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The Development of a Deep Learning-Based STEAM Project Module to Enhance Students' Environmental Literacy through an Eco-Enzyme Initiative

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ABSTRACT: The global environmental crisis demands innovative educational approaches to build environmental literacy from an early age. This study aims to develop a deep-learning-based project module integrated with STEAM (Science, Technology, Engineering, Arts, Mathematics) through an eco-enzyme project to improve the environmental literacy of fifth-grade students at MIN 1 Sidoarjo. The research employed the 4D development model (Define, Design, Develop, Disseminate) with a qualitative–quantitative approach. Data were collected through questionnaires, interviews, observations, and pretest–posttest assessments, then analyzed descriptively and statistically (N-Gain). Validation results from experts in content, media, and pedagogy indicated that the module was highly valid (average scores of 4.26, 3.8, and 4.3). Small- and large-scale trials demonstrated that the module was practical (average student response of 3.4) and effective in enhancing environmental literacy, with significant improvements in both cognitive (N-Gain = 0.70) and affective (N-Gain = 0.72) domains. The eco-enzyme project also strengthens the dimensions of the Pancasila Student Profile, particularly creativity, independence, and collaboration. The implications of this study affirm that integrating STEAM and deep learning within a contextual project module can create meaningful learning, foster 21st-century skills, and cultivate students' ecological awareness. Recommendations include implementing similar modules in elementary schools and developing educational policies that support project-based environmental learning.

KEYWORDS: Deep learning, STEAM, environmental literacy, eco-enzyme, project module

INTRODUCTION

The global environmental crisis has become an urgent issue that demands immediate action from all sectors of society. Climate change, pollution, and biodiversity loss have exposed the fragility of Earth's balance, heavily influenced by human activities. One of the major contributors to this crisis is the lack of ecological awareness and environmental literacy, which are fundamental for understanding and addressing environmental challenges. Therefore, education plays a crucial role in fostering awareness, responsibility, and care for nature, particularly during early childhood education. By instilling environmental consciousness, education empowers students to make informed decisions and adopt behaviors that support sustainability.

To address this pressing issue, deep learning-based instruction integrated with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach offers an innovative solution to improve students' environmental literacy. This integration provides students with the opportunity to not only grasp scientific concepts but also develop essential skills such as critical thinking, problem-solving, collaboration, and empathy for the environment. The incorporation of STEAM in real-world projects, such as eco-enzyme production, creates a hands-on learning experience that reinforces theoretical knowledge while allowing students to engage in practical solutions for environmental issues. This approach aligns well with the Pancasila Student Profile Strengthening Project (P5), which aims to cultivate values such as mutual cooperation, responsibility, and love for nature in students.

At MIN 1 Sidoarjo, initial observations reveal a significant gap in students' environmental awareness. During a typical school day, around 8 to 10 kilograms of waste are produced, predominantly consisting of organic waste such as leftover food and leaves, along with inorganic waste such as plastic drink cups, food packaging, and water bottles. More than sixty percent of this waste is not sorted properly, as students often dispose of organic and inorganic waste together. This situation highlights the urgent need for educational interventions to promote environmental responsibility and waste management practices. In response to this, this study proposes the development of a deep learning module integrated with the STEAM approach to enhance students' environmental literacy through meaningful, contextual, and enjoyable learning experiences.

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The expected outcome of this innovation is the creation of a generation of students who are not only academically competent but also ecologically sensitive, driven to protect the sustainability of the Earth. By integrating deep learning and STEAM, students will develop a holistic understanding of environmental issues and gain 21st-century skills, empowering them to become active participants in environmental conservation.

Deep learning instruction emphasizes the development of comprehensive conceptual understanding, critical thinking, problem-solving, and collaboration within real-world contexts (Hosnan, 2014). Unlike traditional education models that focus on memorization, deep learning encourages students to apply knowledge in practical settings, fostering independent, creative, and adaptive learners. According to the Ministry of Education, Culture, Research, and Technology (2022), deep learning is student-centered, promoting exploration, reflection, and the connection of learning materials to real-life situations. Biggs & Tang (2022) assert that deep learning facilitates understanding of key ideas and their relevance to real-life contexts, moving beyond mere exam preparation. Fajri (2017) highlights critical thinking as a core component of deep learning, designed to promote systematic analysis and effective problem-solving.

The key components of deep learning include meaningful learning, which connects new information with prior knowledge to make learning relevant (Rachmawati & Daryanto, 2015; Ausubel, 1968), mindful learning, which involves full engagement of the learner in the process, enhancing focus and emotional regulation, leading to improved learning outcomes (Melfianora, 2023; Abdurrochim et al., 2024), and joyful learning, which creates a positive learning environment, boosting motivation and encouraging active student participation (Andarwati, 2019).

STEAM is an interdisciplinary approach to learning that integrates Science, Technology, Engineering, Arts, and Mathematics. It nurtures critical, creative, and collaborative thinking skills, offering opportunities for exploration, experimentation, and real-world application of concepts (Yakman, 2008). STEAM has been shown to enhance students' motivation, curiosity, critical thinking, creativity, and collaboration (Wati & Siregar, 2025; Nasrah, 2021; Suardi, 2018). This approach encourages students to solve complex problems in a creative and contextual manner (Mu'minah & Suryaningsih, 2020; Directorate of Junior High Schools, 2021). When combined with deep learning, STEAM becomes a powerful educational tool for addressing environmental issues. For example, an eco-enzyme project allows students to apply their knowledge of science, technology, engineering, art, and mathematics to solve environmental problems, enhancing their environmental literacy.

Eco-enzyme is a liquid created through the fermentation of organic waste, serving multiple purposes such as a natural cleaner, liquid fertilizer, waste treatment agent, and disinfectant (Indraswanti et al., 2022; Vidalia et al., 2023). An eco-enzyme project provides an excellent platform for contextual learning, allowing students to improve their environmental literacy through hands-on experience. The process involves fermenting organic waste with sugar and water over three months, during which microorganisms produce bioactive compounds that benefit the environment (Widyastuti, 2020; Wahyuni, 2020). Within the STEAM framework, the eco-enzyme project teaches scientific concepts like fermentation, technological tools for documentation, artistic elements in packaging design, engineering in procedural planning, and mathematical principles in measurement and data analysis.

Environmental literacy encompasses the knowledge, attitudes, and behaviors necessary to make informed decisions about the environment (Hollweg et al., 2011; Nuraini, 2020). Cultivating environmental literacy in students is crucial for fostering concern, responsibility, and action toward preserving the environment. This literacy empowers students to participate actively in managing natural resources and maintaining environmental sustainability (Law No. 32/2009).

Integrating deep learning with STEAM and the eco-enzyme project offers students a comprehensive, hands-on learning experience that enhances their understanding of environmental issues. Activities such as sorting waste, preparing materials, conducting fermentation, and designing product packaging provide a contextual, meaningful, and collaborative learning experience. These activities foster not only environmental literacy but also critical thinking, creativity, and collaboration, which are vital skills for addressing complex environmental challenges. Through this approach, students gain the knowledge and skills necessary to make informed and responsible decisions that contribute to the sustainability of the Earth.

METHODS

A. Type of Research

This study uses a development approach (Research and Development/R&D) referring to the 4D model (Define, Design, Develop, Disseminate) developed by Thiagarajan, Semmel, and Semmel (1974). This model was chosen because it is suitable for gradually

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and systematically developing and testing the feasibility of a product in the form of a project module. According to Sutarti & Irawan (2017), the 4D model is effective for developing learning tools. This research employs a quantitative–qualitative approach, describing the process of developing a deep-learning instructional module integrated with STEAM through an eco-enzyme project and its impact on students' environmental literacy.

B. Research Population

The study was conducted at Madrasah Ibtidaiyah Negeri 1 Sidoarjo, located on Jalan Balai Desa Banjar Kemantren, Buduran, Sidoarjo. This site was selected due to its implementation of the Merdeka Curriculum, which aligns with P5 (Pancasila Student Profile) activities conducted in the second semester. The research population consisted of 29 fifth-grade students. The research sample was a subset of this population selected based on relevant characteristics.

C. Data Sources

The research data were categorized into the following types:

1. Primary data: collected directly through pretests, posttests, questionnaires, and interviews with fifth-grade students.
2. Secondary data: obtained from books, documentation, archives, and literature related to project module development and environmental literacy.

D. Research Instruments

The research instruments included teacher interview guidelines to assess learning conditions, student characteristics, and opportunities for STEAM integration; student needs-analysis questionnaires to identify prior knowledge, interests, experiences, and needs related to environmental learning; validator assessment questionnaires (for content, media, and instructional design experts) to evaluate the feasibility of the project module; student response questionnaires to assess students' perceptions of the module; along with pretests and posttests designed to measure improvements in students' environmental literacy across cognitive, affective, and psychomotor domains...

RESULTS AND DISCUSSION

A. Description of the Research Object

This study was conducted with fifth-grade students at MIN 1 Sidoarjo, a state Islamic elementary school (madrasah ibtidaiyah negeri) under the Ministry of Religious Affairs of Sidoarjo Regency, East Java Province. MIN 1 Sidoarjo has a strong commitment to strengthening character education and developing environment-based learning. Fifth-grade students were selected as the research subjects because their cognitive development already allows them to engage in project-based learning; they are able to work collaboratively, solve simple problems, and participate in open discussions.

The vision of MIN 1 Sidoarjo, namely "The realization of a madrasah community that is faithful, pious, patriotic, intelligent, skilled, and culturally environmentally caring," is aligned with its status as an Adiwiyata (eco-school) madrasah. The integration of environmental care values into intracurricular, cocurricular, and extracurricular activities supports the development of the STEAM-based eco-enzyme project module, ensuring that students are not only academically competent but also environmentally conscious and equipped with practical skills.

This study employed a Research and Development (R&D) approach using the 4D development model (Define, Design, Develop, Disseminate). Data were obtained through observations, interviews, questionnaires, and module trials. The following are the results of developing the eco-enzyme project module.

B. Define Stage

This stage includes preliminary analysis, needs analysis, and formulation of learning objectives.

1. Front-End Analysis

According to an interview with the fifth-grade teacher, Mr. Rofiul Adib, S.Pd., environmental education plays a vital role in fostering early awareness so that students become individuals who care about and are responsible for nature. The teacher observed that some students have already shown concern, such as throwing trash in its proper place and watering plants, but these habits are not yet widespread. He emphasized the importance of practice-based learning strategies to facilitate students' understanding of environmental concepts.

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2. *Learner Analysis*

The results of the student needs questionnaire showed that all students (100%) were able to distinguish between organic and non-organic waste and were interested in creating something beneficial for the environment. Students showed a strong interest in project-based learning, with 86% of students finding it easier to understand material through projects and 93% enjoying group work. However, digital skills remain a challenge; only 55% of students were interested in using Canva to design products. The results of the learner need analysis are presented in Table 1.

Table 1. Results of the Needs Analysis of Fifth-Grade Students

No	*Question*	*Yes*	*No*
1	Able to distinguish between organic and non-organic waste?	100%	0%
2	Know how to process organic waste?	86%	14%
3	Interested in creating a project to address environmental pollution?	83%	17%

3. *Concept Analysis*

The eco-enzyme project module integrates the dimensions of the Pancasila Student Profile (P5) within the theme of Sustainable Lifestyles. The Global Diversity dimension emphasizes students' ability to evaluate environmental improvement efforts and their impacts. The Independent dimension highlights self-regulation, while the Mutual Cooperation dimension stresses social concern and collaboration.

4. *Task Analysis*

The tasks within the eco-enzyme project are structured to achieve the learning objectivesas well as indicators of attaining the P5 dimensions, including creativity, independence, and collaboration.

C. *Design Stage*

1. *Selection of Materials*

The learning materials are organized in an integrated STEAM format as presented in Table 2.

Table 2. STEAM-Integrated Module

Aspect		Explanation
Science		Students learn how organic waste (fruit peels and vegetable scraps) mixed with molasses and water undergoes fermentation and produces a useful eco-enzyme solution. They learn that bacteria and fungi help decompose organic waste, such as leftover fruits and vegetables, into simpler substances that are beneficial for the soil.

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Technology		Students design the steps for making ecoenzyme. By using Canva, they also learn to use technology to communicate visually and digitally.
Engineering		Students look for used bottles and develop simple engineering skills by using these bottles to design eco-enzyme containers.
Art		Students learn how to design a unique and attractive label for the eco-enzyme using Canva. This activity trains their digital design skills (technology) while also developing the art aspect through the choice of colors, typography, and visual elements that reflect the characteristics of the eco-enzyme and its environmental message.
Mathematics		This project provides opportunities for students to apply mathematical concepts in a real-world context, improve their mathematical skills, and promote conceptual and applied understanding in line with the principles of meaningful learning (deep learning).

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2. Selection of Media

The learning media included used plastic bottles, fermentation containers, labels, and a tutorial video. These materials were readily available, relevant to the project, and support STEAM integration.

3. Selection of Design Format

The module was designed using Canva to be interactive, attractive, and to encourage students' creativity. It comprises a cover page, learning objectives, instructional activities, content materials, and student worksheets (LKPD).

D. Development Stage

1. Material Validation

The material validator, Dra. Farida Hanum, M.Pd., assessed the feasibility of the content, subject material, and language, with an overall score of 4.26 (highly valid). Revisions were made to reduce word repetition and strengthen STEAM integration.

2. Media Validation

Ferdi Afrar evaluated the media's visual design, functionality, and user suitability. The overall score was 3.8 (valid). Revisions were made to the proportion of text to improve readability.

3. Instructional Design Validation

Mrs. Sri Utami, M.Pd., assessed the suitability of the design, feasibility, and practicality of the learning, giving a score of 4.3 (highly valid). Her suggestions focused on strengthening critical thinking and linking practice with real environmental conditions.

E. Product Trials

1. Small Scale

A small-scale trial was conducted with 10 students. The results of student responses showed an average score of 3.4 on the Likert scale, in the good to very good category. The module was considered easy to understand, but needed additional illustrations and more detailed instructions.

2. Large Scale

The large scale trial was conducted with 29 students. Students followed all stages of the project, including practicing how to make eco-enzyme and designing labels. The pretest and posttest results demonstrated a significant improvement in students' environmental literacy.:

Figure 1. Students Collaborating to Practice the Project Module

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Figure 2. Students Harvesting and Labeling the Eco-Enzyme

Table 3. Affective Aspect

Variable	Pretest	Posttest	Gain	Category
Average	27,52	36,48	0,72	High

Table 4. Cognitive Aspect

Variable	Pretest	Posttest	Gain	Category
Average	71,79	91,55	0,70	High

Psychomotor observations revealed improvements in three P5 dimensions: creativity (designing bottles and labels), independence (preparing work plans), and cooperation/gotong royong (group collaboration). These findings indicate that the STEAM-based eco-enzyme project module is effective in improving students' environmental literacy. The project-based approach offers contextual learning experiences that foster student participation, creativity, and collaboration. Expert validation and large-scale trials confirm the module's feasibility, effectiveness, and its capacity to foster the dimensions of the Pancasila Student Profile. Overall, integrating STEAM into the eco-enzyme project provides a holistic learning experience that integrates cognitive, affective, and psychomotor domains. This approach enables students not only to understand the concept of eco-enzymes but also to apply it in real-world contexts while deepening their environmental awareness.

CONCLUSION

The effectiveness of the project module is evidenced by improvements in students' cognitive and affective learning outcomes The average cognitive score increased from 71.79 to 91.55 (N-Gain = 0.70, categorized as high), while the affective score rose from 27.52 to 36.48 (N-Gain = 0.72, also categorized as high).. These results demonstrate that project-based learning grounded in real-world practice can significantly enhance students' conceptual understanding and environmental concern. Furthermore, the improvement in learning outcomes affirms that deep learning—emphasizing conceptual understanding, critical thinking, problem-solving, and knowledge transfer—was successfully achieved through the development of this module.

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