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Pineapple Peel Eco-Enzyme as a Project-Based Learning Medium for Sustainable Science Education in Muaro Jambi Schools

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Abstract
Science learning in schools often remains theoretical and insufficiently connected to local environmental problems. At the same time, organic waste from school activities is frequently underutilized as a contextual learning resource. Pineapple peel-based eco-enzyme offers a practical opportunity to integrate waste management, local resources, and project-based science learning. This paper aims to describe the pedagogical potential and implementation of pineapple peel eco-enzyme as a project-based learning medium for sustainable science education in Muaro Jambi schools. This paper is based on a community service-based educational intervention conducted at SMAN 3 Muaro Jambi, involving teachers and students from SMAN 3 and invited participants from SMKN 8 Muaro Jambi. The program included socialization, technical training, eco-enzyme production, fermentation monitoring, learning-device development, and product exhibition. Eco-enzyme functioned as a project object through which students practiced observation, measurement, recording, reporting, and product utilization. The program produced an average of six liters of eco-enzyme per month, reduced organic waste by 30% during the first six months, and enabled 92% of participants to produce eco-enzyme independently. In addition, 80% of science teachers integrated eco-enzyme-based PjBL into lesson plans, supported by learning modules, scientific worksheets, and an Eco-Enzyme *Adiwiyata* Team. Pineapple peel-based eco-enzyme has practical potential as a locally relevant PjBL medium for linking science concepts, environmental action, and Education for Sustainable Development. Longer-term evaluation is needed to assess sustained learning and behavioral outcomes.

Keywords: eco-enzyme; local resources; organic waste management; pineapple peel; project-based learning; sustainable science education

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INTRODUCTION

Science education increasingly needs to respond to environmental problems that are directly experienced by students in their everyday surroundings. In many school contexts, however, science learning is still dominated by theoretical explanations, while students have limited opportunities to engage with real environmental problems through systematic inquiry and project-based activities. This gap is particularly important in the context of Education for Sustainable Development (ESD), where learning is expected to connect knowledge, skills, values, and action related to sustainability (1).

School-based organic waste provides a concrete entry point for sustainability-oriented science learning. Organic residues from canteens, school gardens, and daily student activities are often treated as waste rather than as learning resources. When these materials are not managed properly, they may create sanitation problems and reduce the quality of the school environment. At the same time, these residues can be transformed into learning objects that allow students to explore biological, chemical, environmental, and social dimensions of sustainability. School-based eco-enzyme activities are relevant in this context because they allow waste management practices to be linked with student participation, environmental awareness, and simple product development (2,3).

Project-Based Learning (PjBL) is relevant for this purpose because it enables students to learn through structured projects, problem identification, collaborative inquiry, sustained investigation, and the development of concrete outputs. In science education, PjBL helps shift learning from passive reception of concepts toward active engagement with real phenomena and authentic problems. Recent literature emphasizes that effective PjBL in science learning requires meaningful driving questions, student collaboration, iterative investigation, teacher facilitation, and alignment between project activities, learning goals, and assessment (4,5). This approach is particularly appropriate for Education for Sustainable Development because sustainability issues require students to understand problems in context, connect scientific

knowledge with local realities, and engage in practical action as part of the learning process (1).

Eco-enzyme has emerged as one possible medium for linking environmental action and science learning. It is produced through the fermentation of organic residues, sugar or molasses, and water. As a school project, eco-enzyme can support student engagement with fermentation, decomposition, pH, changes in odor and color, waste reduction, and product utilization. Previous studies have begun to show the relevance of eco-enzyme in school-based learning and environmental education. Eco-enzyme project-based learning has been reported to improve students' knowledge of SDG 12.5 waste management, while the use of waste from the school environment has also been documented in eco-enzyme production training among junior high school students (2,6). These studies suggest that eco-enzyme can be framed not only as an environmental product but also as a pedagogical medium for contextual science learning.

The community service program discussed in this paper was developed in response to three initial problems identified in SMAN 3 Muaro Jambi: suboptimal organic waste management, limited implementation of PjBL, and limited integration of local wisdom into science learning. The school generated approximately 15 kg of organic waste per day, while only around 30% had been sorted for further management. In addition, only around 30% of science teachers had implemented PjBL, and less than 10% had integrated local wisdom into their teaching (7). These conditions indicate that the school faced both an environmental management problem and a pedagogical gap in contextual science education.

Pineapple peel was selected as the main material because it is locally available and relevant to students' everyday environment. In this program, eco-enzyme was not positioned merely as an organic waste product, but as a project-based learning medium for Biology, Chemistry, Craft, and environmental school programs. The use of local organic material provides an opportunity to connect science concepts with local resources, school

environmental problems, and sustainability-oriented learning. This proceedings paper does not aim to repeat the general implementation report of the community service program. Instead, it focuses on the pedagogical potential of pineapple peel-based eco-enzyme as a PjBL medium for sustainable science education.

METHODS

Analytical Perspective and Program Setting

This paper is not based on a new field intervention, but presents a secondary analytical perspective on the community service program previously reported by Suprayogi et al. (7). The present paper reinterprets the program from a pedagogical perspective, with specific emphasis on the use of pineapple peel-based eco-enzyme as a Project-Based Learning (PjBL) medium for sustainable science education. PjBL was used as the main analytical lens because it enables students to learn through structured projects, problem identification, collaborative work, product development, and reflection on real-world problems (4,5). The program was conducted at SMAN 3 Muaro Jambi, Jambi Province, Indonesia. It involved teachers and students from SMAN 3 Muaro Jambi and invited participants from SMKN 8 Muaro Jambi. The program was designed to integrate organic waste management, local resource utilization, project-based science learning, and school-based environmental education. This design is consistent with the principles of Education for Sustainable Development, which emphasizes the integration of knowledge, skills, values, and action for sustainability (1).

Participants and Learning Context of the Original Program

The original program involved science teachers, students, school committee members, and supporting school stakeholders. For the student learning evaluation, 45 students participated in pre-test and post-test activities. The learning context covered Biology, Chemistry, Craft, and environmental school programs, particularly those connected with the *Adiwiyata* initiative. The program emphasized four capacity-building targets: processing

organic waste into pineapple peel-based eco-enzyme, using eco-enzyme as a contextual science learning medium, integrating project-based learning with local resources, and supporting school-based environmental practices. These targets were developed based on the initial school conditions, which included suboptimal organic waste management, limited implementation of PjBL, and limited integration of local wisdom into science learning.

PjBL-Based Eco-Enzyme Learning Sequence

In this paper, the eco-enzyme activities are analytically reconstructed as a PjBL-based learning sequence (Gambar 1). First, students were introduced to the problem of school organic waste. Second, they identified pineapple peel and other organic residues as potential learning resources. Third, students and teachers planned the production of eco-enzyme using a simple fermentation method. Fourth, students participated in the production process and monitored fermentation indicators. Fifth, the resulting products were used and displayed as part of school-based environmental activities. Finally, students and teachers reflected on the scientific and environmental meaning of the project.

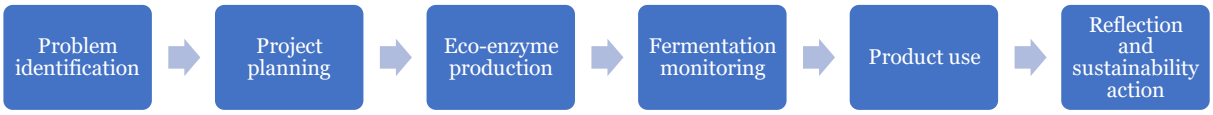

Figure 1. Analytical reconstruction of the eco-enzyme activities as a PjBL-based learning sequence

This sequence was intended to ensure that eco-enzyme production did not remain a one-time technical activity. Instead, the process was interpreted as a learning project involving problem identification, planning, implementation, monitoring, product use, and reflection. Such a sequence is consistent with PjBL principles, where students are encouraged to investigate authentic problems, engage in guided inquiry and collaboration, and produce meaningful outputs (4,5). Previous studies have also shown that eco-enzyme activities can be

framed as project-based learning to strengthen students' waste management knowledge and sustainability awareness (2,6).

Implementation Procedure of the Original Program

The original program was implemented through five main stages. The first stage was socialization and focus group discussion with school stakeholders. The second stage was technical training on eco-enzyme production. The third stage was the establishment of simple fermentation units. The fourth stage was mentoring and monitoring, including observation of fermentation progress and support for learning-device development. The fifth stage was product exhibition and sustainability planning. These stages were adapted from the implementation model reported in the previous community service publication (7), but in this paper, they are interpreted specifically as a PjBL-oriented learning intervention.

The eco-enzyme was produced using pineapple peel as the main organic material, with molasses and water as supporting components. The ratio used was 1 sugar:3 fruit waste:10 water. The fermentation process lasted approximately 6–12 weeks. During fermentation, participants monitored pH, odor, color, and volume. The final product was used for classroom cleaning, laboratory cleaning, school garden activities, and liquid fertilizer. This production procedure follows common eco-enzyme preparation practices that use organic residues, sugar sources, and water through a fermentation process (3,8).

Program Documentation and Supporting Data

This paper used documentation and supporting data from the previously implemented community service program reported by Suprayogi et al. (7). Several instruments were used to document the program process and outcomes, including pre-test and post-test instruments, observation sheets, fermentation monitoring records, participation records, and teacher feedback on learning integration. The pre-test and post-test results were used to describe

changes in student understanding, while observation sheets and monitoring records were used to document the project process, fermentation activities, and product utilization.

The pre-test and post-test consisted of 20 multiple-choice questions covering six measured aspects: basic concepts of eco-enzyme and organic waste, eco-enzyme production procedures and fermentation monitoring, utilization of eco-enzyme products, PjBL and contextual science learning, local wisdom and local resources, and scientific worksheets, evaluation, and program sustainability. The use of identical pre-test and post-test instruments

allowed the program team to compare students' understanding before and after the learning intervention. However, the results were used as descriptive supporting evidence to indicate changes in student understanding, without making causal claims about learning effectiveness.

Data Analysis

The data were analyzed descriptively and reinterpretatively to highlight the pedagogical role of eco-enzyme as a PjBL medium for sustainable science education. Program outputs were summarized based on eco-enzyme production volume, organic waste reduction, participant independence, teacher integration of PjBL, and institutional outputs. The pre-test and post-test results were summarized using average percentage scores to describe changes in student understanding. Observation sheets, fermentation monitoring records, and teacher feedback were used to interpret how eco-enzyme production functioned as a project-based learning process. Because this paper focuses on the pedagogical potential of eco-enzyme in a community service context, the analysis emphasizes implementation patterns, learning processes, and program outputs. Inferential statistical testing was not applied because the pre-test and post-test results were used only as descriptive supporting evidence.

Ethical considerations

This paper uses aggregate documentation from a previously implemented community service and educational capacity-building program. Participation in the original program was coordinated with the schools and relevant stakeholders. Student learning evaluation data were reported only in aggregate form, and no personal identity of students, teachers, or other participants is disclosed in this manuscript. Aggregate learning evaluation data were used to support program reflection and improvement. Individual student performance was not compared or disclosed in this manuscript.

RESULTS

The program outputs were interpreted in relation to their pedagogical relevance for PjBL-oriented science learning and ESD. Rather than treating eco-enzyme only as the final product of organic waste processing, this paper positions the production process, monitoring activities, learning-device development, and institutional follow-up as interconnected components of a learning project. The main outputs and their pedagogical relevance are summarized in Table 1.

Table 1. Summary of Program Outputs and Pedagogical Relevance

Program Output	Result	Pedagogical Relevance
Eco-enzyme production	6 L/month	Provides a concrete product for project-based learning
Organic waste reduction	30% in the first six months	Links science learning with real school waste problems
Participant independence	92% able to produce eco-enzyme independently	Indicates practical skill acquisition
Teacher integration	80% of science teachers integrated eco-enzyme-based PjBL into lesson plans	Shows pedagogical translation into classroom practice
Institutional output	Eco-Enzyme Adiwiyata Team: 15 students and 4 teachers	Supports continuity and school-based environmental action
Learning support	Modules and scientific worksheets developed	Supports structured inquiry, observation, and reflection

Eco-Enzyme as a Project Object

The program showed that pineapple peel-based eco-enzyme can function as a practical project object in science learning. Students were involved in identifying organic waste, preparing materials, observing fermentation, recording changes, and discussing product utilization. This project structure allowed students to connect school waste problems with scientific concepts and practical environmental action. The eco-enzyme production process created opportunities for students to observe biological and chemical changes over time. Monitoring indicators such as pH, odor, color, and volume allowed students to practice basic scientific skills, including observation, measurement, recording, and reporting. In this sense, eco-enzyme production served not only as a waste management activity but also as an authentic learning process.

Learning-Device Development and Teacher Integration

The program also produced learning-related outputs. Teachers developed project-based learning modules and scientific worksheets to support eco-enzyme learning activities. These learning devices helped structure the project so that students could record observations, analyze fermentation progress, and report their results systematically. In terms of teacher integration, 80% of science teachers integrated eco-enzyme-based PjBL into lesson plans. This indicates that the program contributed to the translation of a community service activity into classroom learning practice. The previous community service article also reported that eco-enzyme was integrated into Biology, Chemistry, and Craft learning tools through modules and scientific worksheets.

Environmental and Institutional Outputs

The program generated several environmental and institutional outputs. Eco-enzyme production reached an average of six liters per month, exceeding the initial target of five liters per month. Organic waste was reduced by 30% during the first six months. Approximately 92% of training participants were able to produce eco-enzyme independently. These results indicate that the program supported practical waste management capacity at the school level.

Institutionally, the program established an Eco-Enzyme *Adiwiyata* Team consisting of 15 students and four teachers. This team was formed to support production, monitoring, and continued socialization at school. The program also produced tangible outputs such as eco-enzyme products, compost, Standard Operating Procedures, learning modules, and scientific worksheets. In addition, products and learning outputs were displayed in school exhibitions and *Adiwiyata*-related forums.

Supporting Learning Evaluation

As supporting evaluation data, 45 student participants completed pre-test and post-test activities using the same 20-question instrument. The average score increased from 45% in the

pre-test to 80% in the post-test. This result suggests that participation in the eco-enzyme project was associated with improved student understanding of eco-enzyme concepts, fermentation procedures, product utilization, contextual learning, local resources, and program sustainability. However, because the evaluation used a descriptive pre-test and post-test design without a comparison group, this result indicates a change in student understanding but does not establish a causal effect of the learning intervention.

DISCUSSION

Eco-Enzyme as an Authentic Medium for Science Learning

The results suggest that pineapple peel-based eco-enzyme has pedagogical potential as an authentic science learning medium. Unlike conventional classroom examples, eco-enzyme production begins from a real environmental problem: organic waste generated in the school environment. Students do not only learn about waste management conceptually; they participate in transforming waste into a useful product through a structured process. This is consistent with contextual teaching in environmental science learning, where learning becomes more meaningful when students connect scientific concepts with real environmental issues, local contexts, and practical learning experiences (9).

This is important because science learning becomes more meaningful when students can observe real processes, collect data, and connect concepts with practical applications. In this program, eco-enzyme allowed students to engage with fermentation, decomposition, acidity, material transformation, and product utilization. The learning process therefore moved beyond theoretical explanation and supported scientific practice. Eco-enzyme activities in school contexts have also been reported to encourage students to engage with organic waste processing, environmental awareness, and collaborative learning (2,3).

A comparable example can be found in composting-based environmental science learning. Recent literature shows that composting activities can provide students with opportunities to understand organic matter decomposition, biodegradation processes, and the

environmental purpose of composting. In a study involving primary school classes, students demonstrated broad knowledge of composting materials and processes, while also raising questions about the time required for biodegradation, the underlying processes, and the reasons for composting (10). This comparison strengthens the argument that eco-enzyme, similar to composting, can become a practical medium for science learning because both involve organic waste transformation, observation of biological processes, and environmental application.

Eco-Enzyme and Project-Based Learning

Eco-enzyme is suitable for Project-Based Learning (PjBL) because it provides a concrete product-oriented project. The learning process involves a clear problem, a planned procedure, collaborative activity, observable progress, and a final product. These characteristics are consistent with the logic of PjBL, where students engage in meaningful inquiry, collaborative problem solving, and the production of outputs that can be communicated or used (4,5).

The eco-enzyme project also provides sufficient time for sustained inquiry. Because fermentation requires several weeks, students can observe changes over time and maintain learning records. This temporal dimension is pedagogically valuable because it trains patience, consistency, data recording, and reflection. Students can ask why odor changes, why acidity develops, why color shifts, or how different organic materials influence the product. These questions can be connected to Biology and Chemistry learning. In this sense, the project is not limited to product-making but can become an inquiry-based learning process.

The relevance of eco-enzyme for PjBL is also supported by prior work on eco-enzyme project-based learning in elementary schools (6). Eco-enzyme-based PjBL was used to improve students' waste management knowledge related to SDGs 12.5. Although the education level and implementation context differ from the present program, this literature supports the broader argument that eco-enzyme can be framed as a learning project that connects product-making, scientific inquiry, and environmental education.

Interdisciplinary Potential Across School Subjects

One strength of eco-enzyme as a learning medium is its interdisciplinary character. In Biology, students can study decomposition, microbial activity, and fermentation. In Chemistry, students can discuss acidity, pH, changes in organic compounds, and solution properties. In Craft or entrepreneurship-related learning, students can explore packaging, labelling, product communication, and potential household uses. In environmental education, students can discuss waste sorting, school sanitation, and responsibility toward the local environment.

This interdisciplinary potential is important for Education for Sustainable Development (ESD). ESD requires students to understand sustainability issues as interconnected problems, with links among environmental, social, scientific, and practical dimensions. ESD emphasizes the development of learners' knowledge, skills, values, and actions needed to contribute to sustainable development (1). Therefore, eco-enzyme can serve as a practical and locally grounded medium for implementing ESD in school science learning because it connects environmental problems, scientific concepts, and student participation in one learning project.

The interdisciplinary nature of eco-enzyme also supports the idea that sustainability learning should not be confined to a single subject. The same project can be interpreted through biological, chemical, social, and practical dimensions. This makes eco-enzyme relevant for schools seeking to integrate sustainability into existing subjects without requiring highly complex equipment or costly learning materials.

Local Resources and Local Wisdom in Science Learning

The use of pineapple peel strengthened the local relevance of the program. Instead of using abstract or expensive learning materials, the project used organic residues available in students' surroundings. This allowed students to see that local resources can be transformed into meaningful learning objects. Local materials are important in contextual science learning because they help students connect scientific concepts with their everyday environment (9). Local wisdom-based PjBL is increasingly recognized as relevant for environmental learning because it connects learning projects with local cultural and environmental potential. Local wisdom-based PjBL has been reported to have potential in supporting sustainable education in environmental learning contexts (11). In the present program, local wisdom was expressed using locally available organic resources, community participation, and the connection between environmental practice and school learning.

However, it is important not to overstate this point. The program did not measure local wisdom as a cultural construct in depth. Its contribution lies mainly in using local resources and local environmental problems as the basis for contextual science learning. In this paper, "local wisdom-based learning" is used to describe the integration of local materials, local

environmental issues, and school-based sustainability action. The term is used in a practical pedagogical sense, since the program did not conduct an in-depth assessment of local cultural knowledge.

Institutional Support and Sustainability of PjBL

The program also shows that the sustainability of PjBL-based environmental learning depends on institutional support. Technical training alone is insufficient if teachers do not have learning modules, worksheets, time allocation, and school-level support. In this program, teacher mentoring, learning-device development, and the formation of the Eco-Enzyme *Adiwiyata* Team were important steps to support continuity. This aligns with ESD principles, which emphasize the importance of learning environments, educator capacity, youth participation, and local-level action (1).

Although 80% of science teachers integrated eco-enzyme-based PjBL into lesson plans, some teachers still needed mentoring to strengthen curriculum integration. The need for teacher mentoring in this program is consistent with previous studies showing that the implementation of PjBL in science education requires careful instructional design, teacher support, and alignment between project activities, learning goals, and assessment (5,12). This indicates that the main challenge was not only product-making, but also pedagogical translation. A school environmental project becomes educationally meaningful when it is connected to learning objectives, student inquiry, assessment, and reflection.

The Eco-Enzyme *Adiwiyata* Team is also important because it provides a school-based mechanism for continued production, monitoring, and socialization. Nevertheless, the program has not yet provided long-term evidence of sustained behavior change. The current evidence supports short-term program implementation and immediate learning outcomes, while longer-term evaluation is still required.

Contribution to Education for Sustainable Development

The main contribution of this program lies in demonstrating how a simple local material can be transformed into a PjBL medium for ESD.

The program linked organic waste management with science concepts, teacher capacity development, student participation, learning-device production, and school environmental

practice. It therefore contributes to ESD not through a complex technological intervention, but through a simple and locally relevant learning project.

This contribution aligns with the broader literature showing that ESD in science learning requires active learning, contextual learning resources, interdisciplinary thinking, school collaboration, and links to real sustainability issues (1). Eco-enzyme can support these principles because it connects environmental action and classroom learning in a visible and participatory way. The relevance of eco-enzyme in school-based sustainability learning has also been shown in previous eco-enzyme education programs, particularly in relation to waste management knowledge and student participation (2,6).

Still, the claim should remain modest. This program provides a practical example and early evidence of feasibility, not definitive proof of long-term effectiveness or scalability. Future studies should examine whether eco-enzyme-based PjBL improves long-term scientific literacy, environmental behavior, teacher practice, and sustained school waste management.

CONCLUSIONS

Pineapple peel-based eco-enzyme has practical potential as a locally relevant Project-Based Learning medium for sustainable science education. The program enabled students to engage with organic waste management, fermentation, observation, measurement, reporting, and product utilization through a concrete environmental project. The program also supported teacher capacity by encouraging the development of project-based learning modules and scientific worksheets. Its environmental and institutional outputs included eco-enzyme products, waste reduction, lesson plan integration, and the formation of an Eco-Enzyme *Adiwiyata* Team. This paper argues that the educational value of eco-enzyme lies not only in the final product, but also in the learning process it enables.

Eco-enzyme can connect Biology, Chemistry, Craft, environmental education, local resources, and school-based sustainability action. Further implementation and longer-term evaluation are needed to assess its broader applicability, sustained learning outcomes, and contribution to students' environmental behavior.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

The authors used artificial intelligence-based language tools only to support language refinement, including grammar checking, sentence clarity, readability improvement, and minor assistance in organizing the manuscript structure. Artificial intelligence tools were not used for data collection, data analysis, interpretation of findings, or conclusion formulation. The authors confirm that all AI-assisted outputs and processes were critically reviewed, edited, verified, and approved by the authors to ensure the integrity and reliability of the manuscript. The scientific content, data interpretation, final decisions, and conclusions presented in this article remain solely the responsibility of the authors.

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