 Pontianak showed positive results in improving learning outcomes. The learning activities were carried out on February 5th, 7th, and 12th, 2025. Students participated in the learning process through the five stages of the PjBL-STEM model (reflection, research, discovery, application, and communication) (Maulana, 2020). Details of the implementation of each stage in the learning process can be seen in Table 4

Table 4: Implementation of PjBL-STEM (Shafiul A. et al., 2020)

| PjBL Stage | STEM Stage | STEM Components | PjBL-STEM Outcomes |
|---|---|---|---|
| Formulating essential questions | Reflection | **Science:**Understanding acid-base phenomena<br>**Technology:**Identifying the problem<br>**Engineering:**Determining the requirements for a simple acid-base indicator project<br>**Mathematics:**Defining variables | Students are able to formulate problems and define project objectives, such as creating a simple acid-base indicator using filter paper and testing acids and bases |
| Designing the project | Research | **Science:**Collecting scientific data from literature<br>**Technology:**Analyzing types of natural indicators and their application in simple technologies<br>**Engineering:**Designing a simple acid-base indicator<br>**Mathematics:**Calculating required materials | Students are able to design a scientific project based on STEM knowledge to solve the problem of simple acid-base testing. |
| Developing a project schedule | Discovery | **Science:**Planning scientific steps according to experimental methods<br>**Technology:**Preparing the steps for creating a simple acid-base indicator. | Students are able to independently create a plan and schedule for project implementation. |

| | | | |
|---|---|---|---|
| | | **Engineering:**Developing a workflow for the product<br>**Mathematics:**Designing schedules and timelines | |
| Monitoring the project | Application | **Science**:Observing and recording experimental results<br>**Technology:**Using tools such as a pH indicator<br>**Engineering:**Producing indicators as planned<br>**Mathematics:**Analyzing experimental data | Students are able to carry out experiments and systematically record data |
| Testing the project results | Communication | **Science:**Analyzing and explaining test results<br>**Technology:**Evaluating product effectiveness<br>**Engineering**:Assessing product function and outcome<br>**Mathematics:**Comparing results with initial data | Students are able to present project results in a scientific and communicative manner |

In the learning process, an evaluation of the project outcomes was also conducted, covering aspects such as planning, implementation, presentation of results, and submission of the final report. The students' average scores are shown in Table 5.

Table 5: Average Scores of Students in the Experimental Class.

| Aspect | K1 | K2 | K3 | K4 | K5 | K6 |
|---|---|---|---|---|---|---|
| Planning | 100 | 100 | 100 | 100 | 75 | 100 |
| Implementation | 100 | 75 | 75 | 100 | 100 | 75 |
| Project Presentation | 75 | 50 | 75 | 75 | 100 | 75 |
| Report Submission | 100 | 100 | 100 | 100 | 100 | 100 |
| Average | 93,75 | 81,25 | 87,5 | 93,75 | 93,75 | 87,5 |

**Description:**

K1 - K6 : Groups 1 to 6

Table 5 shows that Groups 1, 4, and 5 achieved the highest project score (93.75). Groups 3 and 6 ranked second (87.5), while Group 2 obtained the lowest score (81.25). Nevertheless, all groups performed very well in designing their projects and presenting the results.

### Control Class Learning

Learning in the control class used the demonstration method integrated with the contextual teaching and learning (CTL) model, and was conducted in Grade XII Chemistry 3 on February 11, 2025. The learning process in the control class followed seven stages (constructivism, questioning, inquiry, learning community, modeling, reflection, and authentic assessment) (Astawa, 2022). The implementation of the demonstration method within the CTL model involved the teacher starting with contextual questions to connect students' experiences with the acid-base material. Demonstrations were carried out using natural materials such as turmeric, red cabbage, and carrots. Students observed color changes, engaged in discussions, drew conclusions, and reflected on what they had learned. As a closing activity, students completed practice questions as a form of authentic assessment.

## DISCUSSION

Each class (experimental and control) was given a pretest aimed at determining the students' initial abilities before the treatment was applied to both the experimental and control classes. Afterwards, a posttest was administered to assess the final abilities of both classes. A comparison of the learning outcomes between the experimental and control class is shown in Figure 2.

Figure 2: Comparison of Learning Outcomes between Control and Experimental Classes

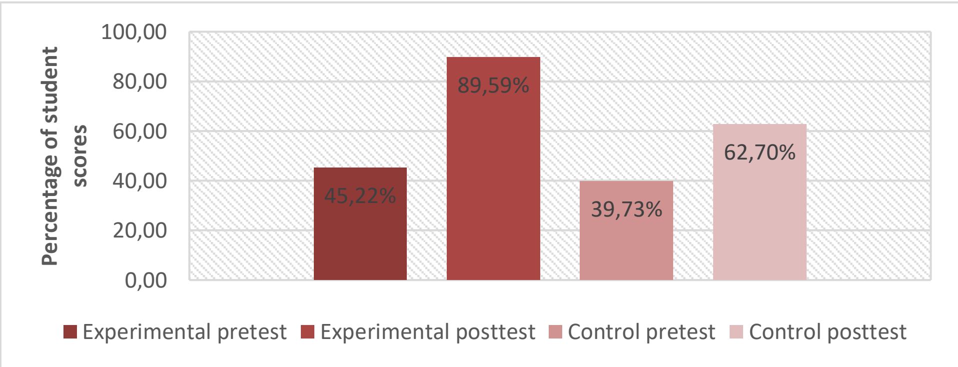


Figure 2 shows a difference in the average learning outcomes of students in Class XI Chemistry 2 (control class) and Class XI Chemistry 3 (experimental class). The learning outcome of students in the control class before being taught using the demonstration method was 39.73%. After the treatment with the demonstration method, the posttest result increased to 62.70%, resulting in a gain of 22.97%. Meanwhile, in the experimental class, the pretest score before the treatment was 45.22%. After being taught using the STEM-based Project-Based Learning (PjBL) model, the posttest score increased to 89.59%, showing an improvement of 44.37%. Based on the learning gains in both classes, it can be concluded that the improvement in the experimental class was higher than in the control class. This difference in learning outcomes indicates that the use of the Project-Based Learning (PjBL) model integrated with STEM concepts is more effective than the demonstration method. Both classes started with similar initial conditions, but the posttest results were significantly higher in the experimental class.

This finding aligns with the research conducted by (Rahayu & Sutarno, 2021), which demonstrated that the application of the STEM-based Discovery PjBL model increased students' average learning outcomes from 11.76% to 44.11% (in the first cycle), and to 79.41% (in the second cycle).

Observations during the learning process revealed a striking difference in student engagement between the experimental and control classes. Students in the experimental class actively designed projects, engaged in discussions, and presented their results, which encouraged cognitive, affective, and psychomotor involvement. In contrast, students in the control class tended to be passive, merely observing without actively participating in the learning process. The conventional method failed to adequately stimulate student exploration and participation. In terms of skills, the experimental class demonstrated better integration of science, technology, engineering, and mathematics (STEM), as well as the development of critical thinking and collaborative skills. Meanwhile, the control class remained limited to following the teacher's instructions.In terms of independence, students in the experimental class were more self-directed in designing and evaluating their projects, taking initiative and responsibility for their learning process. Conversely, students in the control class showed high dependency on the teacher and minimal learning initiative.

## CONCLUSION

The STEM-based Project-Based Learning (PjBL) model has been proven to be significantly more effective than conventional demonstration methods in improving student learning outcomes on acid-base indicator material, with an effect size of 2.085, indicating a strong influence on learning achievement. In addition to enhancing cognitive aspects, this model also contributes to the development of critical thinking skills, conceptual understanding, and collaboration among students. Therefore, PjBL-STEM can be used as an innovative and contextual chemistry learning strategy for acid-base topics.

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