JPPIPA 12(8) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Effectiveness of a Project-Based Learning Module in Chemical Engineering Operations (OTK) to Improve Problem-Solving Skills of Phase F Vocational High School Students

Retno Hardillah[1,2], Minda Azhar[1*], Alizar[1], Syamsi Aini[1], Salsabilla Putri Serli[1]

[1] Department of Chemistry, FMIPA, Universitas Negeri Padang, Jl. Prof. Dr. Hamka, Air Tawar Padang 25132, Indonesia.
[2] SMKN 1 Koto Besar, Jr Koto Tuo, Kelurahan Koto Ranah, Kecamatan Koto Besar, Kabupaten Dharmasraya, 27584, Indonesia.

Received: May 06, 2026
Revised: August 12, 2026
Accepted: August 28, 2026
Published: August 31, 2026

Corresponding Author:
Minda Azhar
minda@fmipa.unp.ac.id

DOI: 10.29303/jppipa.v12i8.15201

Abstract: A project-based learning module on mechanical separation in chemical engineering operations has been tested for validity and practicality. This study aims to determine the effectiveness of using this module to improve the problem-solving skills of Phase F students majoring in industrial chemical engineering at a vocational high school (SMK). This research is a quasi-experimental study employing a pretest-posttest control group design. The research population consists of Phase F students at SMK Negeri 1 Koto Besar. The sampling technique used is random sampling. Class XI TKI 2 serves as the experimental group, while class XI TKI 1 serves as the control group. Based on the t-test results of the problem-solving skills posttest, the calculated t-value is 21.96, which is greater than the t-table value of 1.67 (t_{count} = 21.96 > t_{table} = 1.67). This indicates that using the project-based learning module for mechanical separation in chemical engineering operations effectively improves the problem-solving skills of Phase F vocational high school students.

Keywords: Chemical engineering operations; Learning module; Problem-Solving Skills; Project-Based Learning (PjBL); Vocational High School (SMK)

Introduction

Twenty-first-century education demands the development of adaptive problem-solving skills for learners. The Era of Industrial Revolution 4.0 requires individuals to possess high creativity to overcome various issues in daily life (Irsyad & Sesmiarni, 2024). In this context, vocational high schools (SMK) play a strategic role in preparing skilled workforces ready to compete in the industrial world through the implementation of the *Kurikulum Merdeka* (Independent Curriculum). This curriculum provides flexibility for schools to design learning relevant to industrial needs, including the use of more adaptive project-based learning models (Kurniawati & Hulopi, 2026).

Mastering problem-solving skills is a highly vital intellectual competence, particularly in understanding Chemical Engineering Operations (OTK) material in SMKs. At the Phase F level, students do not only study the concepts of heat or mass transfer theoretically, but they must also be able to apply them in real-world situations, such as reactor optimization or the efficiency of separation processes. This skill involves logical steps starting from problem identification to the evaluation of solutions based on empirical evidence. Therefore, mastering OTK material is crucial for prospective plant operators to face technical challenges to increase operational efficiency in the chemical industry (Ningsih et al., 2024).

However, current educational realities show that students' problem-solving skills remain low due to limitations in teaching materials. Based on observations in several SMKs, it was found that many students experienced difficulties in understanding mechanical separation material, with the percentage of difficulty reaching 76.2% to 95.7%. This obstacle is triggered by a

How to Cite:
Hardillah, R., Azhar, M., Alizar, A., Aini, S., & Serli, S. P. (2026). Effectiveness of a Project-Based Learning Module in Chemical Engineering Operations (OTK) to Improve Problem-Solving Skills of Phase F Vocational High School Students. *Jurnal Penelitian Pendidikan IPA*, *12*(8), 138–143. https://doi.org/10.29303/jppipa.v12i8.15201

dependence on old textbooks that have not been synchronized with the *Kurikulum Merdeka*, as well as teaching methods that are still dominated by theoretical lectures. Consequently, there is a gap between the theory learned in class and the practical needs that demand high analytical skills in the field (Handayani et al., 2022).

The Project-Based Learning (PjBL) model emerges as an innovative and effective solution to promote students' learning activity and independence. PjBL focuses on contextual learning through complex activities where learners act as the main drivers in completing real projects. Through this model, students are encouraged to collaborate, think critically, and take responsibility for every stage of project implementation. Research shows that active involvement in scientific projects directly contributes to the improvement of problem-solving skills compared to conventional methods (Febrila et al., 2023).

The development of the PjBL-based OTK module using the 4-D model (Define, Design, Develop, Disseminate) is a systematic step to produce high-quality learning instruments. The development stage begins with an analysis of students' and curriculum needs to establish appropriate learning requirements. The designed module integrates six syntactic aspects of Project-Based Learning, ranging from providing essential questions to evaluating the learning experience, which are structured systematically. With this approach, the module serves not only as a source of information but also as an independent guide that helps students connect concepts with industrial problems (Plomp et al., 2013).

Problem-solving skills are a vital intellectual competence in mastering Chemical Engineering Operations (OTK) material (Handayani et al., 2022). In OTK learning, technical concepts are not merely studied theoretically but must also be applied to analyze and find optimal solutions to industrial challenges, such as the efficiency of mechanical separation processes or reactor optimization (Irawati, 2014; Habibah, 2024).

Therefore, mastering this skill is extremely important for prospective industrial chemical plant operators so that they are able to face technical challenges to increase efficiency and reduce operational costs in the workplace (Desyandri & Fatimah, 2023).

However, reality in the field indicates that the problem-solving skills of vocational students are still low due to the limitation of relevant teaching materials. Observation results in SMKs show that although the majority of students like the OTK subject, most of them (reaching 76.2% to 95.7%) face difficulties in understanding mechanical separation material. This is caused by the learning process being dominated by theoretical lecture methods and a reliance on old textbooks that have not been fully synchronized with the needs of the *Kurikulum Merdeka* and the characteristics of vocational education.

As an effort to bridge this gap, the development of a PjBL-based OTK learning module becomes urgent to undertake. The systematic and engaging development of the module is expected to facilitate students to learn independently, contextually, and become directly involved in real problem-solving in the chemical industry (Nurmiati et al., 2023). Through the integration of Project-Based Learning syntax into the module, students are expected to sharpen the problem-solving skills that are highly demanded in the current era. Based on this background, this study aims to develop a learning module for Chemical Engineering Operations (OTK) material based on Project-Based Learning to improve the problem-solving skills of Phase F SMK students.

Method

The design of this study is a pretest-posttest control group design, which is a research design with an assessment of problem-solving skills carried out through the administration of a pretest and a posttest (Table 1). The research was conducted at SMK Negeri 1 Koto Besar Dharmasraya using 2 classes: the experimental class and the control class. In the experimental class, the developed product whose effectiveness was tested was the project-based learning chemical engineering operations module in class XI Industrial Chemical Engineering.

Table 1. Pretest-posttest Control Group Design Research Layout

Group	Pre-test	Treatment	Post-test
Experimental	O_1	X	O_2
Control	O_1	Y	O_2

Description: O_1= Pretest score before treatment; O_2 = Posttest score after treatment; X = Treatment given in the form of a learning process using the project-based OTK module; Y= Learning process without using the project-based OTK module.

Data analysis techniques in this study include: Effectiveness Test (N-Gain): to observe the increase in scores between before and after treatment, and the results are categorized as effective if the g_{value} > 0.7; Hypothesis Testing: using an independent sample t-test to determine the significance of the difference in results between the experimental class and the control class at a significance level of α = 0.05; the hypothesis is accepted if the calculated $t_{value} > t_{table}$; Analysis Prerequisite Test: before hypothesis testing, a normality test was performed using the Lilliefors test with the criterion that data is normally distributed if the calculated L_{value} <

L_{table}. Additionally, a homogeneity test was conducted using the F-test (Fisher) to ensure that the data variance is homogeneous, with the criterion that the calculated $F_{value} < F_{table}$; Problem-Solving Skills Analysis: obtained from an observation questionnaire instrument filled out by the teacher by calculating the KPS (Problem-Solving Skills) value. The level of effectiveness is categorized as "very high" if it reaches a percentage of 80–100%.

Result and Discussion

The implementation of the PjBL-based OTK module is proven to improve students' problem-solving skills compared to conventional learning. The posttest results of the experimental class using the Project-Based Learning module showed a much higher increase in problem-solving skills compared to the control class across all Chemical Engineering Operations topics. On the filtration topic, the posttest score reached 99.3 in the experimental class, whereas it was 60.0 in the control class (Table 2).

The posttest values problem-solving skills of the experimental class were higher across all mechanical separation materials after the application of the project-based learning model. The superiority of this experimental class aligns with the active involvement of students in the problem-solving stages, from identifying problems to designing real direct experiments, which can optimize cognitive performance, independence, and students' problem-solving skills in understanding both concrete and abstract mechanical separation concepts (Sanjaya, 2016).

Table 2. Pretest and Posttest of Experimental and Control Classes for Problem-Solving Skills

Class	Sieving		Filtration		Distillation	
	Pre-test	Post Test	Pre-test	Post Test	Pre-test	Post Test
Experimental	47.0	90.7	51.3	99.3	37.2	92.2
Control	28.3	60.8	33.3	60.0	33.8	57.1

Increase in Effectiveness of the Experimental Class and Control Class

The increase in learning effectiveness in the experimental class was much higher compared to the control class, with an N-Gain of 0.89 (high category), while the control class only reached 0.40 (medium category). The project-based learning model in the experimental class provided a much stronger stimulus effect in maximizing students' conceptual understanding. This result is in line with the teaching effectiveness standardization theory by Hake (1998), which states that an N-Gain index above 0.7 indicates a high level of efficiency that is usually triggered by interactive, student-centered learning methods (Table 3).

Analysis results (Table 4) show that the experimental class achieved the High category across all material indicators, with the highest effectiveness increase in the filtration material (N-Gain 98.5%), followed by distillation (86.8%) and sieving (85.6%). Conversely, the control class was lower, ranging between 34.3% and 43.4%. The significant increase in the experimental class proves that the project-based learning model is capable of providing space for students to actively construct a deep understanding of both abstract and concrete materials. This result is consistent with the effectiveness criteria from Hake (1998), which state that an N-gain value ≥ 0.70 represents a high level of effectiveness generally driven by methods focused on interactive engagement, thereby optimizing problem-solving skills measurably compared to one-way conventional learning.

Table 3. N-Gain Analysis Results of Experimental Class and Control Class

Class	N-Gain	Category
Experimental	0.89	High
Control	0.40	Medium

Table 4. N-Gain Score of Experimental Class and Control Class

Material Indicator	Class	Average Pretest	Average post-test	Average N-Gain Score	% N-Gain Score	Category/Effectiveness
Sieving	Experimental	47.04	90.74	0.856	85.6%	Highly Effective
Sieving	Control	28.40	59.60	0.434	43.4%	Less Effective
Filtration	Experimental	51.30	99.26	0.985	98.5%	Highly Effective
Filtration	Control	34.40	61.60	0.411	41.1%	Less Effective
Distillation	Experimental	36.85	92.22	0.868	86.8%	Highly Effective
Distillation	Control	33.20	55.40	0.343	34.3%0	Less Effective

Based on the Independent Sample T-Test results (Table 5), a Sig. (2-tailed) value of 0.000 ($\alpha < 0.05$) was obtained for all material indicators (sieving, filtration, and distillation). This result indicates that the working hypothesis (H_1) is significantly accepted, meaning there is a real and meaningful difference in the improvement of problem-solving skills between the experimental class and the control class. The difference effect is most visible in the filtration material with the highest calculated t-value reaching 16.368, followed by distillation (15.217) and sieving (6.602). These numbers prove that the learning model in the experimental class provides a far superior positive impact than the control class. This finding is supported by Sugiyono (2019), who states that a significance value smaller than 0.05 confirms the existence of a real linear influence or difference of the treatment variable on students' problem-solving skills. The Project Based Learning model is a learning model that is designed so that students gain the ability to solve contextual problems and have the ability to participate in teams (Ardiansyah et al., 2021).

Table 5. Independent Sample T-Test Results of Post-test for Experimental and Control Classes

Material Indicator	Variable	T_{count}	df	Sig.(2-tailed)	Conclusion
Sieving	N-Gain Score	6.602	50	0.000	Significant (H1 Accepted)
Filtration	N-Gain Score	16.368	50	0.000	Significant (H1 Accepted)
Distillation	N-Gain Score	15.217	50	0.000	Significant (H1 Accepted)

Differences in Problem-Solving Skills in the Experimental Class and Control Class

Based on Table 6, the data analysis prerequisite test using the normality test shows that the data distribution in both sample classes is normally distributed. This is proven through the calculated L_{value} in the experimental class of 0.129 and the control class of 0.163. Both values are smaller than the L_{table} value, which stands at 0.173 $L_{count} < L_{table}$. The fulfillment of the normal distribution assumption in both data groups serves as a valid basis for continuing with the t-test analysis. This result aligns with the testing presented by Sudjana (2005), which states that if the calculated value is smaller than the critical table value at a certain significance level α = 0.05, then the sample comes from a normally distributed population, thus meeting the requirement.

Table 6. Normality Analysis Results of Experimental Class and Control Class

Class	L_{count}	l_{table}	Category
Experimental	0.129	0.173	Normal
Control	0.163	0.173	Normal

Table 7. Homogeneity Analysis Results of Experimental Class and Control Class

Class	n	F_{count}	F_{table}
Experimental	27	0.957	1.988
Control	24	0.957	1.988

Based on Table 7, the analysis results show that the data variance between the experimental class n=27 and the control class n = 24 is homogeneous. This is proven statistically through the acquisition of a calculated F-value of 0.957, which is much smaller than the F_{table} value of 1.988 $F_{count} < F_{table}$. With the fulfillment of this variance homogeneity assumption, both sample groups meet the requirements for hypothesis testing using the t-test. This result is consistent with the variance testing criteria stated by Sugiyono (2019), which underscores that if the calculated F_{value} is smaller than the F_{table}, then the variance of the data groups is homogeneous or does not differ significantly.

Table 8. Hypothesis Test Results of Experimental Class and Control Class

Class	n	A	X	S2	t_{count}	t_{table}
Experimental	27	0.05	89.44	87.42	21.96	1.67
Control	24	0.05	39.83	83.53	21.96	1.67

Based on Table 8, the hypothesis testing results using the t-test show that there is a highly significant difference in problem-solving skills between the two sample classes. This is proven through the acquisition of a calculated t_{value} of 21.96, which far exceeds the t_{table} value of 1.67 $t_{count} > t_{table}$ at a significance level of α = 0.05. The mean value X of the experimental class reached 89.44, while the control class was 39.83. Thus, the null hypothesis H0 is rejected and the alternative hypothesis H1 is accepted. This finding aligns with the principles of statistical testing by Sugiyono (2019), which states that if $t_{count} > t_{table}$, the treatment provided is proven to exert a real and significant influence on the improvement of learners' problem-solving skills.

Students who use the Project Based Learning learning model in their learning process will have an organized mindset, which is very important in the problem solving process, and will gain scientific knowledge and science process skills. Apart from that, students need to be trained in independence, collaboration and experimentation using this learning model (Zahirah et al., 2024). Project based learning provides students with the opportunity to create a more interesting and meaningful learning experience, and can improve students' scientific performance in learning, while the teacher's role as facilitator and mediator can be fulfilled well (Nurasiah et al., 2022).

The link between the Project-Based Learning model and observation and problem presentation skills is visible during the stage of posing essential questions. At this stage, students are given essential questions that serve as the starting point for learning activities. Through these questions, students are driven to observe phenomena, collect relevant facts, and determine aspects that need to be observed to solve the given problem (Nur'aini et al., 2025).

Table 9. Problem-Solving Skills Analysis Results of Experimental Class and Control Class

Class	Meeting 1	Meeting 2	Meeting 3	Average	Category/Effectiveness
Experimental	91.48	90.37	90.18	90.67	Highly Effective
Control	67.50	57.50	57.50	60.33	Moderately Effective

Based on Table 9, the attainment level of problem-solving skills of students in the experimental class consistently outperformed the control class at every meeting. The experimental class managed to maintain high scores from Meeting 1 to 3 with an average acquisition of 90.67 (Highly Effective category). Meanwhile, the control class actually experienced a decline with an average score that only reached 60.33 (Moderately Effective category). This achievement of the experimental class proves that the application of a problem-solving-oriented project-based learning model is capable of training students' problem-solving skills stably. Learning that consistently involves problem-solving stages does not merely increase temporary cognitive understanding, but instead effectively forms stable and structured problem-solving skills within the students (Sanjaya, 2016). This is in accordance with the theory that content validity shows that the product developed is consistent with the curriculum and learning (Baidlok et al., 2020).

Modules can be used to improve students' problem-solving skills during learning. These modules guide students to think logically, critically, and systematically because they need to find their own information while learning, and they develop students' creativity so they can solve and answer problems (Dewi & Setyasto, 2024).

Conclusion

Based on the research results and data analysis obtained, it can be concluded that the Project-Based Learning-based Chemical Engineering Operations learning module on Mechanical Separation material is effective in improving the problem-solving skills of Phase F SMK students.

Acknowledgments
The authors would like to thank to all parties who has supported this research.

Author Contributions
Conceptualization, methodology, formal analysis, investigation, resources, data curation, writing—original draft preparation, R.H. and M.A.; writing—review and editing, validation, visualization, A., S.A., and S.P.S. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

References

Ardiansyah, H., Riswanda, J., & Armanda, F. (2021). Pengaruh Model PBL dengan Pendekatan STEM Terhadap Kompetensi Kognitif Peserta Didik pada Materi Sistem Pencernaan Kelas XI di SMA/MA. *Bioilmi: Jurnal Pendidikan*, *7*(1), 46–51. https://doi.org/10.19109/bioilmi.v7i1.9507

Baidlok, F. N., Irmayanti, E., & Surindra, B. (2020). Pengembangan Perangkat dan Model Pembelajaran Open Ended Learning Melalui Media Audiovisual dan Media Grafis pada Materi Media Promosi. *Efektor*, *7*(2), 117-126. https://doi.org/10.29407/e.v7i2.14918

Desyandri, D., & Fatimah, F. (2023). The Use of Puzzle Media to Improve Students' Critical Thinking Skills in Natural Science Material. *Journal of Education and Counseling*, *5*(1), 374-379. https//doi.org/10.31004/jpdk.v5i1.10956

Dewi, I. M., & Setyasto, N. (2024). Development of CanvaBased Digital Flipbook Learning Media for IPAS Subject on Respiratory System. *Jurnal Penelitian Pendidikan IPA*, *10*(5), 2300–2308. https://doi.org/10.29303/jppipa.v10i5.7030

Febrila, L. G., Hanifah, H., Sumardi, H., & Haji, S. (2023). Pengaruh Penerapan Model Project Based Learning Terhadap Kemampuan Pemecahan Masalah Matematika Siswa. *Jurnal Pendidikan Matematika*, *14*(2), 209–217. https://doi.org/10.36709/jpm.v14i2.82

Habibah, U. (2024). Penerapan Model Pembelajaran Projec Based Learning untuk Meningkatkan Kemampuan Siswa SMK Al Musyawirin. *Journal of Comprehensive Science*, *3*(4), 770–782. https://doi.org/10.59188/jcs.v3i4.661

Hake, R. R. (1998). Interactive-Engagement versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory

Physics Courses. *American Journal of Physics*, *66*(1), 64-74. http://dx.doi.org/10.1119/1.18809

Handayani, W., Alimin, A., & Hastini, H. (2022). Penerapan Problem-Based Learning (PBL) untuk Meningkatkan Aktivitas dan Hasil Belajar Operasi Teknik Kimia. *Jurnal Pendidikan dan Profesi Keguruan*, *2*(1), 117. https://doi.org/10.59562/progresif.v2i1.30793

Irawati, R. K. (2014). The Effect of Problem Solving and Problem Posing Models and Innate Ability to Students Achievement. *Jurnal Pendidikan Sains*, *2*(4), 184-192. https://doi.org/10.17977/jps.v2i4.4534

Irsyad, M., & Sesmiarni, Z. (2024). Hubungan Motivasi Kerja dengan Prestasi Guru dan Karyawan di SDIT Haji Jalaluddin. *Jurnal Pendidikan dan Sosial Humaniora*, *4*(3). https://doi.org/10.55606/khatulistiwa.v4i3.3656

Kurniawati, A., & Hulopi, D. (2026). Strategi Pengembangan Bahan Ajar Berbasis Kurikulum Merdeka dalam Pembelajaran Abad 21. *Inovasi Pendidikan dan Anak Usia Dini*, *3*(1), 97–104. https://doi.org/10.61132/inpaud.v3i1.875

Ningsih, S. W., Fatoni, P., Ferdinand, I., M, F., & Jaja, J. (2024). Peningkatan Kualitas Pembelajaran Melalui Kurikulum Merdeka. *Journal of Comprehensive Science*, *3*(8), 2093–2099. https://doi.org/10.59188/jcs.v3i8.803

Nur'aini, I. P., Mukmin, B. A., & Putri, K. E. (2025). Analysis of Validity and Practicality of Interactive Learning Media Development Based on Genially Platform for Grade V Elementary School. *Jurnal Inovasi Pendidikan dan Teknologi Informasi (JIPTI)*, *6*(2), 347-359. Retrieved from https://ejournal.ummuba.ac.id/index.php/JIPTI/article/view/3333

Nurasiah, I., Marini, A., Nafiah, M., & Rachmawati, N. (2022). Nilai Kearifan Lokal: Projek Paradigma Baru Program Sekolah Penggerak untuk Mewujudkan Profil Pelajar Pancasila. *Jurnal Basicedu*, *6*(3), 3639–3648. https://doi.org/10.31004/basicedu.v6i3.2727

Nurmiati, N., Danial, M., & Arsyad, M. (2023). Pengembangan Modul Ajar IPAS Berbasis Project-Based Learning (PJBL) dalam Penerapan Merdeka Belajar. *Chemistry Education Review (CER)*, *6*(2), 134-140. https://doi.org/10.26858/cer.v6i2.45203

Plomp, T., Tjeerd, P., & Nieveen, N. (2013). *Educational Design Research: Part A: An Introduction*. Enschede: SLO.

Sanjaya, W. (2016). *Strategi Pembelajaran Berorientasi Standar Proses Pendidikan*. Jakarta: Kencana.

Sudjana, S. (2005). *Metoda Statistika* (Ed. 6). Bandung: Tarsito.

Sugiyono, S. (2019). *Metode Penelitian Pendidikan: Pendekatan Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta.

Zahirah, B. T. S., Anggreini, A., & Viyanti, V. (2024). The Effect of the STEM Integrated Project-Based Learning Assisted by Electronic Student Worksheets on Students' Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 1442–1450. https://doi.org/10.29303/jppipa.v10i3.5461