

## INNOVATING CLIMATE AND RENEWABLE ENERGY EDUCATION THROUGH DEEP LEARNING AND THE ENGINEERING DESIGN PROCESS

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### Abstract

The rapid advancement of digital technology has transformed educational practices, demanding innovative approaches that foster deep learning and connect knowledge with real-world contexts. This study aims to develop a deep learning pedagogical model based on the Engineering Design Process (EDP) and a triple learning approach (meaningful, mindful, and joyful learning) within renewable energy projects in the digital era. An implementation approach was applied through contextual projects in which students designed and constructed renewable energy systems, engaging in continuous research, critical reflection, and problem-solving. The projects were carried out following the stages of the EDP, namely problem identification, ideation, planning, implementation, testing, and evaluation. The results indicate that the integration of EDP with a deep learning approach enhances active engagement, interdisciplinary conceptual understanding, and reflective awareness of energy sustainability issues. Students demonstrated critical, creative, and collaborative thinking skills through meaningful and enjoyable learning experiences. This model not only fosters ecological awareness but also develops scientific competencies relevant to the demands of 21st-century education. Therefore, the integration of EDP and the triple learning approach represents an educational innovation that supports transformative learning and aligns with the Sustainable Development Goals (SDGs).

**Keywords:** deep learning, educational innovation, Engineering Design Process, renewable energy education

### Introduction

The changing era, marked by advancements in technology and science, necessitates adjustments within the educational system. Education is expected to produce a generation that is not only academically competent but also aware and skilled in addressing global challenges. One of the major issues that must be addressed through education is the climate crisis. Climate change has become one of the defining global challenges of the 21st century, characterized by rising global temperatures, extreme weather events, and environmental crises that threaten the sustainability of human life. One of the primary causes is humanity's dependence on fossil fuels, such as oil, coal, and natural gas, which produce significant greenhouse gas emissions.

In the *Laudato Si'* encyclical, Pope Francis (2016) emphasizes that the environmental crisis is closely linked to a moral and value crisis concerning



humanity's responsibility toward creation. Excessive exploitation of nature and a consumptive lifestyle reflect a failure to understand the moral duty of stewardship over creation. Ultimately, this moral crisis leads to indifference toward the ethical responsibility of preserving creation, including a lack of concern for future generations who will bear the consequences of environmental degradation. Therefore, healing the relationship between humanity and nature requires a transformation of mindset and awareness that caring for the Earth also means upholding human dignity and safeguarding the future of generations to come.

In line with the demands of 21st-century education, students are challenged to develop critical, collaborative, creative, and communicative skills (4C) (World Economic Forum, 2016). These competencies are highly relevant when students are confronted with global issues such as the energy crisis and climate change. The topic of renewable energy can serve as a contextual and meaningful learning medium that simultaneously fosters ecological awareness. Thus, integrating renewable energy issues into educational practices presents a strategic opportunity to cultivate a generation that is adaptive and responsive to global challenges.

However, in reality, the current education system still faces a number of challenges that hinder the achievement of these goals. One of the main factors contributing to students' low awareness of climate change and renewable energy utilization is a curriculum that has not yet fully adapted to the needs of the surrounding environment. A curriculum pattern that places excessive emphasis on theoretical content causes learning to lose its relevance to real-life contexts. As a result, students struggle to develop critical thinking and creativity skills and are often unaccustomed to addressing complex problems systematically.

Furthermore, teaching methods that remain focused on rote memorization exacerbate this issue. Most students are accustomed to memorizing rather than understanding, causing knowledge to become goal-oriented and temporary, limited to achieving report card grades or meeting graduation requirements. Such an approach emphasizes curriculum completion rather than the development of students' learning abilities (Nuha et al., 2024). Consequently, much of the knowledge acquired during basic education tends to be forgotten. This has also been observed by the author during informal mentoring sessions in student scientific competitions, where participants often struggled to grasp the fundamental scientific concepts underlying their research projects.

To address the challenges of 21st-century education and the digital era, a learning approach is needed that not only focuses on product outcomes but also fosters deep and reflective thinking processes. The Engineering Design Process (EDP) integrated with deep learning principles offers an innovative strategy to achieve this objective. Through a systematic sequence of stages, students are trained to connect scientific and technological concepts with real-life contexts (*meaningful learning*), to develop awareness of their cognitive processes and emerging values (*mindful learning*), and to experience positive emotional engagement during exploration (*joyful learning*).

Therefore, this article aims to develop a deep learning pedagogical model based on the EDP and the triple learning approach (meaningful, mindful, and joyful) within renewable energy projects in the digital era. It is expected that this work will make a substantial contribution to the development of educational

practices aligned with the values of *Laudato Si'* while simultaneously supporting the achievement of the Sustainable Development Goals (SDGs).

### ***Deep Learning***

Deep learning in the context of education refers to a learning process that emphasizes deep, critical, and meaningful conceptual understanding. This approach focuses on constructing knowledge through active student engagement, enabling students to move beyond rote memorization (*surface learning*) and to connect learned concepts with real-life contexts (Prihantini et al., 2025). Deep learning encourages students to develop critical and creative thinking skills, as well as problem-solving abilities relevant to the challenges of the 21st century. This approach is not entirely new; rather, it represents a pedagogical orientation aimed at enhancing learning effectiveness by emphasizing student activity, reflection, and collaboration (Khotimah & Abdan, 2025). In the context of Indonesian education, the implementation of deep learning is essential for cultivating critical and adaptive mindsets among both students and teachers, equipping them to navigate the complexities of the digital era and globalization (Diputera et al., 2024).

Furthermore, the deep learning approach integrates three core elements: meaningful learning, mindful learning, and joyful learning (Feriyanto & Anjariyah, 2024). First, *meaningful learning* connects new knowledge with prior understanding, allowing students to comprehend concepts contextually. Second, *mindful learning* emphasizes full awareness, focus, and reflection throughout the learning process. Third, *joyful learning* fosters an enjoyable and motivating learning atmosphere, wherein happiness serves as a crucial factor in enhancing engagement and learning outcomes.

### ***Engineering Design Process (EDP)***

The Engineering Design Process (EDP) is a systematic way of thinking used to teach and apply concepts and skills in an integrated manner. The EDP approach is increasingly used in Science, Technology, Engineering, Arts, and Mathematics (STEAM) education as a strategy to develop students' creative, critical, and collaborative thinking skills. EDP is seen as a new trend in science education reform because it provides contextual learning experiences through systematic engineering stages, from identifying problems, designing solutions, testing, and evaluating, to communicating results (Jolly, 2016; Winarno et al., 2020).

The main stages of EDP include identifying the problem along with criteria and constraints (*identify*), exploring and generating ideas (*imagine*), developing plans and selecting group designs (*plan*), building prototypes and testing results (*create*), and improving designs based on evaluation outcomes (*improve*). This process is iterative, meaning that each step can be repeated to allow for continuous improvement. In its implementation, students are also encouraged to engage in reflection and communication, both about the process and the results, fostering critical thinking, resilience, and more comprehensive STEM skills (Texas Education Agency, 2022).

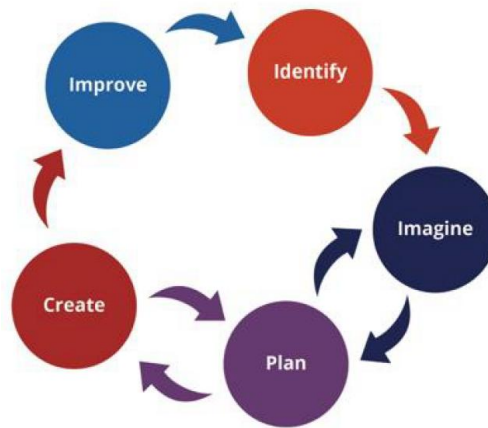


Figure 1. Main stages of the Engineering Design Process (Texas Education Agency, 2022)

By applying EDP, research by Sudrajat et al. (2023) showed a significant improvement in students' creative thinking skills and product creativity in the topic of alternative energy. This finding demonstrates that EDP is not only effective in enhancing the understanding of scientific concepts but also in developing 21st-century skills that are essential for addressing global challenges such as the energy crisis and climate change.

## Method

This study was conducted within the Sanggar Ursula Community, a non-formal, technology-based learning space that serves as a bridge between the application of science in real-world contexts and academic learning. The research subjects included junior and high school students as well as university students participating in the *Electronics Science Program*, either through extracurricular activities or specialized mentoring sessions for scientific project competitions. Participants who joined the Sanggar Ursula Community met several criteria: they demonstrated an interest in science and technology projects and expressed willingness to engage in the full sequence of EDP-based activities. The focus of the study was directed toward observing the learning process, strengthening practical skills, and developing students' abilities to integrate scientific and technological concepts through applied project-based activities.

This research employed a qualitative approach with an implementation study design. This approach was chosen to explore in depth how a project-based learning process focusing on the design and development of renewable energy systems can enhance students' problem-solving skills. The data sources consisted of direct observations of student activities within the Sanggar Ursula Community, where participants engaged in Engineering Design Process (EDP)-based learning.

The study adopted the EDP framework as the primary approach to integrating deep learning into project-based renewable energy system learning. EDP was selected for its systematic stages that encourage students to think critically and creatively through authentic learning experiences. Each stage of the EDP was integrated with the three elements of deep learning, namely meaningful, mindful, and joyful learning, to promote a holistic and reflective learning process.

In the problem identification stage, students were guided to foster *meaningful learning* by generating ideas derived from real-world environmental issues and connecting them to national and global concerns. This process helped students recognize the meaning and relevance of their learning to everyday life. Subsequently, the preliminary research stage was designed to cultivate *mindful learning*, in which students explored the scientific principles underlying their project ideas, conducted observations, and analysed relevant literature to ensure that their project rationales were supported by a strong scientific foundation. In the project planning stage, students developed activity designs, identified necessary resources, and determined timelines and cost estimations. The project implementation stage integrated *joyful learning* through hands-on activities such as executing project plans, collecting data, creating prototypes, and conducting testing. The final evaluation stage involved reflection, discussion, and feedback sessions aimed at encouraging continuous improvement. The EDP framework, when integrated with the three elements of *deep learning*, not only reinforces students' mastery of scientific concepts but also enhances their critical, creative, collaborative, and communicative (4C) skills, competencies that are essential for 21st-century learning.

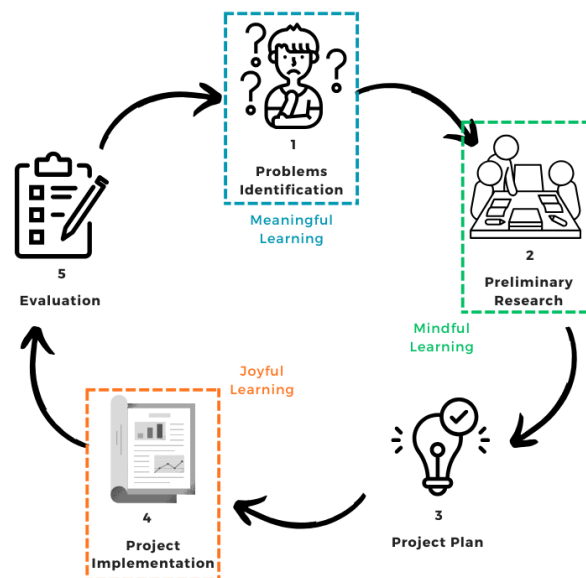


Figure 2. Flow diagram of the Engineering Design Process (Author's illustration)

Data were collected through observation, documentation of students' project activities, and informal interviews. Because the learning environment was non-formal, observations were conducted continuously as students progressed through the stages of the EDP. The researcher observed students' interactions, prototype development, and their reflections and responses to the learning experiences.

Data analysis was conducted using a qualitative-descriptive approach through three stages. The first stage was data reduction, which involved sorting and selecting data obtained from observations, documentation, and students' reflections according to the focus of the study. The second stage was data presentation, in which information was organized into categories such as critical thinking, collaboration, creativity, and problem-solving skills. The third stage was conclusion

drawing, which entailed interpreting the findings based on the EDP and deep learning frameworks to assess students' developmental progress.

### Findings and Discussion

An example of implementing the EDP in the context of climate change and renewable energy is a project focused on regulating the conversion of multiple renewable energy sources, such as solar, hydro, and wind energy, into electrical energy. The idea for this project originated from observations of society's dependence on fossil fuels and their detrimental environmental impacts. On the other hand, the intermittent nature of renewable energy poses unique challenges in maintaining energy supply stability. Students were guided to recognize the importance of clean and sustainable energy and to understand that carbon emission reduction can be achieved through innovations in renewable energy technology.

During the preliminary research stage, students were trained to conduct simple observations of natural energy potentials in their local environment. In addition, they explored literature on the basic principles of energy conversion, including the laws of energy conservation, Ohm's Law, and Kirchhoff's Law, as foundational knowledge for electrical system calculations. This stage not only aimed to deepen their theoretical understanding but also to build a rational foundation for their project ideas based on real-world conditions.

Subsequently, students were introduced to designing a multi-source energy conversion system in the form of a block diagram. The energy generated from various sources was designed to flow into a control system equipped with autonomous correction mechanisms. The system's output was then directed toward an energy storage component.

In the final evaluation stage, the focus was placed on the engineering process of the energy conversion system and the quantitative measurement of the renewable energy fluctuations produced. The primary goal of this learning activity was to introduce students to the principles of renewable energy conversion into electricity while fostering awareness of the interconnection between scientific knowledge and God's creation, nature itself.



Figure 3. Project-based learning activities incorporating the Engineering Design Process (Author's documentation)

As another example, students applied the stages of the EDP through the design of a *Green Bicycle*, a mode of transportation capable of converting solar energy through solar panels and mechanical energy from pedalling into electrical energy. The project began with students' observations of carbon emissions produced by motor vehicles and their impact on climate change. From these

observations and classroom discussions, students realized the need for eco-friendly transportation innovations that could reduce dependence on fossil fuels. This awareness served as the initial foundation for cultivating ecological responsibility and motivation to develop tangible solutions.

During the preliminary research stage, students sought references on the working principles of solar panels, generators, and electrical energy storage systems. They applied these principles to strengthen the design foundation of the project according to real-world needs in their surrounding environment. Subsequently, students were trained to design a system that utilizes solar panels to capture sunlight and generators to convert kinetic energy into electrical energy. In this design process, physics concepts such as kinetic energy, solar energy, and energy efficiency served as the basis for technical decision-making. Next, students were guided to assemble a prototype of the “green bicycle” using simple materials, including used bicycles, mini solar panels, small dynamos, and batteries.

In the final evaluation stage, reflection became the main focus. Students were encouraged to relate the project to global issues of carbon emission reduction and the role of individuals in shaping sustainable technology. The *Green Bicycle* project not only emphasized an understanding of energy concepts but also fostered students’ ecological awareness in seeking environmentally friendly transportation solutions. Beyond increasing awareness of climate change, this learning experience nurtured students’ innovative attitudes, technical skills, and critical thinking in exploring sustainable alternative energy solutions.



Figure 4. *Green Bicycle* as part of the Engineering Design Process (Author’s documentation)

Both projects demonstrate that the implementation of the EDP, when integrated with deep learning, plays a crucial role in fostering meaningful learning experiences. Through this approach, students not only solve technical problems but also connect learning with social and environmental contexts. Each stage of the EDP serves as a reflective space where students learn to link concepts, conduct scientific exploration, and reassess their work outcomes. This process reflects the essence of deep learning, which emphasizes meaningful understanding and reflective awareness.

The integration of meaningful learning is evident when students recognize the relevance between energy concepts and real-life applications. They do not merely comprehend physical theories; rather, they connect scientific concepts with social contexts and ecological implications. In the multisource energy project, students learned that managing renewable energy sources can reduce dependence on fossil

fuels and promote environmental sustainability. Meanwhile, in the *Green Bicycle* project, they discovered how simple technologies can contribute to carbon emission reduction. The connection between scientific concepts and social contexts fosters ecological awareness, making the learning process more meaningful and contextual.

The element of mindful learning emphasizes reflective awareness toward thinking and acting during scientific inquiry. In the multisource energy project, students not only designed an automatic system to regulate energy conversion but also consciously observed energy supply imbalances, questioned their causes, and sought solutions. In the *Green Bicycle* project, as one student expressed, “*Tujuannya membuat energi bersih, karena energi kotor merusak dunia. Nggak mau kan nanti pas anak-anak dan cucu kalian harus pakai masker setiap mau keluar rumah,*” (“The goal is to create clean energy because dirty energy harms the world. You wouldn’t want your children and grandchildren to have to wear masks every time they go outside, would you?”). This shows their ability to connect technical decisions with ethical and environmental implications. This reflective process strengthens students’ ability to recognize the interrelationship between human actions, technology, and environmental sustainability. Hence, mindful learning cultivates a scientific mindset that is conscious of ecological consequences and the ethics of technology, making science learning not only intellectually rigorous but also morally grounded.

Meanwhile, the application of joyful learning creates a more engaging and creative learning atmosphere. Students expressed excitement when the Green Bicycle successfully powered a lamp, with several noting that it was their first time seeing their own energy production in action. This experience shows that project-based learning serves not only as a cognitive platform but also as an emotional and motivational one. The sense of joy and active engagement encouraged students to continuously explore new ideas and develop sustainable innovations.

Overall, the integration of meaningful, mindful, and joyful learning establishes a comprehensive, deep learning process, in which students not only develop a reasoned understanding of interdisciplinary concepts but also demonstrate reflective awareness of ecological issues and creative innovation in designing sustainable energy solutions. Theoretically, the findings indicate that integrating the three elements of deep learning with the Engineering Design Process (EDP) reinforces the characteristics of deep learning pedagogy within the context of digital era education. This learning model not only facilitates mastery of renewable energy concepts but also cultivates reflective, creative, and ecologically conscious ways of thinking. Thus, this approach can serve as a prototype for sustainable digital pedagogy that is relevant to the STEAM domain, particularly in addressing issues related to energy and environmental sustainability.

Observations and reflections of the learning process revealed that 21st-century skills, such as collaboration, scientific communication, and critical thinking, were effectively developed among students. They were able to engage in scientific discussions, present their design outcomes, and explain the operational principles of their prototypes to peers and instructors. In terms of awareness, project-based learning nurtured ecological empathy and a sense of environmental responsibility. Students began to perceive climate change not merely as a global problem but as a challenge that can be addressed through innovation and concrete

local actions. However, some students had not yet developed process awareness, as EDP and deep learning, based approaches require habituation to reflective thinking rather than focusing solely on final results.

Based on interviews and observations, students reported that project-based learning was far more effective than conventional, theory dominant methods. One student expressed,

*“Menurut saya pembelajaran dengan metode project-based learning ini jauh lebih efektif dibandingkan belajar teori aja. Perlu diadakan di sekolah-sekolah, karena pada kenyataannya pengetahuan bukan sekedar ilmu, tetapi digunakan di dunia nyata. Tantangannya adalah bagaimana cara menggunakan ilmu itu,”* (“In my opinion, project-based learning is far more effective than just learning theory. It should be implemented in schools because knowledge is not merely information; it is meant to be used in the real world. The challenge is how to apply that knowledge.”).

They perceived a direct connection between learning and real-world contexts, which made it easier to comprehend grand theoretical concepts. This finding aligns with the perspectives of Piaget and Dewey, who emphasized that students construct understanding through engagement with “real-life” experiences (Lu S.-Y. et al., 2021).

Despite these positive outcomes, implementing project-based learning through EDP and deep learning approaches also presents challenges. Some students required additional time to adapt, as such methods are rarely practiced in formal schools. Furthermore, internal motivation and social environmental support significantly influence project success. Therefore, to ensure sustainability, it is essential to provide teacher training, adequate learning facilities, and institutional policies that allow space for innovative pedagogical approaches.

## **Conclusion**

Project-based learning through the Engineering Design Process (EDP) has been proven to foster a deep learning process that is meaningful, reflective, and joyful. Students not only comprehend the concepts of energy and their real-world applications but also internalize the values of sustainability and ecological responsibility as an integral part of their scientific awareness. The integration of meaningful, mindful, and joyful learning within each stage of EDP strengthens the learning process by emphasizing the interconnection between scientific knowledge, reflection on real-world problems, and innovation development. Therefore, this approach has the potential to serve as an innovative pedagogical model in the digital era, promoting STEAM learning that emphasizes environmental sustainability and the cultivation of critical and creative thinking skills.

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