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A Project-Based Learning Approach for Chemical Engineering Students Involving Waste Cooking Oil Biodiesel Production for Portable Stove Application

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Abstract: This study implemented project-based learning in a bioenergy engineering course at the Pondok Meja Campus, Universitas Jambi, involving 17 chemical engineering students during the first semester of the 2024/2025 academic year. Conducted over 13 weeks, the project involved biodiesel production from waste cooking oil using NaOH and CaO catalysts, followed by fuel application in a portable stove. The highest biodiesel yield was 92.3% (3% NaOH, 1:6 oil-to-methanol) and 42.0% (6% CaO, 1:12). The density ranged from 0.87 to 0.89 g/cm³, with stove fuel consumption rates of 0.0607 ml/s (NaOH) and 0.0412 ml/s (CaO). Evaluation involved class participation, lab performance, product presentation, and final reporting, yielding an overall project score of 87/100. Student feedback showed high agreement (mean 4.45/5) in teamwork, problem solving, critical thinking, time management, and proactiveness, supported by lecturer assessments (13.1/15). Challenges included equipment limitations and time constraints, yet all groups completed the project on time. This hands-on approach effectively achieved subject-specific and transferable skills, fostering engineering competence and readiness for real-world bioenergy challenges.

Keywords: Biodiesel Production; Project-based Learning; Subject-specific; Transferable Skills.

Introduction

Project-based learning (PBL) has emerged as an essential pedagogical approach within chemical engineering education, addressing the critical need to bridge theoretical knowledge with practical industrial applications (Sarkawi et al., 2024). This approach proved particularly valuable for chemical engineering students as it integrated theoretical principles with hands-on experiences, bridging the gap between classroom learning and industrial applications (Rajan et al., 2019). The chemical engineering study program at Universitas Jambi strategically implemented an Outcome-Based Education (OBE) curricular approach. This curricular approach prioritized student-centered learning methodologies, positioning PBL as a cornerstone pedagogical strategy for achieving predetermined competency benchmarks (Apriana et al., 2025). In a field requiring a strong foundation in scientific knowledge and practical problem-solving, PBL enabled students to engage in interdisciplinary projects, often mirroring the challenges they would face in their professional careers (Kolmos & Graaff, 2015). This method played a crucial role in preparing future engineers to meet the complex needs of the chemical engineering sector (Hasanah et al., 2024).

Indonesian higher education institutions faced increasing pressure to implement collaborative and participatory learning methods as mandated by Main

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Performance Index (Indeks Kinerja Utama, IKU) No. 7, which assessed the implementation of team-based project learning in instructional approaches (Batubara & Irayani, 2024; Kemendikbud, 2021). This directive was further elaborated in the Strategic Plan (RENSTRA) of the Faculty of Science and Technology (FST) 2022–2026, which established a target of 45% course implementation of team-based project methodologies by 2026. In accordance with these directives, the Chemical Engineering Program at Universitas Jambi has strategically integrated outcome-based and experiential learning pedagogical frameworks into its curriculum design. The Bioenergy Engineering Technology course exemplifies this integration, with its Semester Learning Plan *(Rencana Pembelajaran Semester, RPS)* explicitly delineating course learning outcomes that require students to critically evaluate the potential, production processes, and quality parameters of various bioenergy sources. Moreover, students were expected to apply this knowledge in assessing the technical and economic viability of these sources as alternative fuel options in real-world contexts. Within this framework, there emerged a critical need to assess not only the technical outcomes of biodiesel production from waste cooking oil but also the depth and effectiveness of students' experiential learning processes. This included examining how well students engaged with the project-based learning cycle, developed problem-solving and collaborative skills, and translated theoretical understanding into practical bioenergy applications.

The objective was to assess student learning outcomes and facilitate the acquisition of critical competencies in the Bioenergy Engineering Technology (Teknologi Rekayasa Bioenergi) course, specifically to improve students' practical mastery of biodiesel production from waste cooking oil and its application on a portable stove. This initiative was implemented during the 2024/2025 odd semester and introduced to 17 students, with a total of 2 credit hours accumulated. The competencies targeted were clearly defined in the official curricula of the Chemical Engineering study program at the University of Jambi. Students were expected to develop both transferable and subject-specific skills. Transferable skills included problem-solving, adapting to new situations, teamwork, decision-making, applying theoretical knowledge to practical situations, creativity, and motivation to achieve goals. In addition to these general skills, students were required to understand subject-specific areas deeply. For instance, they had to master biodiesel production from waste cooking oil and evaluate its performance in portable stove application. These competencies were essential for their academic and professional development.

Method

The main objective of this project was to investigate the performance comparison between homogeneous (NaOH) and heterogeneous (CaO) catalysts in the production of biodiesel from waste cooking oil, specifically focusing on the application as fuel for a portable stove. The project investigated the effects of catalyst type with NaOH concentrations (1%, 2%, 3% w/w) and CaO concentrations (4%, 5%, 6% w/w), along with oil-to-methanol molar ratios (1:6 and 1:12) on biodiesel yield. According to previous research, homogeneous and heterogeneous catalysts represented two distinct catalytic approaches with fundamentally different mechanistic pathways and performance characteristics (Ganesan et al., 2021). Homogeneous NaOH catalysis proceeded via rapid dissolution in the reaction medium, facilitating immediate interaction between the catalyst's active sites and reactant molecules. Conversely, heterogeneous CaO catalysis operated through surface-mediated reactions wherein reagents were required to adsorb onto specific active sites at the solid-liquid interface. It is concluded that under equivalent reaction durations, NaOH could produce more biodiesel (Kibar et al., 2023). To achieve this goal, implementing PBL became an appropriate method in the learning process. Gomez-del Rio & Rodriguez (2022) explained that the PBL must include the following stages: teach content through knowledge and skills; create a need to know essential and fundamental content; need critical thinking, problem-solving, and collaboration or teamwork; develop investigation; provide continuous feedback; and present or deliver the final product.

Project Description and Project-based Learning Design

The total number of students in class was 17. The recommended group size was 3 people in each group. There were 3 lecturers in the laboratory and each one was in charge of 2 or 3 groups and they had to meet the students' needs and questions. The total laboratory experience included two sessions of 4 hours each, with one weekly session lasting for 8 weeks. The overall duration of the project spanned 13 weeks. In-class sessions were conducted during Weeks 1 to 5 to enhance students' conceptual understanding and technical skills. The laboratory activities and project implementation occurred from Weeks 6 to 13, culminating in submitting the final project report. To reflect the PBL stages as outlined by Gomez-del Rio & Rodriguez (2022) as previously discussed, this learning design was structured into four main stages, see Fig. 2, namely, Delivering content through expertise and skills: Students developed an academic understanding of the basic concepts of bioenergy engineering and gained relevant competencies throughout the project. This included knowledge, practical skills, and professional attitudes; Designing a project proposal: Students created a project implementation plan for the bioenergy project. the lecturer formed working groups to conduct biodiesel production experiments; Carrying out project assignments: students conducted experimental activities within their working groups to solve project-related problems and transformed project designs into tangible outputs. The lecturer provided mentorship, supervision, and evaluation throughout the project; Evaluation: the evaluation process assessed students' learning achievements and competencies, serving as a basis for feedback and improvement. both the project's workflow and final results were evaluated. Assessment criteria included problem solving, critical thinking, team-work, time management, proactiveness, and final product quality. Students presented the biodiesel product as fuel for a portable stove.

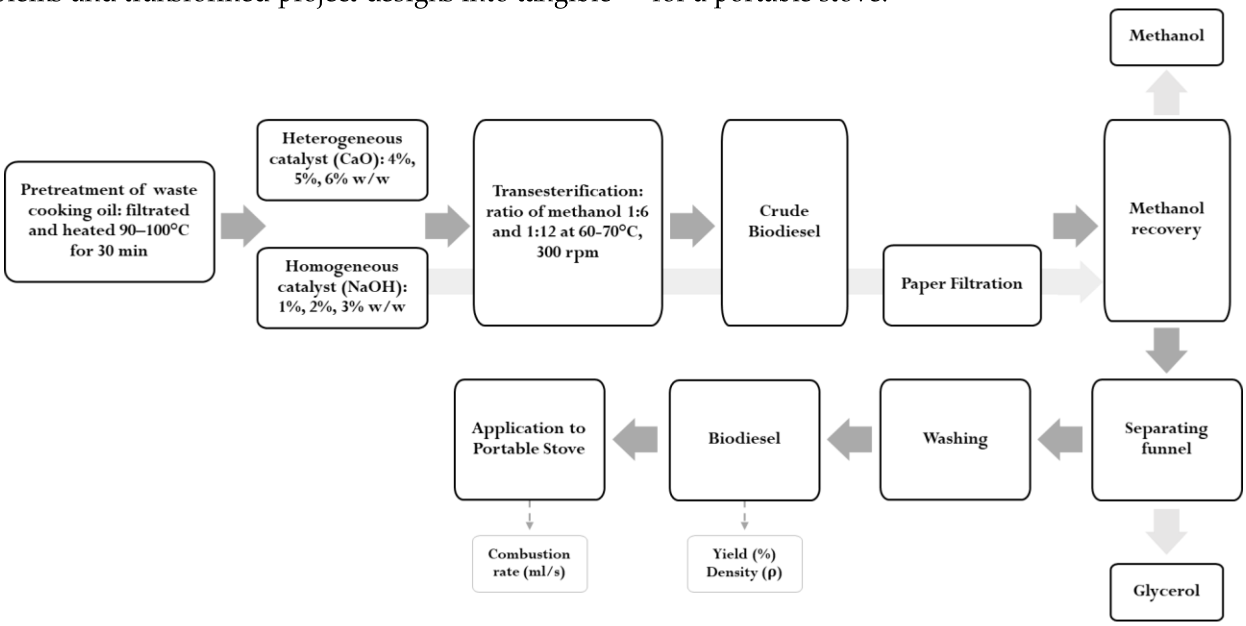

Figure 1. Schematic Diagram of Biodiesel Production and Application Project

Bioenergy is energy produced from biomass, which includes organic materials from plants, animals, and industrial cultivation waste (Kalak, 2023). It can be utilized in biofuels, biomass electricity, biodiesel, and bioethanol (Anggereini et al., 2023). While traditional bioenergy sources like firewood and charcoal are still prevalent in rural areas, the development of modern bioenergy products such as wood pellets, biomethanol, and biobutanol is ongoing (Singh et al., 2022). As the global energy system shifts from fossil fuels to renewable resources, bioenergy is vital in improving environmental quality, reducing greenhouse gas emissions, and lessening dependence on fossil fuel imports (Lette et al., 2022).

Biodiesel, produced from vegetable oils or animal fats through transesterification, shares many characteristics with conventional diesel but generates fewer greenhouse gases and can be used directly in diesel engines without significant modifications (Vignesh et al., 2021). Demirbas (2009) noted its benefits, such as high biodegradability, low toxicity, and a reduction in pollutants, though challenges like raw material availability and its higher cost compared to fossil fuels persist. Waste cooking oil is a promising alternative, Sipayung & Budiyono (2022) explained that it reduced production costs and mitigated environmental issues. Approximately 3 million tons of waste cooking oil in Indonesia were produced annually but remain underutilized. In biodiesel production, catalysts are critical, with homogeneous base catalysts (NaOH and KOH) often used for their efficiency and low cost (Faruque et al., 2020). However, heterogeneous catalysts like CaO are emerging as viable alternatives because they do not produce soap during the process (Gupta & Pal Singh, 2023). Given these findings and the potential benefits, it is clear that further research is urgently needed to compare the performance of homogeneous and heterogeneous catalysts in biodiesel production from waste cooking oil and to explore their application as fuel for portable stoves. This study could significantly advance students' understanding and application of biodiesel production.

Waste cooking oil was used as the primary feedstock for biodiesel production. The experimental setup involved standard laboratory glassware, including Erlenmeyer flasks, beakers, and measuring cylinders for precise liquid measurement. A separatory funnel and filter paper were employed for the separation and purification steps. The transesterification reaction was conducted in a three-neck flask equipped with a reflux condenser to prevent methanol evaporation. A magnetic stirrer and heating mantle provided uniform mixing and temperature control. Distilled water was used to wash the crude biodiesel product.

Prior to the transesterification process, a pretreatment step was carried out in which the oil was filtered to remove any residues and heated to 90–100°C for 30 minutes to reduce moisture content (Sipayung & Budiyono, 2022). The oil was then cooled to 40°C before reacting with a methanol–catalyst solution. The study investigated homogeneous and heterogeneous catalysts: sodium hydroxide (NaOH) at 1%, 2%, 3% w/w, and calcium oxide (CaO) at 4%, 5%, 6% w/w. Two oil-to-methanol molar ratios (1:6 and 1:12) were employed to assess the influence of alcohol excess on biodiesel yield and quality (see Fig. 1). Each combination of catalyst type, concentration, and methanol ratio was tested by separate groups in a complete factorial design.

The transesterification reaction was conducted in a three-neck round-bottom flask equipped with a condenser to minimize methanol loss by evaporation. The mixture was stirred using a magnetic stirrer and heated on a hot plate at 60–70°C for one hour. After the reaction, excess methanol was removed via simple distillation. The reaction mixture was then transferred into a separatory funnel and allowed to settle for 12–18 hours to achieve phase separation. The denser glycerol layer was decanted, and the upper biodiesel layer was subjected to successive washes with distilled water at 50°C until a clear phase was obtained, indicating the removal of residual catalyst and methanol. Finally, the washed biodiesel was reheated gently to eliminate the remaining moisture content.

The dependent variables were biodiesel yield, density, and combustion performance in a portable stove. Control variables such as reaction temperature at 60–70°C, reaction duration for 1 hour, stirring speed at 300 rpm, and type of waste cooking oil were kept consistent across all trials to ensure valid comparative analysis. The biodiesel density was measured using a pycnometer.

Application experiments were conducted to evaluate biodiesel quality in a portable stove configuration. The experimental setup included an auxiliary blower mechanism designed to enhance combustion efficiency, where the blower speed was adjusted to maintain the air-to-fuel ratio. Quality assessment parameters included the combustion rate, which was measured as fuel consumption (ml/min).

Pedagogical framework and educational context

PBL in education has shown significant potential in nurturing essential skills such as critical thinking, problem-solving, and understanding real-world challenges (Yayuk Srirahayu & Arty, 2019). PBL distinguished itself from conventional learning approaches by engaging students in projects that required applying their theoretical knowledge to solve complex, authentic problems (Hulyadi et al., 2023). PBL involved actively constructing knowledge via hands-on experience (Monika et al., 2023). It created more room for creativity and experimentation as the students could test their ideas on a working model. Students were indirectly exposed to technically unfeasible methods, besides learning things that worked in a system (Yang, 2021).

One of the fundamental advantages of PBL was the ability to develop critical thinking and problem-solving skills by engaging students in tasks that required them to analyze complex issues and create innovative solutions (Werdhiana et al., 2025). Research has shown that PBL encourages deeper learning and helps students better understand the subject matter (Pamenang et al., 2024). In this course, students could apply scientific principles related to biofuel production, thereby gaining a deeper understanding of the technical aspects while developing essential skills such as teamwork and decision-making.

Figure 2. Learning design and project activities

Students gained theoretical knowledge of biomass feedstock variability, including differences in lipid content between virgin vegetable oils and waste cooking oil. They developed analytical skills to evaluate catalyst selection, as catalytic materials critically influenced reaction kinetics and product yields. Students conducted empirical investigations and quantitative analyses to address the correlation between operational conditions. Laboratory-scale apparatus configurations provided hands-on platforms to study engineering principles underlying process design, such as heat transfer efficiency, mixing dynamics, and separation methodologies. A key focus was stoichiometric efficiency in transesterification reactions, particularly the need for excess reactants in methyl ester synthesis to drive reactions toward completion and maximize conversion efficiency. Furthermore, the biodiesel produced was applied to a portable stove equipped with an auxiliary blower to evaluate combustion performance. The integration of the blower system highlighted the importance of auxiliary components in real-world energy systems, reinforcing students' ability to design and troubleshoot integrated bioenergy solutions.

In the context of the Bioenergy Engineering Technology course at the University of Jambi, PBL was implemented to enhance student learning outcomes and develop critical competencies, both transferable and subject-specific. Students engaged in a project focusing on producing biodiesel from waste cooking oil and evaluating its performance in portable stove application. This hands-on project enabled students to integrate their theoretical knowledge of bioenergy with practical skills, bridging the gap between classroom instruction and real-world applications.

The project intended to address the main learning outcomes of this course, broadly, the ability to analyze the potential, production process, and quality of bioenergy from various sources and apply this knowledge to evaluate the feasibility of its use as fuel. This learning model was particularly suitable for chemical engineering studies, where students were often required to integrate knowledge and experience from different courses to solve complex experimental problems. To evaluate this project, assessment was conducted through multiple-stage activities, including in-class evaluations, monitoring during laboratory sessions, and final presentations. For quality assessment of the learning outcomes, students performed self-assessments related to their participation and contributions to the project, providing valuable insights into their perceived competency development and understanding of the subject matter.

Project Evaluation

The evaluation step in PBL was essential in assessing the efficacy of learning and the success of projects worked on. The evaluation of project success was holistic, considering aspects of the process, product, and individual learning. To ensure holistic evaluation, the rubrics define the criteria and weightings for project assessment, this information was communicated to the students during the first week, as presented in Table 1, it provides opportunities for students to learn from the experiences and feedback they receive by the lecturers.

Table 1. Project assesment criteria and final score

Criteria	Weightage (%)	Group Score
Work capabilities, attitude, and values (Problem solving, critical thinking, team-work, time management, and proactiveness)	15	13.1
Understanding the project task, defining the problems, and writing the literature review	15	12.4
Designing the experimental variables and implementation in laboratory	20	16.9
Result analysis and data interpretation	10	8.0
Product application (biodiesel for portable stove)	5	5.0
Activities review (during project)	10	9.2
Final reports submission	15	13.8
Project presentation	10	8.8
Overall	100	87.0

The lecturers were ready to solve questions and collaborate with the students, providing feedback and constructive comments before starting any subsequent task, during, and after the project-task in laboratory. Step Providing content through knowledge and skills is given in weeks 1-4 of the semester. The project starts in week 6, strengthening competencies related to biodiesel production in the laboratory in week 5. During the project, teaching and learning continued as usual. To monitor student progress in detail, students reported their experimental activities to the instant message application (WhatsApp) chat group, both their products and the obstacles they faced during the process. Feedback was always given to help with problem-solving and analytical thinking to produce relevant biodiesel products. As for the evaluation, students demonstrate biodiesel products as portable stove fuel and submit their reports. The students would have to justify the chemical reaction used, the effect of catalyst type, catalyst concentrations, and methanol ratio on biodiesel yield and its application. Students would have to portray their understanding of all objectives in the reports.

Assessment of learning outcomes

Self-assessment in PBL has gained prominence for its multifaceted benefits that enhance student engagement, foster independent learning, and promote critical thinking (Lanthony et al., 2018). Implementing self-assessment in PBL allows students to take ownership of their learning processes and provides them with the necessary tools to recognize their strengths and weaknesses, thereby facilitating personal growth and improved academic outcomes (Bagheri et al., 2020; Khoiriyah et al., 2015). The impact of self-assessment in PBL extends beyond academic performance. Evidence from various studies suggests that effective self-assessment practices can lead to higher self-efficacy among students, as they develop the skills needed to navigate complex project tasks (Schaffer et al., 2012). The self-assessment was conducted with a 3rd-year cohort taking Bioenergy Engineering Technology *(Teknologi Rekayasa Bioenergi)* in the 2024/2025 academic year. These formative comments and feedback allowed students to reflect on their work and critically review and iterate their design solutions. As such, assessing the project in laboratory involved more scheduled interactions and timely feedback between students and lecturers.

A survey was conducted via Google Form (Table 1) to assess the learning outcomes, students' perceptions, and satisfaction with the PBL. The project assessment survey questions and the students' responses are shown, respectively. The questions asked were reflective of the project's intention, apart from achieving a technical understanding of the project. Questions 1-14 relate to the project's contribution to student learning outcomes and time management, where:

Questions Q1-Q3, for instance, utilized closed-answer formats to analyze the relationship between the biodiesel production project and chemical engineering understanding; The soft skills and interpersonal development domain assessed through questions Q4-Q7, which evaluated general soft skills improvement, including communication, leadership, and decision-making capabilities (Q4), teamwork and leadership development (Q5), time management and professional courtesy (Q6), and academic discourse skills with respect for diverse perspectives (Q7); Project design and implementation assessment was conducted through questions Q8-Q12, which examined the appropriateness of various project parameters and team dynamics. Question Q13 comprehensively assessed how project-based and cooperative learning affected the overall learning experience and skill development improvement; and The final two questions (Q14-Q15) were designed in open-answer formats to gather detailed qualitative feedback on project benefits, challenges, and professional skill development.

A 5-point Likert Scale was used to measure their answers: 1) Disagree, 2) Slightly Agree, 3) Agree (Neutral), 4) Moderately Agree, 5) Strongly Agree. This type of statement was aligned with distinctive learning outcomes and has been assumed to be influential in assessing the learning outcomes. Meanwhile, Q14-Q15 were open questions about their satisfaction and opinion on their laboratory activity and learning outcomes.

Table 2. Detailed question assessment of learning outcomes

Number	Questions
Q1	This project helped me connect the fundamentals and application of knowledge to real-world practice
Q2	This project further enhanced my understanding of other chemical engineering knowledge
Q3	This project helped me strengthen my technical skills to solve chemical engineering-related problems
Q4	This project helped me improve my soft skills (e.g., communication, leadership, and decision-making)
Q5	This project helped me sharpen my teamwork/leadership skills and ability to work in a team
Q6	This project improved my time management skills and also respected other people's time
Q7	This project taught me to respect other people's opinions and discuss topics academically
Q8	The time allocation for this project was sufficient/appropriate
Q9	This project was time-consuming but balanced with only one project required rather than different projects
Q10	The complexity of the problem was appropriate for a team of 2-3 people
Q11	The number of team members (2-3 people) was sufficient to prevent any member from being inactive in solving the problem
Q12	The strengths and weaknesses of the team members were evenly distributed
Q13	The application of the project and cooperative learning improved my learning experience and skills
Q14	What are the advantages and challenges of working on this project?
Q15	Can this project improve professional practical skills (laboratory or engineering)?

Result and Discussion

This section presents the experimental results of student teams in a PBL environment focused on biodiesel production from waste cooking oil and its application in portable stove combustion. Each team varied according to different variables, namely the oil-to-methanol molar ratio (1:6 and 1:12) and the type and concentration of catalyst (homogeneous NaOH at 1%, 2%, and 3% w/w, or heterogeneous CaO at 4%, 5%, and 6% w/w). This methodical approach yielded various outcomes that enabled comparative analysis of various catalytic strategies for biodiesel production. The biodiesel production process began with a pre-treatment step, followed by a transesterification reaction and separation. Students occasionally faced difficulties when draining the glycerin from the separatory funnel. During the washing phase, which involved distilled water at 50°C, students learned that maintaining gentle agitation was necessary to prevent emulsion formation. After washing, the biodiesel was reheated to remove any remaining moisture before being tested as fuel in portable stoves.

Quantitative analysis of biodiesel yield revealed that NaOH consistently outperformed CaO. At a 1:6 oil-to-methanol ratio, yield increased from 81.84% at 1% NaOH to 92.30% at 3% NaOH, indicating improved catalytic efficiency at higher concentrations, but these findings have lower results reported by Mercy Nisha Pauline et al. (2021). Conversely, at a 1:12 ratio, the yield peaked at 80.95% with 2% NaOH but dropped to 71.00% at 3%, possibly due to excess methanol hindering phase separation or promoting soap formation (Abdelmigeed et al., 2021).

In contrast, CaO catalysts demonstrated significantly lower yields. At a 1:6 ratio, the yield ranged from 23.07% at 4% CaO to only 28.20% at 6%. With the 1:12 ratio, yield slightly improved, reaching 42.00% at 6% CaO, suggesting that higher methanol concentration enhanced contact in the solid-liquid system but remained inefficient compared to NaOH (Liu et al., 2010). The biodiesel produced using NaOH was visually clearer, indicating more complete transesterification and easier purification. CaO biodiesel often exhibits turbidity, which may be from incomplete reactions or residual solid particles. Enhancements such as increased reaction time, agitation, or methanol reflux could improve CaO's performance (Li et al., 2020).

The density of the waste cooking oil used as feedstock was measured at 0.923 g/cm³. The resulting biodiesel samples exhibited densities in the 0.870–0.895 g/cm³ (Table 3) across all experimental conditions, representing a significant density reduction of approximately 4.5-6.6% compared to the original feedstock. Students claimed that the substantial density decrease provided quantitative evidence of successful transesterification, as converting triglycerides to fatty acid methyl esters inherently resulted in lower molecular weight compounds with reduced density. The observed density reduction aligned with theoretical expectations for complete transesterification reactions and served as a reliable indicator of conversion efficiency (Farrell & Cavanagh, 2014).

For NaOH catalyst at the 1:6 oil-to-methanol ratio, biodiesel density values ranged from 0.871 to 0.885 g/cm³. These density values were acceptable for biodiesel fuel ASTM D6751 standard (0.820-0.900 g/cm³), indicating successful transesterification and fuel quality compliance (Sumari et al., 2021). CaO catalyst produced biodiesel with slightly higher density values than NaOH across all tested conditions. The inverse relationship between biodiesel yield and density for CaO catalyst indicated that higher density values were associated with lower conversion efficiency and possible retention of unreacted triglycerides or catalyst residues.

a)

b)

Figure 3. The flame of biodiesel on a portable stove produced with (a) NaOH (b) CaO as catalyst

The functional performance of the produced biodiesel was evaluated using a portable stove application test. Quantitative combustion testing was conducted using 17 ml biodiesel samples produced with both catalyst systems at the 1:12 oil-to-methanol ratio. The application testing revealed significant performance differences between catalyst-produced biodiesels. The 17 ml of biodiesel produced with NaOH lasted 4 minutes and 40 seconds, with a combustion rate of 0.0607 ml/s. In comparison, the biodiesel produced with CaO took much longer to combust, lasting 6 minutes and 53 seconds, with a combustion rate of 0.0412 ml/s. This difference in reaction time demonstrated the higher reactivity and efficiency of the NaOH-produced biodiesel. The faster reaction time with NaOH-produced biodiesel indicated its suitability for applications. Conversely, the slower reaction time for CaO may suggest challenges, such as lower catalytic activity. Additionally, the combustion rate was lower than in Farrell & Cavanagh (2014), likely due to differences in combustion methods, where this study used an auxiliary blower.

Additionally, visual observation of the flame characteristics further supported these findings (Fig. 3). The NaOH-based biodiesel consistently generated a clean, stable blue flame, indicative of more complete combustion and better fuel quality. On the other hand, biodiesel produced with CaO occasionally exhibited reddish flames during combustion, suggesting incomplete combustion, possible impurities, or poor atomization. These results confirmed that NaOH provided higher yields and enhanced combustion quality, making it more suitable for practical applications such as use in portable stoves.

Table 3. Yield and Density of Biodiesel

Catalyst concentration		1:6 (Oil: Methanol)		1:12 (Oil: Methanol)	
		Yield (%)	Density (g/cm³)	Yield (%)	Density (g/cm³)
NaOH	1%	69.23%	0.874	76.19	0.878
	2%	65.66%	0.871	80.95	0.881
	3%	92.30%	0.885	71.00	0.876
CaO	4%	23.07%	0.891	35.75	0.888
	5%	32.20%	0.894	39.20	0.892
	6%	28.20%	0.889	42.00	0.895

The experimental setup for application testing included an auxiliary blower mechanism designed to enhance combustion efficiency. The blower speed was carefully adjusted during operation to optimize the air-fuel mixture, which ensured more complete combustion of the biodiesel. As a result, the final flame characteristics closely resembled those of a conventional gas stove, exhibiting a stable and clean blue flame indicative of efficient combustion and indicating that the biodiesel fuel was atomized correctly and supplied with sufficient oxygen.

Throughout the project's implementation over the semester, nearly all student teams successfully produced biodiesel that passed quality testing, with properties and performance results consistently falling within the expected ranges. The teams that have experienced failure must reproduce the biodiesel and engage in problem-solving.

Project Implementation and Evaluation

Project preparation was conducted during weeks 1–4, and the project officially started in week 6. The students were given a total of 7 weeks to complete the project and submit their final report. A total of 12 biodiesel product samples were produced, with 6 groups scheduling their laboratory sessions. Each group was responsible for producing two sample variables (2 × 12 hours) per week, ensuring that the entire project was completed within 6 weeks. During each laboratory session, lecturers facilitated a brief discussion session lasting 5–10 minutes. Additionally, after each experimental session, students were required to provide a live report via a WhatsApp group, including photos of the activities, encountered challenges, and the resulting products. Most of the students demonstrated enthusiasm while working on the project and successfully obtained the desired biodiesel results. They were immediately responding to technical problems, such as reaction failures, the occurrence of saponification reactions, fluctuating temperatures, and basic calculations required for data analysis. As reported by Farrell & Cavanagh (2014), where a failed batch occurred during the use of waste cooking oil in a similar project, students in this study also experienced comparable challenges. Three groups initially encountered transesterification reaction failures; however, they successfully addressed the issue by performing a pretreatment process on the feedstock.

Figure 4. Examples of transesterification processes that failed due to saponification

The project was evaluated through multiple-stage activities, including in-class activities, laboratory performance, product presentations, and final reports. A team of 3 lecturers conducted the evaluation. The final project reports were submitted by week 13 of the semester, after which the lecturers assessed the reports and provided feedback during the project presentation. The group of students was provided with the specified timeframe to present their project (10 minutes of presentation), highlighting key aspects such as the identified problem, the project design, experimental methods and findings, analysis of the results, logical conclusions drawn, any recommendations for future work, and the challenges or obstacles encountered throughout the study period. The questions were designed to assess students' understanding of each aspect of the project. They were required to justify their analysis of product yield, product characteristics, and variations in flame type and duration when using the portable stove. Students were required to demonstrate their understanding of the project’s objectives. To achieve high marks, they needed to present clear evidence of their calculations and decision-making processes in the report. The demonstration of the biodiesel application was recorded in a video for the lecturers to observe.

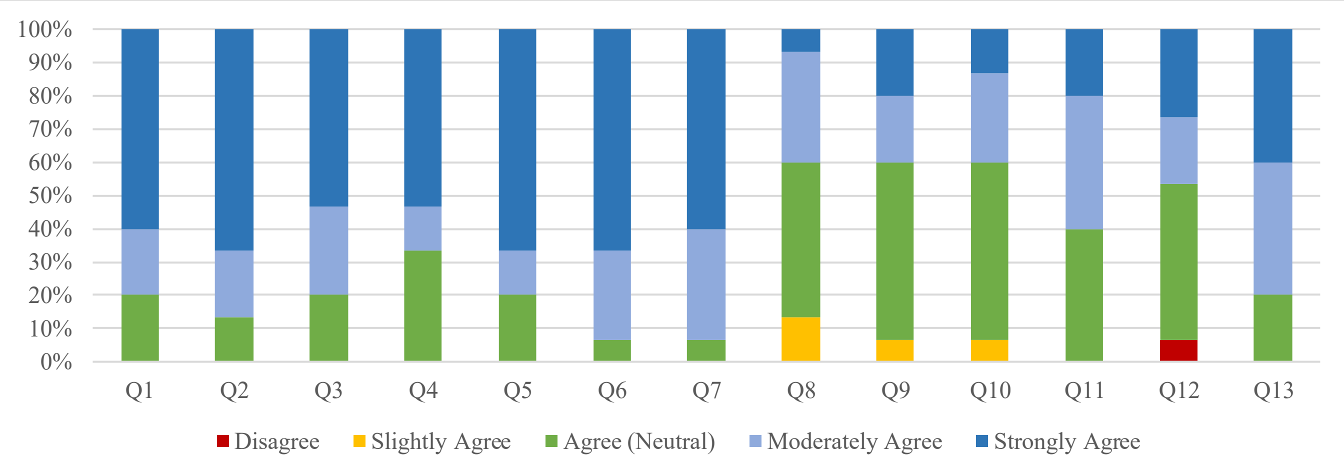

Figure 5. Result Survey of Learning Outcomes

Overall, the project achieved an 87/100 (Table 1), which can be considered an excellent performance. The project effectively integrated theoretical chemical engineering concepts with hands-on learning and laboratory-scale processes, enabling students to analyze the potential, production process, and quality of biodiesel from various sources and apply this knowledge to evaluate the feasibility of its use as fuel. The final report and product application represented their ability to synthesize knowledge into practical outcomes, aligning well with learning outcome. This holistic approach strengthened both transferable and subject-specific competencies that has been mentioned before.

Students' Responses and Discussion

Fig. 5 shows the students' responses to the Assessment of Learning Outcomes questions. The questions asked reflected the project's intention apart from achieving a technical understanding of the project. 15 out of 17 students responded to the survey, and the participation number was 88.2%. The Likert scale, which employed five response categories, was treated as continuous data. Accordingly, statistical analyses were conducted using mean scores, and the percentage of agreement with each item was calculated. This combined approach provided an understanding of student perceptions by quantifying central tendency and agreement trends (Castleberry & Peeters, 2023; Harpe, 2015).

The majority of students agreed that the project was able to improve their understanding of fundamental and technical skills related to chemical engineering. The responses to questions Q1 to Q3 indicated that nearly all participants (over 90%) rated these statements as "Moderately Agree" or "Strongly Agree". The corresponding mean scores for these items were 4.40 (Q1), 4.53 (Q2), and 4.33 (Q3), respectively. These high average scores reflected a strong agreement among students that the project was influential in connecting theoretical knowledge to real-world practice and enhancing technical skills. Similarly, questions Q4 to Q7 received comparably high levels of agreement, where the statements addressed proactiveness, teamwork, time management, and respect for diverse opinions. The average score for these four questions was 4.45, confirming a strong consensus among students regarding the project's benefits in enhancing these competencies. It suggests that, beyond technical expertise, the project effectively promoted essential interpersonal and organizational skills. It aligns with the lecturers' perspective, where the average score for the "Work Capabilities, Attitude, and Values" criterion was 13.1 out of 15. Despite facing several challenges during implementation, students completed the project on time, demonstrating resilience and responsibility.

However, the responses to questions Q8 and Q9 reflected mixed opinions regarding project time management and allocation. The mean scores for Q8 and Q9 were 3.33 and 3.53, respectively, indicating moderate agreement and highlighting that students held mixed perceptions. For Q8, while a significant portion of participants agreed that the time allocation was sufficient, a noticeable number of respondents rated it as "Agree" (Neutral) or "Slightly Agree." It suggests that some participants may have experienced time constraints or challenges in completing the project, indicating a potential area for improvement in project timing or pacing. Similarly, for Q9, a notable minority marked "Slightly Agree" or "Agree," suggesting that, while the project was perceived as time-consuming, it remained manageable due to the focus on a single project requirement. This feedback highlights the intensity of the workload, pointing to possible adjustments that could be made to balance workload expectations better and improve participants' overall experience. It is related to Q14, which concerns the project's challenges. Due to the transesterification reaction failure and limited laboratory facilities and equipment, it consumes more time than expected. However, despite the many challenges, this project taught them to be more proactive in reading more literature and improve each individual's problem-solving and critical-thinking skills. Below are some examples of the students' responses to Q14.

"*The advantage was that my mistakes helped me better understand the biodiesel production process. The main challenge in completing this project was the limited laboratory equipment, which had to be shared and used alternately between groups…*"

"*The advantage was that I gained new technical knowledge and skills, especially in renewable energy and biodiesel production processes. Completing this project was quite time- and energy-consuming, with the possibility of encountering process-related obstacles that could hinder progress or affect the expected outcomes…*"

"*As a benefit, I gained a better understanding of how waste cooking oil can be repurposed into renewable energy. One of the main challenges we faced was frequent failures and soap formation during the separation stage because the process temperature wasn't consistently maintained…*"

Q10-Q12 addressed the project's complexity in terms of team size and dynamics. The mean score of these three questions was 3.62, suggesting a moderate consensus that the project was appropriately aligned with the composition and capacity of the teams. For Q10, most participants felt that the project complexity was well-suited for a small team, suggesting it was challenging yet manageable for a 2-3-person group. This balance was essential in collaborative environments as it fosters teamwork without overwhelming individual members. For Q10, the mean score of 3.47 suggested that participants had a moderate agreement that the project complexity was well-suited for a small team, indicating that it was challenging yet manageable for a 2-3-person group. For Q11, the relatively higher mean score (3.80) demonstrated strong agreement regarding the sufficiency of team size. It indicated that the small team structure promoted active participation and minimized inactivity, emphasizing the effectiveness of focused teams in collaborative projects. However, responses to Q12 were slightly more varied, with a small portion of participants disagreeing on the even distribution of team strengths and weaknesses. It suggests that many teams had a balanced mix of skills, which shows that the team's performance needs to be balanced against the complexity of the project or the personality of each student. To address these issues, future project iterations could include clearer scaffolding of tasks and structured team formation strategies using skill-mapping questionnaires, which may help ensure more balanced team compositions. Lastly, nearly unanimous positive feedback on Q13 highlights that the cooperative and hands-on approach of the project significantly enhanced participants' learning experiences and skills, underscoring the effectiveness of collaborative learning methods in engaging students and improving educational outcomes, which aligned with the answer to Q1-Q3, supported by evidence from the project assessment score.

Throughout the monitoring process, it became clear that the students displayed notable creativity in designing their biodiesel project proposals. One significant challenge they faced was the instability of the laboratory heater, a crucial element in the transesterification process. Instead of being discouraged, the students proactively tackled this issue, frequently consulting with lecturers for guidance. This initiative underscored their dedication to learning and commitment to achieving optimal results. This limitation was evident in the yield results (Table 3), which showed that the experimental outcomes were, on average, lower than those reported in the previous study by (Naseef & Tulaimat, 2025). Students stated that this discrepancy can be attributed to the inadequacy of the laboratory equipment used. Their problem-solving skills were further exemplified by their response to the transesterification process failures, which sometimes led to unintended saponification reactions. To address this, the students conducted a pre-treatment process on the waste cooking oil to minimize the reaction. However, some groups still encountered challenges. Demonstrating a collaborative and analytical approach, these students documented the successful operating conditions of other groups and applied these insights to their experiments. For many, overcoming these obstacles was rewarding and motivating, strengthening their resolve to excel in the project.

For the open questions Q14-Q15, the results of this biodiesel project evaluation highlight several key learning outcomes and challenges. Many students reported that the project significantly improved their technical knowledge and practical laboratory skills, reinforcing their understanding of biodiesel production and building upon prior coursework. This hands-on experience allowed them to acquire valuable insights into renewable energy while deepening their understanding of safety protocols, problem-solving techniques, and professionalism. Students displayed notable adaptability and resourcefulness in addressing various technical challenges. Challenges with laboratory equipment and methodology were frequently mentioned, particularly the limited availability and inconsistent quality of shared tools. Beyond technical skills, the project fostered a strong appreciation for environmental sustainability.

Students recognized the societal and environmental benefits of repurposing waste cooking oil into biodiesel. This aspect of the project enhanced their awareness of the real-world implications of renewable energy solutions, underscoring the importance of sustainable practices in engineering. Students overwhelmingly agreed that the project enhanced their practical skills and deepened their understanding of biodiesel production, thus achieving the intended learning outcomes of a hands-on, project-based approach. The experience of navigating technical and procedural challenges fostered a sense of accomplishment and readiness for future engineering tasks.

Conclusion

The PBL implementation in the Bioenergy Engineering Technology course effectively engaged students in producing and applying biodiesel from waste cooking oil using NaOH and CaO catalysts with varying methanol-to-oil ratios. The highest biodiesel yield was 92.3% using 3% NaOH and a 1:6 methanol ratio, while CaO-based biodiesel yielded up to 42.0%. Both types met the acceptable density range (0.87–0.89 g/cm^3), and biodiesel from both catalysts could be applied successfully in a portable stove, NaOH-produced with a combustion rate of 0.0607 mL/s, and CaO-produced with 0.0412 mL/s.

Student assessment scores showed that the project was successful for learning, with an overall score of 87/100. The highest marks were in experimental design (16.9/20), final report (13.8/15), and soft skills (13.1/15). Based on survey results, the mean score of Q1-Q7 was 4.44, and 90% of students agreed that the project helped them better understand fundamental and technical aspects of chemical engineering.

The survey showed strong agreement that students became more proactive, better at managing time, and respectful of others' opinions. Although some students had concerns about time limits (Q8 = 3.33, Q9 = 3.53) and team workload (Q10–Q12 = 3.62), most showed resilience. Even with challenges like failed reactions and limited lab tools, students used the experience to build their problem-solving and critical-thinking abilities. It indicated that the project succeeded technically and served as an impactful educational model, integrating engineering problem-solving with transferable skills development.

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Author Contributions
A. R. and S. R conceptualized the study, developed the methodology, performed the formal analysis, and drafted the original manuscript. N. supervised the project, provided resources, reviewed and edited the manuscript, and served as the corresponding author for all communication during the submission process and publication. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors report no competing interests related to this research. The funding institution had no involvement in study design, data collection, analysis, interpretation, manuscript preparation, or publication decisions.

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