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FROM CONCEPTS TO PRACTICE: STRENGTHENING TEACHERS' CAPACITY FOR SUSTAINABLE SCIENCE EDUCATION

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Abstrak: *Education for Sustainable Development* (ESD) merupakan sarana strategis untuk mengintegrasikan nilai-nilai keberlanjutan ke dalam proses pendidikan. Namun, penerapan ESD di sekolah masih menghadapi tantangan, terutama pada keterbatasan pemahaman dan keterampilan guru dalam merancang pembelajaran kontekstual. Kegiatan pengabdian kepada masyarakat ini bertujuan untuk memperkuat kapasitas guru IPA dalam mengimplementasikan prinsip-prinsip ESD melalui pelatihan berbasis praktik yang relevan dan kolaboratif. Pelatihan diikuti oleh 12 guru IPA di Kabupaten Garut, dengan tiga tahapan utama: pembekalan konsep, on-the-job training, dan simulasi proyek pembelajaran. Hasil evaluasi menunjukkan dampak positif, dengan lebih dari 80% peserta merasakan manfaat langsung, menilai kegiatan sesuai kebutuhan, dan menyatakan kepuasan serta kesiapan mengintegrasikan ESD. Temuan ini mengindikasikan bahwa pelatihan yang bersifat aplikatif dan berbasis pengalaman nyata mampu meningkatkan pemahaman konseptual, keterampilan pedagogis, serta kesiapan guru dalam mengintegrasikan ESD ke dalam pembelajaran IPA. Program ini memberikan dasar bagi pengembangan program pelatihan ESD berkelanjutan yang dapat diadaptasi dan direplikasi di berbagai konteks sekolah, serta memperkuat kemitraan sekolah–perguruan tinggi dalam mendukung transformasi pendidikan menuju pencapaian Tujuan Pembangunan Berkelanjutan (SDGs).

Kata Kunci: Education for Sustainable Development (ESD), pembelajaran IPA, penguatan kapasitas guru

Abstract: Education for Sustainable Development (ESD) serves as a strategic means to integrate sustainability values into the educational process. However, ESD implementation in schools still faces challenges, particularly teachers' limited understanding and skills in designing contextual learning. This community service program aimed to strengthen science teachers' capacity to implement ESD principles through practice-based and collaborative training. The program involved 12 science teachers from Garut Regency and consisted of three main stages: conceptual briefing, on-the-job training, and a project-based learning simulation. Evaluation results showed positive impacts, with more than 80% of participants reporting direct benefits, relevance to their needs, satisfaction, and readiness to integrate ESD into science teaching. These findings indicate that experiential training effectively enhances teachers' conceptual understanding and pedagogical skills. This program provides a basis for developing sustainable and replicable ESD training and for strengthening school–university partnerships to support educational transformation toward achieving the Sustainable Development Goals (SDGs).

Keywords: Education for Sustainable Development (ESD), science learning, teacher capacity strengthening

Introduction

Education for Sustainable Development (ESD) has become increasingly important amid growing global challenges, including climate change, environmental degradation, and natural resource crises. Through ESD, individuals are equipped with knowledge, skills, and attitudes that support sustainability. Thus, they can contribute to achieving the Sustainable Development Goals

(SDGs) and creating a more sustainable future (Purnamasari & Hanifah, 2021; UNESCO, 2017).

Natural Science (IPA) education has significant potential for implementing ESD, as its characteristics align with various sustainability issues. Moreover, science is taught at all levels of education, thereby supporting the ongoing implementation of ESD from primary to higher education (Eilks, 2015). Therefore, ESD needs to be implemented widely and extensively to have a greater impact on shaping sustainable awareness and behavior at various levels of education.

The effectiveness of ESD implementation largely depends on the extent to which sustainability issues are comprehensively integrated into the learning process. Climate change, environmental degradation, social inequality, and the exploitation of natural resources are examples of global issues that demand serious attention in education (Mochizuki & Fadeeva, 2010; Purnamasari & Nurawaliyah, 2023; Riess et al., 2022). By linking these issues to learning, students will not only gain academic knowledge but also develop awareness of the long-term impacts of every action on the environment and society.

Recent studies have highlighted various approaches for integrating ESD into science education, including project-based learning, inquiry-based strategies, and digital learning platforms (Damayanti & Surjanti, 2022; Kamdi et al., 2022; Matitaputty et al., 2022; Pratiwi et al., 2019; Setiyaningsih et al., 2024). These models have proven effective in enhancing students' sustainability literacy and problem-solving skills. However, most initiatives have focused primarily on student-centered interventions and have not systematically built teachers' capacity to design and implement ESD-based lessons. Furthermore, few programs combine conceptual enrichment, contextual lesson design, and direct classroom application as a holistic model. This gap underscores the need for teacher capacity-building initiatives that address both pedagogical understanding and practical implementation of ESD.

In addition to content integration, learning approaches play an essential role in realizing ESD values in the classroom. Integrating sustainability issues into ESD is not only about embedding them as learning content but also about shaping a framework of thinking that builds critical thinking and responsible decision-making skills (Nurwidiawati, 2024; Vioreza et al., 2023). By applying appropriate learning strategies, students can analyze real-world issues and seek science-based, innovative solutions. This approach also allows students to work collaboratively, develop empathy, and understand the importance of balancing economic, social, and environmental aspects in their daily lives. Therefore, learning is not merely theoretical but also encourages concrete actions that support sustainable development.

Furthermore, sustainability issues are closely related to various topics in science learning. Concepts such as climate change, environmental pollution, recycling, and energy conservation align with science topics such as ecosystems, the carbon cycle, and energy and its transformations (Riess et al., 2022). This integration helps students understand that science is not just classroom theory but also a tool for solving real-world problems.

Despite its great potential, implementing ESD in schools' science education still faces numerous challenges. Several studies have shown that teachers' understanding of ESD concepts remains limited, exacerbated by the lack of training and relevant learning resources (Eliyawati

et al., 2023; Erlina, 2021; Purnamasari et al., 2022). The current curriculum has also not fully integrated sustainability issues, making it difficult for teachers to translate ESD concepts into contextually relevant and applicable teaching practices. Limitations in teaching media, laboratories, and access to information are additional obstacles in developing optimal science learning based on ESD (Zulfah et al., 2024). As a result, the potential of science education as a medium for developing sustainability literacy has not yet been fully realized.

To overcome these challenges, concrete efforts are needed in the form of mentoring or training programs for science teachers to enhance their capacity to design and implement ESD-based learning. One approach is to integrate sustainability issues into science teaching, so that learning is not only focused on mastering concepts but also encourages students to engage in understanding and solving real-world environmental problems actively. Through this strategy, students will not only gain scientific knowledge but also develop critical thinking skills, collaboration, and social awareness of sustainability.

Based on the urgency and challenges described, it is necessary to organize programs that support teachers in improving their understanding, skills, and readiness to integrate sustainability issues into science learning as part of ESD implementation in schools. This activity is expected to make a tangible contribution to strengthening the role of education, particularly science learning, in achieving the SDGs and shaping a generation that is conscious of and cares about the future of the Earth and humanity. Therefore, systematic and continuous teacher training is essential as a key strategy for ensuring the effective and sustainable implementation of ESD in school science education.

Method

The program was implemented through three systematically structured stages aimed at strengthening teachers' competencies in integrating Education for Sustainable Development (ESD) into science learning: (1) Conceptual Briefing, (2) On-the-Job Training for Lesson Planning, and (3) Project Simulation and Reflection. The activities involved 12 science teachers from various schools in Garut Regency. The three stages were designed to be integrative and continuous, ensuring a gradual and sustainable approach to teacher capacity-building (Figure 1). consistent with staged professional development models that combine theoretical input, practical application, and reflective activities (Purnamasari et al., 2024).

In the conceptual briefing, participants were introduced to the fundamental principles of ESD, including systems thinking, critical thinking, anticipatory competence, and collaborative problem solving, as well as the urgency of ESD implementation in responding to global sustainability challenges and its relevance to science education (UNESCO, 2017, 2020). This stage was designed to build a strong theoretical foundation for teachers' understanding of ESD-oriented learning.

The on-the-job training focused on lesson planning, where teachers received mentoring through guided workshops, small-group discussions, and continuous facilitator feedback. Participants analyzed curriculum content, identified sustainability-related issues, and designed

ESD-integrated lesson plans suited to their school contexts. Facilitators supported this process by providing pedagogical guidance and examples of learning activities to ensure the lesson plans were feasible, meaningful, and aligned with curriculum requirements.

Finally, the project simulation and reflection stage provided teachers with opportunities to implement one of their lesson plans through a project-based activity, with the exploration of solar energy as a renewable resource chosen as a representative example. This stage emphasized experiential and project-based learning to connect sustainability concepts with real-world applications and classroom practice (Nguyen, 2025). Teachers worked with teaching materials, student worksheets, and simple project tools. Reflection was supported by structured facilitator feedback based on observation sheets focusing on the quality of ESD integration, lesson coherence, and the feasibility of classroom implementation. In addition, student questionnaires administered after the project were used to capture levels of learning engagement and sustainability awareness as indicators of lesson effectiveness.

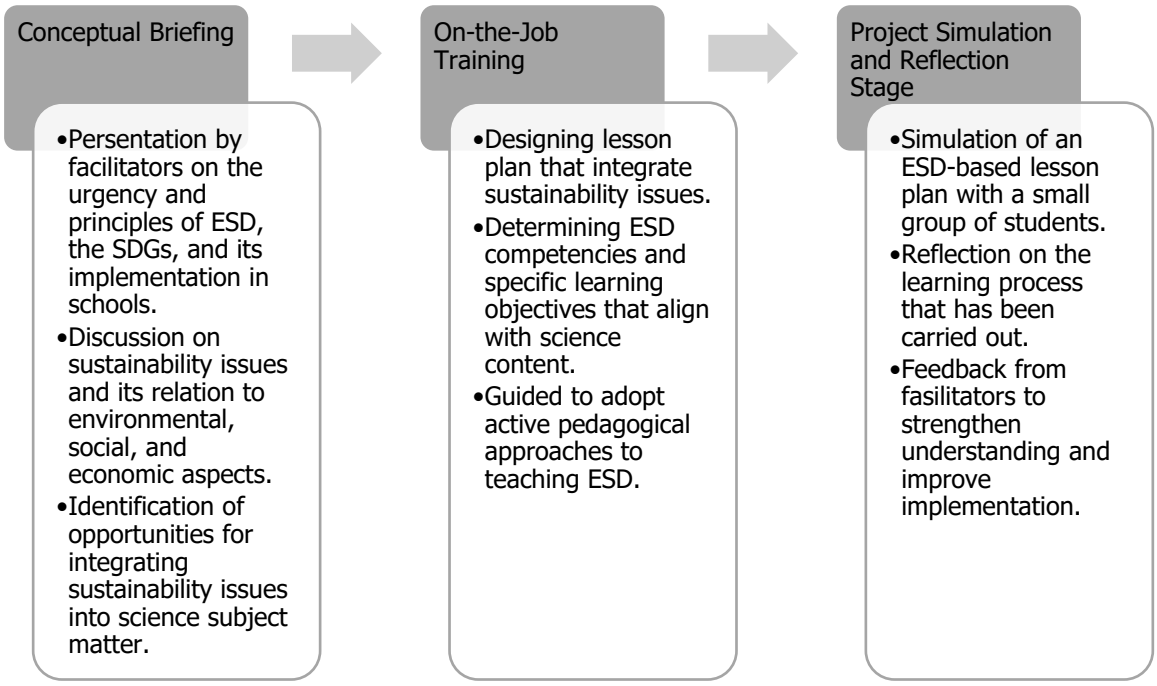


Figure 1. Activity Framework for Strengthening Science Teachers' Capacity in Implementing ESD

Results and Discussion

During the on-the-job training, teachers selected specific science themes or topics to develop lesson plans that integrated sustainability principles. These topics were tailored to align with the existing science curriculum and address local environmental issues (see Table 1 for details). This approach ensured that the lesson plans were relevant to students' everyday lives while embedding the broader context of sustainability. Teachers' selection of themes also reflected the flexibility of the training model, which allowed participants to adapt ESD integration to the specific needs and conditions of their schools. Similar flexibility and contextual adaptation have been identified as key factors contributing to the effectiveness of community-based

capacity-building programs, particularly when participants are encouraged to align new approaches with their existing practices (Hamdiani et al., 2024).

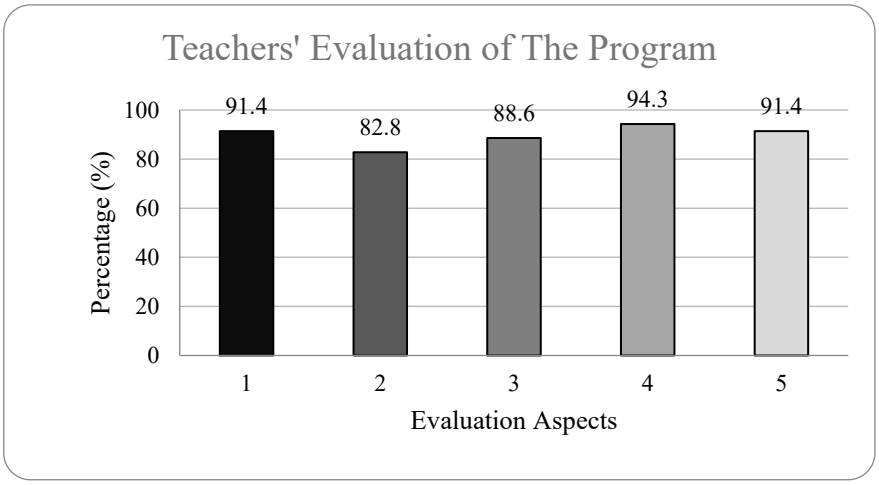
Table 1. Science Topics Chosen by Participants for ESD-Integrated Lesson Planning

No.	Science Topics	Related SDGs
1.	Renewable energy	SDG 7, SDG 13, SDG 9
2.	Waste management	SDG 12, SDG 6, SDG 11
3.	Biotechnology and food security	SDG 2, SDG 3, SDG 9
4.	Ecology and biodiversity conservation	SDG 14, SDG 15, SDG 13
5.	Water cycle systems	SDG 6, SDG 13, SDG 11
6.	Human body system and well-being	SDG 3, SDG 2, SDG 6
7.	Disaster mitigation and climate change	SDG 13, SDG 11, SDG 3

This community service program was conducted to strengthen the capacity of science teachers in integrating ESD values into their teaching practices. The program's effectiveness was evaluated using a satisfaction questionnaire distributed to participants after all activities were completed. The data show that the program had a positive, relevant impact on participants, as illustrated in Figure 2.

Based on Figure 2, 91.4% of participants stated that the program met their needs as science teachers. This result indicates that the approach and training content, particularly during the conceptual briefing stage, were well-targeted and successfully addressed the real challenges teachers face in implementing sustainability-based (ESD) teaching. The conceptual briefing session conducted by the university team (Figure 3) served as a crucial foundation in strengthening participants' understanding of integrating sustainability principles into classroom practice. Consistent with UNESCO (2017) perspective, teachers need contextual professional development opportunities to equip students with the knowledge, skills, and values required to address global issues responsibly. The relevance of the training content to real-world classroom needs is also reinforced by Ortan et al. (2021), who emphasized that training aligned with teachers' daily experiences and challenges tends to produce greater impact and more tangible benefits for participants.

Furthermore, 82.8% of participants stated that the program met their expectations. This percentage indicates that the majority felt the program met their initial expectations regarding content, training methods, and its relevance to their professional roles as educators. This level of satisfaction underscores the importance of training designed based on real needs and classroom contexts. As Nezhad & Stolz (2025) asserted, the effectiveness of teacher professional development largely depends on the connection between training content and authentic classroom practice. Moreover, as Ford et al. (2018) note, teachers' satisfaction levels are strongly influenced by elements such as structured mentoring, relevant and applicable training content, and a collaborative learning environment, all of which are factors closely linked to the perceived relevance of professional development programs.



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

Figure 2. Graph of Participants' Evaluation of the Training Program.

Figure 3. The conceptual briefing session was conducted by the team for the training participants

The participants' overall satisfaction rate was also high at 88.6%. This rate demonstrates that the participatory and hands-on approach used in the training provided a meaningful learning experience that went beyond passive content delivery. According to Ajani (2023), adult learners tend to be more motivated to learn when the learning is relevant and applicable, particularly when it involves direct experience and critical reflection.

The highest percentage (94.3%) was recorded among participants who experienced direct benefits from the program. These benefits included improved understanding of ESD concepts, enhanced skills in designing contextual lessons, and hands-on experience in conducting a solar energy project with students. This project served as a critical medium for introducing renewable energy issues while embedding sustainability awareness through active learning. In this regard, the use of projects as an experiential learning vehicle is considered strategic, as Chiu & Lee (2019) stated that effective learning occurs when participants actively experience and reflect on the process.

Beyond participants' perceptions, the quality of lesson design and classroom simulation was examined through structured facilitator feedback and observation sheets. These indicated

improvements in ESD integration, lesson coherence, and classroom implementation feasibility. Teachers demonstrated clearer alignment among sustainability concepts, learning objectives, and instructional activities, reflecting strengthened pedagogical capacity to design contextually oriented ESD lessons. For instance, one facilitator noted:

> "*Teachers began integrating reflective questions in their lessons, but could further encourage students to connect classroom learning with community sustainability practices*"

At the same time, feedback highlighted areas requiring further refinement, particularly related to assessment strategies and classroom time management. These findings underscore the importance of continuous professional feedback in supporting reflective practice and the sustainable implementation of ESD-based instruction (Li et al., 2024).

The success of these outcomes is closely linked to the program's design, which integrated on-the-job training during the second stage (Figure 4). This approach allowed participants not only to receive theoretical knowledge but also to be guided in developing ESD-based teaching materials tailored to their school contexts. Intensive mentoring encouraged teachers to reflect on previous teaching practices, adopt new approaches, and enhance their pedagogical skills directly within their working environments. This strategy proved effective in building teachers' readiness and confidence to implement ESD teaching sustainably. As Darling-Hammond et al. (2017) noted, training programs conducted over a sufficient duration with continuous support yield a stronger impact on changes in teaching practice.

Figure 4. On-the-job training session on ESD-based lesson design

The third stage, the teaching simulation, further reinforced the program's impact. The simulation provided teachers with an opportunity to test the lesson plans they had developed in real classroom settings with students (Figure 5). This activity fostered both technical and reflective skills, enabling teachers to receive immediate feedback from students and facilitators and to revise their instructional strategies accordingly. This stage was therefore crucial in connecting conceptual understanding, lesson planning, and classroom practice holistically. The simulation's implementation also aligns with the principles of design-based implementation research (DBIR), in which teaching practices are tested in authentic contexts to generate feedback for continuous improvement (Fishman et al., 2013). The simulation served as a bridge between innovation and real-world practice, strengthening the sustainability of the program's impact.

Figure 5. ESD-based project simulation activity with small groups of students

To examine initial classroom-level impacts, a post-project questionnaire was administered to 24 students following the solar oven activity. The questionnaire measured student engagement and sustainability awareness. As shown in Figure 6, students' responses were consistently positive across all items, with all responses falling within the "agree" and "strongly agree" categories. Students reported high enjoyment, interest, and satisfaction with the learning activity, as well as positive collaborative experiences and willingness to engage in similar projects. In addition, students expressed greater awareness of environmental issues, a stronger sense of personal responsibility for sustainability, and an interest in applying sustainable practices in daily life. These findings provide preliminary evidence that ESD-integrated, project-based learning can foster meaningful engagement while also supporting the development of sustainability-oriented attitudes, consistent with research showing that project-based and ESD-oriented interventions enhance student engagement and sustainability awareness in science education contexts (Nurazizah et al., 2024; Setiawan et al., 2023).

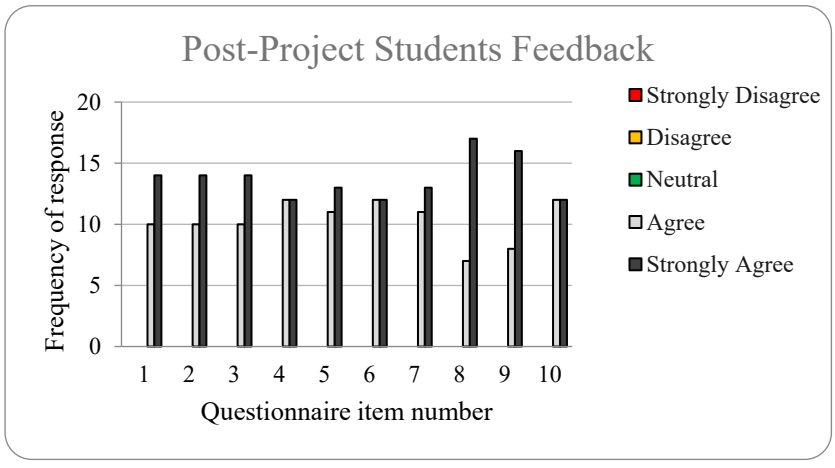


Figure 6. ESD-based project simulation activity with small groups of students

Finally, 91.4% of participants expressed hope that similar programs would continue, highlighting the ongoing need for teacher capacity-building initiatives that support contextual, applicable, and sustainability-oriented science education. This finding is consistent with similar community-based sustainability programs, which also report strong participant commitment to program continuity, indicating that well-designed initiatives can foster long-term engagement and institutional impact (Yolanda et al., 2024). To sustain the program's impact, a light-touch

mentoring approach tailored to teachers' needs can be implemented. This approach enables teachers to seek guidance during the early stages of classroom implementation without creating excessive demands, while fostering continuous professional interaction and collaborative problem-solving. Thus, this community service program not only achieved its short-term objectives but also created opportunities for sustainable professional development to enhance the quality of science education through Education for Sustainable Development.

Conclusion

Based on the program's results, it can be concluded that strengthening science teachers' capacity through contextual training focused on implementing Education for Sustainable Development (ESD) has proven effective as a strategy for sustainable education. The high percentage of participants who stated that the training content met their needs and expressed satisfaction with the program indicates that training designed for real field conditions, accompanied by easily understandable conceptual briefings and hands-on practice, can better prepare teachers to implement ESD in the classroom. These findings underscore the importance of designing teacher training programs that are contextual and applicable, not only delivering theoretical knowledge but also providing direct learning experiences relevant to classroom challenges. Such training improves teachers' understanding and skills in integrating the principles of Education for Sustainable Development (ESD) and strengthens collaboration between higher education institutions and schools in supporting educational transformation toward greater sustainability. Future programs should consider involving more participants and schools to broaden impact and ensure the scalability of this model of teacher capacity-building.

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