A PROJECT-BASED LEARNING APPROACH FOR CHEMICAL ENGINEERING STUDENTS: WASTE COOKING OIL BIODIESEL PRODUCTION FOR PORTABLE STOVE APPLICATIONS

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Abstract

Modern engineering education emphasizes bridging theoretical knowledge with practical application, aligning with industry needs. This study explores the impact of project-based learning in a bioenergy engineering course at the University of Jambi, focused on producing biodiesel from waste cooking oil for portable stove applications. Conducted with 17 chemical engineering students over the 2024/2025 academic year, this project-based learning initiative aimed to develop both subject-specific and transferable skills, such as problem-solving, teamwork, and adaptability. The project involved hands-on laboratory work, emphasizing critical steps in biodiesel production, including transesterification and product purification using both homogeneous and heterogeneous catalysts. Students demonstrated notable improvement in technical competencies and soft skills, with over 90% indicating enhanced understanding and application of biodiesel production processes. Despite challenges with equipment limitations and occasional reaction failures, students showed resilience and resourcefulness by consulting with lecturers and documenting successful procedures. Mixed responses were observed regarding time allocation, highlighting areas for potential refinement in workload management. Ultimately, the project fostered an appreciation for sustainable practices and deepened students' understanding of renewable energy solutions. The findings affirm that project-based learning effectively supports holistic skill development, preparing students for real-world engineering challenges and reinforcing the value of sustainable engineering practices.

Keywords: Project-Based Learning, Biodiesel Production, Engineering Skills

1. Introduction

Modern engineering education is increasingly focused on delivering both theoretical knowledge and practical skills that align with the demands of the evolving industry. One of the emerging trends in academia is project-based learning, which has gained significant attention as an alternative approach to traditional teaching methods. Project-based learning emphasizes active learning through student-led projects that tackle real-world problems, promoting a deeper understanding of complex concepts while developing essential skills such as teamwork, communication, and critical thinking (Amish & Jihan, 2023). For chemical engineering students, this approach is particularly valuable as it integrates theoretical principles with hands-on experiences, bridging the gap between classroom learning and industrial applications (A Sagala et al., 2019). In a field that requires a strong foundation in both scientific knowledge and practical problem-solving, project-based learning enables students to engage in interdisciplinary projects, often mirroring the challenges they will face in their professional careers (Kolmos & Graaff, 2015). This method plays a crucial role in preparing future engineers to meet the complex needs of the chemical engineering sector.

Prince & Felder (2006) state that project-based learning is a widely acknowledged approach in engineering education. Many engineering programs, both at the undergraduate and graduate levels, emphasize laboratory and practical work as core elements of their curriculum. Laboratory practices allow students to work with tools and variables and collaborate with peers from diverse backgrounds, fostering teamwork. This hands-on experience reinforces the concepts taught in lectures and assignments, which is why the authors chose to apply this strategy (Gomez-del Rio & Rodriguez, 2022).

The objective was to enhance student learning outcomes and facilitate the acquisition of critical competencies. These competencies are clearly defined in the official curricula of the Chemical Engineering study program at the University of Jambi. Students are expected to develop both transferable and subject-specific skills. Transferable skills include 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 are required to gain a deep understanding of subject-specific areas. For instance, they must master biodiesel production from waste cooking oil and evaluate its performance in portable stove applications. These competencies are essential for their academic and professional development. The course involved Bioenergy Engineering Technology (Teknologi Rekayasa Bioenergi), and this initiative was implemented during the 2024/2025 odd semester and introduced to 17 students, with a total of 2 credit hours accumulated.

2. Method and Experimental Setup

The main objective of this project was to produce biodiesel from waste cooking oil as an alternative fuel in portable stoves, using variables in catalyst and methanol as reactants. The quality of the deliverable product was determined by the biodiesel yield and its use in portable stove applications. Gomez-del Rio & Rodriguez (2022) The project-based learning must include the following stages: 1) teach content through knowledge and skills, 2) create a need to know essential and fundamental content, 3) need critical thinking, problem-solving, and collaboration or teamwork, 4) develop investigation, 5) provide continuous feedback and 6) present or deliver the final product.

2.1. Project Description and Project-based Learning Design

Bioenergy is energy produced from biomass, which includes organic materials from plants, animals, and industrial cultivation waste. It can be utilized in biofuels, biomass electricity, biodiesel, and bioethanol. 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. 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. Demirbas (2009) notes 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. Lam et al. (2010) explained that it reduces production costs and mitigates environmental issues. Approximately 3 million tons of waste cooking oil in Indonesia are produced annually but remain underutilized (Sudradjat et al., 2015). In biodiesel production, catalysts are critical, with homogeneous base catalysts (NaOH and KOH) often used for their efficiency and low cost. However, heterogeneous catalysts like CaO are emerging as viable alternatives because they do not produce soap during the process (Syahputri & Broto, 2020). 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 the primary feedstock, with a ratio of methanol 1:6 and 1:12. Distilled water was used for washing the crude biodiesel. The experimental setup involved standard laboratory glassware such as Erlenmeyer flasks, beakers, and measuring cylinders for precise liquid measurement. A separatory funnel and filter paper were utilized for the separation and purification steps. The primary reaction was in a three-neck flask equipped with a condenser to prevent evaporation. A magnetic stirrer and a hot plate or heating mantle were used to ensure uniform mixing and heating throughout the process.

Biodiesel production began with a pre-treatment step, where waste cooking oil was filtered and heated to 90–100°C for 30 minutes to reduce its moisture content. The oil was then cooled to 40°C before being combined with a catalyst solution in methanol. The catalyst was either homogeneous (NaOH) 1%, 2% w/w, or heterogeneous (CaO) 4%, 5% w/w. The transesterification reaction was carried out at 60–70°C for one hour, after which excess methanol was removed via distillation. The biodiesel was separated from glycerol using a separatory funnel, allowing the mixture to settle for 12–18 hours. The biodiesel was washed several times with distilled water at 50°C to remove residual catalysts and methanol. Once the biodiesel cleared, it was reheated to remove any remaining moisture.

The total number of students in each class is 17. The recommended group size is 3 people in each group. There are two lecturers in the lab and each one is in charge of 2 or 3 groups and they must meet the students' needs and questions. The total lab experience includes two sessions of 4 h each one, one class a week over 8-10 weeks.

This learning design will have four main stages that will be implemented, namely, 1) Providing content through knowledge and skills: Students understand basic concepts of bioenergy engineering academically and competencies throughout the project. This can include knowledge, practical skills, and attitudes; 2) Designing a Project Proposal: The bioenergy project proposal to be implemented is made in the form of a Project Implementation Plan. The lecturer will create a working group to conduct biodiesel production experiments. 3) Carrying out Project Assignments: Implementing project assignments is an experimental activity of student working groups to solve problems related to the project, making the project design into a tangible object. The role of the lecturer is mentoring, supervising, and evaluating students during the project; 4) Evaluation: aims to reveal the achievement of the learning process and student competencies so that they become assessment and evaluation materials. Evaluation is carried out on the project's work process and final results. The assessment includes problem-solving, creativity, collaboration, and final product quantity criteria. Students present biodiesel products as portable stove fuel.

2.2. Pedagogical framework and educational context

Project-based learning in education has shown significant potential in nurturing essential skills such as critical thinking, problem-solving, and understanding of real-world challenges. Project-based learning distinguishes itself from traditional learning approaches by engaging students in projects that require applying their theoretical knowledge to solve complex, authentic problems. Project-based learning involves actively constructing knowledge via hands-on experience (Krajcik & Shin, 2014). This creates more room for creativity and experimentation as the students can test their ideas on a working model. Students are indirectly exposed to technically unfeasible methods besides learning things that work in a system.

One of the fundamental advantages of project-based learning is its ability to develop critical thinking and problem-solving skills by immersing students in tasks that require them to analyze complex issues and create innovative solutions. Research has shown that project-based learning encourages deeper learning and helps students better understand the subject matter (Pan & Allison, 2010). 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.

In the context of the Bioenergy Engineering Technology course at the University of Jambi, project-based learning 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 applications. 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 intends 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. The authors designed this project-based laboratory. This learning model is particularly suitable for chemical engineering laboratories, where students are often required to integrate knowledge and experience from different courses to solve complex experimental problems.

2.3. Project Evaluation

The evaluation step in Project-Based Learning is essential in assessing the efficacy of learning and the success of projects worked on. The evaluation of project success is holistic, considering aspects of the process, product, and individual learning. It provides opportunities for students to learn from the experiences and feedback they receive. 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 is 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 applications. Students would have to portray their understanding of all objectives in the reports.

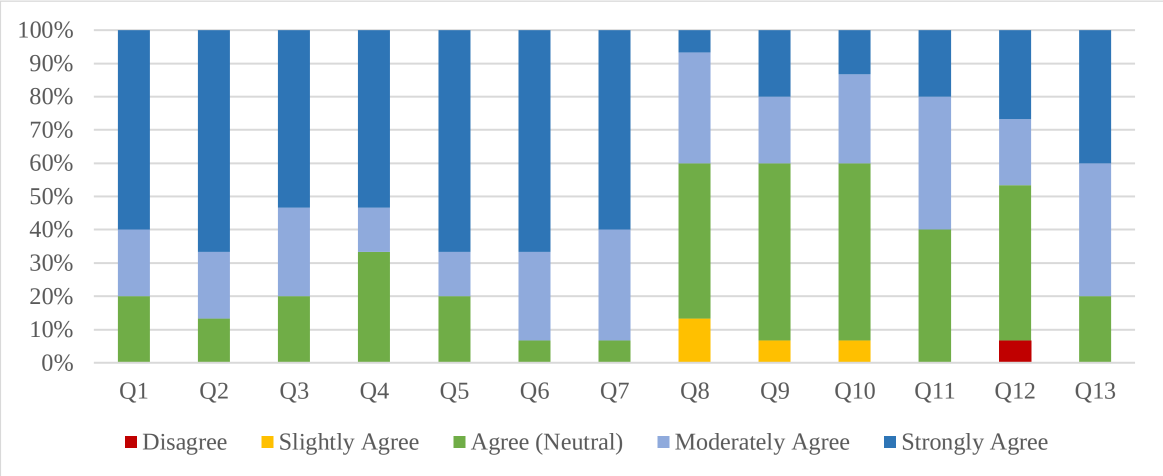

Figure 1. Result Survey of Learning Outcomes

Table 1. 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)?

2.4. Assessment of learning outcomes

The assessment was conducted with a 3rd-year cohort taking Bioenergy Engineering Technology (Teknologi Rekayasa Bioenergi) in the 2024/2025 academic year. The lecturers were ready to solve questions and collaborate with the students, providing feedback and constructive comments before starting any subsequent task, before, during, and after the laboratory session. 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-based laboratory involves 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 project-based learning. 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. 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 is aligned with distinctive learning outcomes and has been assumed to be influential in assessing the learning outcomes. Meanwhile, Questions 15-16 are open questions about their satisfaction and opinion on their laboratory activity and learning outcomes.

3. Results and Discussion

Fig. 1 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 majority of students agreed that the project was able to improve their understanding of fundamental and technical skills related to chemical engineering. In addition, the majority also believed that this project improved communication and decision-making skills, ability to work in a team, and respect for other people's opinions professionally. The responses to questions Q1 to Q3 indicate that nearly all participants (over 90%) rated these statements as "Moderately Agree" or "Strongly Agree." This high level of agreement suggests that the project was influential in connecting theoretical knowledge to real-world practice and enhancing technical skills, demonstrating its success in bridging academic knowledge with practical application in chemical engineering. Similarly, questions Q4 to Q7 received comparable high agreement levels, particularly for statements related to soft skills, teamwork, time management, and respect for diverse opinions. This indicates that, in addition to technical skills, the project also fostered necessary interpersonal and time management skills, which are essential in professional settings. Together, these responses reflect the project's comprehensive impact on technical and soft skill development, equipping participants with a balanced skill set for future challenges.

However, the responses to questions Q8 and Q9 reflect mixed opinions regarding project time management and allocation. 60% answered slightly agree and neutral, showing that the project's time distribution is sufficient. 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." This 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. This relates to question 15, which concerns the project's challenges. Due to the transesterification reaction failure and limited laboratory facilities and equipment consume 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.

Questions 10-12 about the project's complexity against the number of teams and the distribution of team strengths and weaknesses is well distributed. The majority answered slightly agree and neutral. The responses to questions Q10 through Q12 reflect a positive perception of the project's complexity and team dynamics. For Q10, the majority of participants felt that the project complexity was well-suited for a small team, suggesting that it was challenging yet manageable for a 2-3-person group. This balance is essential in collaborative environments as it fosters teamwork without overwhelming individual members. Similarly, Q11 received strong agreement regarding the sufficiency of team size, indicating 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. This 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. This statement can be used for the next project to assess the complexity against the number of students and divide the project groups more appropriately. 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 cooperative learning methods in engaging students and improving educational outcomes.

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. 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.

4. Conclusion

Implementing project-based learning in the biodiesel project successfully enhanced students' practical competencies in bioenergy engineering. Beyond achieving technical proficiency in biodiesel production, this project also imparted crucial soft skills, including problem-solving, teamwork, adaptability, and time management. Furthermore, integrating project-based learning into the Bioenergy Engineering Technology course allowed students to apply theoretical concepts in real-world scenarios, bridging classroom knowledge with hands-on practice. This study effectively aligned learning objectives and assessments with project-based learning activities, fostering a comprehensive and impactful learning experience that engaged multiple learning domains simultaneously. The project could be further optimized by refining time allocation and group distribution to improve team dynamics and workload management, addressing minor challenges highlighted by students. Additionally, increasing the complexity of future projects may enhance learning outcomes, equipping students with more advanced skills. Re-evaluating current methods to emphasize collaboration and sustainability in engineering will contribute to an even more meaningful learning experience, supporting students' academic growth and character development by exploring renewable energy solutions and real-world problem-solving. These findings support the effectiveness of project-based learning in chemical engineering education, as it not only strengthens student competencies holistically but also fosters a sustainable mindset, positioning them as capable professionals in the field.

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