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The effectiveness of STEM-PjBL in enhancing science process skills in Chemistry: A focus on stoichiometry

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Abstract

The challenges of 21st-century education require students to develop critical thinking, creativity, and problem-solving skills. Science Process Skills (SPS) are essential in cultivating scientific competence, particularly in chemistry learning. This study investigates the effectiveness of the STEM-Project Based Learning (STEM-PjBL) model in enhancing students' SPS on the topic of stoichiometry. A quasi-experimental design with a pretest-posttest control group was used, involving 66 tenth-grade students from SMA Islam Al-Azhar 5 Cirebon, equally assigned to experimental and control groups through cluster random sampling. The experimental class was taught using the STEM-PjBL model, while the control class received conventional instruction. Instruments included a validated SPS test and observation sheets. Test data were analyzed using SPSS 26, while non-test data were processed using percentage calculations. Results showed that the STEM-PjBL model significantly enhanced students' SPS, as indicated by a t-test ($p = 0.00 < 0.05$) and a higher average N-gain in the experimental group (0.574, moderate) compared to the control group (0.274). Improvements occurred across all 11 SPS aspects. Observation data revealed greater student engagement in scientific inquiry, collaborative projects, and scientific practices. These findings confirm that implementing the STEM-PjBL model effectively improves students' science process skills and understanding of chemistry concepts.

Keywords: science process skills, STEM-PjBL, stoichiometry

INTRODUCTION

Education in the 21st century demands a paradigm shift in learning processes to produce a generation with strong competencies and character. The *Kurikulum Merdeka* is an educational innovation designed to prepare future leaders by strengthening student competencies and character through flexible, project-based, and essential-content-focused learning (Hanifa et al., 2024). As part of national educational reform, the integration of STEM education (Science, Technology, Engineering, and Mathematics) is a strategic approach to improve learning quality and equip students with the skills needed to face 21st-century challenges (Wijayati et al., 2019). STEM education emerged from the need for an interdisciplinary approach that emphasizes the interconnectedness of STEM in solving real-world problems (Bybee, 2013; Roehrig & Karışan, 2022). In the Indonesian educational context, the embedded STEM approach, which integrates STEM concepts into existing school subjects such as chemistry without altering the curriculum structure, is considered more feasible (Roberts & Cantu, 2012). When combined with Project-Based Learning (PjBL), this integrated model—known as STEM-PjBL—encourages students to engage in meaningful, contextual, and hands-on scientific explorations. Consequently, the implementation of the STEM-PjBL model is considered a promising approach to enhance students' Science Process Skills by immersing them in authentic learning experiences.

Science Process Skills (SPS) play a vital role in fostering scientific reasoning and supporting conceptual mastery in chemistry. According to (Purnamasari et al., 2024; Septiani & Rustaman, 2017; Rustaman, 2005), there are 11 aspects of SPS, namely: observing, classifying, interpreting, predicting, questioning, hypothesizing, planning experiments, using tools and materials, applying concepts, communicating, and conducting experiments. However, many previous studies that implemented either STEM or PjBL models tended to measure only a subset of these skills (Zahirah et al., 2024; Irawan et al., 2024), limiting a comprehensive understanding of students' scientific development. This indicates a gap in the literature regarding the need for more holistic and inclusive assessments of SPS in chemistry learning. To address this gap, the present study assumes that all 11 indicators of SPS can be effectively fostered and assessed through a carefully designed STEM-PjBL implementation. Unlike previous studies that focused on isolated skills, this research integrates SPS holistically into each phase of project-based learning. In addition, both the assessment instruments and instructional strategies were intentionally aligned to support the emergence of all aspects. This comprehensive approach seeks to offer a more nuanced and in-depth understanding of the potential of STEM-PjBL in systematically fostering scientific reasoning within the context of chemistry education.

In particular, stoichiometry is a fundamental yet abstract topic in chemistry that is often associated with a high incidence of student misconceptions (Anugrah, 2019; Fitriani et al., 2024). To address this challenge, the STEM-PjBL model contextualizes abstract concepts through real-world problems and hands-on projects, enabling students to visualize and apply stoichiometric relationships in tangible ways. By engaging in tasks such as designing chemical products or conducting scaled chemical reactions, students actively construct meaning and reduce cognitive gaps between symbolic representations and practical understanding. Therefore, an instructional approach that bridges theoretical concepts with practical applications is essential. STEM-PjBL supports this goal by allowing students to construct knowledge through engineering design processes, where they solve authentic problems, apply concepts in real contexts, and develop creative thinking skills (Capraro et al., 2013; Laboy-Rush, 2010).

Although various studies have demonstrated the positive effects of STEM-PjBL on enhancing motivation, scientific literacy, higher-order thinking skills, and scientific attitudes (Dibyantini et al., 2023;Admawati, 2018) few have focused specifically on measuring the improvement across all 11 aspects of Science Process Skills, particularly within the stoichiometry topic. This gap highlights the need for targeted research that comprehensively assesses students' scientific competencies through integrative models such as STEM-PjBL.

Therefore, this study aims to analyze the implementation and effectiveness of the STEM-PjBL model in stoichiometry learning to enhance students’ science process skills in a comprehensive manner. The findings are expected to contribute to the development of more contextual, student-centered, and scientifically rigorous instructional strategies in high school chemistry education.

RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental design in the form of a pretest-posttest control group. The participants consisted of two classes of Grade 10 students (N = 66) from SMA Islam Al-Azhar 5 Cirebon, with 33 students assigned to the experimental group and 33 to the control group. Selected through cluster random sampling. The classes were divided into an experimental group, which received instruction using the STEM-PjBL model, and a control group, which was taught using conventional methods.

The independent variable in this study was the STEM-PjBL learning model, while the dependent variable was students SPS. The learning material focused on stoichiometry, a fundamental chemistry topic that is often challenging for high school students due to its abstract and quantitative nature. The STEM-PjBL model was implemented based on Laboy-Rush’s (2010) five-phase framework: reflection, research, discovery, application, and communication.

The instruments used in this study consisted of four components, each serving a specific role in data collection and analysis:

1. Pretest and Posttest

   Essay-based assessments were administered before and after the learning intervention to measure students SPS. The test consisted of items covering five SPS indicators: observing, predicting, classifying, applying concepts, and interpreting data. These instruments underwent expert validation to ensure content and construct accuracy. Furthermore, the test items were pilot-tested and analyzed using the ANATES program, which confirmed their validity, reliability, appropriate difficulty level, and discriminating power.
2. Observation Sheets

   These were used to assess students’ engagement and practical performance throughout the implementation of the STEM-PjBL model. The observation instrument included 32 statements covering eight SPS indicators: observing, classifying, asking questions, hypothesizing, planning experiments, using tools and materials, communicating, and conducting experiments. Each item was rated on a 4-point scale. The instrument was validated by experts and categorized as highly valid.

3. Student worksheets
   Student worksheet were utilized in the experimental class to facilitate the STEM-PjBL learning process. They guided students through project design, problem-solving, and concept application stages. The worksheets were designed to promote collaboration, creativity, and contextual understanding in line with the stoichiometry topic.
4. Teaching Modules
   Teaching modules were prepared to ensure consistency in content delivery across both the experimental and control groups. These modules contained structured lesson plans, materials, and instructions tailored to each instructional model, supporting the effective implementation of classroom activities.

SPS were measured based on 11 indicators adapted from (Purnamasari et al., 2024; Septiani & Rustaman, 2017; Rustaman, 2005), encompassing both cognitive and psychomotor aspects. Students' responses were scored using a rubric and converted into a 0–100 scale. The psychomotor aspects were totaled and converted into group percentages, then categorized according to Arikunto's (2010) criteria: very good, good, fair, poor, and very poor. Data from the experimental class's pretest and posttest were analyzed to test the research hypothesis.

All four instruments used in this study—pretest, posttest, observation sheets, student worksheets, and teaching modules—were validated through expert judgment using Gregory's content validity matrix to ensure relevance and alignment with the indicators of science process skills (SPS). The reliability of the pretest and posttest instruments was tested using Cronbach's Alpha, with a value greater than 0.70 indicating acceptable internal consistency.

Quantitative data were analyzed using SPSS 23.0. The data analysis procedure involved several steps. First, item analysis of the pretest and posttest was conducted using Anates software to determine item difficulty and discrimination indices. Next, normality and homogeneity tests were performed using the Kolmogorov–Smirnov test and Levene's test, respectively, with a significance level set at 0.05. The effectiveness of the STEM-PjBL model was then evaluated using normalized gain (N-gain) scores, categorized as high ($g > 0.7$), moderate ($0.3 < g \leq 0.7$), or low ($g \leq 0.3$) according to Hake's criteria. Finally, an independent samples t-test was applied to compare the posttest scores of the experimental and control groups, in order to determine whether there was a statistically significant difference in learning outcomes. A p-value < 0.05 was interpreted as a statistically significant difference in SPS improvement. The integration of observation, test scores, and project performance allowed for a more comprehensive evaluation of students' scientific process skills.

FINDINGS & DISCUSSION

The STEM-PjBL model was implemented to enhance students' science process skills (SPS) through project-centered and contextually based learning. This approach involves five main phases based on Laboy-Rush's (2010) framework: *Reflection, Research, Discovery, Application,* and *Communication*. In the *Reflection phase*, students were encouraged to identify contextual problems and relate them to stoichiometric principles. This activity stimulated their skills in observation and scientific questioning. The *Research phase* focused on literature exploration and deeper understanding of stoichiometric concepts, fostering the ability to pose questions and organize information. Subsequently, the *Discovery phase* guided students in designing experiments, including formulating hypotheses and systematically planning scientific steps. The *Application phase* served as the implementation of the planned experiments, during which students conducted chemical experiments, observed changes, recorded data, and categorized the results. Finally, in the *Communication phase*, students presented their experimental findings through written reports and video presentations. This process trained their abilities to interpret data and effectively convey scientific information.

Analysis of Student Activities and Science Process Skills

Observation of learning activities showed that the experimental class showed high involvement in most stages. Especially in *Application* (conducting experiments) and *Discovery* (planning experiments). However, the scientific communication aspect needs to be improved.

The analysis of student activities and science process skills is conducted to evaluate the extent to which the implementation of STEM-PjBL in stoichiometry instruction enhances the development of students' skills. The activities undertaken by students during the learning process encompass a range of aspects, including observation, data classification, prediction of experimental outcomes, as well as the formulation of questions and application of chemical concepts to real-world contexts. A total of eleven aspects were measured through an observation sheet, while three additional aspects were assessed using the student worksheets in the experimental class. The table below presents a detailed summary of the student activities and the corresponding science process skills evaluated during the learning sessions. This analysis facilitates the identification of both improvements and potential gaps in students' science process skills, offering insights into the relationship between the activities performed and the overall development of these skills.

Table 1. Analysis of Student Science Process Skills

Aspects SPS	Experimental Class		Control Class	
	%	Category	%	Category
Observing	93	Excellent	77	Good
Classifying	56	Fair	47	Fair
Making predictions	95	Excellent	-	-
Applying concepts	85	Excellent	-	-
Asking questions	65	Good	43	Fair
Developing hypotheses	80	Good	41	Fair
Designing experiments	94	Excellent	28	Poor
Utilizing Instruments and Materials	100	Excellent	81	Excellent
Interpreting	68	Good	-	-
Communicating	53	Fair	47	Fair
Performing experiments	100	Excellent	100	Excellent

The analysis of science process skills (SPS) through observation shows that the experimental class achieved higher average scores across all measured aspects compared to the control class. Overall, the implementation of STEM-PjBL in the experimental class effectively enhanced students' SPS, proving more effective than the scientific method used in the control class. The improvement was particularly noticeable in problem-solving and scientific investigation aspects, such as hypothesis formulation, questioning, and classification, which showed significant progress in the experimental class. Observed SPS in the experimental class varied, with the highest percentage (100%) observed in activities like performing experiments and using tools and materials. The "fair" category included classification and using tools and materials; while "good" was seen in questioning and hypothesis developing. "Excellent" was achieved in observing, planning experiments, performing experiments, and communication.

It is important to note that three aspects of science process skills namely making predictions, applying scientific concepts, and interpreting scientific data were not assessed in the control class because these indicators were integrated specifically into the project-based tasks guided by the student worksheet. As the control group did not use the worksheet, which facilitated contextual problem-solving and guided inquiry, these aspects could not be meaningfully evaluated in that setting.

Development of Science Process Skills Based on Essay Tests

The analysis of pretest and posttest results showed that the experimental class experienced significant improvement across all aspects of science process skills (SPS). The highest gains were observed in the aspects of applying concepts (N-Gain = 1.1) and classifying (N-Gain = 0.71). The skill of interpreting data showed consistent improvement despite some fluctuations, while the skill of predicting remained stable. Observing skills were already at an excellent level from the beginning, thus showing no significant gain.

Table 2. Comparison of Students' Science Process Skills Scores

Group	Pretest Mean	Posttest Mean	N-Gain Mean
Experimental Class	58,3	83,9	0,574
Control Class	55,8	70,7	0,274

The results of the normality test (Kolmogorov-Smirnov) indicated that the data were normally distributed ($p > 0.05$). The homogeneity test (Levene's test) also showed that the data were homogeneous ($p > 0.05$), allowing the use of parametric tests. The independent t-test revealed a significant difference between the posttest scores of the experimental and control classes (Sig. 2-tailed = 0.000 < 0.05). This indicates that the STEM-PjBL-based instruction had a significant impact on improving students' SPS.

Table 3. Summary of Hypothesis Test Results

Test	t/U Value	p-Value	Conclusion
Independent Samples t-test	0,827	0,000	Significant ($p < 0,05$)

Comparison of the average KPS scores between experimental and control classes based on pretest and posttest results. In general, there was an increase in scores in both classes after learning, but a more significant increase was seen in the experimental class that applied the STEM-PjBL model. six aspects of SPS measured through tests, namely observing, predicting, classifying, applying concepts, and interpreting, experienced a higher increase in the experimental class than the control class. This shows that the STEM-PjBL approach is more effective in improving students' science process skills than the learning method applied in the control class. The effectiveness of this approach is reinforced by the results of the following statistical analysis which revealed a significant difference between the experimental and control classes.

The statistical analysis reveals significant differences in learning outcomes between the experimental and control groups. The independent samples t-test yielded a significance value (Sig. 2-tailed) of 0.000 ($p < 0.05$), demonstrating a statistically significant improvement in the experimental class compared to the control group. These findings confirm that the STEM-PjBL learning model significantly enhances students' science process skills. Further supporting this conclusion, the N-Gain analysis shows the experimental class achieved medium improvement (average N-Gain = 0.56), while the control class remained in the low category (average N-Gain = 0.32). This comparative analysis underscores the effectiveness of the STEM-PjBL approach in promoting science process skill development.

The implementation of STEM-PjBL provided students with the opportunity to engage in the full scientific process—from formulating questions to presenting results. This project-based learning approach enhanced students' engagement, curiosity, and critical thinking skills. The projects were based on real-world contexts, such as mass conversions in chemical reactions or the creation of stoichiometry-based products, making the concepts more understandable and applicable.

The skills of planning and conducting experiments developed rapidly as students were given responsibility to design and carry out their own experiments. This aligns with constructivist principles that emphasize the construction of meaning through direct experience. One of the challenges encountered was in the area of communication, where students were not yet accustomed to organizing and presenting data in a scientific manner. Therefore, it is recommended that explicit training in scientific communication be integrated at every stage of project-based learning.

STEM-PjBL-based learning has proven effective in enhancing students' science process skills in stoichiometry topics. All SPS aspects improved, particularly in classifying and applying concepts. This model is well-suited for high school chemistry instruction, as it fosters critical thinking, collaboration, and communication skills that are essential in the 21st century. These findings are consistent with previous research (Wahyuni & Rosdiana, 2023; Jannah & Shofiyah, 2023), which demonstrated that the STEM-PjBL approach effectively enhances higher-order thinking skills and conceptual understanding in science education.

The overall improvement SPS in the experimental class was higher compared to the control class, with aspects such as categorizing and applying concepts showing the most significant improvement. In contrast, the control class showed a lower improvement, with most aspects falling in the moderate category. Overall, the STEM-PJBL model proved to be more effective in improving SPS, and the results of the t-test and N-gain further support the effectiveness of this model. The STEM-PJBL model is recommended for wider implementation, with attention to better time and resource management for optimal project success (Purwati et al., 2025; Wahyuni & Rosdiana, 2023; Khoiri, 2021). Follow-up actions recommended include enhancing students' observation skills through visual or interactive media, employing varied assessment methods such as reflective journals to capture deeper learning processes, and extending implementation duration to optimize the development of science process skills through sustained engagement with the STEM-PjBL model.

CONCLUSION

The implementation of the STEM-PjBL model in stoichiometry demonstrated a significant improvement in students' Science Process Skills (SPS). Supported by Student Worksheets and collaborative projects, students engaged in activities that fostered the development of 11 SPS aspects, including observing, classifying, making predictions, applying concepts, asking questions, developing hypotheses, designing experiments, utilizing instruments and materials, interpreting, communicating, and performing experiments. This conclusion is supported by consistent results from multiple assessment methods, including non-test observations and essay-based assessments, which showed that students in the experimental group performed well across all targeted aspects. Essay responses offered additional insight into students' reasoning and engagement, complementing the quantitative data. While these findings confirm the model's effectiveness in enhancing procedural scientific skills, further research is recommended to investigate its long-term impact on conceptual understanding. The t-test results (p-value = $0.00 < 0.05$) reinforce the significant difference in outcomes between the experimental and control groups, highlighting the potential of the STEM-PjBL model in improving the quality of chemistry education.

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