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# Empowering Science Teachers to Implement ESD through Project-Based Learning: A Community Service Program for Professional Development

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## Abstract

The integration of Education for Sustainable Development (ESD) into science instruction remains limited in secondary schools due to teachers' insufficient understanding and practical skills. To address this, a professional development program was conducted to enhance the capacity of junior and senior high school science teachers to implement ESD through project-based learning (PjBL). The program consisted of three phases: conceptual enrichment, on-the-job training, and microteaching. A total of 12 science teachers completed the program. During the microteaching phase, one teacher served as a model by delivering an ESD-integrated lesson to 24 students, focusing on a solar energy project. Data were collected through facilitator observations, teacher reflections, and post-program questionnaires completed by both teachers and students. The findings indicate improved teacher understanding of ESD principles, greater ability to design PjBL activities linked to sustainability goals, and increased instructional confidence. Student feedback revealed high levels of engagement, satisfaction, and awareness of sustainability issues. These outcomes suggest that structured and practice-based professional development can effectively support science teachers in integrating ESD into classroom practice. Expanding similar programs may foster transformative science education and help prepare students to take informed action on sustainability challenges.

Keywords: ESD, PjBL, Science Learning, Teacher professional development.

## *Abstrak*

*Integrasi Education for Sustainable Development (ESD) dalam pembelajaran IPA di sekolah menengah masih mangalami berbagai hambatan, terutama karena keterbatasan pemahaman dan keterampilan praktis guru. Untuk mengatasi masalah ini, dilaksanakan kegiatan pengabdian kepada masyarakat sebagai program pengembangan profesional guna meningkatkan kapasitas guru IPA SMP dan SMA dalam mengimplementasikan ESD melalui pembelajaran berbasis proyek (PjBL). Pogram ini terdiri atas tiga tahap: penguatan konseptual, on-the-job training, dan microteaching. Sebanyak 12 guru berpartisipasi dalam kegiatan ini. Pada tahap microteaching, seorang guru berperan sebagai model dan melibatkan 24 siswa dalam proyek energi surya. Pengumpulan data dilakukan melalui observasi, refleksi guru, serta angket guru dan siswa. Hasil menunjukkan adanya peningkatan pemahaman guru terhadap prinsip-prinsip ESD, kemampuan yang lebih baik dalam merancang kegiatan PjBL yang berkaitan dengan tujuan keberlanjutan, serta peningkatan kepercayaan diri dalam mengajar. Umpan balik siswa memperlihatkan tingkat keterlibatan, kepuasan, dan kesadaran terhadap isu-isu keberlanjutan yang tinggi. Hasil ini mengindikasikan bahwa program pengembangan profesional yang berbasis praktik dan terstruktur dapat secara efektif mendukung guru IPA dalam mengintegrasikan ESD ke dalam pembelajaran di kelas. Pengembangan program serupa dapat memperkuat pendidikan IPA yang transformatif dan mendorong siswa untuk terlibat aktif dalam isu keberlanjutan.*

*Kata Kunci*: *ESD, PjBL, Pembelajaran IPA, Pengembangan professional guru.*

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## Introduction

Education for Sustainable Development (ESD) is an instructional framework designed to equip students with the essential knowledge, competencies, attitudes, and values needed to contribute to a sustainable future across environmental, social, and economic domains. According to UNESCO (2017), ESD is not merely about raising awareness of environmental problems, but about fostering changes in thinking and behavior that support Sustainability. It holds a crucial role in nurturing students to become environmentally aware, think critically, and make informed decisions in response to global issues such as climate change, energy shortages, and environmental degradation (Mochizuki & Fadeeva, 2010; Purnamasari & Hanifah, 2021). Given the country's ongoing socio-economic and ecological challenges, embedding ESD within the school system is increasingly vital. Enhancing teachers' abilities to facilitate sustainability-oriented learning is, therefore, key to ensuring that students not only understand sustainability issues but are also motivated and prepared to address them through meaningful actions.

Although the importance of ESD has been widely recognized, its implementation at the school level-particularly in lower and upper secondary education-continues to face several challenges. One of the major obstacles is the limited capacity of teachers to integrate ESD principles and values into their instructional practices, especially in science subjects. Findings from Purnamasari et al. (2022) revealed that 75% of the surveyed teachers had never implemented ESD in their classrooms, primarily because they lacked sufficient understanding of ESD concepts and approaches. Supporting this, a study by Cahyani et al. (2025) showed that while most junior high school science teachers had general awareness of the SDGs, only a small proportion demonstrated a deep, substantive understanding needed to support ESD in classroom practice effectively. This gap not only affects the quality of science education but also limits students' opportunities to engage with real-world sustainability problems in meaningful ways. Without adequate teacher preparation and support, efforts to embed ESD within the curriculum risk becoming superficial or fragmented. Furthermore, the absence of structured training programs, limited access to teaching resources, and a lack of institutional encouragement further hinder teachers from adopting ESD-based pedagogies (Nugroho et al., 2025).

Before program implementation, a needs assessment was conducted through teacher interviews with three science teachers from three junior high schools to identify challenges in integrating ESD into classroom practice. Many teachers admitted that they struggled to connect sustainability topics with the existing curriculum, especially in physics and chemistry lessons, where ESD-related examples are less apparent. Some noted the lack of readily available teaching materials related to local environmental issues, which made it challenging to design relevant classroom activities. Others pointed to time constraints, as ESD was often seen as an "extra" topic rather than an integral part of regular science instruction. Teachers also expressed limited confidence in facilitating open-ended, project-based activities, as they worried that such approaches might not align with current assessment demands. These challenges show that teachers' difficulties are both conceptual and practical in nature.

To address these challenges, it is essential to provide targeted professional development programs that build teachers' conceptual understanding of ESD and equip them with practical strategies for integrating Sustainability into classroom instruction. Strengthening teacher

competence in this area is a critical step toward transforming science education into a driver of Sustainability and empowering students to become agents of change in their communities. One promising approach to effectively implementing ESD in science education is through project-based learning (PjBL). This instructional model aligns well with the science curriculum and engages students in experiential activities that explore sustainability-related challenges (Budiati et al., 2025; Marwa et al., 2025; Rosmiati et al., 2025). For instance, projects such as building simple wind turbines, creating solar-powered ovens, or designing small-scale biogas systems can serve as entry points for students to explore the intersection of science and Sustainability. Such projects not only foster collaboration, critical thinking, and problem-solving skills but also cultivate students' ecological awareness and sense of responsibility toward their environment. In parallel, teachers benefit from practical experience in designing, facilitating, and evaluating learning activities grounded in sustainability contexts (Jumaidin et al., 2025; Setiawan et al., 2023). This program offers a novel contribution by situating project-based learning within a structured ESD framework tailored to the real-world constraints and needs of science teachers.

Recognizing the pivotal role of teachers as key facilitators of ESD, this community services activity provides professional development programs to enhance the capacity of science teachers in integrating ESD into their teaching practices through project-based learning approaches. The program offers both conceptual enrichment and hands-on training to help teachers design contextual and application-oriented learning experiences that address current sustainability challenges. Through these activities, teachers are expected to become empowered agents of change who not only deliver content but also inspire students to take meaningful action in support of sustainable development.

## Method

This community service-based professional development program was implemented through three systematically organized phases aimed at enhancing the capacity of junior and senior high school science teachers to integrate ESD into their instructional practices through project-based learning (PjBL). A total of 12 science teachers from various schools in Garut Regency participated in the whole program, which was designed to provide both conceptual foundations and hands-on experience in adapting science education to address sustainability issues.

The first phase focused on conceptual enrichment. Teachers were familiarized with the core principles of ESD, encompassing essential sustainability values and the pressing need to address global issues such as climate change, environmental degradation, and social disparities. This phase also underscored the significance of embedding ESD within science education by illustrating the connections between scientific content and authentic sustainability problems that are relevant to students' everyday experiences. Key topics covered in this phase included: 1) the urgency, concepts, and learning objectives of ESD, 2) effective strategies for implementing ESD-based science instruction, 3) integrating sustainability issues into science topics, and 4) designing project-based science learning aligned with ESD principles.

The second phase involved on-the-job training, where teachers engaged in collaborative, discussion-based sessions to design science learning activities using PjBL as

the instructional model. Emphasis was placed on developing lessons that were locally relevant, curriculum-aligned, and capable of promoting both scientific literacy and sustainability competencies. Facilitators provided ongoing pedagogical and technical feedback to help participants refine their lesson plans and strengthen connections between science topics and real-world sustainability challenges.

The third phase consisted of a microteaching simulation that offered teachers the opportunity to implement their ESD-integrated lesson designs in a classroom setting. One participant delivered a model lesson on renewable energy, guiding 24 students through the process of designing and testing a simple solar-powered device. While the lesson was delivered, the remaining participants observed and provided structured peer feedback on the implementation. The session concluded with a reflection activity in which teachers analyzed the strengths and areas for improvement in the delivery of the lesson. This final phase emphasized experiential learning, peer feedback, and reflective practice to reinforce teachers' confidence and ability to apply ESD principles in their classrooms.

To evaluate the program's effectiveness, three types of instruments were employed. Facilitator observations were conducted throughout the sessions to monitor teachers' participation, engagement, and the extent to which they applied ESD principles in each phase of the program. In addition, teacher reflections were collected at the end of each activity to capture participants' personal insights, perceived challenges, and learning gains. Finally, a post-program questionnaire using a five-point Likert scale was administered to both teachers and students to assess teachers' satisfaction with the program and students' responses to the implementation of ESD-integrated project-based learning. The data obtained from facilitator observations and teacher reflections were analyzed qualitatively through thematic coding to identify recurring patterns and challenges. The questionnaire data were analyzed descriptively using percentages to capture the overall trends in teachers' and students' responses.

## Results and Discussion

This section presents the outcomes of the three-phase professional development program designed to integrate ESD into science teaching. Each phase-conceptual enrichment, on-the-job training, and project simulation-yielded specific insights into participants' learning, instructional design capabilities, and reflective practices.

### *Strengthened Conceptual Understanding of ESD among Teachers*

This phase of the professional development program significantly enhanced teachers' conceptual understanding of Education for Sustainable Development (ESD). Most participants reported a heightened awareness of sustainability values and the importance of addressing complex global challenges. Through structured discussions and contextualized content, they demonstrated improved comprehension of core ESD principles such as systems thinking, intergenerational equity, and the interdependence of environmental, social, and economic dimensions of development.

The emphasis on topics beyond climate change-such as plastic pollution, biodiversity loss, and energy inequity-enabled teachers to recognize that Sustainability is a multidimensional construct, not confined to environmental degradation alone. This broader framing aligns with the framework proposed by UNESCO (2017), which emphasizes that

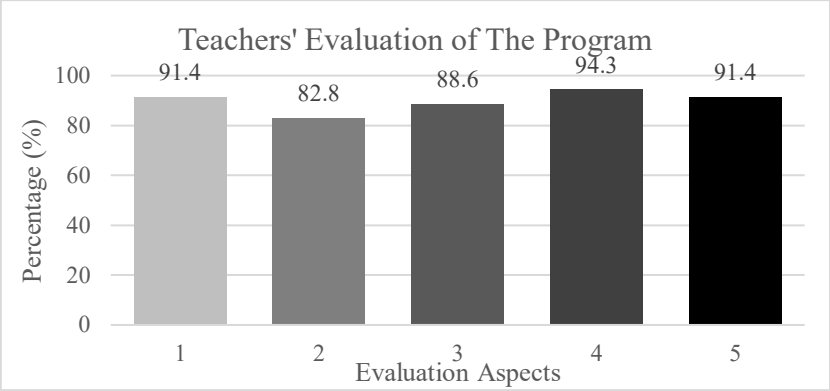
ESD should cultivate the ability to connect knowledge across domains and make informed decisions for sustainable action. Teachers began to view science not merely as a body of knowledge but as a dynamic tool to foster students' critical consciousness and sustainability-oriented behavior.

This shift aligns with the theoretical foundation of transformative learning theory (Mezirow, 2018), which posits that adult learning becomes meaningful when it challenges existing assumptions and leads to a transformation of perspective. In this context, the program provided disorienting dilemmas-such as the exploration of ecological injustice or the real-world consequences of unsustainable practices-that prompted teachers to critically reflect on their role in preparing students to navigate and influence global sustainability issues. Through this process, they moved from a content-transmission paradigm to one of education as empowerment, consistent with the aims of ESD.

Moreover, the conceptual phase was designed to be interactive and reflective, incorporating collaborative meaning-making, case analysis, and guided inquiry. This approach aligns with the core features of effective professional development, as outlined by Darling-Hammond et al. (2017), particularly its focus on content, active learning, and coherence with professional needs.

In addition to qualitative evidence, post-program questionnaire results further support the effectiveness of this phase. Although baseline data were not collected before program implementation, program outcomes were evaluated using post-program questionnaires to capture participants' perceptions of program relevance, satisfaction, direct benefits, and expectations for future programs. A visual summary of these responses is presented in **Figure 1**, which illustrates the high level of participant agreement across all measured indicators. Participants reported high levels of agreement regarding the relevance of the training activities to their professional needs (91.4%) and their alignment with initial expectations (82.8%). Satisfaction with the training program was also notably high (88.6%), and 94.3% of participants agreed that the training provided direct benefits to their teaching practices. Furthermore, 91.4% expressed a strong desire for the continuation of similar capacity-building programs. These findings suggest that the conceptual enrichment activities were both impactful and well-aligned with the participants' professional contexts, laying a solid foundation for their deeper engagement in subsequent phases of the program.

These findings suggest that the conceptual enrichment phase not only met the immediate professional expectations of the participants but also laid a foundational cognitive and motivational platform for deeper engagement in subsequent practical and pedagogical phases. The high level of teacher satisfaction and the expressed desire for continued training further underscore the program's alignment with both the teachers' situated learning needs (Hayes & Allen, 2025) and the broader objective of integrating Sustainability into science education in a meaningful and lasting manner.




Aspects: 1) Relevance of the program to participants' needs; 2) Relevance of the program implementation to participants' expectations; 3) Participants' satisfaction with the program; 4) Direct benefits of the program for participants; and 5) Participants' expectation for the continuation of similar programs

***Figure 1**. Teachers' evaluation of the professional development program based on post-program questionnaire results.*

### *Improved Ability to Design ESD-Integrated Science Lessons*

The second phase of the program, which emphasized on-the-job training and collaborative lesson design, significantly enhanced teachers' ability to integrate Education for Sustainable Development (ESD) principles into science instruction. This improvement was achieved through a scaffolded professional learning process that combined project-based learning (PjBL) design, contextual application, peer collaboration, and continuous formative feedback.

During structured planning workshops, participants co-developed PjBL-based science lessons that not only met the demands of the national curriculum but also addressed locally relevant sustainability challenges (**Figure 2**). These included practical projects, such as constructing composting systems to manage school food waste and designing small-scale renewable energy devices, including solar ovens and wind turbines. This approach promoted alignment between scientific competencies and sustainability goals, reflecting the core principle of ESD to equip learners with actionable knowledge and values for sustainable living (UNESCO, 2017).

***Figure 2**. Teachers are designing ESD-based learning through on-the-job training sessions.*

This process aligns with situated learning theory, which emphasizes learning as a social and context-bound practice. Teachers, as participants in a community of practice, engaged in meaningful collaboration that allowed them to negotiate understanding, draw from collective experience, and translate abstract sustainability concepts into pedagogical practices rooted in their own classrooms and communities. The integration of authentic tasks and real-world

problem-solving into lesson planning was essential in facilitating this transformation (Coen, 2025; Purbasari et al., 2025).

Observation notes from facilitators recorded a progressive shift in the quality of teachers' instructional design. Initially, many participants viewed Sustainability as a generic theme, often appended to science topics without meaningful integration. However, as peer discussions deepened and examples of interdisciplinary ESD-PjBL were shared, teachers began articulating specific, measurable learning objectives that embedded Sustainability within the scientific method and inquiry-based frameworks.

This transformation reflects findings from Redman et al. (2021), who identified systems thinking, anticipatory competence, and integrated problem-solving as essential competencies for the effective implementation of ESD. The shift also resonates with Fullan & Langworthy's (2014) concept of "deep learning", which emphasizes the importance of connecting curriculum with real-life contexts to enhance engagement and enduring understanding.

Teachers reported increased confidence and creativity, particularly in designing community-linked science projects that encouraged students to engage critically with environmental and social justice issues. This professional growth was bolstered by ongoing mentoring and peer feedback, which allowed for iterative refinement of lesson plans. The structured use of peer feedback also fostered reflective practice. It contributed to pedagogical adaptability and innovation, as supported by recent studies demonstrating the positive impact of reflective peer observation and participant feedback cycles on teacher development (Cholifah et al., 2020; Karakaş & Yükselir, 2025).

Facilitators captured this evolution through reflective commentary:

> "Initially, some participants treated sustainability as a general theme. But as discussions evolved, they began embedding it directly into the learning goals of their science lessons." (*Facilitator 1 – Lesson Design Session)*

> "One group designed a solar energy lesson where students built simple solar-powered ovens. The activity offered a meaningful way to explore renewable energy concepts while allowing students to engage in real-world problem-solving." *(Facilitator 2 – Renewable Energy Project Observation)*

Following further group deliberation and analysis of feasibility, alignment with ESD competencies, and adaptability across contexts, the solar oven project was selected as the model lesson for implementation in the program's third phase. The decision was based on the project's capacity to engage students in hands-on, inquiry-driven exploration of renewable energy, while reinforcing values of conservation, innovation, and personal responsibility. Its success also echoes findings from Craps & Brugnach (2021), who emphasize that practical ESD activities promote experiential learning, student agency, and interdisciplinary connections.

Ultimately, this phase demonstrated how well-structured professional development, which emphasizes collaboration, contextual relevance, and reflection, can effectively bridge the gap between ESD theory and practice. It empowered teachers to move from theoretical awareness to actionable pedagogy, fostering classrooms where Sustainability is not an add-on, but an integral lens through which scientific inquiry is viewed and taught.

### *Simulation and Reflective Evaluation through Microteaching*

The third phase of the professional development program incorporated a microteaching simulation, which served as a pivotal experiential platform for both practice and reflection. This phase was designed to operationalize theoretical knowledge into classroom practice by immersing teachers in a low-stakes, high-feedback environment where pedagogical strategies could be tested, observed, and refined. Rooted in Kolb's Experiential Learning Theory, this component emphasized learning through doing, reflecting, and modifying instruction based on real-time insights and peer evaluation (Chiu & Lee, 2019).

One participating teacher implemented a model lesson on renewable energy, integrating solar technology as a central theme. During this simulation, 24 students actively collaborated with the teacher to co-design and test a solar-powered device, providing an authentic context to explore scientific principles such as energy transformation, efficiency, and environmental impact (**Figure 3**). This hands-on engagement with sustainability topics aligns with the PjBL approach, which has been shown to significantly enhance student motivation, science literacy, and deep conceptual understanding in sustainability-focused learning environments (Setiawan et al., 2023; Setyowati et al., 2022). This hands-on engagement with sustainability topics mirrors the PjBL approach, which has been widely recognized for fostering student motivation and deep conceptual understanding.

Simultaneously, fellow teachers served as observers and evaluators. They assessed aspects such as the clarity of ESD integration, student engagement, inquiry facilitation, and instructional organization. This peer feedback mechanism fostered reflective dialogue, combining observation and self-reflection to support professional growth. Peer observation fosters constructive feedback, collaborative reflection, and the adoption of innovative teaching strategies, thereby significantly contributing to teachers' pedagogical development. Through this process, teachers not only critiqued pedagogical moves but also internalized new strategies for improving their own teaching practices (Ridge & Lavigne, 2020; Saborido et al., 2024).

The feedback from observers revealed key successes, including high levels of student engagement, the authenticity of the solar project, and the effective blending of science content with sustainability values. These elements align with the framework of sustainability competencies, particularly in relation to systems thinking, anticipatory competence, and normative understanding (Chopra & Banerjee, 2022; Demssie et al., 2023; Purnamasari & Nurawaliyah, 2023).

***Figure 3**. Students engaged in PjBL-ESD-based activities during the microteaching session.*

However, the simulation also revealed areas needing refinement, such as classroom time management and the design of formative assessment tools. This balance of strengths and areas

for growth highlights the power of microteaching not only as a formative assessment tool but also as a site of collaborative professional inquiry, where theory is directly tested against practice.

To extend the learning outcomes and gain insight into the student perspective, a post-project questionnaire was administered. The instrument assessed students' perceptions of the project-based experience and their awareness of sustainability issues. As shown in **Figure 4**, student responses were overwhelmingly positive. Students expressed enthusiasm for working with real-world problems and appreciated the opportunity to participate in activities that connected science learning with environmental relevance. These findings resonate with research by Dianita (2023) and Shutaleva (2023), who found that contextualized, experiential science instruction significantly enhances both environmental awareness and critical thinking.

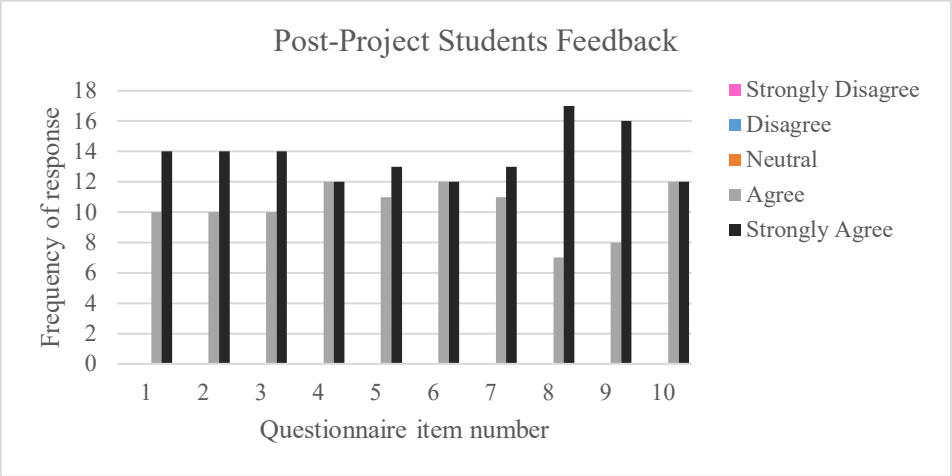



***Figure 4**. Post-project student feedback on engagement and sustainability awareness.*

Questionnaire items:

1. I enjoyed participating in the project-based learning activity.
2. I found the solar oven activity interesting and engaging.
3. I felt satisfied with how the lesson helped me understand science in a meaningful way.
4. The group collaboration made the activity more enjoyable for me.
5. I want to participate in more science projects like this in the future.
6. I understand how using solar energy can reduce environmental problems.
7. I became more aware of the importance of conserving energy and natural resources.
8. This activity helped me realize the impact of human actions on the environment.
9. I feel more responsible for contributing to a sustainable future.
10. I am interested in incorporating sustainable practices into my daily life following this activity.

Furthermore, this simulation phase exemplifies principles of constructive alignment, where learning objectives, activities, and assessments are tightly interlinked. By aligning the project to both curriculum standards and ESD goals, the lesson supported meaningful learning and skill development across multiple domains-cognitive, affective, and behavioral (Chand, 2023).

In conclusion, the microteaching simulation provided a crucial bridge between pedagogical planning and classroom application, enabling teachers to experiment, receive targeted feedback, and reflect meaningfully on their practice. It also served as a proof of concept for the practical integration of ESD into science education, validating the PjBL approach as both feasible and impactful. This simulation-based professional learning model

offers a replicable pathway for equipping teachers with the confidence, creativity, and competence to deliver transformative science instruction rooted in sustainability values.

## Conclusion

The three-phase professional development program effectively enhanced teachers' understanding of ESD, instructional design skills, and classroom implementation capacity. Results showed significant gains in teachers' conceptual clarity, ability to integrate Sustainability into science lessons, and confidence in delivering project-based learning (PjBL). Student feedback from the simulation phase confirmed high levels of enjoyment, satisfaction, and increased awareness of Sustainability, supporting the relevance and impact of the lesson design. To strengthen future programs, it is recommended that schools provide ongoing support for teacher collaboration, reflection, and access to contextually adaptable ESD resources. These findings suggest that well-structured, practice-oriented professional development can play a crucial role in integrating sustainability principles into science education, ultimately empowering students to engage with real-world environmental challenges through meaningful learning experiences.

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