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Project-Based Learning in Basic Chemistry Practice: Its Impact on Vocational Students' Analytical Abilities

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Abstract
Vocational chemistry education is expected to develop not only procedural competence but also higher-order analytical abilities aligned with industrial demands. However, Basic Chemistry Practice in vocational high schools is often dominated by teacher-centered instruction, limiting students' capacity to interpret experimental data and connect theory with practice. This study aimed to examine the impact of Project-Based Learning (PjBL) on vocational students' analytical abilities and to explore students' and teachers' perceptions of its implementation. A quantitative pre-experimental design using a one-group pretest–posttest model was employed. The participants were 34 Grade X Industrial Chemical Engineering students at a vocational high school. Analytical ability was measured using HOTS-based open-ended questions aligned with Bloom's revised taxonomy, and perception data were collected through Likert-scale questionnaires. Statistical analysis included the Shapiro–Wilk normality test, paired sample t-test, and normalized gain (N-gain) analysis. The results showed a significant improvement in analytical ability, with the mean score increasing from 41.0 to 73.5 ($p < 0.001$) and an N-gain value of 0.55, categorized as moderate. Students and teachers reported highly positive perceptions, particularly regarding engagement, collaboration, and analytical skill development. These findings suggest that PjBL provides an effective pedagogical framework for strengthening analytical competence in vocational chemistry practice. The novelty of this study lies in the integration of HOTS-based assessment into authentic vocational chemistry projects within a PjBL framework, an approach that is still rarely reported in vocational chemistry education. By combining learner-centered project implementation with structured higher-order thinking assessment, this study offers a practical and context-relevant model for improving analytical competence in vocational education settings.

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INTRODUCTION

Vocational education is expected to prepare students not only with technical competencies but also with higher-order cognitive abilities that enable them to perform effectively in complex industrial environments (Haryani et al., 2021; Nogales-Delgado et al., 2022). In Industrial Chemical Engineering programs at vocational high schools, Basic Chemistry Practice is a foundational subject through which students develop laboratory skills, understand chemical processes, and apply safety procedures relevant to industrial work settings (Wiyarsi et al., 2020; Goloșie, 2025). However, current workplace demands increasingly require graduates to do more than follow procedures; they must also analyze data, interpret results, and justify decisions based on evidence. Within the framework of Higher-Order Thinking Skills (HOTS), analytical ability includes differentiating relevant information, organizing data, and attributing meaning by linking empirical evidence to conceptual knowledge (Widana, 2017;

Kania & Kusumah, 2025). Therefore, strengthening analytical ability in vocational chemistry practice is essential for aligning school learning outcomes with industrial expectations.

A growing body of literature has shown that student-centered pedagogies can improve higher-order thinking and science learning outcomes. Meta-analytic and review studies report that project-based and inquiry-oriented learning generally contribute positively to academic achievement, engagement, and higher-order cognitive development (Chen & Yang, 2019; Zhang & Ma, 2023; Kokotsaki et al., 2016). In chemistry learning contexts, guided inquiry and project-based laboratory activities have been associated with gains in science process skills, scientific literacy, and critical thinking (Rahayu & Sari, 2023; Dewi et al., 2025; Chu et al., 2023). These findings indicate that active, learner-centered instruction is more promising than teacher-centered transmission for cultivating analytical competence.

Despite this progress, the instructional reality in many chemistry laboratory settings remains dominated by lecture, demonstration, and procedural replication, especially in contexts where time constraints, assessment traditions, and teacher routines favor efficiency over analytical exploration (Hofstein & Lunetta, 2004; Zhang & Ma, 2023). In such "cookbook" laboratory environments, students often complete experimental steps correctly but have limited opportunities to interpret evidence, explain anomalies, or connect experimental observations to underlying chemical principles (Chu et al., 2023). This creates a persistent gap between procedural performance and analytical understanding—an issue that is particularly consequential in vocational education, where laboratory work is expected to simulate real industrial reasoning.

This gap was also evident in the local context of the present study. A preliminary diagnosis in a Grade X Industrial Chemical Engineering class at SMK Negeri 3 Mataram (involving 34 students and 3 teachers) indicated that Basic Chemistry Practice instruction was still largely conducted through lectures and demonstrations, with limited structured project-based activities. Students reported difficulty understanding the material when learning was not supported by direct, meaningful hands-on engagement. Classroom observations further showed that students were generally able to reproduce procedural steps in laboratory reports, but many struggled to explain the relationships among pH values, chemical composition, and product safety. This local evidence is important because it demonstrates that the problem is not only theoretical in the literature but also present in the actual vocational chemistry classroom targeted by this study.

The urgency of this issue was reinforced by students' initial analytical performance in the same class, where the average pretest score was 41.0, indicating relatively low analytical proficiency prior to the intervention. This pattern is consistent with prior reports that students often experience conceptual difficulty when they cannot meaningfully connect observed phenomena with deeper chemical representations and explanations (Wiyarsi et al., 2020; Rahmawati et al., 2025). In other words, students may perform laboratory routines, yet still lack the analytical competence needed to evaluate results, make evidence-based claims, and apply chemistry concepts in vocationally relevant contexts.

Addressing this problem requires an instructional approach that not only provides practical experience but also explicitly structures opportunities for analysis, reflection, and conceptual integration. From a constructivist perspective, learning is an active process in which learners build understanding through interaction with experiences and social contexts (Bodner, 1986; Smith et al., 2003; Dewi et al., 2022). Experiential learning perspectives similarly emphasize that meaningful understanding develops through cycles of concrete experience, reflection, conceptualization, and experimentation (Zumbach et al., 2020). In laboratory-based vocational subjects, these perspectives imply that practical tasks should be designed not merely as procedural exercises but as learning experiences that require students to interpret evidence, justify decisions, and connect practice with theory.

Project-Based Learning (PjBL) is well aligned with these theoretical foundations because it engages students in authentic tasks, collaborative inquiry, and the production of meaningful outputs (Kokotsaki et al., 2016; Guo et al., 2020; Matilainen et al., 2021). In vocational chemistry education, product-oriented projects such as producing liquid detergent or dishwashing soap can provide a realistic context for students to plan procedures, identify the function of ingredients, evaluate pH and product characteristics, and interpret quality-related outcomes. Such project environments are particularly relevant for vocational students because they more closely resemble industrial problem-solving situations than isolated procedural practicums.

However, although previous studies support the value of PjBL in chemistry and vocational education, important gaps remain. First, many studies emphasize general learning achievement, motivation, scientific literacy, or critical thinking, rather than examining analytical ability as a specific cognitive construct within HOTS/Bloom's revised taxonomy (e.g., Chen & Yang, 2019; Dewi et al., 2025; Rahmawati et al., 2021; Dewi & Rahayu, 2023). Second, studies conducted in laboratory settings often focus on higher education chemistry courses (e.g., analytical or inorganic chemistry laboratories), which differ substantially from the curriculum structure, learner characteristics, and instructional constraints of vocational secondary schools (Matilainen et al., 2021; Chu et al., 2023). Third, relatively few studies examine PjBL in vocational Basic Chemistry Practice using authentic product-based tasks that simulate industrial production processes while simultaneously measuring targeted analytical indicators and capturing pedagogical acceptability from both students and teachers. Consequently, the empirical basis for designing analytically oriented PjBL in vocational secondary chemistry remains limited.

In response to these gaps, the present study investigates the implementation of Project-Based Learning in Basic Chemistry Practice in a Grade X Industrial Chemical Engineering class, using projects focused on the production and analysis of chemical cleaning products (liquid detergent and dishwashing soap). The study is grounded in constructivist and experiential learning perspectives and operationalizes analytical ability through HOTS-based open-ended assessment indicators, including differentiating chemical components, organizing experimental observations, linking theory with laboratory findings, and drawing evidence-based conclusions.

The novelty of this study is not merely the use of PjBL in chemistry, which has been widely reported, but integration of three elements within a vocational secondary classroom framework: (1) authentic product-based vocational chemistry projects that resemble industrial practice, (2) HOTS-oriented analytical measure-ment focused specifically on analytical ability rather than broad achievement or general critical thinking, and (3) combined impact and acceptability evidence through pretest–posttest analysis and student–teacher perception data. Compared with previous studies that largely examine general PjBL effects or non-vocational/higher-education laboratory settings, this study provides a more targeted account of how PjBL can streng-then analytical competence in vocational basic chemistry practice under real classroom conditions.

Accordingly, the objectives of this study are to examine the extent to which Project-Based Learning in Basic Chemistry Practice influences vocational students' analytical abilities and to explore students' and teachers' perceptions of its implementation. The study is limited to one Grade X Industrial Chemical Engineering class in a vocational high school, with analytical ability measured through validated HOTS-based open-ended assessments and perception data collected through structured questionnaires. Based on this scope, the research questions are: (1) Is there a statistically significant difference in vocational students' analytical abilities before and after the implementation of Project-Based Learning? and (2) What are students' and teachers' perceptions of Project-Based Learning in Basic Chemistry Practice?

METHOD

Research Design

This study employed a quantitative pre-experimental design, specifically the One-Group Pretest–Posttest Design, to examine the effect of Project-Based Learning (PjBL) on students' analytical abilities in Basic Chemistry Practice. A quantitative approach was selected because the study generated numerical data (pretest–posttest scores and questionnaire ratings) that were analyzed using inferential and descriptive statistics. Pre-experimental designs are appropriate when researchers aim to evaluate the effect of an instructional treatment in situations where random assignment and control groups are not feasible (Sugiyono, 2013; Creswell, 2016).

The selection of this design was particularly suited to the context of the present study, which was limited to one intact Grade X Industrial

Chemical Engineering class in a vocational school. In this setting, class reorganization for randomization was not pedagogically and administratively possible, and withholding the intervention from a comparable class was not feasible within the school schedule and instructional arrangement. Therefore, the one-group pretest–posttest design was used as a practical and context-sensitive approach to obtain initial empirical evidence of instructional impact under authentic classroom conditions.

The design can be symbolically represented as:

$$O_1 \rightarrow X \rightarrow O_2$$

While:

O_1 = Pretest (measurement before intervention)
X = Treatment (PjBL implementation)
O_2 = Posttest (measurement after intervention)

Through this design, changes in the same students' analytical performance could be examined directly before and after the intervention. Although the absence of a control group limits causal generalization, this design remains appropriate for exploratory classroom-based intervention research and for generating evidence to support future, more rigorous quasi-experimental studies.

Research Setting and Participants

The study was conducted at SMK Negeri 3 Mataram, a vocational high school offering an Industrial Chemical Engineering program. The research took place during the second semester of the 2024/2025 academic year, from July to September 2025. The school was selected because it provides laboratory facilities suitable for project-based chemistry instruction and offers Basic Chemistry Practice as a core subject.

The population consisted of all Grade X students enrolled in the Industrial Chemical Engineering program, totaling 34 students. Given the relatively small and homogeneous population, a total sampling (saturated sampling) technique was employed, meaning that all members of the population were included as research participants (Sugiyono, 2013). This approach ensured that the data represented the entire class without requiring generalization beyond the study context. In addition to student participants, three subject teachers were involved in providing perception data regarding the implementation of Project-Based Learning. Their responses were collected to complement quantitative findings with pedagogical insights.

Preliminary Study

Prior to the main intervention, a preliminary (feasibility-oriented) study was conducted to identify the existing instructional conditions and students' learning challenges in Basic Chemistry Practice, as preliminary/pilot studies are commonly used to test procedures and inform refinement before full-scale implementation (Hassan et al., 2006; Teresi et al., 2022). Questionnaires were administered to three teachers and 34 students to collect initial perceptions of classroom practices and the potential relevance of Project-Based Learning (PjBL), which is an appropriate strategy for assessing perceptions and other non-observable constructs when survey instruments are developed systematically (Artino et al., 2014). The preliminary findings indicated that most instruction relied on lectures and demonstrations, with limited structured project-based activities. Students also reported difficulty understanding the material without direct hands-on engagement, a pattern that is consistent with research emphasizing the importance of meaningful laboratory experiences and active knowledge construction in science/chemistry learning (Hofstein & Lunetta, 2004; Bodner, 1986). These findings supported the need for an instructional intervention aimed at strengthening analytical ability through experiential, learner-centered, and constructivist approaches such as PjBL (Kokotsaki et al., 2016; Guo et al., 2020).

Research Instruments

2.4.1 Analytical Ability Test

Students' analytical abilities were measured using a set of HOTS-based open-ended essay questions constructed with reference to the analytical dimension (C4) in Bloom's revised taxonomy (Pujawan et al., 2022). In this study, analytical ability was operationalized into four indicators: (1) differentiating relevant chemical components, (2) organizing experimental observations/data, (3) linking theoretical concepts with laboratory findings, and (4) drawing evidence-based conclusions. These indicators were selected to reflect the type of analytical reasoning required in vocational Basic Chemistry Practice, particularly in product-oriented chemistry projects.

The development of the HOTS test followed several stages. First, a test blueprint (table of specification) was prepared by mapping each item to the analytical indicators, learning objectives, and project contexts used in the intervention (e.g., liquid detergent and dishwashing soap production/analysis). Second, item prompts were written in an open-ended format to encourage students to explain reasoning, interpret laboratory evidence, and justify conclusions rather than merely recall procedural steps. Third, each item was paired with an analytic scoring rubric to ensure consistency in scoring across indicators.

The same construct of analytical ability was assessed in both the pretest and posttest to allow direct comparison of students' performance before and after the intervention. Scoring was conducted using structured criteria for each indicator (e.g., accuracy of component identification, coherence of data organization, appropriateness of theory–data linkage, and quality of evidence-based conclusion), and scores were then converted into comparable numerical values for statistical analysis. This procedure was designed to ensure that the measurement captured higher-order analytical performance rather than procedural memorization alone. To improve scoring consistency, students' responses were assessed using indicator-based rubric descriptors for each analytical component. Responses showing accurate identification of relevant chemical variables, logical organization of observations, explicit theory–evidence linkage, and well-supported conclusions received higher scores than responses limited to procedural description. This rubric-based scoring approach was intended to capture the depth of analytical reasoning demonstrated in students' written explanations.

Perception Questionnaires

To address students' and teachers' perceptions of Project-Based Learning, Likert-scale questionnaires were used. Each item was rated on a four-point scale: 4 = Strongly Agree, 3 = Agree, 2 = Disagree, 1 = Strongly Disagree. The questionnaire measured aspects such as engagement, collaboration, conceptual understanding, analytical skill development, and instructional effectiveness.

Validity and Reliability Testing

Instrument quality was examined through content validity, construct alignment, and reliability procedures. Content validity was established through expert judgment involving two chemistry education experts and one vocational chemistry subject teacher, who reviewed the instruments in terms of content relevance, alignment with analytical indicators/HOTS (C4), contextual suitability for vocational chemistry practice, and language clarity. The expert review process was conducted in a structured manner using a validation sheet, and reviewer feedback was discussed to refine item wording, improve indicator alignment, and ensure that the prompts elicited analytical responses rather than factual recall. The average validation score of 3.6 (on a four-point scale) indicated that the instruments were valid and appropriate for implementation.

Construct validity was strengthened by explicitly mapping each analytical test item to the analytical indicators derived from Bloom's revised taxonomy (Pujawan et al., 2022), namely differentiating, organizing, linking theory with findings, and drawing evidence-based conclusions. This mapping ensured that the test measured the intended construct (analytical ability) rather than general achievement alone. Reliability was supported in two ways. First, analytic scoring rubrics were used to reduce scoring subjectivity in the open-ended HOTS test. Second, internal consistency testing was conducted for the questionnaire items to ensure stable measurement of students' and teachers' perceptions. Together, these procedures enhanced the trustworthiness of the data generated by both the analytical ability test and the perception questionnaires.

Data Collection Procedure

Data collection was conducted in three sequential stages are pretest administration: Students completed the analytical ability test prior to the intervention. Project-Based Learning Implementation: The instructional treatment was delivered across four meetings. Posttest and Questionnaire Administration: Students completed the posttest, and perception questionnaires were distributed to both students and teachers. Documentation, including classroom observations and photographs, supported data triangulation (Sugiyono, 2013).

Data Analysis Techniques

Prior to inferential analysis, the Shapiro–Wilk test was conducted to assess data normality because the sample size was fewer than 50 participants. A paired sample t-test was used to determine whether there was a statistically significant difference between pretest and posttest scores. According to Sugiyono (2013), this test is appropriate for comparing two related means. To measure instructional effectiveness, the normalized gain (Hake, 1999) was calculated using the formula: N-gain = (Posttest − Pretest) / (Maximum Score − Pretest). The interpretation criteria were: ≥ 0.7 = High, 0.3–0.69 = Moderate, < 0.3 = Low. Questionnaire responses were analyzed descriptively by calculating mean scores and categorizing them into interpretation ranges. This analysis provided insight into the practical acceptability of Project-Based Learning.

RESULTS AND DISCUSSION

Significant difference in vocational students' analytical abilities before and after the implementation of Project-Based Learning

To examine the improvement in students' learning outcomes following the implementation of the Project-Based Learning (PjBL) model, a series of quantitative data analyses was conducted. The analysis began with prerequisite testing to ensure that the data met the fundamental assumptions required for parametric analysis. This was followed by a comparison of mean scores using a Paired Sample t-test. Finally, the effectiveness of the improvement in learning outcomes was calculated using the normalized gain (N-gain) analysis. The prerequisite test was conducted to verify that the data were normally distributed, thereby satisfying the assumptions necessary for parametric statistical testing. In this study, the Shapiro–Wilk test was employed because the sample size was fewer than 50 participants (n = 34). The results of the normality test are presented in Table 1 below.

Table 1. Shapiro–Wilk Normality Test Results

Data	Statistic W	Sig. (p)	Remarks
Pretest	0,9876	0,9596	Normal
Posttest	0,9586	0,2207	Normal

Based on Table 1, the significance value (p) for the pretest data was 0.9596, while the posttest data yielded a p-value of 0.2207. Since both values are greater than 0.05, it can be concluded that the pretest and posttest data are normally distributed. With the assumption of normality satisfied, the analysis proceeded using parametric statistical testing. A Paired Sample t-test was conducted to determine whether there was a significant difference in students' analytical abilities before and after the implementation of the Project-Based Learning (PjBL) model. The results of the t-test are presented in Table 2 below.

Table 2. Pretest and Posttest Paired T Test Results

Variabel	Mean Pretest	Mean Posttest	t Count	df	Sig. (p)
Analytic Ability	41,0	73,5	24,77	33	0,000

Based on Table 2, the calculated t-value was 24.77 with a significance level (p) of less than 0.001. Since the p-value is below 0.05, it can be concluded that there is a statistically significant difference between the pretest and posttest scores. This finding indicates that the implementation of the Project-Based Learning (PjBL) model had a significant effect on improving students' learning outcomes. The mean score difference of 32.5 points further strengthens the conclusion that students developed a better conceptual understanding after participating in project-based instruction. To determine the extent of improvement in students' analytical abilities, a normalized gain (N-gain) analysis was conducted by comparing the difference between pretest and posttest scores relative to the maximum possible score. The results of the N-gain calculation are presented in Table 3 below.

Table 3. Results of Analysis of Student Analytical Ability (N-gain)

Category N-Gain	Range	Number of Students	Percentage (%)
High	≥ 0,7	3	8,82%
Moderate	0,3-0,69	31	91,18%
Low	< 0,3	0	0,00%
Total		**34**	**100%**

Based on Table 4.8, the mean N-gain value of 0.55 falls within the moderate category. A total of 91.18% of students were classified in the moderate improvement category, 8.82% achieved high improvement, and no students were categorized as low. These results indicate that the implementation of Project-Based Learning (PjBL) led to a moderate yet meaningful improvement in students' analytical abilities. Nearly all students benefited from the instructional intervention, although only a small proportion reached the high-gain category.

The N-gain distribution shows an important nuance in the intervention outcome. Although no students fell into the low category and nearly all students improved, most students (91.18%) were still classified in the moderate category, with only a small proportion (8.82%) reaching the high category. This pattern suggests that the PjBL intervention was broadly effective in elevating baseline analytical performance, but the depth of analytical mastery required for high gains was not achieved equally by all students. In this study, this result is pedagogically plausible because the intervention was implemented within a relatively short instructional window (four meetings), and teacher responses also indicated that time allocation was one of the main constraints. In addition, the lowest student perception score was found on the ability to relate project outcomes to theoretical concepts, indicating that theory–practice integration remained the most challenging aspect for some learners.

This interpretation is consistent with wider PjBL research showing that learning gains are often moderated by implementation conditions rather than determined by the model alone. A large meta-analysis reported that PjBL effectiveness varies by subject area, course type, class size, group size, and experimental period, with stronger effects often observed in laboratory courses and under well-structured implementation conditions; the same study also noted that duration and design features influence the magnitude of outcomes. Similarly, recent chemistry laboratory work has shown that PjBL tends to be most effective when accompanied by scaffolded inquiry, explicit feedback, and staged preparation for independent project work. In Chu et al.'s inorganic chemistry laboratory course, scaffolded inquiry in the early phase helped students understand the purpose of techniques and connect them to a larger project before PjBL was introduced more independently.

The predominance of moderate gains may also reflect the inherent cognitive demands of analytical tasks in chemistry, especially when students are asked to move beyond procedural completion toward explanation and justification. Evidence from analytical chemistry PjBL contexts indicates that students often perceive the design phase, data collection, and information gathering as the most challenging parts of project work, even when they value the experience overall. This aligns with the present finding that students still experienced difficulty linking project outcomes to theory. More broadly, a qualitative synthesis of K–12 PjBL perceptions identified recurring challenges such as time consumption, initial uncertainty ("jitter"), and content insufficiency, despite strong gains in engagement and 21st-century skills. In vocational chemistry contexts, implementation constraints are also not new: an Indonesian study on PjBL for laboratory-scale ethanol production in Industrial Chemistry vocational students reported obstacles related to limited equipment and insufficient time.

The present findings are consistent with the broader evidence base that PjBL improves student learning outcomes, while also adding a more specific contribution to vocational chemistry practice. Meta-analytic evidence has shown a medium-to-large positive effect of PjBL on student achievement compared with traditional instruction (e.g., Chen & Yang, mean weighted effect size d+ = 0.71), and more recent meta-analytic work further indicates positive effects on academic achievement, thinking skills, and affective outcomes, with particularly favorable application in laboratory-type courses and engineering/technology-related subjects. The current study supports these patterns by showing significant improvement in analytical ability in a vocational chemistry practicum context and by documenting highly positive student–teacher responses under authentic classroom conditions. At the same time, this study should be positioned more explicitly within a continuum of vocational and chemistry-specific PjBL research.

In Indonesia, earlier work in vocational industrial chemistry reported the effectiveness of PjBL for laboratory-scale ethanol production and also highlighted practical constraints such as limited time. In another Indonesian vocational context, Rahmawati et al. (2021) implemented STEM-PjBL in electrochemistry with vocational students and emphasized the development of critical thinking through project-based activity design. Beyond secondary vocational settings, recent chemistry laboratory studies also provide relevant support: Chu et al. (2023) showed the value of combining scaffolded inquiry and PjBL in an inorganic chemistry laboratory course, while Matilainen et al. (2021) documented both skill development and challenge points in analytical chemistry PjBL experiences.

Recent developments also suggest that product-oriented, industry-relevant project designs are becoming increasingly important in chemistry-related vocational and professional education. For example, a developed a project-based teaching factory model in the chemical cleaning industry, integrating PjBL and teaching factory practices, and reported significant gains in soft skills and entrepreneurial intention in a one-group pretest–posttest design.

Although the outcome focus differs from the present study (soft skills and entrepreneurial intention vs. analytical ability), the context similarity (chemical cleaning product domain and authentic production orientation) reinforces the relevance of product-based project ecosystems for chemistry vocational learning. In addition, recent chemistry-education reviews and quasi-experimental studies continue to report that PjBL supports engagement, conceptual understanding, and laboratory competence, while also noting barriers such as time constraints, limited resources, and insuffi-cient teacher training.

These findings affirm that PjBL not only exerts a positive influence but also produces a statistically and pedagogically significant impact on students' analytical competence. This conclusion is consistent with previous research. Matilainen et al. (2021) reported that PjBL effectively enhances analytical skills because it actively engages students in designing, implementing, and reflecting on projects. Similarly, Chen & Yang (2019), in their study entitled Project-Based Learning and Analytical Skills Development in Vocational Education, found that students exposed to PjBL demonstrated a 45% improvement in chemical data analysis compared to control groups.

García-Ponce et al. (2021), through meta-analysis, concluded that PjBL consistently improves students' analytical ability with an effect size of 0.82 in science education contexts. Azizah et al. (2025) also reported a significant increase in analytical ability in vocational chemistry practicum, with an N-gain value of 0.68. Furthermore, Ruslan et al. (2021) found that digitally integrated PjBL enhanced students' analytical and problem-solving abilities by 52%. Chen & Yang (2019) emphasized that scaffolding within PjBL plays a critical role in strengthening analytical skills, particularly in connecting experimental data with theoretical concepts.

The results of this study are also aligned with broader findings in project-based pedagogy. Ling et al. (2024) demonstrated that PjBL significantly improves students' learning outcomes, including cognitive performance and affective development, compared to traditional instructional models. Azizah et al. (2025) highlighted that PjBL contributes substantially to the development of 21st-century skills such as collaboration, problem-solving, and critical thinking.

Budner & Simpson (2018) further supported these conclusions by showing that PjBL enhances critical thinking skills through exploration, collaborative problem-solving, and reflective learning. Additionally, Movahedzadeh et al. (2012) reported that integrating PjBL with a STEM approach promotes higher-order thinking skills and improves chemistry learning outcomes at the secondary level. Achappa et al. (2020) found that PjBL facilitates active and independent learning while strengthening analytical competencies in analytical chemistry. Anitha et al. (2018) likewise concluded that PjBL implementation significantly improves students' learning outcomes, particularly critical thinking skills.

Further supporting evidence comes from Ijirana et al. (2022), who demonstrated that team-based project learning improves critical thinking skills among chemistry education students. Susanto et al. (2023) emphasized that project-based laboratory inquiry supports the development of analytical skills in analytical chemistry education. Carmel et al. (2017) described how PjBL in analytical chemistry laboratories promotes students' research competencies. Finally, Dwikoranto et al. (2020) demonstrated that PjBL-STEM integration strengthens higher-order thinking skills and chemistry learning outcomes at the high school level. Taken together, these findings demonstrate strong consistency between the present study and prior empirical research. The evidence collectively supports the conclusion that Project-Based Learning is an effective instructional model for enhancing analytical abilities and critical thinking skills, particularly in chemistry education contexts.

Students' and teachers' perceptions of Project-Based Learning in Basic Chemistry Practice

The students' responses to the implementation of the Project-Based Learning (PjBL) model are presented in figure 1.

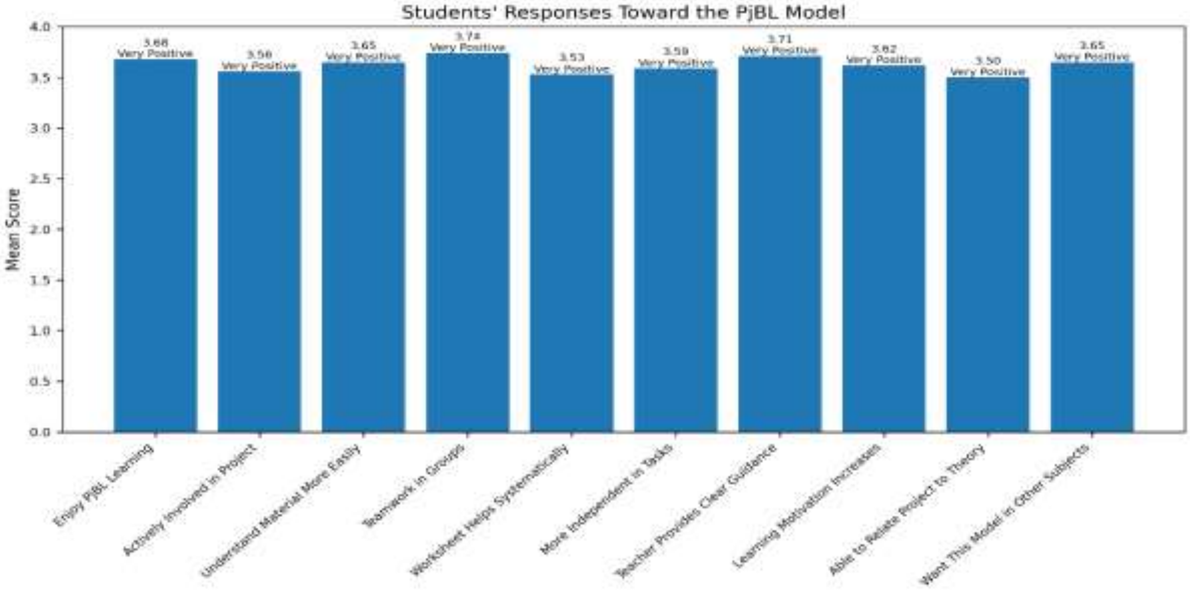

Figure 1. Students' Response of the PjBL Model

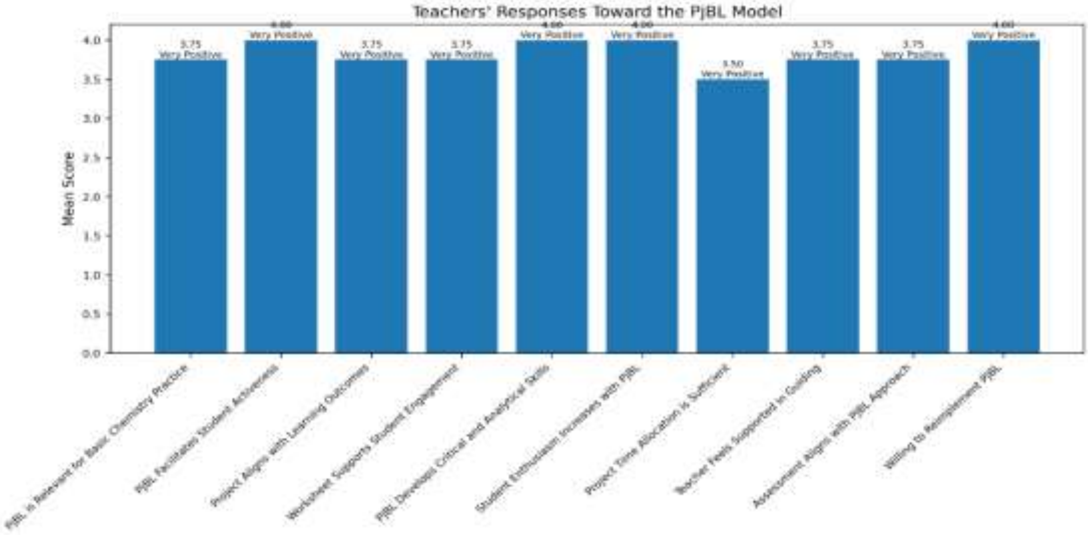

Figure 2. Teachers' Response of the PjBL Model

Based on Figure 1, all statements obtained mean scores above 3.50. The highest score was recorded for the statement "Working collaboratively in groups" (3.74), while the lowest score was found for the statement "Being able to relate the project to theoretical concepts" (3.50). These results indicate that students' responses fall within the positive category across all measured indicators. Furthermore, the results of teachers' responses to the implementation of the PjBL model are presented in Figure 2.

The questionnaire results indicate that all statements obtained mean scores above 3.50, which fall within the "very positive" category. The highest score was recorded for statement number 4, "I can collaborate effectively within project groups" (3.74). This finding suggests that the PjBL model effectively promotes students' collaborative abilities, which is consistent with one of its core characteristics—emphasizing teamwork in completing authentic projects. In addition, high scores were observed for indicators related to teacher guidance, learning motivation, and conceptual understanding. These results demonstrate that project-based instruction not only enhances students' conceptual comprehension but also strengthens intrinsic motivation. Students became more active, enthusiastic, and responsible for their own learning outcomes because they were directly involved in meaningful project activities.

Nevertheless, the lowest mean score (3.50) was recorded for statement number 9, concerning students' ability to relate project outcomes to theoretical concepts. Although still within the positive range, this result indicates that some students experienced difficulty connecting practical experiences with the underlying scientific principles. Therefore, additional instructional strategies—such as guided reflection or structured post-project discussions—may be necessary to deepen theoretical integration and facilitate more effective knowledge transfer.

Teacher responses also reflected highly positive perceptions, with average scores exceeding 3.50. Three statements received perfect scores (4.00): (1) PjBL facilitates active student engagement, (2) PjBL helps develop critical thinking skills, and (3) teachers intend to reapply PjBL in other subjects. These findings indicate that teachers recognized tangible benefits from PjBL implementation, both in terms of increasing student participation and enhancing instructional facilitation. The only relatively lower score (3.50) concerned the adequacy of project time allocation. Several teachers noted that PjBL stages require more flexible time planning to ensure that all phases—from project design to presentation—are completed thoroughly without compromising conceptual depth.

Overall, both students and teachers expressed highly positive responses toward the implementation of PjBL in Basic Chemistry Practice. These findings reinforce the results of the first research question, demonstrating that the application of PjBL positively influences the improvement of students' analytical abilities. Consequently, PjBL can be considered a feasible and effective instructional model for sustained implementation and is recommended for adaptation in other vocational subjects that demand critical and collaborative thinking skills. The convergence of positive cognitive outcomes and favorable perceptions provides strong empirical support that Project-Based Learning not only enhances learning achievement but also cultivates collaborative attitudes, responsibility, and high learning motivation. These findings form a robust basis for concluding that PjBL contributes positively to both analytical development and the overall quality of the learning process.

The present findings are consistent with prior studies highlighting positive acceptance of PjBL among students and teachers. Susanti et al. (2022) reported that students felt more motivated and enthusiastic when participating in project-based learning. Sari (2018) emphasized that collaboration within project groups enhances social skills and responsibility. Deveci & Ayish (2018) found that teachers perceived PjBL as effective in Personal responsibility and interpersonal communication. Nugroho et al. (2025) underscored that authentic project experiences enable students to connect theoretical concepts with practice more effectively. Fitri & Rofiqoh (2025) reported that PjBL strengthens intrinsic motivation and critical thinking skills. Lestari et al. (2024) showed that students developed greater confidence and responsibility through project work. Wijayanti & Santoso (2024) observed that PjBL improved teachers' perceptions of student engagement and instructional effectiveness. Prasasti et al. (2025) emphasized that clear and structured teacher guidance is crucial for successful PjBL implementation. Finally, Wijayanti & Santoso (2024) concluded that positive responses from both students and teachers indicate broad acceptance of PjBL and support its sustainable implementation. Collectively, these findings reinforce the conclusion that PjBL not only enhances collaborative skills and motivation but is also widely recognized by teachers as an effective instructional strategy in chemistry education.

The findings have important implications for curriculum and instructional development in vocational chemistry education. First, the combination of significant pretest–posttest improvement and predominantly moderate N-gain suggests that PjBL is effective as a foundational strategy for raising analytical competence, but stronger gains may require a longer implementation cycle, iterative practice, and more explicit conceptual scaffolding. In practical terms, curriculum planning for Basic Chemistry Practice should allocate sufficient time not only for product making but also for pre-lab concept preparation, guided data interpretation, post-project reflection, and theory-linking discussions, because the weakest area identified by students was precisely the connection between project outcomes and theoretical concepts. Second, these results are aligned with the direction of Kurikulum Merdeka, which emphasizes improved learning quality through leaner content coverage, greater flexibility, and more student-centered instructional approaches tailored to learners' contexts and needs. The Ministry's academic curriculum document explicitly notes that the reduced scope of material is intended to enable more student-centered methods and give schools/teachers flexibility in designing contextual learning. This policy orientation strengthens the curricular relevance of PjBL in vocational chemistry, especially when projects are designed around authentic products and local/industrial contexts.

Third, the present study supports the need for cross-subject and product-based. A recent bibliometric analysis of PjBL in vocational high schools reported that subject integration in VHS remains limited and recommended collaborative product-project integration across subjects to better support graduate competencies. For vocational chemistry curricula, this implies opportunities to integrate Basic Chemistry Practice with entrepreneurship, occupational safety, technical communication, or mathematics/statistics through shared project outputs and authentic assessment. Such integration may help move more students from moderate to high analytical gains by reinforcing repeated opportunities to interpret data, justify decisions, and communicate evidence across learning contexts.

CONCLUSION

This study confirms that the implementation of Project-Based Learning (PjBL) in Basic Chemistry Practice significantly improves vocational students' analytical abilities, as evidenced by the substantial increase in mean scores from 41.0 to 73.5 and the statistically significant paired sample t-test result ($p < 0.001$), supported by a moderate normalized gain (N-gain = 0.55). The findings demonstrate that engaging students in authentic, product-based chemical projects fosters meaningful analytical development, particularly in differentiating chemical components, organizing experimental data, linking theory with laboratory results, and drawing evidence-based conclusions. Beyond cognitive gains, the consistently positive perceptions of both students and teachers indicate that PjBL enhances engagement, collaboration, intrinsic motivation, and instructional effectiveness, thereby improving the overall quality of the learning process. The novelty of this study lies in the finding that a PjBL model embedded in authentic vocational chemistry production tasks and evaluated through HOTS-oriented analytical indicators can simultaneously strengthen students' analytical competence and improve classroom learning dynamics in Basic Chemistry Practice. Theoretically, this study reinforces the alignment between Project-Based Learning, Higher-Order Thinking Skills, constructivist learning theory, and experiential learning, showing that structured experiential projects provide a viable and context-relevant pathway for cultivating analytical competence in vocational education contexts. The contribution of this research lies in its focused examination of analytical ability as a distinct cognitive construct within authentic vocational chemistry practice, thereby extending prior studies that have largely emphasized general achievement or critical thinking without situating learning in industrial-simulated laboratory environments. Although limited by its pre-experimental design and single-class context, the study provides empirical evidence supporting the pedagogical significance of PjBL in vocational chemistry education.

RECOMMENDATION

For future research, stronger designs are recommended to increase the robustness of the findings. In particular, subsequent studies should consider using a quasi-experimental or experimental design with a comparison/control group to allow stronger causal inferences regarding the effect of PjBL on students' analytical abilities. If random assignment is not feasible in school settings, researchers may use intact parallel classes with equivalent pretest measures to compare PjBL and conventional practicum instruction. Future studies are also encouraged to involve larger samples across multiple vocational schools, extend the intervention duration, and include follow-up assessments to examine the sustainability of analytical skill development over time. In addition, mixed-method designs (e.g., interviews, classroom observation, and analysis of student work) may provide deeper explanations of why some students achieve only moderate gains while others reach high gains.

The findings also suggest several practical recommendations for vocational chemistry teachers who plan to implement PjBL more effectively. First, teachers should provide clear project scaffolding, including step-by-step milestones, role distribution within groups, and explicit expectations for product quality and analytical reasoning. Second, because students may complete procedures without fully understanding the underlying concepts, teachers should include structured theory–practice linking activities, such as pre-lab concept discussions, guided questioning during experimentation, and post-project reflection sessions focused on interpreting data and drawing evidence-based conclusions. Third, teachers are encouraged to use analytic rubrics and formative feedback throughout the project process, not only at the final stage, to help students improve progressively. Fourth, to increase student engagement, teachers may design projects that are authentic, context-relevant, and vocationally meaningful (e.g., products related to household chemicals or local industry practices). Finally, schools and teachers should consider time allocation, laboratory resources, and collaborative planning when implementing PjBL, as these factors strongly influence the depth of student participation and learning outcomes.

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