

PROJECT-BASED LEARNING-STEAM INTEGRATED WEB ENHANCES HOTSEP AND ENVIRONMENTAL LITERACY IN ORGANIC AND PLASTIC WASTE

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Abstract. Students need higher-order thinking skills, environmental problems (HOTSEP), and environmental literacy to overcome ecological problems. Alternative solutions using the Project-Based Learning-Science, Technology, Engineering, Art, and Mathematics Learning (PjBL-STEAM) integrated web can enrich students' HOTSEP in the context of wetlands and innovation to overcome environmental problems in daily life and society. The research aims to evaluate the effectiveness of the PjBL-STEAM integrated web approach in improving students' HOTSEP and environmental literacy regarding organic and plastic waste. The research design used is an experimental method with a one-group pretest-post-test design. This study was conducted on 40 chemistry education students at FKIP, Lambung Mangkurat University, Banjarmasin. The data collection technique used a HOTSEP instrument and an environmental literacy questionnaire. Data analysis techniques were used, descriptive analysis with N-gain. The research results show that the PjBL-STEAM integrated web approach can increase students' HOTSEP and environmental literacy competency with an overall gain score > 0.70 in the high category. Student attitudes and behavior show positive actions towards the environment. This research recommends that educational practitioners use the PjBL-STEAM integrated web to develop students' HOTSEP and environmental literacy competencies for education for sustainable environmental development (EESD).

Keywords: environmental literacy, HOTSEP, organic and plastic waste, PjBL-STEAM integrated web

INTRODUCTION

Students' low literacy and environmental awareness need to be addressed through the integration of STEAM and web technology in chemistry 4.0 learning towards Society 5.0 in the field of education, which must follow technological developments. Lecturers need to create meaningful learning media and experiences for students that involve Higher Order Thinking Skills Environmental Problems (HOTSEP) and environmental literacy. STEAM learning is a good way for people to understand and apply environmental literacy, which focuses on solving problems in real, everyday life. Environmental literacy (EL) is related to understanding the importance of awareness, knowledge, and attitude as components of EL (Dada, 2017; Tuncer Teksoz et al., 2014).

The web-based STEAM approach developed in this research refers to the theoretical framework from Kartika et al. (2021). Web-based science learning media are relevant and synergistic with the STEAM approach (Murder et al., 2023). The STEAM approach is effective in fostering critical, creative, inventive, and collaborative thinking skills, as well as meeting the demands of the twenty-first century (Guyotte et al., 2015; National STEM Education Center, 2014; Zakiyah &

Published by: Program Studi Pendidikan Kimia FKIP Universitas Lambung Mangkurat
How to Cite: Syahmani, S., Iriani, R., Leny, L., Prasetyo, Y. D., Raidimas, M. N. (2026). Project-Based Learning-STEAM Integrated Web Enhances HOTSEP and Environmental Literacy in Organic and Plastic Waste. *QUANTUM: Jurnal Inovasi Pendidikan Sains*, 17(1), 41-53. <http://dx.doi.org/10.20527/quantum.v17i1.21132>.

Article History:

Received : 12-05-2025, Accepted : 17-03-2026, Published : 30-04-2026

Sudarmin, 2022); developing environmental literacy (Ozsoy et al., 2012; Saltan & Divarci, 2017); and improving learning outcomes and creativity and problem-solving (critical thinking) skills in real life (Chistyakov et al., 2023; Keane & Keane, 2016; Allina, 2017; Kant, Burkhard, & Meyers, 2018).

STEAM learning incorporates engineering design process stages (Shahali, 2016) and project- and web-based learning (Rahmah & Musadad, 2024; Chatwattana & Nilsook, 2017; Laboy-Rush, 2011). The web can make project-based learning features more effective by strengthening interactivity and smoother communication and facilitating learning based on real problems and situations (Basilotta Gómez-Pablos et al., 2017; Habib et al., 2020). Additionally, online learning resources have the potential to enhance students' learning outcomes (Orooji & Taghiyareh, 2015).

The focus of research is the study of the PjBL-STEAM approach integrated with the web, which would be appropriate for increasing students' HOTSEP and environmental literacy by utilizing organic and plastic concepts in the wetland context. Subsequently, local wisdom is able to reinforce the nature of precious learning as well as drive all of the students to become thoughtful in solving any problems in their daily lives. Thus, local knowledge (local wisdom) is useful while teaching chemistry.

Increasing human activities produce waste (organic and plastic), which causes serious problems for the environment. An alternative strategy for reducing organic waste and plastic is by making environmentally friendly bioproducts, such as organic fertilizer (compost) and bioplastics. Biodegradable plastics can contribute to a more sustainable society through the use of renewable resources and contribute to the reduction in CO₂ emissions during production. Furthermore, biodegradable plastics offer new end-of-life management options, such as anaerobic digestion or composting (Narancic et al., 2018), that have lower or no negative impacts on the environment. Research on the synthesis of biodegradable polymers has been conducted (Cerrone et al., 2015; Narancic & O'Connor, 2019) and the conversion of non-degradable polymers to biodegradable polymers (Guzik et al., 2014; Tiso et al., 2020).

Cellulose is a material that is available in nature most abundantly and cheaply. This ingredient is traditionally extracted from plants or their waste. Cellulose is a biopolymer that can be obtained from agricultural products. Agricultural polymers have thermoplastic properties and thus have the potential to be formed or molded into bioplastics. Superiority: This type of polymer is available throughout the years (renewable) and easily destroyed naturally (biodegradable). Cellulose as a raw material for bioplastics has great potential because Indonesia has a lot of biocellulose raw materials, including pineapple, coconut, straw, and grass. Rice straw is an alternative source of cellulose as a biodegradable material (Esa et al., 2014).

Environmental literacy has been studied at multiple ages, including K-12 students (McBeth et al., 2008; Ozsoy et al., 2012; Saltan & Divarci, 2017) and university students (Lloyd-Strovas et al., 2018). EL divided the domain of environmental literacy (EL) into four components: knowledge, skill, affective, and action/behavior (Karimzadegan & Meiboudi, 2012; McBeth & Volk, 2010). This research aims to evaluate the effectiveness of the PjBL-STEAM integrated web approach in a wetland context with the topic "Creating bio-products for solutions for handling organic and plastic waste" to increase students' HOTSEP and environmental literacy.

METHOD

Research design

The research design used is an experimental method with a one-group pretest-post-test design (Ng & Adnan, 2018).

Table 1. One Group Pretest-Post-Test Design

O ₁	X	O ₂
Pretest	Treatment	Post-test

The forty students attended six online PjBL-STEAM sessions with a web link: <https://www.teknologihibau.my.id/proyek-green-chemistry/bioplastik>, exploring green technology and environmental issues via a dedicated website featuring discussions, activities, and evaluations.

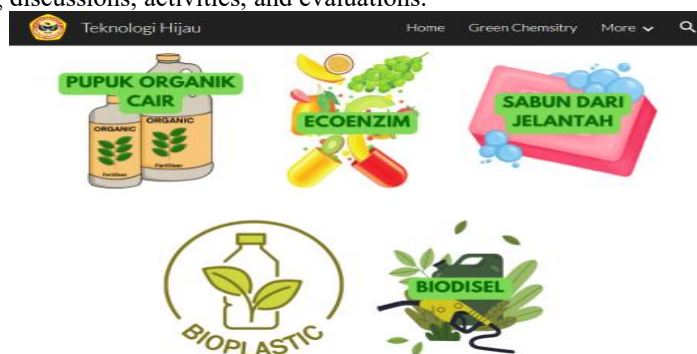


Figure 1. Display web green technology

Sample and Data Collection

Research data were obtained from 40 students of the chemistry education study program. Before the lecture, students finished a HOTSEP pretest and an environmental literacy questionnaire. During the next six meetings, they learned how to apply the PjBL-STEAM in a limited trial. Following that, the pupils retok the post-test of the environmental literacy questionnaire. PjBL-STEAM classrooms integrate web assessment to evaluate authentic content's impact on developing solutions to real-world problems. Continuous progress assessment occurs through a 65-item environmental literacy questionnaire, reflecting knowledge, cognitive skills, affective domain, and behavior, based on the National Environmental Literacy Assessment (McBeth et al., 2011; McBeth & Volk, 2010; Erdogan & Ok, 2011).

Procedures

Implementation of PjBL-STEAM integrated web in the classroom has unique value: (a) the integration of math, science, and technological content through hands-on activities in a holistic systems approach; (b) the application of STEAM principles to real-world problems by first providing a framework for problem solving and scientific inquiry, rather than just charging into math equations; and (c) the breadth and capacity of technology and engineering to solve problems that have social relevance, for example, environmental themes like organic and plastic waste. The activities of the PjBL-STEAM integrated web are effective in the classroom, as shown in Table 2.

Table 2. The Activities of the PjBL-STEAM integrated web

The PjBL-STEAM Syntax (Shahali et al., 2016; Rahmah & Musadad, 2024; Chatwattana & Nilsook, 2017)	HOTSEP indicators (Syahmani et al., 2023)	Environmental literacy indicators (Liu et al., 2015; McBeth et al., 2011)
Ask (Reflection). Students recognize the project theme. Identify problems (S, T), for example, organic and plastic waste	Criticizing environmental	Feelings about the environment. Identification and issue analysis
Imagine (Discovery). Information gathering for the project (S, T)	Solving environmental problems	Ecological knowledge, Environmental sensitivity
Plan (Research). Students discuss tools and materials for utilizing bioplastics to reduce environmental pollution		
Create (Application). Students design bioplastics and tools. creating prototypes for the application and testing (S, T, E, A, M)		
Improve (Communication). Groups present their work; the instructor provides feedback/evaluation, while students assess. and evaluate peers' efforts. (S, T)	Developing innovations about the environment	Action plan Verbal commitment Actual commitment Pro-environmental behavior

Note: Science (S), Technology (T), Engineering (E), and Mathematics (M)

Research Instrument

The PjBL-STEAM integrated web instrument used has a validity level of 0.90 and a Cronbach's alpha reliability value of 0.86. Most studies show the reliability of the instrument in the high category, because the alpha coefficient is 0.70 or more (Fraenkel et al., 2023; Syahmani et al., 2017; Taber, 2018).

Analyzing Data

The effectiveness analysis technique uses the N-Gain test; this study's analysis technique measures the average increase in students' HOTSEP and environmental literacy. The formula used by Hake (1998) is the basis for the scientific literacy improvement acquisition scores and categories: $(g) > 0.7$ (high), $0.3 < (g) < 0.7$ (medium), and $(g) < 0.3$ (low).

RESULTS AND DISCUSSION

We have developed a PjBL-STEAM integrated web with the aim of (1) training practical skills in making organic fertilizer and bioplastics. (2) consciously reuse organic waste products to minimize environmental pollution. (3) increase understanding of knowledge, HOTSEP, and students' environmental literacy. The STEAM experiential learning activities are planned and organized according to flexible principles and processes. Our emphasis on green technology goods is to use PjBL-STEAM-integrated web activities to teach students practical skills in bioplastics and organic fertilizers.

The PjBL-STEAM framework involves five steps, such as reflection, research, discovery, application, and communication, that foster active student engagement and develop skills, HOTSEP, deep understanding of concepts, and students' environmental literacy (Figure 2). In chemistry, it enhances comprehension of STEAM, applying a hands-on methodology to real-world problem-solving.

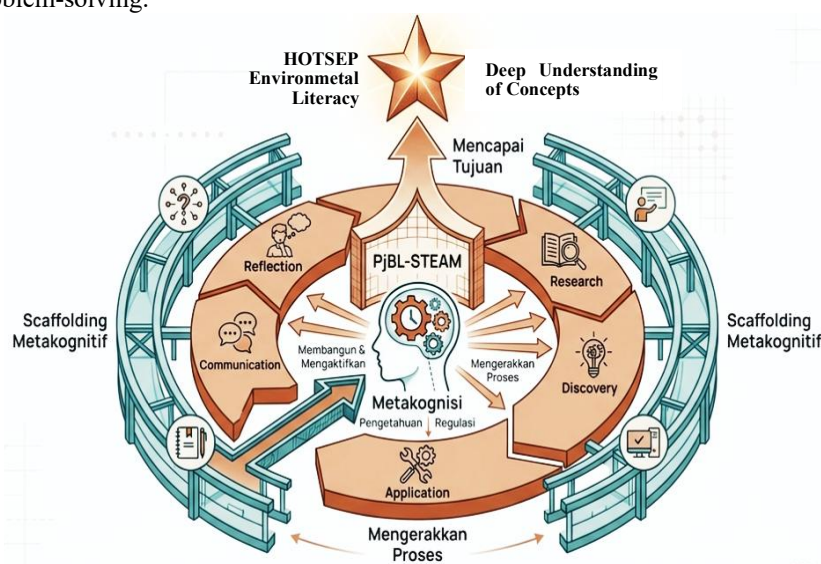


Figure 2. Illustration of PjBL-STEAM

Kim (2017) suggested integrating cognitive, metacognitive, motivational, and strategic scaffolds into fixed and adaptive frameworks to foster student learning. Cognitive scaffolds emphasize task essentials, while strategic ones offer completion strategies. Metacognitive scaffolds promote reflection, motivational scaffolds enhance interest, and social scaffolds facilitate collaboration. These scaffolds should operate as a cohesive system to meet learning goals (Ustunel & Tokel, 2018). PjBL-STEAM with metacognitive scaffolding draws on Vygotsky's concept to provide temporary support, helping learners manage awareness and regulate their thought processes during learning and problem-solving (Kamelia & Pujiastuti, 2020). Scaffolding aids problem presentation, guiding students to solutions on bioplastics and composting.

Problem: Organic waste and plastic cause environmental pollution, so we need alternative, environmentally friendly bioproduct makers. a) How can we make bioplastics from wetland biomass? b) How do you process organic waste into organic fertilizer (compost)?

Six meetings were held to conduct this study. Before the first meeting lecture, students were asked to complete a pretest. Following that, students learned using the PjBL-STEAM integrated web approach for six weeks. As post-test data, they retok the test at the most recent meeting. Students were introduced to the application of the PjBL-STEAM integrated web approach. Flexible processes and principles are used to plan and organize STEAM experience-based learning activities. The lecturer introduced bioplastics technology. To address the issue of plastic waste, the teacher sets a challenge for the students to create bioplastic from starch. Students are encouraged to use their imaginations when they look for

appropriate materials to make bioplastic. Sample answers from the students: (1) Bioplastics can be made from a wide range of different materials. It can be prepared with potato or sago starch. Students look up methods for making bioplastics from a variety of materials. The class is given presentations by the students. In the group, the students will (1) arrange the materials and tools, (2) begin making the bioplastics based on the recommended design, and (3) record the entire bioplastic-making process. Throughout the project, the students are constantly being observed. Students talk to their lecturer about any problems they may have had while making the bioplastics. Below, we will present Table 3 regarding STEAM analysis related to bioproducts such as bioplastics and organic fertilizer.

Table 3. The PjBL-STEAM Analysis of Bioproducts

Characteristics	Making bioplastics	Composting
Integrated content:		
Art	Using tapioca/sago flour as a bioplastic material	Swamp plants as raw materials for making compost,
Science	Utilize bioplastics to reduce environmental impact and pollution.	Waste classification; role of microorganisms in waste treatment; effects of compost.
Technology	Investigate bioplastic literature via the internet and bioplastic technology.	Composting and microbiology/effective microorganisms (EM4) technology.
Engineering	Create and produce bioplastic. <i>Reduce, reuse, and recycle</i> plastic waste;	Process of making organic fertilizer Design and create a simple composter tool
Mathematics	Calculate the material ratio needed to create the bioplastic.	Utilization, incubation, and mixing rate calculations.
Main activities:		
Reflection	How to minimize environmental pollution due to the use of plastic?	How to process organic waste into environmentally friendly fertilizer products.
Discovery	Information about the raw materials and the making of bioplastics.	Students collaborate to explore information about raw materials and how to make organic fertilizer/compost.
Research	Students develop and design the production of bioplastics.	Students develop and design the production of compost/organic fertilizer
Application	Students work in groups to make bioplastic.	Students tested the effectiveness of organic fertilizer on the growth of onion plants.
Communication	Instructors assess student knowledge and HOTSEP.	Instructors assess student knowledge and HOTSEP.

Production of Bioplastics. Necessary tools: stove, silicone mat, spatula, pot. Ingredients: 1 tbsp each of tapioka, water, vinegar, and glycerin. 1) Put all the ingredients in a saucepan, cover, and lower the heat. Stir until well combined at 70°C. 2) Continuously stir the liquid with a spatula. The mixture will eventually thicken and turn clear, and bubbles will begin to appear. 3) Remove from the heat before pouring. Pour the mixture onto a large plastic lid or silicone mat. The thickness of the spread will be about ¼ to ½ centimeters. 4) Allow the mixture to dry out through dehydration. Figure 3 shows the production procedure of bioplastics, and Figure 4 displays bioplastic products from the wetland plant.

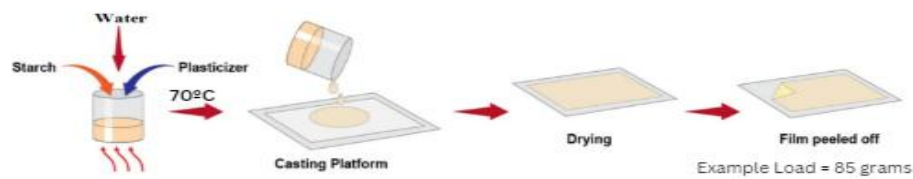


Figure 3. Procedure for the production of bioplastics (Surendren et al., 2022)



Figure 4. Bioplastic products from (a) sago and (b) tapioca.

Amylopectin and amylose in natural starch molecules, when exposed to temperature, will undergo gelatinization and produce bioplastic (Abe et al., 2021). Following the bioplastic load test, the sample object's weight (load = 85 grams) could be supported. The current study has examined the rate at which bioplastics decompose in a 28-30°C drying oven and static incubation for 30 days. The degradation of bioplastics was 55%. In line with research findings, Bandini et al. (2020) confirmed that starch-based bioplastics degraded to a greater extent when co-digested with anaerobic sludge food waste at 35 °C and 23 days of static incubation; the biodegradation of bioplastics was 85%. One advantage of bioplastics is that they emit less CO₂. More affordable, flexible, and producing less toxic waste than plastics, bioplastics are derived from renewable resources.

In this context, creating bio-sourced and biodegradable plastics from local resources involves various bioplastic productions from starch (Chaisu 2016). Cassava starch was modified using vinegar, glycerol, and distilled water to create bioplastic sheets (Mojibayo et al. 2020). Coconut husk fibers were also used to reinforce bioplastics made from cassava starch (Babalola and Olorunnisola 2019). Using glycerin and corn starch, condensation polymerization was used to create bioplastics and create nanocomposites for packaging (Ateş and Kuz 2020). Tapioca, wheat, and potatoes are additional sources of starch. Tapioca starch was used to create the strongest, smoothest, most flexible bioplastic (Gökçe 2018).

Starch is a cheap, renewable, and widely available biopolymer that is used extensively in the food industry for packaging. Polysaccharides (starch) can be compatibly used with two plasticizers: sorbitol and glycerol (Ginting et al., 2015, 2017; Khan et al., 2017; Maulida et al., 2016). The reason plasticizers work is that they can shorten the intermolecular hydrogen bonds between polymer molecules.

The plasticizer effect causes the polymeric matrix's microstitial volume to rise, which increases the flexibility of bioplastics. Plasticizer loading was found to range from 1.5 weight percent to 45 weight percent to obtain the best mechanical properties. After the glycerol plasticizer reached an optimal loading of 37.5%, Isroi et al. (2017) noticed a similar trend in the increase in tensile strength of the starch-cellulose bioplastic film. Disposable tableware, compostable bags, and food packaging are just a few examples of everyday household items that already contain various bioplastics.

Production of Organic Fertilizer. Types of potential organic fertilizer from swamp plant biomass: (a) Water hyacinth (*Eichhornia crassipes*) contains 2.90% N, 0.52% P, and 0.98% K (Yuliatin et al., 2018; Hasibuan et al., 2023). The process of

making organic fertilizer can be done anaerobically. Stages of making compost (1) Chopping water hyacinth, (2) Adding rice husks, (3) Adding EM4 solution, (4) Putting a mixture of EM4 and organic water hyacinth fertilizer into a closed container to ferment for 14 days, (5) Stirring and daily gas discharge. After 14 days, the compost/organic fertilizer is ready. Compost has many variants, such as bokashi fertilizer, liquid organic fertilizer, and tablet organic fertilizer. Figure 5 shows the process of making organic fertilizer.



Figure 5. Making organic fertilizer (compost) (Source: Author Documentation)

Table 4 shows that each aspect of HOTSEP experienced an increase in the average score from pre-test to post-test with an n-gain value of 0.74 in the high category. The highest N-gain was obtained in the aspect of analyzing environmental problems (C4). Based on the data presented, it also shows that students are able to analyze environmental problems related to previous knowledge and new information, provide hypotheses and explanations, and conclude the results of the analysis of the problems given regarding organic and plastic waste. Higher levels of HOTS have been shown to play an important role in increasing capabilities in dealing with environmental problems (Primarini et al., 2021).

Table 4. Average of students' HOTSEP

Aspect of HOTSEP	Pre-test	Post-test	N-gain	Category
Criticizing environmental/ethnoscience issues	24.00	82.00	0.76	High
Solving environmental problems	28.20	81.20	0.74	High
Developing innovations about the environment	20.50	77.33	0.71	High
Average	20.23	80.18	0.74	High

In the aspect of solving environmental problems (C5), with an n-gain value of 0.74 in the high category. N-gain in the aspect of solving environmental problems (C5) is the lowest compared to the two aspects because students' ability has not significantly increased in evaluating problems related to organic fertilizers and bioplastics and providing solutions in the form of relevant assumptions, evidence, and reasons related to them. The problem was presented. The achievement of cognitive level C5 (evaluating) is lower than the achievement of cognitive level C4 (analyzing) because not all students can decide problems, assess problems, support

or reject, and predict problems correctly. The C5 level of thinking is to assess an opinion, solution, or problem and determine its benefits. Some students still find it difficult to conclude and even provide solutions to solve environmental problems related to organic waste and plastics.

Then, in the aspect of developing environmental innovation (C6), with an n-gain of 0.71 in the high category. Based on the data presented, it shows that in the aspect of developing innovation regarding the environment (C6), students experienced an increase in proposing an idea or solution accompanied by evidence for the claim of the problem by paying attention to the impacts caused. In line with research by Nurhayati (2024), which states that the results of students solving HOTS questions show that students are able to plan and carry out problem-solving plans correctly, understand the meaning of the question correctly, and provide the right reasons/evidence so that the answer written will answer the question.

The PjBL-STEAM approach to organic fertilizer and bioplastic technology has an impact on increasing students' environmental literacy (EL) regarding aspects of ecological knowledge and environmental influence with an n-gain of 0.71 in the high category shown on Table 5.

Table 5. Pre-test and post-test scores of students' environmental literacy

Component of SEL	Specific Variables MSELS	Item	Pre-test	Post-test	N-Gain	Category
Ecological	Ecological Knowledge	1-15	53.40	90.00	0.79	High
Environmental Affect	General environmental feelings	16-46	55.00	86.95	0.68	Moderate
Cognitive	Environmental Sensitivity					
	Issue Identification	47-55	59.65	86.75	0.71	High
	Issue analysis					
	Action Planning					
Behavior	Actual Commitment	56-65	52.00	83.90	0.66	Moderate
	Pro-environmental Behavior					
Total		65	55.01	86.90	0.71	High

Research findings in line with Erhabor & Don (2016) and Schmitz & Rocha (2018) indicate that improvements in aspects of cognitive skills and student behavior towards the environment are in the moderate category. The influence of personality, attitude, and intention to act on responsible environmental behavior (Pratiwi et al., 2019).

CONCLUSION

The PjBL-STEAM integrated web approach can effectively increase students' HOTSEP and environmental literacy competency with an overall gain score > 0.70 in the high category. Student attitudes and behavior show positive actions towards the environment. This research recommends that educational practitioners can use the PjBL-STEAM integrated web approach to train students' HOTSEP and environmental literacy competencies towards education for sustainable environmental development (EESD).

ACKNOWLEDGEMENTS

The authors would like to thank Lambung Mangkurat University (ULM) for providing funding support through the 2024 ULM PDWM Research Grant with Contract Number: SP DIPA-023.17.2.677518/2024.

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