



A Study of Project-Based Learning with a Research-Based Approach: Improving Conceptual Understanding and Scientific Skills

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Abstract

This study aims to analyze the effect of implementing the Project-Based Learning with a Research-Based Approach (PjBL-RBA) model in chemistry practicum on improving students' conceptual understanding and scientific process skills. The research employed a quantitative approach with a one-group pretest–posttest design. The sample consisted of 26 undergraduate students from the Chemistry Education Study Program, Faculty of Teacher Training and Education, Mulawarman University, Indonesia, selected purposively to represent learners actively engaged in laboratory-based courses. Data collection instruments included a conceptual understanding test, an observation sheet for scientific process skills, and documentation of practicum activities. The data were analyzed using a paired sample t-test to determine statistical significance and N-Gain scores to measure the level of improvement. The results showed a significant enhancement in both variables with a p-value < 0.05. The average N-Gain scores of 0.53 for conceptual understanding and 0.38 for scientific process skills indicate a moderate level of improvement. The novelty of this study lies in the integration of Project-Based Learning with a Research-Based Approach in chemistry laboratory practice, which has rarely been explored simultaneously in previous literature. Therefore, the implementation of the PjBL-RBA model is proven effective and recommended as an innovative instructional strategy to strengthen students' conceptual and scientific learning outcomes in higher education chemistry practicum.

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INTRODUCTION

Chemistry learning in higher education plays an important role in developing students' scientific thinking abilities and scientific process skills. The chemistry practicum serves as a key activity that bridges theoretical concepts with real-world applications through direct experimental experiences. However, in practice, many students still face difficulties in understanding the abstract concepts of chemistry and demonstrate limited skills in applying scientific methods. (Kurniawati, 2021). Several studies have highlighted that one of the main challenges in chemistry education is the abstract nature of chemical concepts, which often leads to misconceptions and difficulties in connecting macroscopic, microscopic, and symbolic representations. Laboratory activities are therefore considered essential to bridge these gaps, as they provide students with opportunities to directly observe phenomena, apply scientific methods, and strengthen their conceptual understanding (Mundy et al., 2024).

As an alternative, the project-based learning model, known as Project-Based Learning (PjBL), has been widely proposed and implemented in chemistry education. PjBL allows students to

work on real projects, design and conduct experiments, solve problems, and critically reflect on their results. Recent literature indicates that PjBL can enhance conceptual understanding, motivation, active engagement, as well as collaboration and communication skills in the context of chemistry. For example, a study in the “Fundamental Chemistry I” program at a university reported that students were able to critically propose project titles, carry out projects, and present their results both orally and in written scientific formats (Subagia & Sudiarmika, 2023). Recent meta-analyses reinforce the claim of PjBL’s potential: this model shows a significant effect on chemistry learning outcomes, particularly in the knowledge (cognitive) domain, with a high level of effectiveness ((Desyafrianti et al., 2024). In addition, literature reviews highlight the success of PjBL in deepening conceptual understanding as well as developing laboratory competence and scientific literacy (Aslam et al., 2025).

Integrating Project-Based Learning with a Research-Based Approach represents a novel direction in chemistry education. While PjBL emphasizes active engagement through project design and execution, RBA requires students to experience the complete scientific cycle, including problem formulation, hypothesis testing, data analysis, and scientific reporting. This combined model has the potential to foster deeper conceptual understanding and scientific literacy by positioning students not only as learners but also as novice researchers. Recent studies in science education highlight that research-based learning can significantly enhance students’ inquiry skills, critical thinking, and ability to connect theory with practice (Rahmawati, et al., 2020); (Agustian, 2025). However, its integration into chemistry laboratory practice remains underexplored, making this study an important contribution to the literature.

However, although much evidence supports PjBL, most studies have focused on general aspects of chemistry learning (theory, project tasks, collaboration) and have not specifically considered the integration of a research-based approach (RBA) into PjBL. RBA requires students not only to carry out projects but also to engage in the complete scientific process from problem formulation, experiment implementation, and data analysis to reflection and scientific reporting. This combined approach has rarely been explored in the literature, especially in the context of chemistry laboratory practice at the university level. A recent study on organic synthesis laboratory practice among university students showed that implementing PjBL improved learning outcomes when students were involved in the design and execution of projects; however, such research remains limited in number (Yunita Putri Olii et al., 2024).

In the Indonesian higher education context, strengthening chemistry laboratory practices is particularly urgent due to the persistent challenges students face in connecting theoretical knowledge with experimental applications. National curriculum reforms emphasize the importance of inquiry-based and contextual learning approaches, yet empirical evidence on the integration of Project-Based Learning with a Research-Based Approach in local chemistry education remains scarce. Addressing this gap is essential not only for improving students’ conceptual understanding and scientific process skills but also for aligning chemistry education with broader goals of scientific literacy and sustainable development in Indonesia (Renner & Griesbeck, 2020); (Nugroho & Dewi, 2025).

Thus, the scientific novelty of this research lies in the implementation of the PjBL model combined with a research-based approach (RBA) in university chemistry laboratory practice, with an evaluative focus on students’ conceptual understanding and scientific process skills—two aspects that previous literature has rarely emphasized simultaneously. Based on this novelty, the research question in this study is formulated as follows: “To what extent does the implementation of the RBA-based PjBL model in chemistry laboratory practice enhance students’ conceptual understanding and scientific process skills?” From this question emerges the hypothesis that the application of PjBL-RBA will lead to a significant improvement in both aspects compared to the initial condition (pretest). Based on this novelty, the research question

in this study is formulated as follows: “To what extent does the implementation of the RBA-based PjBL model in chemistry laboratory practice enhance students’ conceptual understanding and scientific process skills?” From this question emerges the hypothesis that the application of PjBL-RBA will lead to a significant improvement in both aspects compared to the initial condition (pretest).

Therefore, the purpose of this study is to evaluate the effect of implementing PjBL-RBA in chemistry laboratory practice on students’ conceptual understanding and scientific process skills through a combination of quantitative data (pretest-posttest, N-Gain) and qualitative data (process observation, laboratory documentation). Thus, this research is expected to provide new empirical evidence for the development of a more contextual and scientific chemistry laboratory learning model.

METHOD

Research Design

This study employed a quasi-experimental method with a one-group pretest-posttest design. The pretest data were obtained from laboratory assessments conducted before the treatment, while the posttest data were collected from laboratory assessments after applying the Project-Based Learning model based on the Research-Based Approach (PjBL-RBA). This design was chosen because it allows for the examination of the effects of implementing the Project-Based Learning model based on the Research-Based Approach (PjBL-RBA) on students’ conceptual understanding and scientific process skills by comparing results before and after the treatment.

The one-group pretest–posttest design is widely used in chemistry education research because it is effective in measuring improvements in students’ learning outcomes and scientific skills following the implementation of innovative learning models. For instance, Minarni et al. (2022) applied this design to evaluate the effectiveness of PjBL in improving science process skills and student learning outcomes in colloidal chemistry, while (Susilawati et al. (2025) employed a similar approach to assess the impact of STEM-PjBL-based teaching materials on students’ science literacy in acid–base topics. Furthermore, Anantasia & Rindrayani (2025) emphasized that quasi-experimental one-group pretest–posttest designs are methodologically appropriate for educational research, as they enable researchers to analyze learning improvements despite the absence of a control group.

The one-group pretest-posttest design is widely used in chemistry education research because it is effective in measuring improvements in students’ learning outcomes and scientific skills following the implementation of the Project-Based Learning model based on the Research-Based Approach (PjBL-RBA). The overall research design is summarized in Table 1.

Tabel 1. One-Group Pretest–Posttest Design

Stage	Treatment	Test
Pretest	-	O ₁
Treatment	x	-
Posttest	-	O ₂

Notes :

O₁ = observation or measurement at the pretest stage.

X = the intervention or treatment applied (in your case, PjBL-RBA).

O₂ = observation or measurement at the posttest stage.

The procedure of this research from the preparation stage and implementation of the PjBL-RBA model to the evaluation through pretest–posttest, observation, and project documentation is visually summarized in the flowchart in figure 1.

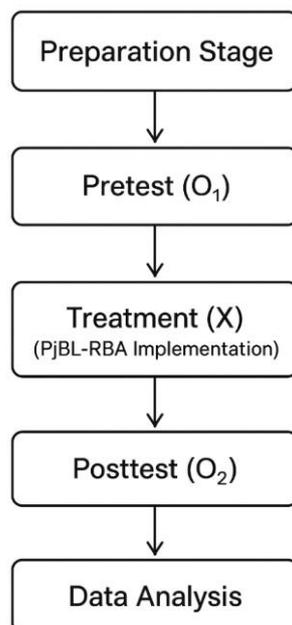


Figure 1. Research Flowchart for Implementing PjBL-RBA in Practicum Activities

Research Subjects

A total of 26 second-semester students of the Chemistry Education Study Program who were enrolled in the Basic Chemistry Practicum course participated in this study. The subjects were selected through purposive sampling, considering that they had completed Basic Chemistry I and possessed relatively homogeneous prior knowledge. The use of purposive sampling is consistent with previous studies in chemistry education, which emphasize the importance of selecting participants based on specific characteristics relevant to the research objectives (Islawati et al., 2025); (Nyimbili & Nyimbili, 2024).

Research Procedure

The study was conducted in three stages: preparation, implementation, and evaluation. This three-stage structure is consistent with previous PjBL research in chemistry and science education which emphasize the importance of developing learning materials and instruments during preparation, applying project-based activities during implementation, and conducting assessments and documentation during evaluation (Gozde & Akoglu, 2023); (Islawati et al., 2025).

Research Instruments

The research instruments consisted of a conceptual understanding test developed from practicum reports Rahmawati, et al. (2022); Talens et al. (2025), an observation sheet for science process skills including indicators of observation, classification, hypothesis formulation, and data interpretation (Wazni & Fatmawati, 2022), as well as documentation of students' project outcomes as evidence of achievements in conceptual understanding and science process skills (Dulanlebit et al., 2024); (Islawati et al., 2025).

Data Analysis Technique

Quantitative data (pretest–posttest) were analyzed using a paired sample t-test to determine the significance of learning gains (Talikan et al., 2024); (Strunk & Mwavita, 2024). The

improvement in conceptual understanding was calculated using the N-Gain score, which is widely applied in educational research to measure learning effectiveness (Wahyu Setiyadi et al., 2024). Qualitative data obtained from observations and documentation were analyzed descriptively to illustrate students' science process skills and creativity during project activities, consistent with approaches used in recent studies (Harjono & Ahmad, 2024); (Puspita et al., 2024).

RESULTS AND DISCUSSION

Based on the statistical analysis of 26 students who participated in the chemistry practicum using the Project-Based Learning model with a Research-Based Approach (PjBL-RBA), a significant improvement was found in both conceptual understanding and science process skills.

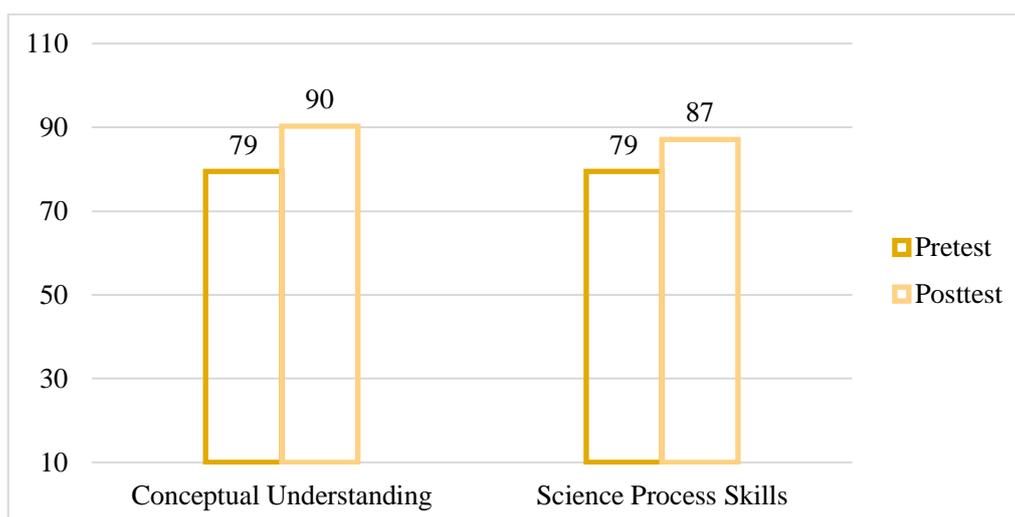


Figure 2. Average pretest and posttest scores of students' conceptual understanding and science process skills

Figure 2 shows a clear increase between the average pretest and posttest scores for both conceptual understanding and students' science process skills. The pretest average score of 79 for both aspects rose to 90 for conceptual understanding and 87 for science process skills. This increase suggests that implementing the Project-Based Learning with Research-Based Approach (PjBL-RBA) model has had a positive impact on the quality of students' learning outcomes both cognitively and psychomotorically. The increase in scores indicates that during the practicum, students shifted from passive learning toward active, inquiry-based learning. This is consistent with the findings of Rahmawati et al. (2020), who demonstrated that the implementation of STEM Project-Based Learning in the chemistry curriculum can enhance students' chemical literacy through engagement in contextual scientific processes.

Within the PjBL-RBA approach, students did not merely conduct experiments by following instructions; they engaged in the entire scientific process, including formulating questions, designing experiments, and analyzing observational data. A systematic review by Jegstad, (2023) emphasized that inquiry-based chemistry education fosters higher-order thinking skills and deeper conceptual understanding, particularly when students are given opportunities to design and evaluate experiments. This involvement enables meaningful learning, where previously abstract chemical concepts become easier to comprehend through contextual research activities. Furthermore, Halimatuzzahra & Louise (2025), in their systematic literature review, highlighted that the application of Project-Based Learning in chemistry education significantly contributes to the development of 21st-century problem-solving skills, aligning

with the objectives of the PjBL-RBA framework. These findings align with prior research a recent systematic review on PjBL in chemistry education reports that PjBL significantly enhances students' conceptual understanding and laboratory competencies (Aslam et al., 2025). Similarly, studies have shown that PjBL fosters development of scientific process skills such as observation, data interpretation, and reflection on experimental results (Munawwarah & Side, 2025).

Moreover, the improvement in science process skills indicates that this model is effective in cultivating students' practical scientific abilities. Students become more adept at identifying variables, using laboratory equipment correctly, and drawing conclusions based on empirical evidence. This finding is consistent with research that demonstrates PjBL can improve science process skills through direct engagement in authentic experimentation and collaborative group work (Juwita Sman, 2022).

Tabel 2. Summary of the Paired Sample t-test results comparing pretest and posttest scores for students' conceptual understanding and science process skills.

Variable	t-value	p-value	Description
Conceptual Understanding	16.11	0.000	significant
Science Process Skills	6.45	0.000	significant

Tabel 3. N-Gain Scores of Students' Conceptual Understanding and Science Process Skills

Variable	N-Gain score	Category
Conceptual Understanding	0.53	Medium
Science Process Skills	0.38	Medium

The paired t-test results in Table 2 show a significant difference between the pretest and posttest scores for students' conceptual understanding and scientific process skills, with a p-value < 0.05, thus the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. The implementation of Project-Based Learning integrated with a Research-Based Approach (PjBL-RBA) has been proven to positively influence the improvement of learning outcomes, effectively bridging theoretical aspects with laboratory practice so that students not only understand chemical concepts declaratively but also construct knowledge through exploration and investigation. This finding is consistent with international studies in the last five years. Rahmawati et al. (2020) reported that integrating STEM Project-Based Learning into the chemistry curriculum enhances students' chemical literacy and higher-order thinking skills. Halimatuzzahra & Louise (2025), emphasized the effectiveness of PjBL in developing problem-solving abilities as part of scientific process skills. Wardat et al. (2025), highlighted the significant contribution of project-based approaches to mastering 21st-century skills (critical thinking, creativity, collaboration, and communication). Thus, the results of this study reinforce global evidence that PjBL-RBA is a relevant and effective approach to improving chemistry learning outcomes as well as students' scientific process skills

These findings are further supported by meta-analysis research, which shows that PjBL has a significant impact on chemistry learning outcomes across various educational levels (Desyafrianti et al., 2024). The study emphasizes that a project-based approach enhances students' learning motivation, conceptual understanding, and critical thinking skills. Similar results were also reported by (Rahmad & Suryani, 2024), who developed Project-Based Learning Student Worksheets (LKPD) on stoichiometry material. The use of project-based LKPD was proven to enhance students' scientific thinking skills and awareness of the real-life applications of chemistry concepts.

Research conducted by Puspitasari et al. (2023) also found that project-based clinical chemistry learning modules significantly improved students' cognitive and psychomotor aspects. This improvement highlights that the project approach encourages students to actively participate in

laboratory activities emphasizing scientific inquiry and reflection on experimental results. Sholahuddin et al. (2023) demonstrated the effectiveness of the PjBL model in improving conceptual understanding of acid-base solution materials, making this approach relevant for various chemistry topics to strengthen the integration between theory and practice.

Furthermore, the N-Gain values presented in Table 3 indicate moderate improvement in both conceptual understanding (0.53) and science process skills (0.38). These findings are consistent with Islawati et al. (2025), who reported that Project-Based Learning has shown sustained effectiveness in enhancing conceptual understanding and learning outcomes in chemistry education over the past decade. Similarly, Munawwarah & Side (2025) emphasized that PjBL significantly strengthens students' scientific process skills, particularly in hypothesis formulation, experimental execution, and result interpretation. Thus, the moderate N-Gain values in this study reinforce global evidence that research-based project learning provides meaningful opportunities for students to bridge theory with practice and achieve sustainable improvements in chemistry learning.

A study by Munawwarah & Side (2025) reported similar results, showing that the implementation of Project-Based Learning (PjBL) consistently enhances students' scientific process skills and analytical thinking abilities through exploratory and reflective activities in chemistry experiments. Moreover, research by Ananda et al. (2023) demonstrated that the integration of design thinking and the STEAM approach within PjBL can strengthen students' analytical and reflective skills in interpreting experimental outcomes in chemistry learning. Likewise, the study conducted by Yunita Putri Olii et al. (2024) found that project-based learning experiences in organic compound synthesis practicum significantly improve students' practical skills and conceptual understanding. Therefore, the improvement in learning outcomes identified through the paired *t-test* and N-Gain analysis in this study aligns with previous research findings, consistently demonstrating that the PjBL-RBA model is an innovative and effective instructional strategy for supporting 21st-century chemistry learning outcomes. As a result of the practicum using the PjBL-RBA model, which promotes the enhancement of students' conceptual understanding and process skills through research-based activities, the outcomes obtained by Nurhadi et al. (2017) can be seen in Figures 3, 4, 5, and 6.

Natural Material	Color in Acid (0.1 M HCl)	Color in Base (0.1 M NaOH)	Documentation
Butterfly Pea Flower	Light red, Purple, Blue	Blue, Green, Yellow	

Figure 3. Results of the Identification of Color Changes in Acid and Base Samples Using Natural Indicators from Butterfly Pea Flower (*Clitoria ternatea*)

Image	Description													
	Name: Butterfly Pea Flower Species: <i>Clitoria ternatea</i> L. Color changes and pH range are presented below.													
	pH-Color Range of Butterfly Pea Flower Extract													
	Basic	1	2	3	4	5	6	7	8	9	10	11	12	13
														

Figure 4. Color Change Reaction of Natural Acid-Base Indicator from Butterfly Pea Flower (*Clitoria ternatea*) in Solutions with pH 1–14

pH	1	2	3	4	5	6	7	8	9	10	11	12	13	14
λ (nm)	620	620	450	450	450	450	450	450	450	450	450	570	570	570
Absorbance	0.486	0.680	1.294	1.309	2.787	2.862	0.677	2.149	0.598	0.605	0.645	0.502	0.433	0.396

Figure 5. Adsorption Capacity Measurement Values of Natural Acid-Base Indicator from Butterfly Pea Flower (*Clitoria ternatea*) in Solutions with pH 1–14

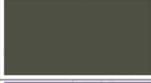
No.	Sample	pH	Sample Color	Original Color	λ (nm)	Absorbance
1	X	2			620	0.908
2	Y	12			570	0.673
3	Z	3			450	1.250

Figure 6. Application of Natural Acid-Base Indicators in Determining the pH Range of a Sample

The data presented in Figures 3 to 6 represent documented student products resulting from laboratory activities implemented through the Project-Based Learning integrated with a Research-Based Approach (PjBL-RBA) model. These products illustrate how students were able to integrate research findings into their laboratory practices to identify, analyze, and present chemical concepts in a more meaningful way.

Through this process, students not only produced learning artifacts such as experimental data and visualizations of practical results but also demonstrated improvements in conceptual understanding and science process skills. Project- and research-based laboratory activities encouraged students to engage in systematic scientific thinking from problem formulation, experimental design, data collection, to result interpretation. These findings are consistent with the study of (Munawwarah & Side (2025), which showed that Project-Based Learning effectively develops science process skills in chemistry students, as well as (Rahmawati et al. (2020), who emphasized that integrating research-based projects in chemistry learning enhances chemical literacy and higher-order thinking skills. Furthermore, Febriani et al. (2025) highlighted that the application of PjBL in the context of green chemistry contributes to improved conceptual understanding while fostering students' environmental awareness.

Therefore, the data in Figures 3–6 not only reflect the tangible outcomes of implementing the PjBL-RBA model in strengthening students' ability to connect theory with practice but also align with national and international empirical evidence underscoring the development of 21st-century competencies, particularly scientific inquiry, critical thinking, scientific literacy, and collaborative learning.

CONCLUSION

Based on the results of the paired t-test analysis and N-Gain values, the implementation of the Project-Based Learning model with a Research-Based Approach (PjBL-RBA) in basic chemistry practicum has proven effective in enhancing students' conceptual understanding and scientific process skills. The integration of theoretical concepts of acids and bases with

empirical experiences through the use of natural indicators enables students not only to comprehend the theory of color changes in indicators but also to test and analyze the reactions of natural indicator color changes across various pH levels. These findings affirm that the application of PjBL-RBA contributes not only to the improvement of cognitive achievement and scientific skills but also fosters awareness of green chemistry principles, the utilization of local resources, and the strengthening of scientific attitudes, scientific literacy, and critical thinking skills competencies essential for sustainable chemistry learning in the 21st century.

RECOMMENDATIONS

Based on the findings, the implementation of the Project-Based Learning with a Research-Based Approach (PjBL-RBA) model has proven effective in enhancing students' conceptual understanding and scientific process skills; however, several challenges remain, including limited practicum time, laboratory facilities, and lecturers' readiness to integrate research-oriented approaches into project-based learning. Therefore, future research is recommended to expand the application of this model across various chemistry topics and educational levels, as well as to combine it with virtual laboratory technologies to allow students' research activities to be more flexible and in-depth. Moreover, professional development and training for lecturers in research project design and authentic assessment are essential to ensure the sustainability of PjBL-RBA implementation. The implication of this study is that the application of PjBL-RBA not only has the potential to strengthen the quality of chemistry learning in higher education but also fosters the development of a scientific culture and students' scientific literacy aligned with the demands of 21st-century education.

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BIBLIOGRAPHY

- Agustian, H. Y. (2025). Recent advances in laboratory education research. *Chemistry Teacher International*, 7(2), 217–224. <https://doi.org/10.1515/CTI-2024-0071/XML>
- Ananda, L. R., Rahmawati, Y., & Khairi, F. (2023). Critical Thinking Skills Of Chemistry Students by Integrating Design Thinking With STEM-PjBL. *Journal of Technology and Science Education*, 13(1), 352–367. <https://doi.org/10.3926/JOTSE.1938>
- Anantasia, G., & Rindrayani, S. R. (2025). Metodologi Penelitian Quasi Eksperimen. *Adiba: Journal of Education*, 5(2), 183–192.
- Aslam, S., Ikhsan, J., Ali, S., & Ali, S. (2025). A Systematic Review of PjBL in Chemistry Education: Bridging Theory and Practice. *Jurnal Inovasi Pendidikan IPA*, 11(2), 363–377. <https://doi.org/10.21831/JIPI.V11I2.81122>
- Desyafrianti, V., Qurrata, F., Desyafrianti, A., & Aini, Q. (2024). Meta Analysis: The Effect

- of Project-based Learning on Students' Learning Outcomes in Chemistry Learning. *Hydrogen: Jurnal Kependidikan Kimia*, 12(4), 753–760. <https://doi.org/10.33394/HJKK.V12I4.12315>
- Dulanlebit, Y. H., Hernani, H., Liliarsari, L., & Amran, M. B. (2024). Enhancing Critical Thinking Skills through Project-Based Chemistry Practicum Using Seaweed Hydrogel Design. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, 9(2), 403–412. <https://doi.org/10.24042/TADRIS.V9I2.24847>
- Febriani, F., Hasan*, M., Khaldun, I., & Khwaengmek, W. (2025). Impact of Project-Based Learning Implementation on Students' Achievement in Green Chemistry Concepts. *Jurnal IPA & Pembelajaran IPA*, 9(3), 1020–1031. <https://doi.org/10.24815/jipi.v9i3.48944>
- Gozde, K., & Akoglu, K. (2023). Project-based learning in science education: A comprehensive literature review. *Interdisciplinary Journal of Environmental and Science Education*, 2023(3), 2633–6537. <https://doi.org/10.29333/ijese/13677>
- Halimatuzzahra, H., & Louise, I. S. Y. (2025). Implementation of Project-Based Learning in Improving Students' Problem-Solving in Chemistry Learning: A Systematic Literature Review. *Jurnal Pendidikan MIPA*, 26(2), 810–822. <https://doi.org/10.23960/JPMIPA.V26I2.PP810-822>
- Harjono, Ahmad Firdaus, F. (2024). Improving Students' Science Process Skills Through Project Based Learning Models: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, 10(10), 711–720. <https://doi.org/10.29303/JPPIPA.V10I10.9381>
- Islawati, I., Rohaeti, E., & Priyambodo, E. (2025). A Decade of Project-based Learning in Chemistry Education (2015–2025): Trends in Conceptual Understanding and Learning Outcomes. *Journal of Global Research in Education and Social Science*, 19(4), 230–243. <https://doi.org/10.56557/JOGRESS/2025/V19I49978>
- Jegstad, K. M. (2023). *Studies in Science Education Inquiry-based chemistry education: a systematic review*. <https://doi.org/10.1080/03057267.2023.2248436>
- Juwita Sman, R. (2022). Best Practice Membangun Keterampilan Proses Sains Melalui Model Project Based Learning Pendekatan Steam Materi Asam Basa Kelas Xi Ipa Sman 1 Bontang. *LEARNING: Jurnal Inovasi Penelitian Pendidikan Dan Pembelajaran*, 2(3), 268–277. <https://doi.org/10.51878/LEARNING.V2I3.1581>
- Kurniawati, K. (2021). Penerapan Model Pembelajaran Inkuiri Terbimbing Untuk Meningkatkan Keterampilan Proses Sains Siswa. *Primary: Jurnal Pendidikan Guru Sekolah Dasar*, 10(2). <https://doi.org/10.33578/JPFKIP.V10I2.8250>
- Minarni, M., Epinur, E., Fuldiaratman, F., Yusnidar, Y., & Wardiah, R. (2022). Application of Project Based Learning Model on Basic Chemical Colloidal Materials to Improve Science Process Skills and Student Learning Outcomes. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, 5(2). <https://doi.org/10.33258/birci.v5i2.5663>
- Muhammad Khairul Wazni, B. F. (2022). Study of Science Process Skills Student Using Worksheet based on Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, 8(2), 436–443. <https://doi.org/10.29303/JPPIPA.V8I2.1281>
- Munawwarah, M., & Side, S. (2025). The Effectiveness of Project-Based Learning on Science Process Skills in Chemistry Education: A Research Findings Perspective. *Journal of Educational Sciences*, 9(2), 513–525. <https://doi.org/10.31258/JES.9.2.P.513-525>

- Mundy, C. E., Potgieter, M., & Seery, M. K. (2024). A design-based research approach to improving pedagogy in the teaching laboratory. *Chemistry Education Research and Practice*, 25(1), 266–275. <https://doi.org/10.1039/D3RP00134B>
- Nugroho, P. A., & Dewi, N. D. L. (2025). Implementation of The Project Based Learning Model in Science Learning To Improve Scientific Literacy on The Issue of Global Climate Change. *Scientica Education Journal*, 2(4), 26–35. <https://doi.org/10.62872/D8WCMF60>
- Nurhadi, M., Erika, F., & Intan Widiyowati, I. (2017). The development of learning media of acid-base indicator from extract of natural colorant as an alternative media in learning chemistry. *AIP Conf. Proc.*, 1823, 20017. <https://doi.org/10.1063/1.4978090>
- Nyimbili, F., & Nyimbili, L. (2024). Types of Purposive Sampling Techniques with Their Examples and Application in Qualitative Research Studies. *British Journal of Multidisciplinary and Advanced Studies*, 5(1), 90–99. <https://doi.org/10.37745/BJMAS.2022.0419>
- Puspita, L., Hidayah, N., Indrawan, A. R., Komarudin, K., & Carolina, H. S. (2024). Analysis of Science Process Skills: The Impact of Project-Based Learning Assisted by Mind Mapping on Biology Subjects. *Biosfer: Jurnal Tadris Biologi*, 15(2), 179–191. <https://doi.org/10.24042/BIOSFER.V15I2.25564>
- Puspitasari, R. D., Nelson, N., & Tarigan, I. L. (2023). Improving Students' Cognitive and Psychomotor Performance through the Development of Project-Based Clinical Chemistry Learning Modules. *Hydrogen: Jurnal Kependidikan Kimia*, 11(1), 82–87. <https://doi.org/10.33394/HJJK.V11I1.6178>
- Rahmad, N. Y., & Suryani, O. (2024). Development of LKPD Based on Project Based Learning Stoichiometry Material by Utilizing Organic Waste for Phase F SMA/MA. *Hydrogen: Jurnal Kependidikan Kimia*, 12(3), 625–647. <https://doi.org/10.33394/HJJK.V12I3.12443>
- Rahmawati, Y., Dushita Andanswari, F., Ridwan, A., Gillies, R., & Charles Taylor, P. (n.d.). STEM Project-Based Learning in Chemistry: Opportunities and Challenges to Enhance Students' Chemical Literacy. *International Journal of Innovation, Creativity and Change*. *Www.Ijicc.Net*, 13(7), 2020. Retrieved December 18, 2025, from www.ijicc.net
- Rahmawati, Y., Hartanto, O., Falani, I., & Iriyadi, D. (n.d.). *Journal of Technology and Science Education Students' Conceptual Understanding In Chemistry Learning Using Phet Interactive Simulations*. <https://doi.org/10.3926/jotse.1597>
- Renner, M., & Griesbeck, A. (2020). Think and Print: 3D Printing of Chemical Experiments. *Journal of Chemical Education*, 97(10), 3683–3689. <https://doi.org/10.1021/ACS.JCHEMED.0C00416>
- Sholahuddin, S., Fadhillah, R., Kurniasih, D., & Artikel, S. (2023). Efektivitas Model Pembelajaran Berbasis Proyek terhadap Pemahaman Konsep pada Materi Larutan Asam Basa. *Hydrogen: Jurnal Kependidikan Kimia*, 11(5), 666–675. <https://doi.org/10.33394/HJJK.V11I5.8675>
- Strunk, K. K., & Mwavita, M. (2024). Paired samples t-test case studies. *Design and Analysis in Quantitative Educational Research*, 208–213. <https://doi.org/10.4324/9781003442011-18>
- Subagia, I. W., & Sudiarmika, R. S. (2023). Project-Based Learning Implementation in Fundamental Chemistry Courses to Meet the 21st Century Learning Target. *Jurnal Pendidikan Kimia Indonesia*, 7(2), 79–86. <https://doi.org/10.23887/JPKI.V7I2.70368>

- Susilawati Amdayani*, Ratu Evina Dibyantini, Dewi Syafriani, & M. D. (2025). Development of STEM-PjBL-Based Teaching Materials to Enhance Students' Science Literacy on Acid-Base Topic. *Jurnal Pendidikan MIPA*, 26(3), 1289–1307. <https://doi.org/http://dx.doi.org/10.23960/jpmipa.v26i3.pp1289-1307>
- Talens, C. U., Ong, I., Chiu, M. H., & Sevilla, F. B. (2025). Assessing conceptual understanding in high school chemistry: particulate nature of gas concept test (PNGCT) with Rasch modeling. *Chemistry Teacher International*, 1–13. <https://doi.org/10.1515/CTI-2024-0062/XML>
- Talikan, A. I., Salapuddin, R., Aksan, J. A., Rahimulla, R. J., Ismael, A., Jimlah, R., Idris, N., Dammang, R. B., Jamar, D. A., Sarahadil, E., & Ajan, R. A. (n.d.). *On Paired Samples T-Test: Applications, Examples and Limitations*. <https://doi.org/10.5281/zenodo.10987546>
- Wahyu Setiyadi, M., Istri Agung Rai Sudiatmika, A., Suma, K., Suardana, N., & Al Amin Dompu Jl Lintas Wawonduru No, S. (2024). Meta-Analysis: The Effect of Project Based Learning on Science Process Skills. *Jurnal Pembelajaran Dan Biologi Nukleus*, 10(1), 52–62. <https://doi.org/10.36987/JPBN.V10I1.5227>
- Wardat, E., Setiawan, Y., Iksan, A. H., Rauf, Z. H., Kusumaningrum, R. A. A., & Nurdiana, W. I. (2025). Developing 21st Century Skills Through STEM-Based Lesson Study and Project-Based Approaches in Chemistry Learning. *Educational Process: International Journal*, 19, 2025534. <https://doi.org/10.22521/edupij.2025.19.534>
- Yunita Putri Olii, N., Choirul, M., Tasya, I., Lestari, S., Rahmadani, A., Pahu, M., & Kalimantan, E. (2024). Student experiences and effectiveness of project-based learning in an organic practicum chalcone synthesis experiments. *Research and Development in Education (RaDEn)*, 4(2), 1408–1417. <https://doi.org/10.22219/RADEN.V4I2.36737>