IJOLAE Indonesian Journal on Learning and Advanced Education

http://journals.ums.ac.id/index.php/ijolae

Ethno-STEM-Based Web-Based Learning Enhances Students' HOTSEP and Environmental Literacy in Green Technology Project

Syahmani[1]✉, Yogo Dwi Prasetyo[2], Rilia Iriani[3], Leny[4], Azlan Bin Kamari[5], Kustomo[6], Nani Apriyani[7], Rusmansyah[8], Milana Sari[9], Muhammad Noor Raidimas[10]

[1-4, 8-10]Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Indonesia
[5]Department of Chemistry, Universiti Pendidikan Sultan Idris, Malaysia
[6]Department of Chemistry, National University of Singapore, Singapore
[7]Department of Pharmacognosy, Semmelweis University, Hungary

DOI: 10.23917/ijolae.v8i2.10813
Received: March 25th, 2026. Revised: May 18th, 2026. Accepted: May 22nd, 2026
Available Online: May 28th, 2026. Published Regularly: May, 2026

Abstract

The transition toward renewable energy and sustainable development requires innovative learning approaches that foster students' Higher-Order Thinking Skills on Environmental Problems (HOTSEP) and Environmental Literacy (EL). However, the integration of local wisdom, STEM disciplines, and digital learning environments in green technology education remains limited. This study aimed to develop and evaluate an Ethno-STEM-based Web-Based Learning (WBL) model integrated with Green Technology (GT) projects to enhance students' HOTSEP and EL. The study employed the ADDIE research and development model involving 40 Chemistry Education students at Universitas Lambung Mangkurat, Indonesia. Data were collected through expert validation sheets, observation sheets, student response questionnaires, HOTSEP tests, and EL instruments. Data were analyzed using Aiken's V, Cronbach's Alpha, N-gain, paired t-tests, and Wilcoxon tests. The results showed that the developed GT website achieved a very high validity score (92.58%) and demonstrated excellent practicality based on readability and student responses. The implementation of the Ethno-STEM WBL model significantly improved students' HOTSEP and EL ($p < 0.05$), with N-gain scores of 0.74 and 0.71, respectively, both categorized as high. Students actively engaged in bioethanol and biodiesel projects, enabling them to connect scientific concepts, local knowledge, and environmental problem-solving practices. The novelty of this study lies in the integration of Ethno-STEM, web-based learning, and green technology projects within a renewable energy context to simultaneously develop HOTSEP and environmental literacy. This framework offers an innovative approach for advancing sustainability-oriented science education and supporting the achievement of the Sustainable Development Goals.

Keywords: advanced learning, ethno-STEM, green technology, higher-order thinking skills, innovative learning design, lifelong learning, sustainable education, web-based learning

✉***Corresponding Author:***
Syahmani, Faculty of Teacher Training Education, Universitas Lambung Mangkurat, Indonesia
Email: syahmani_kimia@ulm.ac.id

1. Introduction

Indonesia is shifting towards renewable energy, aiming for 23% use by 2025 and 31% by 2050, in line with the National Energy Policy (NEP) (Syafii et al., 2021). This transition supports Sustainable Development Goals (SDGs) 7 (affordable and clean energy) and 13 (climate action) to ensure sustainable energy and mitigate climate change impacts.

Education for Sustainable Development (ESD) is essential for achieving renewable energy in Indonesia, requiring comprehensive resources. Building quality human resources through education fosters skills necessary for a sustainable future in energy.

The approach to ESD involves integrated green technologies (GT), chemistry projects, and media/ICT (Kanvaria & Yadav, 2024). Integrating project-based learning and collaboration enhances meaningful student experiences in the national curriculum (Farisi, 2016) that involve Higher-Order Thinking Skills of Environmental Problems (HOTSEP), and Environmental Literacy (EL) (Fensham & Bellocchi, 2013).

The results of the initial study show that students' HOTSEP and EL remain low. Therefore, innovation of digital learning materials (website) is needed according to the University's vision of a wetland environment, through the development of innovative learning designs.

From an advanced learning perspective, this condition indicates that current instructional practices have not fully facilitated higher-order cognitive engagement, adaptive thinking, and knowledge transfer across contexts. Advanced learning emphasizes deep conceptual understanding, critical inquiry, problem-solving, innovation, and the ability to transfer knowledge across complex real-world contexts. In this perspective, learning should not only improve academic achievement but also cultivate environmental responsibility, sustainability awareness, and adaptive competencies required in the twenty-first century (Mahat et al., 2024). Therefore, innovative learning designs integrating digital technology, local wisdom, and interdisciplinary STEM knowledge are essential to support progressive and challenging learning experiences. Therefore, the integration of digital learning environments such as web-based platforms should not only deliver content but also promote innovation-oriented and inquiry-driven learning experiences.

Several previous studies have shown that Ethno-STEM learning is able to improve students' HOTSEP, critical thinking, creativity, and metacognition (Sumarni & Kadarwati, 2020). The Ethno-STEM approach combines cultural knowledge with STEM curricula to enhance inclusivity and engagement, valuing diverse scientific understandings and incorporating students' cultural heritage in education (Chahine, 2021).

In addition, this approach aligns with the principles of lifelong learning, where students continuously construct knowledge by connecting scientific concepts with local wisdom and real-life experiences. Lifelong learning in this context supports the development of adaptive learners who are capable of continuously updating their knowledge and skills in response to environmental and technological changes (Sudarmin et al., 2023).

Furthermore, the Ethno-STEM approach contributes to character education by fostering environmental responsibility, collaboration, ethical decision-making, and awareness of sustainable resource utilization. Through engagement with local wisdom and community-based environmental issues, students develop values-oriented competencies that support responsible citizenship and sustainable development (Kale & Goh, 2014).

Integrated project activities in the Ethno-STEM and WBL approach aim to develop students' HOTSEP and EL, thereby simplifying their understanding of Green Technology (GT). The existence of Ethno-STEM-WBL can encourage students' interest and interaction in the learning materials being studied (Hendri et al., 2021) and can be designed according to students' needs and characteristics.

Ethno-STEM WBL approach with the Engineering Design Process (EDP) describes five steps: ask, imagine, plan, create, and improve (Shahali et al., 2016). The EDP learning has a positive impact on improving students' skills in solving science and mathematics-based problems (Syukri et al., 2018). STEM learning can be considered a promising approach to finding creative and sustainable solutions to environmental problems with GT (Lenger et al., 2020).

Green technology reduces environmental harm from products, lowers greenhouse gas emissions, and promotes the use of organic resources. The GT topic is used to improve students' HOTSEP and EL through group discussions to solve problems. The state of the art of this research is the Ethno-STEM WBL approach in GT. Web content merges culture and STEM, promoting project-based learning. Improving students' creative thinking skills, character, environmental literacy, attitudes, and HOTSEP are all facilitated by an ethno-STEM approach (Izzah et al., 2023). Students create tech products while facing 21st-century challenges, designing and implementing low-carbon energy systems, which also involve renewable energy sources, for example, bioethanol (Guragain et al., 2016) and biodiesel (Abdullah et al., 2017). Unlike previous studies that primarily examined Ethno-STEM, project-based learning, or environmental literacy separately. This study uniquely combines Ethno-STEM, Web-Based Learning, Green Technology, and the Engineering Design Process into an integrated framework, enhancing advanced learning, environmental literacy, and problem-solving skills through renewable energy projects rooted in local wisdom.

2. Method

This study employed the ADDIE model for research and development for creating learning resource products (Almelhi, 2021). The ADDIE model comprises the following phases: Analyze, Design, Develop, Implement, and Evaluate (Syahmani et al., 2024). Within this study, the ADDIE model is implemented not only as an instructional design framework but also as a scaffold for advanced learning, where iterative evaluation supports continuous improvement, reflective thinking, and adaptive learning processes. This aligns with innovation learning principles that emphasize experimentation, feedback integration, and knowledge refinement.

These phases are sequential, with each one depending on the successful conclusion of the one before it. Furthermore, as an iterative feedback model, the ADDIE model closes the loop by incorporating feedback from the evaluation phase into subsequent iterations of the learning product. Table 1 shows the stages of ADDIE development. Five experts validated the web GT using a sheet. Forty Chemistry Education students from Semester III at Lambung Mangkurat University participated in this activity. Ethno-STEM WBL was the research focus.

This development begins with the analysis stage, where researchers analyze the aspects needed for the development of web/e-modules, such as a preliminary analysis of the initial state of the student. Subsequently, the design stage commences when the GT web has begun to be designed in the form of a first draft, which still needs to be revised according to the suggestions and input received. After revising, the next step is testing. This research used data collection with instrument tests and questionnaires in a Google form. The data analysis consists of validity, practicality, and effectiveness.

Table 1. Steps for Developing the ADDIE Model

Step	Sample Task	Sample Output
Analysis	Needs analysis, task analysis, and instructional analysis	Learner profile and problem statement, description of instructional content, and establish what must be learned.
Design	Identification of objectives, plan instruction, and identify resources	Measurable objectives, instructional strategy, and specification.
Development	Developing learning materials, expert validation, and small group testing	Module prototype and validator comments
Implementation	Product trials and implementation on students were followed by data collection on the practicality and effectiveness of the teaching materials.	Student comments and data on the practicality and effectiveness of the Ethno-STEM WBL.
Evaluation	The research team and lecturers evaluated the implementation process and products, as well as HOTSEP measurements and students' environmental literacy (EL).	Empirical products in the form of teaching materials, lesson plans, research instruments, and student HOTSEP and EL measurement results.

Table 2. Data Collection Instruments

Aspect	Instrument
Validity	Web GT validation sheet
Practicality	Observation sheet, readability, and student response questionnaires.
Effectiveness	Test of students' HOTSEP and EL.

a. Analysis of validity and reliability

The validation test of the data was analyzed using Aiken's V formula. The following categories were used to interpret the validity of the website GT, a test of students' HOTSEP and EL:

1) $85 < x \leq 100$ (very valid),
2) $70 < x \leq 85$ (valid),
3) $50 < x \leq 70$ (less valid), and
4) $x \leq 50$ (invalid) (Yunita et al., 2021).

Reliability test using Alpha Cronbach with the categories:

1) $0.90 < \alpha \leq 1$ (very high),
2) $0.70 < \alpha \leq 0.90$ (high),
3) $0.50 < \alpha \leq 0.70$ (medium),
4) $\alpha \leq 0.50$ (low) (Syahmani et al., 2017).

A HOTSEP test with 15 items, a two-tier diagnostic test. Indicators of HOTSEP are criticizing environmental issues, solving environmental problems, and developing innovations about the environment (Ichsan & Rahmayanti, 2020; Islami et al., 2021; Primarini et al., 2021). Analysis of students' HOTSEP in learning activities referring to the rubric scoring guidelines.

The environmental literacy (EL) instrument utilized the Middle Schools Environmental Literacy Survey/Instrument (MSELS/I) from the National Environmental Literacy Assessment, NELA (McBeth et al., 2011) with modifications to green chemistry content. The MSELS test includes environmental literacy components: knowledge, cognitive skills, and affective and behavioral domains (Karimzadegan & Meiboudia, 2012; McBeth et al., 2011).

b. Analysis of practicality

The practicality analysis of data was analyzed by using a readability and student response questionnaire, a lecturer observation sheet with the following practicality categories:

1) 81.00% - 100.00% (very practical),
2) 61.00% - 80.00% (practical),
3) 41.00% - 60.00% (practical enough),
4) 21.00% - 40.00% (impractical), and
5) 00.00% - 20.00% (very impractical).

c. Analysis of effectiveness

The effectiveness analysis of the improvement of students' HOTSEP and EL before and after learning. Data were analyzed descriptively and inferentially to evaluate HOTSEP's impact on students' EL development.

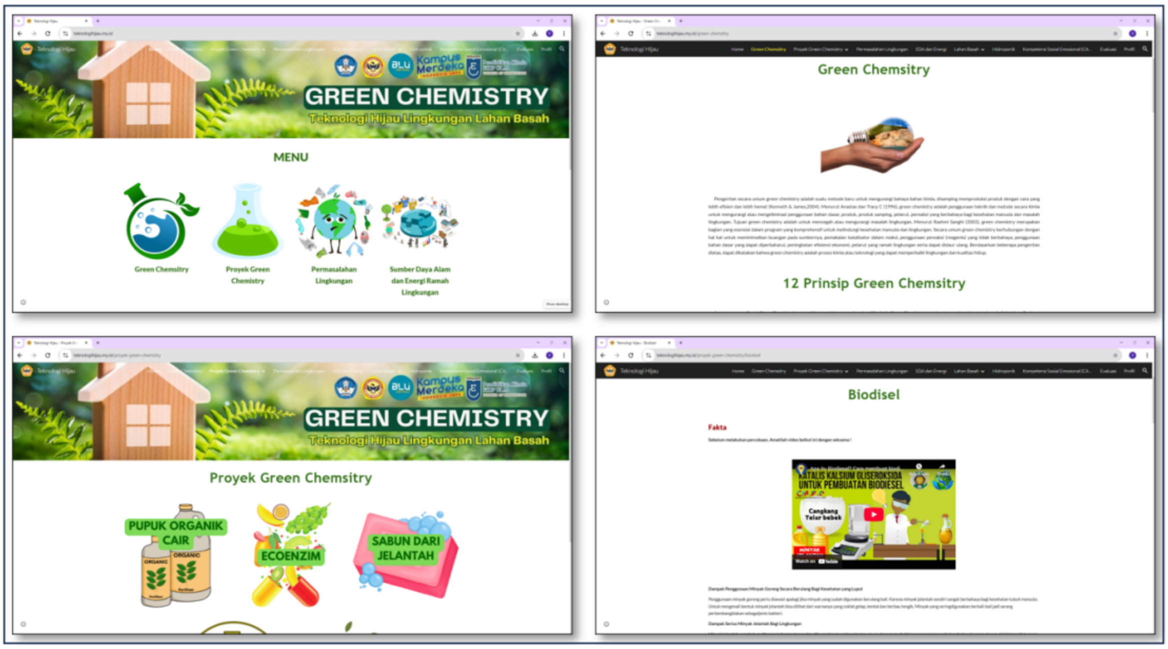

Figure 1. Display the Website of GT

N-Gain was used to calculate the magnitude of the improvement. The categories to interpret the average N-gain of students' HOTSEP and EL: $g > 0.7$ (high), $0.3 < g \leq 0.7$ (moderate), and $g \leq 0.3$ (low) (Hake, 1998). Paired t-tests (parametric) or Wilcoxon tests (non-parametric) compared pretest and posttest outcomes for significant increases.

3. Result and Discussion

a. What features of the GT web?

Research findings on the GT web will align with established goals, showcasing its usefulness and efficacy through concise, comprehensible, and well-organized content tailored to student needs. This web has to be accessible with a link: www.teknologihijau.my.id (Figure 1) via computers/smartphones at any time, anywhere. The web also contains environmental problems in everyday life related to the main study, scientific activities and discussions, images, videos, and evaluations.

Beyond serving as a digital content repository, the GT website functions as an innovative learning environment that supports self-directed learning, collaborative inquiry, reflective thinking, and project-based problem-solving. These features align with contemporary trends in learning technology literacy and progressive education, enabling students to construct knowledge through authentic environmental challenges.

b. How is the validity and practicality of the Ethno-STEM WBL?

The validity of the web GT is based on the assessment of 5 experts. This validity assessment consists of several aspects, namely the feasibility of content, presentation, language, and media. The validation results can be seen in Table 3. Based on Table 3, the overall validity of the web is 92.58%. Yunita et al. (2021) state that the range 81%-100% is the "very valid" category. The validator noted the web GT's completeness, relevance, and suitability for illustration.

Table 3. Validation Results of Web GT

Aspects	Percentage	Category
Content	90.67	Very valid
Presentation	95,07	Very valid
Media	93.00	Very valid
Language	91.56	Very valid
Average	**92.58**	**Very valid**

Validation of GT's presentation includes introduction, content, and conclusion; students' projects show reliable HOTSEP and EL with Cronbach's alpha 0.71, 0.76. *Readability averaged 85.88%, and 95.5% had a positive online experience. Ethno-STEM WBL positively impacted HOTSEP and EL.*

The production of biofuel (bioethanol and biodiesel) involves Ethno-STEM WBL can easily highlight any socio-scientific issues (SSI) (Tytler, 2012). The syntax of the Ethno-STEM WBL approach is displayed in Table 4. Lecturer enhances project performance across five phases: Ask, Imagine, Plan, Create, and Improve (Shahali et al., 2016; Purwaningsih et al., 2020).

1) The Ask Phase

The learning chemistry class begins with an introduction to the SDGs, and students identify problems: *New Renewable Energy (NRE) aims to reduce reliance on fossil fuels, targeting 23% usage by 2025 and 31% by 2050. How can biofuels, as an alternative energy source, be made from biomass or waste cooking oil (WCO)?.*

2) The Imagine Phase

Students then engage in group activities to gather information and conceptualize NRE projects in GT about biofuels from biomass or WCO.

3) The Plan and Create Phase

Students plan and develop laboratory projects, researching plant feedstocks for biofuels. They design solutions and prototypes, presenting findings while monitoring progress in class. Group activities enhance their NRE-Biofuels projects, with teacher support for overcoming challenges.

4) The Improve Phase

After project completion, students perform product testing and improvement, and evaluation.Assessment includes project and product design through an evaluation rubric. Finally, a test to assess HOTSEP (covering the cognitive levels of analyzing, evaluating, and creating) was administered, and students completed an EL questionnaire for each indicator.

The GT web is implementable. The practicality of the Ethno-STEM WBL was very good (Table 4). The 'Ask, Imagine, and Plan' stage is in a very good category. While the 'Create and Improve' stage is in the good category. Ethno-STEM WBL can be used as teaching material in chemistry learning for GT.

The learning sequence reflects a challenging learning environment where students are encouraged to investigate complex environmental issues, formulate evidence-based solutions, and evaluate the societal implications of renewable energy technologies (Živković et al., 2017). Such experiences are essential components of advanced learning and critical education, where learners actively construct knowledge rather than passively receive information.

Table 4. The Syntax of the Ethno-STEM WBL

The Ethno-STEM-WBL Syntax	HOTSEP Indicator	Environmental Literacy Indicator
Ask (Reflection). Identify problems (S, T) **Imagine (Discovery).** Gather information to support the project (S, T)	Criticizing environmental issues	Feelings towards the environment; Issue identification and issue analysis
Plan (Design). Designing solution ideas and simple tools (E, Ethno, M)	Solving environmental problems	Ecological knowledge; Environmental sensitivity
Create (Develop, Present). Making prototype products and presentation (S, T, Ethno) **Improve (Improvement and Evaluation).** Product testing and improvement (S), and evaluation (S, T)	Developing innovations in the environment	Action plan; Verbal commitment; Actual commitment; Pro-environmental behaviour

(Chatwattana & Nilsook, 2017; Laboy-Rush, 2011; Shahali et al., 2016)
Note: Science (*S*), Technology (*T*), Engineering (*E*), and Mathematics (*M*)

The Ethno-STEM WBL syntax presented in Table 4 serves as a pedagogical framework that systematically integrates cultural knowledge, scientific inquiry, technological applications, engineering design, and mathematical reasoning into green technology learning activities. Through the sequential stages of Ask, Imagine, Plan, Create, and Improve, students are encouraged to identify environmental issues, formulate potential solutions, develop innovative products, and evaluate the effectiveness of their proposed solutions (Zabed et al., 2014). This learning sequence fosters HOTSEP, environmental literacy, and connects scientific concepts with local wisdom and real-world sustainability issues

(Almubarak et al., 2025).

In the context of renewable energy education, biofuel production projects offer a relevant and meaningful platform for implementing the Ethno-STEM approach. Bioethanol and biodiesel production activities require students to apply interdisciplinary knowledge involving chemistry, biotechnology, process engineering, and quantitative analysis (Syahmani et al. 2021). Furthermore, the utilization of locally available biomass resources and waste materials reflects the integration of indigenous knowledge and environmental sustainability principles (Sudarmin et al., 2024). Through project-based investigations, students gain practical experience in designing production processes, evaluating product quality, and understanding the role of green technology in supporting sustainable development goals. The integration of Ethno-STEM components in biofuel projects is summarized in Table 5.

Table 5. Integration of Ethno-STEM in Biofuels

Ethno	Science	Technology	Engineering	Mathematics
Using biomass or local material for bioethanol and biodiesel	Making biofuel (bioethanol and biodiesel) with testing the product.	Fermentation technology Heating, catalyst, and stirring technology	Designing procedures, tools, and materials for making biofuels.	Calculate tool and material costs, and measure biofuels' volume and properties

5) Bioethanol Production

Sugar, starch, and cellulose serve as feedstock for bioethanol (Germec et al., 2015). To produce bioethanol, sterilize sugarcane, then ferment with 150 g/L sugar at pH 5.0 and 30-35°C for 72 hours using Saccharomyces cerevisiae (Zakhartsev et al., 2015), followed by distillation and purification (Figure 2). Yields of bioethanol from honey pineapple and sugarcane are 70.35% and 71.41%, respectively, after processing.

Bioethanol produced and its physical properties are presented in Table 6. The amount of bioethanol generated increases with the amount of sugar. Before being used as biofuel, the bioethanol must be refined by 90% limestone or zeolite to remove the remaining 94.0–99.5% of its bioethanol concentration (Muhaji & Sutjahjo, 2018; Candra et al., 2019). Zeolite absorbs water, allowing for the precipitation of distilled ethanol from sugarcane and pineapple, which is then filtered to meet the required standards.

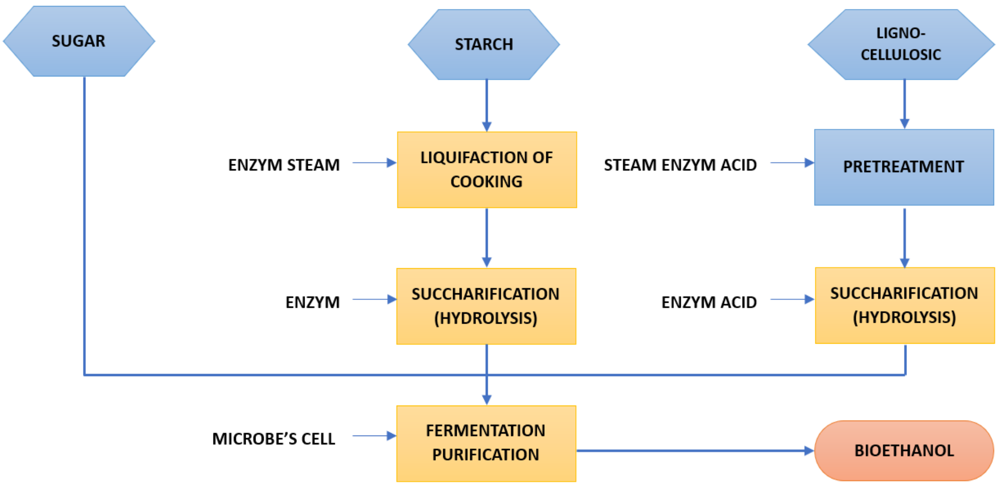

Figure 2. Procedure for Making Bioethanol

Figure 2 illustrates the overall pathway of bioethanol production from various biomass sources, including sugar-rich, starch-rich, and lignocellulosic feedstocks. The process begins with feedstock preparation, followed by conversion into fermentable sugars through different pretreatment routes (Annisa et al., 2024). Sugar-based materials can be directly fermented, whereas starch-containing biomass requires liquefaction and saccharification to convert complex carbohydrates into simple sugars (Qori et al., 2020). Lignocellulosic biomass undergoes pretreatment and hydrolysis to break down cellulose and hemicellulose into fermentable monosaccharides. Subsequently, the resulting sugars are subjected to microbial fermentation using *Saccharomyces cerevisiae*, producing ethanol as the primary product. The fermentation broth is then purified through distillation and dehydration processes to obtain bioethanol with a higher concentration suitable for fuel applications (Putri et al., 2023). This production pathway demonstrates the integration of scientific principles, technological processes, and engineering design within the Ethno-STEM learning framework, enabling students to understand renewable energy production through hands-on project activities and sustainable resource utilization.

Table 6. Physical Properties of Bioethanol Produced

Feed-stocks	Free Sugar (%)	Bioethanol Yield (%)	Density (g/mL)	SNI (2008)
Sugarcane	14,66	70.35	0.7985	0.7936-0.7961
Honey Pineapple	15,80	71.41	0.7959	0.7936–0.7961

6) Biodiesel

Biodiesel, or FAMEs (fatty acid methyl esters), is an alcoholic ester derived from plant oil, microalgae lipids, and animal fat, through trans-esterification (Brahma et al., 2022; Saputro et al., 2022; Elma et al., 2017). Transesterification for biodiesel uses homogeneous catalysts like sulfuric acid, sodium hydroxide, and potassium hydroxide (Yang *et al.*, 2018; Neumann et al., 2016; Reyero et al., 2015). Heterogeneous base catalysts offer environmental benefits, reduced disposal issues, non-corrosiveness, and can be engineered for enhanced activity, selectivity, longevity, and easier separation (Jayakumar et al., 2021; Abdullah et al., 2017). Eggshell-derived calcium oxide acts as a heterogeneous transesterification (Yusuff et al., 2024; Ahmad et al., 2020; Degfie et al., 2019; Chavan et al., 2015; Lee & Wilson, 2015; Lee et al., 2015) for the synthesis of biodiesel (methyl ester) from waste cooking oil (WCO).

The pre-treatment methods for producing biodiesel include esterification processes, followed by transesterification triglycerides or WCO (as shown in Figures 3 and 4). This method is suitable for oils or fats with high free fatty acid (FFA) content and low-quality ingredients.

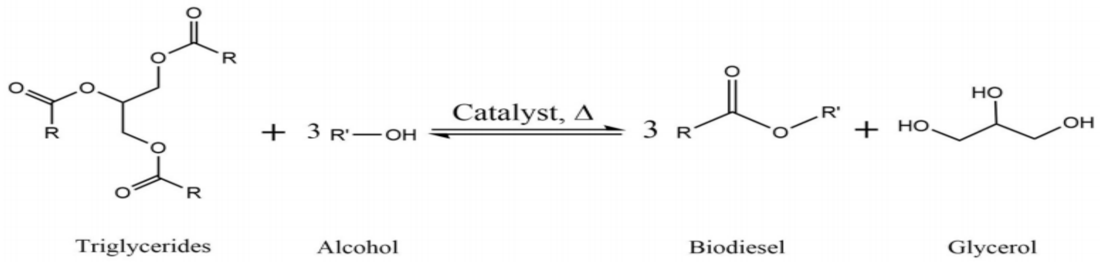

Figure 3. The General Transesterification Reaction of Triglycerides to Biodiesel Uses Homogeneous Catalysts

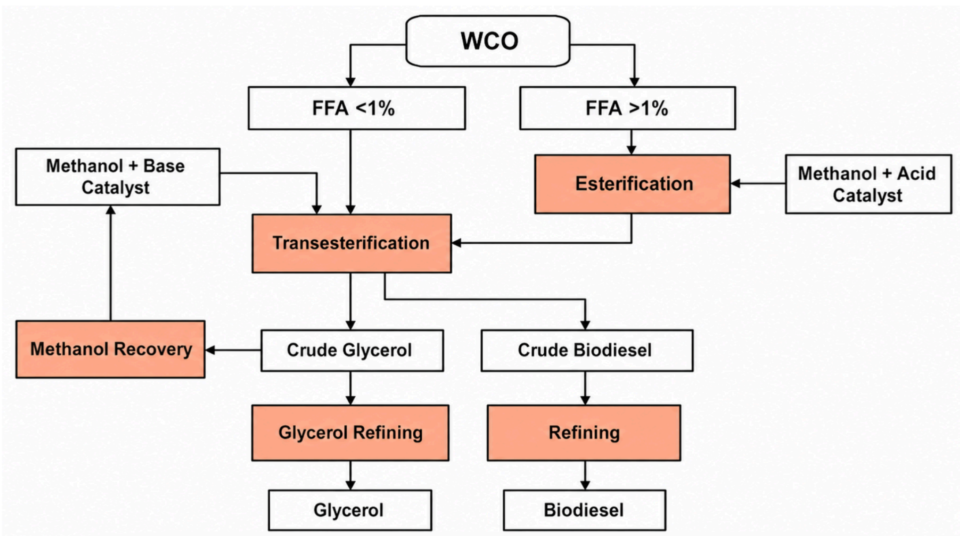

Figure 4. The Transesterification of WCO to Biodiesel (Adapted from Trirahayu *et al.*, 2022)

A titration method was used to quantify FFA in a sample, determining the amounts of sodium hydroxide (NaOH) and methanol that reacted with WCO to form biodiesel. This process requires a catalyst, such as sodium hydroxide or catalyzed egg shells derived calcium oxide (CES, CaO), and methanol, to react with WCO. Using catalysts enhances yield, reduces energy needs, and minimizes equipment and side effects.

Fatty acid methyl esters (FAME), commonly referred to as biodiesel, along with glycerol, are the final products resulting from the decomposition of triglycerides (Akubude et al., 2019). During the reaction process, triglycerides decompose into FAME, which represents biodiesel, while glycerol is formed as a byproduct (Khoobbakht et al., 2020). The percentage volume yield of WCO biodiesel (Table 7).

The transesterification process occurs (Figure 4) in three sequential stages (Basumatary et al. 2023).

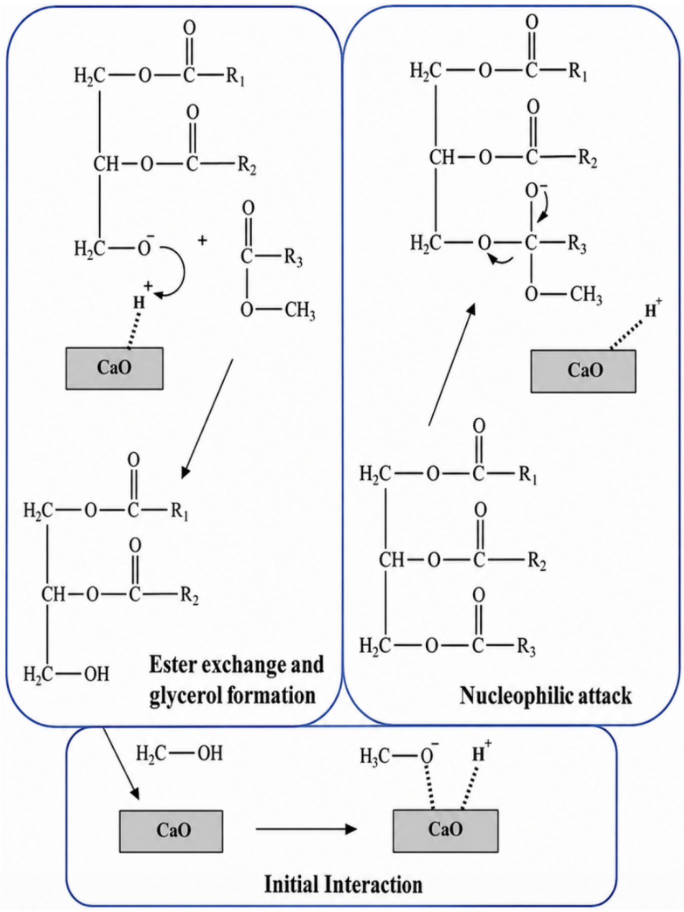

Figure 4. Mechanism for the Synthesis of Biodiesel Using CaO Catalyst

7) Initial interaction

The fundamental surface sites of CaO nanoparticles draw in and hold triglyceride molecules. Elements like surface area and pore architecture affect the quantity of accessible active sites for triglyceride adsorption (Syahmani et al., 2023).

8) Nucleophilic Attack

Methanol adsorbs on CaO, enabling proton abstraction to create the methoxide anion, which then attacks the carbonyl carbon of triglyceride ester linkages. Efficiency relies on temperature, methanol-to-oil ratio, and catalyst loading (Yusuff et al., 2024).

9) Ester exchange and glycerol formation.

Through nucleophilic attack, creating a tetrahedral intermediate. This collapses into diglyceride and FAME, stabilizing the diglyceride anion. The process repeats, attacking all triglyceride carbonyl centers, yielding three moles of FAME and one mole of glycerol (Basumatary et al. 2023).

Table 7. Comparison of Biodiesel Products

Feedstock	Methanol to Oil Ratio (mol)	Catalyst (wt.%)	Reaction Temperature (°C)	Reaction Time (h)	Biodiesel Yield (%)	Methyl Ester (%) SNI 2015	Density (kg/m^3)	Density (kg/m^3) SNI 2015
WCO + NaOH	9:1	3	65	3	94.00	96.50.00	903	850–890
WCO + CES	9:1	3	65	3	95.00		900	
WCO + CES	9:1	3	60	2	96.00		890	

The yield and density of WCO biodiesel are close to the Indonesian National Standard (SNI). The density of biodiesel from WCO with CES (CaO) meets the SNI, but the yield is slightly below it. Students present project outcomes, guided by the lecturer, facilitating group discussions and responses regarding their findings and achievements.

c. How effective is the Ethno-STEM WBL to improve students' HOTSEP and EL?

Ethno-STEM WBL enhances students' creativity, environmental literacy, and conceptual awareness. Based on n-gain, t-test, and Wilcoxon test results (Table 8), the lesson was generally successful. The Kolmogorov-Smirnov test results showed that the pretest and posttest data on students' HOTSEP are normally distributed (Sig., 2-tailed, p-value >0.05), but the data on students' EL are not normally distributed (Sig., 2-tailed, p-value <0.05). The inferential analysis reveals a significant difference between the post-test and pretest scores. Thus, the STEAM-WBBL effectively increased HOTSEP and students' EL (p Sig. < 0.05; with n-gain > 0.70 (high criteria) in the broad trial. The integration of Ethno-STEM WBL will strengthen knowledge construction through students' experiences and Long-Term Memory (LTM), plus project execution that is appropriate to the students' relevant situations. Students who have LTM have scientific literacy competency and HOTSEP that are aligned in a positive direction (Saduglo, 2018). Findings support experts' views on the importance of students' HOTSEP and EL (Ichsan et al., 2021; Sari et al., 2023; Prabawati et al., 2025).

Table 8. The n-Gain, t-Test, and Wilcoxon Test for All Groups

Assessment aspect	Trial	N	Descriptive analysis				Paired t-test		Wilcoxon test		Conclusion
			Pre-test	Post-test	<g>	N-Gain	t	*p*(Sig.)	Z	*p*(Sig.)	
HOTSEP	LT	12	30.90	81.45	0.73	High	-30.256	0.000*	-	-	H_o is rejected
	BT	40	20.23	80.18	0.74	High	-47.353	0.000*	-	-	H_o is rejected
EL	LT	12	55.01	85.92	0,69	Moderate	-	-	-4.370	0.000*	H_o is rejected
	BT	40	55.01	86.90	0,71	High	-	-	-5.512	0.000*	H_o is rejected

1) Students' HOTSEP

Students' HOTSEP performance is presented in Table 9. The results indicate that the implementation of the Ethno-STEM WBL approach substantially improved students' Higher-Order Thinking Skills on Environmental Problems (HOTSEP) across all measured indicators. As shown in Table 9, the aspect of solving environmental problems achieved an N-gain score of 0.74, which falls within the high category. This result demonstrates that students were able to enhance their capacity to analyze environmental issues, evaluate alternative solutions, and formulate evidence-based recommendations after participating in the learning activities.

Although the improvement was categorized as high, the N-gain score for solving environmental problems was slightly lower than that of the criticizing environmental issues aspect. This finding may be attributed to the greater cognitive demands associated with problem-solving tasks, which require students not only to identify and analyze environmental issues but also to evaluate available evidence, justify their arguments, and propose feasible solutions based on scientific reasoning. Such activities involve higher levels of cognitive processing, particularly at the evaluation level (C5), where students must investigate complex environmental situations and support their decisions with relevant evidence and logical explanations (Martawijaya et al., 2023; Garcia, 2015).

The findings suggest that students were generally more proficient in recognizing and critiquing environmental problems than in developing comprehensive solutions to address them. Nevertheless, the high N-gain value indicates that the Ethno-STEM WBL approach effectively facilitated the development of advanced problem-solving competencies by engaging students in authentic environmental projects and collaborative inquiry activities (Ichsan & Rahmayanti, 2020). These experiences encouraged students to apply scientific knowledge in real-world contexts, thereby strengthening their critical thinking, decision-making, and environmental problem-solving skills.

Table 9. Average of Students' HOTSEP

Aspect of HOTSEP	Level of Cognitive	Pre-test	Post-test	N-gain	Category
Criticizing environmental issues	C4	24.00	82.00	0.76	High
Solving environmental problems	C5	28.20	81.20	0.74	High
Developing innovations in the environment	C6	20.50	77.33	0.71	High
Average		**20.23**	**80.18**	**0.74**	**High**

The achievement of cognitive levels C5 (Solving environmental problems) and C6 (Developing innovations in the environment) is lower than that of cognitive level C4 (Criticizing environmental issues) because not all students can correctly decide, assess, and predict problems. This aligns with the findings of Priemer et al. (2020), who suggest that STEM and computing education can help students improve their problem-solving skills. The lowest increase was observed in level C6, with an n-gain of 0.71 in the high category. This finding aligns with the research results obtained by Musfira & Badjeber (2023), which indicate that most students experienced difficulty in learning concepts and solving verbal problems presented in questions (C5) and (C6), specifically evaluating and creating. Some students struggle with drawing conclusions and finding solutions to environmental issues; the teacher assesses both the processes and outcomes. Students experienced an increase in proposing ideas or solutions accompanied by evidence to support their claims about the problem by paying attention to the impacts caused. In line with research highlighting the role of STEM education in enhancing HOTSEP and environmental (Ammar et al., 2024; Ichsan et al., 2021).

2) Students Environmental Literacy

The students' environmental literacy (EL) achievement is presented in Table 10. The results indicate that the implementation of the

Ethno-STEM Web-Based Learning (WBL) approach in green technology significantly improved students' environmental literacy, as evidenced by an N-gain score greater than 0.70, which falls within the high category. This finding suggests that the integration of cultural context, STEM disciplines, and project-based green technology activities effectively enhances students' understanding of environmental issues and fosters responsible environmental behavior (Ichsan et al,. 2021). Through active engagement in biofuel production projects, students were able to connect scientific concepts with real-world environmental challenges, thereby strengthening their ecological awareness and sustainability-oriented decision-making skills.

These findings are consistent with previous studies demonstrating that environmental education programs play a crucial role in improving learners' environmental knowledge, attitudes, and awareness (Schmitz & Rocha, 2018; Suryawati et al., 2020; Liu et al., 2015). The Ethno-STEM WBL approach provides meaningful learning experiences that encourage students to investigate environmental problems, evaluate alternative solutions, and develop environmentally responsible actions. Consequently, the learning process not only promotes cognitive gains but also supports the development of affective and behavioral dimensions of environmental literacy, which are essential for preparing environmentally conscious citizens capable of contributing to sustainable development.

Table 10. Pre-test and Post-test Scores of Students' EL

Aspects of Environmental Literacy (EL)	Item	Pre-test	Post-test	N-gain	Category
Ecological Knowledge	1-15	53.40	90.00	0.79	High
Environmental Affect	16-46	55.00	86.95	0.68	Moderate
Cognitive Skills	47-55	59.65	86.75	0.71	High
Behavior	56-65	52.00	83.90	0.66	Moderate
Average		**55.01**	**86.90**	**0.71**	**High**

Toward aspects of ecological knowledge and cognitive skills in the high category. In line with research by Erhabor & Don (2016), environmental education influences students' environmental attitudes and knowledge. While improvements in environmental effects and student behavior are moderate, influenced by personality and attitudes (Pratiwi et al., 2019). The Ethno-STEM WBL fosters interdisciplinary skills through project activities (Syahmani et al., 2023; Pease et al., 2020). This approach focuses on data-driven exploration to enhance chemistry understanding through project activities, observations, and active teacher engagement in problem-solving.

4. Conclusion

Based on the results of this study, the web GT developed was declared valid and practical. The Ethno-STEM WBL learning approach is also effective in enhancing students' HOTSEP and EL (p Sig. < 0.05) with N-gain values of 0.74 and 0.71, respectively, in the high category. The Ethno-STEM WBL approach represents an innovative learning design that effectively integrates local wisdom, STEM disciplines, digital learning technology, and green technology projects to foster students' HOTSEP and environmental literacy. Beyond improving learning outcomes, the approach promotes advanced learning, sustainability-oriented character development, and progressive educational practices that are relevant to the demands of twenty-first-century education and the Sustainable Development Goals.

The scientist makes some recommendations to improve the quality of related future research. For example, the GT website can be made more interactive, allowing users to engage with it through the Ethno-STEM WBL approach to solve real-world problems and integrate with other learning systems, namely (1). Interactive Ethno-STEM integration includes simulations for local problem-solving (e.g., indigenous organic waste management) and problem-based challenges addressing environmental, energy, or health issues. (2) The WBL approach is reinforced through project modules like designing natural water filters or creating bioplastics from cassava and sago, linking these to local STEM career profiles. (3) Collaboration potential allows integration with LMS platforms like Moodle or Google Classroom for tracking progress. (4) Superior interactive features encompass virtual labs to enhance scientific skills and a four-tier simulation system promoting higher-order thinking and cultural reflection.

5. References

Abdullah, S. H. Y. S., Hanapi, N. H. M., Azid, A., Umar, R., Juahir, H., Khatoon, H., & Endut, A. (2017). A review of biomass-derived heterogeneous catalysts for sustainable biodiesel production. *Renewable and Sustainable Energy Reviews*, *70*, 1040–1051. https://doi.org/10.1016/j.rser.2016.12.008

Ahmad, S., Chaudhary, S., Pathak, V. V., Kothari, R., & Tyagi, V. V. (2020). Optimization of direct transesterification of Chlorella pyrenoidosa catalyzed by waste egg shell-based heterogeneous nano–CaO catalyst. *Renewable Energy*, *160*, 86-97.

Akubude, V.C., Nwaigwe, K.N., Dintwa, E., 2019. Production of biodiesel from microalgae via nanocatalyzed trans-esterification process: A review. *Mater. Sci. Energy Technol.* 2, 216–225.

Almelhi, A. M. (2021). Effectiveness of the ADDIE Model within an E-Learning Environment in Developing Creative Writing in EFL Students. *English Language Teaching*, *14*(2), 20. https://doi.org/10.5539/elt.v14n2p20

Almubarak, A., Prayogi, R., Yasim, S., & Adhani, A. (2025). Canonical Correlation Analysis for Understanding Foundational-Advanced Chemistry Classes Relationship and Their Role in Preparing Preservice Teacher. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 445-460.

Ammar, M., Al-Thani, N. J., & Ahmad, Z. (2024). Role of pedagogical approaches in fostering innovation among K-12 students in STEM education. *Social Sciences & Humanities Open*, *9*, 100839. https://doi.org/10.1016/j.ssaho.2024.100839

Annisa, D., Sutrisno, H., Laksono, E. W., & Yanda, S. N. (2024). Evaluating Students' Academic Resilience in Chemistry Learning: Insights from a Rasch Model Analysis. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 328-349.

Basumatary SF, Brahma S, Hoque M et al (2023) Advances in CaO-based catalysts for sustainable biodiesel synthesis. *Green Energy Resour* 1:100032. https://doi.org/10.1016/j.gerr.2023.100032

Brahma, S., Nath, B., Basumatary, B., Das, B., Saikia, P., Patir, K., & Basumatary, S. (2022). Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. *Chemical Engineering Journal Advances*, *10*, 100284.

Candra, K. P., Kasma, K., Ismail, I., Marwati, M., Murdianto, W., & Yuliani, Y. (2019). Optimization Method for Bioethanol Production from Giant Cassava

(*Manihot esculenta var. Gajah*) Originated from East Kalimantan. *Indonesian Journal of Chemistry*, *19*(1), 176. https://doi.org/10.22146/ijc.31141

Chahine, I. C. (2021). *Evidence-Based Inquiries in Ethno-STEM Research Investigations in Knowledge Systems Across Disciplines and Transcultural Settings* (J. de Beer, Ed.). Information Age Publishing.

Chatwattana, P., & Nilsook, P. (2017). A Web-based Learning System using Project-based Learning and Imagineering. *International Journal of Emerging Technologies in Learning (IJET)*, *12*(5), 4. https://doi.org/10.3991/ijet.v12i05.6344

Chavan, B., Kumbhar, R. R., Madhu, D., Singh, B., & Sharma, Y. C. (2015). Synthesis of biodiesel from Jatropha curcas oil using waste eggshell and study of its fuel properties. *RSC Advance*, *5*, 63596–63604.

Degfie, T. A., Mamo, T. T., & Mekonnen, Y. S. (2019). Optimized biodiesel production from waste cooking oil (WCO) using calcium oxide (CaO) nano-catalyst. *Scientific reports*, *9*(1), 18982.

Elma, M., Suhendra, S.A., Wahyuddin, W., Saputri, W., Utami, S.A.A. (2017). Optimum ratio between waste cooking oil and coconut oil as raw material for biodiesel production. *Int. J. Adv. Sci. Eng. Inf. Technol.* 7, 1227–1233.

Erhabor, N. I., & Don, J. U. (2016). Impact of Environmental Education on the Knowledge and Attitude of Students towards the Environment. *International Journal of Environmental and Science Education*, *11*(12), 5367–5375.

Farisi, M. I. (2016). Developing 21st-century social studies skills through technology integration. *Turkish Online Journal of Distance Education*, *17*(1), 16–30. https://doi.org/10.17718/tojde.47374

Fensham, P. J., & Bellocchi, A. (2013). Higher-order thinking in the chemistry curriculum and its assessment. *Thinking Skills and Creativity*, *10*, 250–264. https://doi.org/10.1016/j.tsc.2013.06.003

Garcia, L. C. (2015). *Biology Education and Research in a Changing Planet* (E. Gnanamalar Sarojini Daniel, Ed.). Springer Singapore. https://doi.org/10.1007/978-981-287-524-2

Germec, M., Turhan, I., Karhan, M., & Demirci, A. (2015). Ethanol production via repeated-batch fermentation from carob pod extract by using Saccharomyces cerevisiae in biofilm reactor. *Fuel*, *161*, 304–311. https://doi.org/10.1016/j.fuel.2015.08.060

Guragain, Y. N., Probst, K. V., & Vadlani, P. V. (2016). Fuel Alcohol Production. In *Encyclopedia of Food Grains* (pp. 235–244). Elsevier. https://doi.org/10.1016/B978-0-12-394437-5.00137-6

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. https://doi.org/10.1119/1.18809

Hendri, M., Rasmi, D. P., & Ananda, W. (2021). Analysis of the needs of developing teaching materials in the form of STEM-based web modules using scaffolding. *Jurnal Penelitian Pendidikan IPA*, *7*, 139–144. https://doi.org/10.29303/jppipa.v7ispecialissue.1019

Ichsan, I. Z., & Rahmayanti, H. (2020). HOTSEP: Revised Anderson's Taxonomy in Environmental Learning of COVID-19. *European Journal of Educational Research*, *9*(3), 1257–1265. https://doi.org/10.12973/eu-jer.9.3.1257

Ichsan, I. Z., Purwanto, A., & Rahmayanti, H. (2021). E-learning in new normal COVID-19 era: Measure HOTS and pro-environmental behavior about environmental pollution. *International Journal of Evaluation and Research in Education (IJERE)*, *10*(3), 790. https://doi.org/10.11591/ijere.v10i3.21382

Ichsan, I. Z., Rahmayanti, H., Purwanto, A., Vivanti Sigit, D., Kurniawan, E., Tanjung, A., Putri Panjaitan, R. G., Pertiwi, N., & Swaran Singh, C. K. (2021). Thinking Level in Education: A Complete Revision of Anderson's Taxonomy. *Pedagogika*, *141*(1), 53–78. https://doi.org/10.15823/p.2021.141.3

Ichsan, I. Z., Sigit, D. V., Miarsyah, M., Ali, A., Arif, W. P., & Prayitno, T. A. (2019). HOTS-AEP: Higher order thinking skills from elementary to master students in environmental learning. *European Journal of Educational Research*, *8*(4), 935–942. https://doi.org/10.12973/eu-jer.8.4.935

Islami, A. A., Rahmayanti, H., Iriani, T., Ichsan, I. Z., Koc, I., & Darussyamsu, R. (2021). Vocational students' HOTS and HOTSEP overview in developing ITA learning model. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *7*(3), 267–274. https://doi.org/10.22219/jpbi.v7i3.16392

Izzah, S. N., Sudarmin, S., Wiyanto, W., & Wardani, S. (2023). Analysis of science concept mastery, creative thinking skills, and environmental attitudes after ethno-STEM learning implementation. *Interna-tional Journal of Instruction*, *16*(3), 777–796. https://doi.org/10.29333/iji.2023.16342a

Jayakumar, M., Karmegam, N., Gundupalli, M. P., Bizuneh Gebeyehu, K., Tessema Asfaw, B., Chang, S. W., Ravindran, B., & Kumar Awasthi, M. (2021). Heterogeneous base catalysts: Synthesis and application for biodiesel production – A review. *Bioresource Technology*, *331*, 125054. https://doi.org/10.1016/j.biortech.2021.125054

Kale, U., & Goh, D. (2014). Teaching style, ICT experience and teachers' attitudes toward teaching with Web 2.0. *Education and Information Technologies*, *19*(1), 41–60. https://doi.org/10.1007/s10639-012-9210-3

Kanvaria, V. K., & Yadav, A. (2024). Integrating and Innovating: The Role of ICT in Education's Evolution -An In-depth Analysis of Emerging Technologies, Current Trends, Challenges, and Future Directions in the Digital Age. *International Journal for Multidimensional Research Perspectives*, *2*(2), 33–48.

Karimzadegan, H., & Meiboudia, H. (2012). Exploration of Environmental Literacy in Science Education Curriculum in Primary Schools in Iran. *Procedia - Social and Behavioral Sciences*, *46*, 404–409. https://doi.org/10.1016/j.sbspro.2012.05.131

Khoobbakht, G., Kheiralipour, K., Rasouli, H., Rafiee, M., Hadipour, M., Karimi, M., 2020. Experimental exergy analysis of transesterification in biodiesel production. *Energy* 196, 117092. https://doi.org/10.1016/j.energy.2020.117092

Laboy-Rush, D. (2011). *Integrated STEM Education through Project-Based Learning*. Http://www.Learning.Com/Imaginemars.

Lee, A. F., & Wilson, K. (2015). Recent developments in heterogeneous catalysis for the sustainable production of biodiesel. *Catalysis Today*, *242*, 3–18. https://doi.org/10.1016/j.cattod.2014.03.072

Lee, S. L., Wong, Y. C., Tan, Y. P., & Yew, S. Y. (2015). Transesterification of palm oil to biodiesel by using waste obtuse horn shell-derived CaO catalyst. *Energy Conversion and Management*, *93*, 282–288. https://doi.org/10.1016/j.enconman.2014.12.067

Lenger, M. T., Laroche, A. M., & Pruneau, D. (2020). Using design thinking to solve a local environmental problem in the context of a university civil engineering course - an intrinsic case study. *Global Journal of Engineering Education*, *22*(1), 6–12.

Liu, S.-Y., Yeh, S.-C., Liang, S.-W., Fang, W.-T., & Tsai, H.-M. (2015). A national investigation of teachers' environmental literacy as a reference for promoting environmental education in Taiwan. *The Journal of Environmental Education*, *46*(2), 114–132. https://doi.org/10.1080/00958964.2014.999742

Mahat, M., Plenty, L., Hawkes, J., Golding, J., Mackerras, A., & Wallace-Richards, L. (2024). The Impact of Teacher Collaborative Pedagogies on Student Learning. In *Teachers as Researchers in Innovative Learning Environments: Case Studies from Australia and New Zealand Schools* (pp. 107-122). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-7367-5_8

Martawijaya, M. A., Rahmadhanningsih, S., Swandi, A., Hasyim, M., & Sujiono, E. H. (2023). The Effect of Applying the Ethno-STEM-Project-based Learning Model on Students' Higher-Order Thinking Skills and Misconception of Physics Topics Related to Lake Tempe, Indonesia. *Jurnal Pendidikan IPA Indonesia*, *12*(1),1–13. https://doi.org/10.15294/jpii.v12i1.38703

McBeth, B., Hungerford, H., Marcinkowski, T., Volk, T., Cifranick, K., Howell, J., & Meyers, R. (2011). *National environmental literacy assessment, phase two (Final research report)*.

Muhaji, M., & Sutjahjo, D. H. (2018). The characteristics of bioethanol fuel made of vegetable raw materials. *IOP Conference Series: Materials Science and Engineering*, *296*, 012019. https://doi.org/10.1088/1757-899X/296/1/012019

Musfira, M., & Badjeber, R. (2023). Kesulitan peserta didik dalam menyelesaikan soal higher order thinking skill (HOTS) ditinjau dari kemampuan komunikasi matematis. *Jurnal Absis*, *6*(1), 726-740. https://doi.org/10.30606/absis.v6i1.1907

Neumann, K., Werth, K., Martín, A., & Górak, A. (2016). Biodiesel production from waste cooking oils through esterification: Catalyst screening, chemical equilibrium, and reaction kinetics. *Chemical Engineering Research and Design*, *107*, 52–62. https://doi.org/10.1016/j.cherd.2015.11.008

Pease, R., Vuke, M., Maker, C., & Muammar, O. (2020). A practical guide for implementing the STEM assessment results in classrooms: using strength-based reports and real engagement in active problem solving. *Journal of Advanced Academics*, 367-406

Prabawati, M. A., Yamtinah, S., & Bramastia, B. (2025). Validity of the Development of PjBL-Based Science Teaching Modules Containing Ethno-STEAM to Empower Creative Thinking Skills on Ecology and Biodiversity Materials in Indonesia. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 736-744.

Pratiwi, R. D., Rusdi, R., & Komala, R. (2019). The effects of personality and intention to act toward responsible environmental behavior. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *5*(1), 169–176. https://doi.org/10.22219/jpbi.v5i1.7120

Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Zu Belzen, A. U. (2020). A framework to foster problem-solving in STEM and computing education. *Research in Science and Technological Education*, *38*(1), 105–130. https://doi.org/10.1080/02635143.2019.1600490

Primarini, H. E., Rahmayanti, H., Widiasanti, I., Ichsan, I. Z., Koc, I., Rogayan Jr., D. V., Darussyamsu, R., Titin, T., Marhento, G., Nurfadhilah, N., & Sa'diyah, R. (2021). HOTSEP analysis to develop a disaster research integrated book for vocational education (Drica) in the 21st Century. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, *6*(2), 243–252. https://doi.org/10.24042/tadris.v6i2.8710

Purwaningsih, E., Sari, S. P., Sari, A. M., & Suryadi, A. (2020). The Effect of STEM-PjBL and Discovery Learning on Improving Students' Problem-Solving Skills of Impulse and Momentum. *Jurnal Pendidikan IPA Indonesia*, *9*(4), 465–476. https://doi.org/10.15294/jpii.v9i4.26432

Putri, M. D. S., Muhdhar, M. H. I. Al, Mardiyanti, L., Suradi, S., Idayati, I., & Utami, S. (2023). Relationship between problem-solving skills and environmental literacy of students. *AIP Conf. Proc. 2569*, 020005. https://doi.org/10.1063/5.0112734

Qori, P. H., Sudarmin, S., Sumarni, W., Subali, B., & Saptono, S. (2020). Implementation of STEM Integrated Ethnoscience-based Vocational Science Learning in Fostering Students' Higher Order Thinking Skills (HOTS). *International Journal of Active Learning*, *5*(2), 53–61.

Reyero, I., Arzamendi, G., Zabala, S., & Gandía, L. M. (2015). Kinetics of the NaOH-catalyzed transesterification of sunflower oil with ethanol to produce biodiesel. *Fuel Processing Technology*, *129*, 147–155. https://doi.org/10.1016/j.fuproc.2014.09.008

Sadoglu, G.P.(2018). Engineering Students' Opinions on Science Literacy.*Universal Journal of Educational Research* 6(8): 1819-1830. DOI:10.13189/ujer.2018.060827

Saputro, E. A., Rizaldi, A., Simamora, T., Erli-yanti, N. K., & Yogaswara, R. (2022). A biodiesel production technology from used cooking oil: A review. *IPTEK The Journal for Technology and Science*, *33*(1), 59. https://doi.org/10.12962/j20882033.v33i1.11729

Sari, P., Purnomo, T., & Hariyono, E. (2023). Research trend of environmental education in science based on the Scopus database. *IJORER: International Journal of Recent Educational Research*, *4*(3), 296–308. https://doi.org/10.46245/ijorer.v4i3.296

Schmitz, G. L., & Rocha, J. B. T. (2018). Environmental education programs as a tool to improve children's environmental attitudes and knowledge. *Education*, *8*(2), 15–20.

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2016). STEM Learning through Engineering Design: Impact on Middle Secondary Students' Interest towards STEM. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(5). https://doi.org/10.12973/eurasia.2017.00667a

Sudarmin S., Handayani L., Sarwi S., Hardianti R. D., Eralita N., Sumarni W., & Hutagalung F. D. (2024). Development of Innovative Ethno-Vlog Media Based on Ethno-STEM to Equip Students' Creativity and Realize UNNES Conservation Vision. *Journal of Innovation in Educational and Cultural Research*, *5*(3), 529–539.

Sudarmin, Pujiastuti, S. E., Asyhar, R., Prasetya, A. T., Diliarosta, S., & Ariyatun. (2023). Chemistry Project-Based Learning for Secondary Metabolite Course With Ethno-STEM Approach to Improve Students' Conservation and Entrepreneurial Character in The 21st Century. *Journal of Technology and Science Education*, *13*(1), 393–409 https://doi.org/10.3926/jotse.1792

Sudarmin, S., Prasetya, A. T., Kusuma, A. H., Setiawan, B., Pujiastuti, Rr. S. E., Zain, H. H. B. M., & Winarto, W. (2024). How to increase students' global diversity character: Study of the influence of Ethno-STEM-Integrated Project Learning Model on Indonesian tea aroma volatile compounds. *Pakistan Journal of Life and Social Sciences (PJLSS)*, *22*(1), 4707–4722. https://doi.org/10.57239/PJLSS-2024-22.1.00347

Sumarni W, Kadarwati S. Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *J Pendidikan IPA Indonesia.* 2020;*9*(1):11–21.

Suryawati, E., Suzanti, F., Zulfarina, Z., Putriana, A. R., & Febrianti, L. (2020). The implementation of local environmental problem-based learning student worksheets to strengthen environmental literacy. *Jurnal Pendidikan IPA Indonesia*, *9*(2), 169–178. https://doi.org/10.15294/jpii.v9i2.22892

Syafii, S., Anugrah, P., Laksono, H. D., & Yamashika, H. (2021). Economic Feasibility Study on PV/Wind Hybrid Microgrids for Indonesian Remote Island Application. *TEM Journal*, *10*(4), 2001–2006. Doi: 10.18421/TEM104-66

Syahmani, S., Hafizah, E., Sauqina, S., bin Adnan, M., & Ibrahim, M. H. (2021). STEAM approach to improve environmental education innovation and literacy in waste management: Bibliometric research. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 130-141.

Syahmani, Leny, Prasetyo, YD., Warohmah, A., Raidimas, MN., Sopranti, N. & Mustarianti, L. (2023). Exploration and design of Ethno-STEM as a learning source in Phyto-chemistry to improve metacognitive skills and students' higher-order thinking skills of environmental problems, *Journal of Wetlands Environmental Management*, ***11***(2), 108-127.

Syahmani, S., Iriani, R., Kusasi, M., Prasetyo, Y. D., Norhasanah, H., & Rahman, N. F. A. (2024). Culturally Wetland Responsive Teaching to Improve Science Literacy and Wasaka Character. *Journal of Innovation in Educational and Cultural Research*, *5*(2), 196–206. https://doi.org/10.46843/jiecr.v5i2.1075

Syahmani, S., Suyono, S., & Imam, Z. I. (2017). Validity of i-SMART learning model: an innovative learning to improve students' metacognitive skills and understanding of chemistry. *Proc. ICLIQE*, 283–296.

Syukri, M., Halim, L., Mohtar, L. E., & Soewarno, S. (2018). The Impact of the Engineering Design Process in Teaching and Learning to Enhance Students' Science Problem-Solving Skills. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 66–75. https://doi.org/10.15294/jpii.v7i1.12297

Trirahayu, D.A., Abidin, A.Z., Putra, R.P., Hidayat, A.S., Safitri, E., Perdana, M.I., 2022. Process Simulation and Design Considerations for Biodiesel Production from Rubber Seed Oil. *Fuels* 3, 563–579. https://doi.org/10.3390/fuels3040034

Tytler, R. (2012). Socio-Scientific Issues, Sustainability, and Science Education. *Research in Science Education*, *42*(1), 155–163. https://doi.org/10.1007/s11165-011-9262-1

Ullah, Z., Bustam, M. A., Ullah, M., Khan, A. S., Shah, S. N., Shah, M. U. H., ... & Khan, K. A. (2024). Unveiling biodiesel production: exploring reaction protocols, catalysts, and influential factors. *ChemBioEng Reviews*, *11*(6), e202400028. https://doi.org/10.1002/cben.202400028

Yang, X.-X., Wang, Y.-T., Yang, Y.-T., Feng, E.-Z., Luo, J., Zhang, F., Yang, W.-J., Bao, G.-R., 2018. Catalytic transesterification to biodiesel at room temperature over several solid bases. *Energy Convers. Manag.* 164, 112–121. https://doi.org/10.1016/j.enconman.2018.02.085

Yunita, A., Suyidno, S., & Syahmani, S. (2021). The validity of the science e-module based on the authentic problem. *Journal of Physics: Conference Series*, *1760*(1), 1–6. https://doi.org/10.1088/1742-6596/1760/1/012037

Yusuff AS, Thompson-Yusuff KA, Igbafe AI (2024). Synthesis of biodiesel via methanolysis of waste frying oil by biowaste-derived catalyst: process optimization and biodiesel blends characterization. *Biomass Convers Biorefinery* 14:1781–1792. https://doi.org/10.1007/s13399-022-02389-1

Zabed, H., Faruq, G., Sahu, J. N., Azirun, M. S., Hashim, R., & Nasrulhaq Boyce, A. (2014). Bioethanol Production from Fermentable Sugar Juice. *The Scientific World Journal*, *2014*(1), 1–11. https://doi.org/10.1155/2014/957102

Zakhartsev, M., Yang, X., Reuss, M., & Pörtner, H. O. (2015). Metabolic efficiency in yeast Saccharomyces cerevisiae in relation to temperature-dependent growth and biomass yield. *Journal of Thermal Biology*, *52*, 117–129. https://doi.org/10.1016/j.jtherbio.2015.05.008

Živković, S. B., Veljković, M. V., Banković-Ilić, I. B., Krstić, I. M., Konstantinović, S. S., Ilić, S. B., Avramović, J. M., Stamenković, O. S., & Veljković, V. B. (2017). Technological, technical, economic, environmental, social, human health risk, toxicological, and policy considerations of biodiesel production and use. *Renewable and Sustainable Energy Reviews*, *79*, 222–247. https://doi.org/10.1016/j.rser.2017.05.048