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Integrating Science and Engineering Design through EDP-STEM Projects on Light and Heat Energy in Primary Education

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Abstract

This study implements the Engineering Design Process (EDP) within a STEM learning framework to enhance fifth-grade students' problem-solving skills in science topics on light and heat energy. Employing a descriptive qualitative approach, the implementation was conducted at SD Negeri Bawakaraeng 1 Makassar with thirty students over eight learning sessions. Classroom observations, students' reflective notes, and project documentation were used to portray how learners engaged with science concepts through engineering design tasks. Learning activities followed five EDP–STEM stages: problem scoping, idea creation, designing and constructing, assessing design, and redesigning centered on a solar-oven project that connected theory to real-world application. Results showed progressive development in identifying problems, generating creative ideas, testing hypotheses, and revising designs. The iterative process strengthened understanding of light and heat concepts while fostering collaboration, creativity, and critical thinking. The findings suggest that integrating EDP–STEM into primary science learning provides authentic, hands-on experiences that cultivate scientific reasoning and twenty-first-century competencies.

Keywords: Engineering Design Process, STEM Learning, Light and Heat Energy, Primary Education

1 INTRODUCTION

Preparing students for twenty-first-century challenges requires science education that goes beyond memorizing facts and formulas. Learners must think critically, collaborate, communicate ideas, and design creative solutions to real-world problems (Daryanes et al., 2023; Mourtzis et al., 2022). In Indonesia, these demands are embedded in the Merdeka Curriculum, which emphasizes inquiry-based and contextual learning. However, many classroom practices remain traditional—dominated by teacher explanations and routine exercises that limit opportunities for hands-on investigation and exploratory thinking (Babalola et al., 2020; DeCaro et al., 2023). To align with curriculum expectations, science learning needs to shift toward approaches that promote authentic inquiry and active knowledge construction.

To make science learning meaningful, young students need experiences that mirror how scientists and engineers solve problems in the real world. One approach that bridges both domains is the Engineering Design Process (EDP), which guides learners to identify problems, generate ideas, design and build prototypes, test their solutions, and refine their thinking (English et al., 2017; King & English, 2016). When embedded within a STEM framework, EDP encourages students to apply scientific concepts through experimentation, creative reasoning, and teamwork, skills often underdeveloped in elementary classrooms (Bybee, 2013; Ziaeefard et al., 2017). The process further supports persistence, reflection, and self-confidence qualities essential for developing scientific literacy and engineering thinking (Erol, 2024; Estapa & Tank, 2017).

Energy topics, especially light and heat, provide an excellent entry point for this integration. These concepts are visible in everyday life and can be connected to environmental awareness and sustainable technology. However, many students still struggle to explain how light interacts with materials or how absorbed light can transform into heat (Métioui, 2023; Wahyudiana et al., 2021). Turning such abstract ideas into tangible experiences helps them see the relevance of science. A simple yet powerful project is designing a solar oven, where students use mirrors, foil, and recycled materials to capture sunlight and convert it into heat. Through this activity, they not only learn about reflection and insulation but also experience the satisfaction of engineering something functional and eco-friendly.

This paper presents a classroom practice that integrates science and engineering design through an EDP–STEM project on light and heat energy for fifth-grade students. The paper highlights how the design process supports active inquiry and authentic problem-solving in primary science learning. It illustrates how the EDP stages were implemented to guide students' conceptual exploration and collaborative reasoning during the solar-oven activity. The discussion highlights how each phase of the EDP encourages students to think, test, and refine their ideas collaboratively, demonstrating that engineering design can serve as an effective pathway to foster curiosity and creativity in science classrooms.

2 RESEARCH METHODS

The main objective of this study was to describe how the Engineering Design Process (EDP) within a STEM framework was implemented to support primary-school students' learning of light and heat energy. The classroom implementation was designed to give students opportunities to explore scientific ideas, construct prototypes, test their designs, and engage in collaborative reasoning through a solar-oven project. The study aimed to portray students' learning experiences naturally, without manipulating the instructional setting or applying experimental treatment.

A descriptive qualitative approach was employed, which is suitable for capturing classroom interactions, processes, and students' thinking in an authentic learning environment (Creswell, 2012). The implementation took place at SD Negeri Bawakaraeng 1 Makassar, Indonesia, involving 30 fifth-grade students during the 2025 academic year. Data were collected through observations, documentation, and students' written reflections. Classroom observations were carried out across eight learning sessions to record how students engaged with each EDP stage: problem scoping, idea creation, designing and constructing, assessing design, and redesigning—based on the EDP framework described in previous studies (English et al., 2017). Documentation included students' worksheets, design sketches, prototype photos, and project outcomes, while reflective journals provided insight into students' reasoning, difficulties, and ideas during the activity. All data were analyzed descriptively to identify emerging patterns related to student interaction, inquiry, and conceptual understanding throughout the EDP–STEM cycle.

3 RESULT AND DISCUSSION

3.1. Result

The integration of the Engineering Design Process (EDP) within STEM learning provided a dynamic framework for students to explore scientific ideas through hands-on design. Throughout the project, students gradually developed more systematic ways of thinking and problem-solving as they moved through the five iterative stages of the EDP model: problem scoping, idea creation, designing and constructing, assessing design, and redesigning. The following results present key learning moments and reflections from each phase.

3.1.1 Problem Scoping: Framing Real-World Challenges

At the beginning of the project, students were introduced to the concept of renewable energy and discussed how sunlight could be converted into heat energy. They shared everyday experiences such as how cars feel hotter under sunlight or how black objects warm up faster. These discussions helped them connect prior knowledge with the design challenge—creating a solar oven that could utilize sunlight effectively. Guided questioning led students to identify variables such as material type, color, and shape that influence heat absorption. Students began to see science as a means to address environmental and practical issues, rather than merely to answer textbook questions.

3.1.2 Idea Creation: Generating and Evaluating Design Possibilities

During the brainstorming stage, students proposed a wide range of possible designs for their solar ovens. They explored options involving reflectors, insulation layers, and different box shapes. Working in groups allowed students to negotiate ideas, compare options, and select designs that were feasible based on available materials. Their ideas showed increasing creativity and originality as they considered how to maximize heat absorption and retention.

3.1.3 Designing and Constructing: Translating Ideas into Prototypes

After selecting their preferred designs, students created sketches and began building prototypes using cardboard boxes, aluminum foil, plastic wrap, and other recycled materials. They measured and cut materials accurately, adjusted angles, and experimented with different surface configurations. Students demonstrated persistence and careful attention to detail as they assembled their prototypes. Several groups made early adjustments when they noticed misalignment or weak insulation during construction.

3.1.4 Assessing Design: Testing and Interpreting Results

Each group tested their solar ovens under direct sunlight and recorded temperature changes at consistent time intervals. The results varied among groups; some prototypes heated rapidly while others warmed more slowly. Students compared their measurements, noted differences in efficiency, and identified potential causes such as insufficient insulation, weak reflector angles, or incomplete sealing of the oven window. They began recognizing how specific design choices affected the performance of their ovens.

3.1.5 Redesigning: Refining and Reflecting on Learning

In the final stage, students refined their prototypes based on the testing outcomes. They strengthened structural components, added additional reflective surfaces, improved insulation, and modified flap angles to capture more sunlight. Many groups observed improved heating performance after redesigning their ovens. Students expressed greater confidence in modifying their designs and were able to explain how their changes influenced the results. This stage highlighted their ability to apply feedback and make purposeful improvements.

Overall, students showed progressive development in identifying problems, generating ideas, constructing prototypes, evaluating outcomes, and refining designs. Their participation across all stages demonstrated increasing engagement, creativity, and understanding of how light and heat interact within the context of engineering design. The observable progression of their learning is summarized in Table 1.

Table 1. Summary of Students' Learning Process during EDP–STEM Implementation on Light and Heat Energy Project

EDP Stage	Main Activities in the Solar Oven Project	Observed Problem-Solving Skills	Learning Highlights
Problem Scoping	Discussing sunlight, heat, and daily-life phenomena; identifying issues	*Defining the problem* – recognizing real-world challenges	Students linked their experiences (e.g., sunlight on car windows)

	related to renewable energy.	and relevant variables.	with the concept of energy transfer.
Idea Creation	Brainstorming various oven designs using recycled materials; evaluating possible structures.	*Formulating questions and strategies.*	Students compared designs, debated which materials best absorb or reflect heat, and selected feasible options collaboratively.
Designing and Constructing	Sketching plans and building solar ovens using cardboard, foil, and plastic wrap.	*Considering and finding solutions.*	Students demonstrated persistence and creativity while constructing; they measured and adjusted reflective angles independently.
Assessing Design	Testing ovens under direct sunlight; measuring temperature changes using thermometers.	*Evaluating implemented solutions.*	Students analyzed data, discussed why some ovens worked better, and reflected on variables affecting efficiency.
Redesigning	Revising prototypes based on test results; improving insulation and reflector placement.	*Drawing conclusions and continuous improvement.*	Students became more confident and aware that design requires testing, reflection, and iteration.

The results across all stages demonstrate how students progressed conceptually and procedurally through the EDP cycle.

3.2. Discussion

The implementation of the EDP–STEM approach in the light and heat energy project demonstrated that hands-on, iterative design tasks can effectively cultivate students' scientific reasoning and problem-solving abilities at the primary level. Through each stage of the design cycle, students learned not only scientific concepts but also how to apply them to authentic, real-world challenges. This reflects the essential purpose of STEM education to integrate knowledge across disciplines and engage learners in practical innovation (Bybee, 2013; Kelley & Knowles, 2016).

The project provided evidence that elementary students are capable of engaging in engineering design thinking when given structured guidance. As King and English (2016) note, the process of ideating, building, testing, and redesigning nurtures both creative and analytical skills. In this study, students transitioned from intuitive reasoning toward systematic inquiry, a progression that aligns with the problem-solving stages described in the literature (Greenstein, 2012), namely defining problems, formulating strategies, testing solutions, and drawing conclusions. These shifts were visible in how students generated design hypotheses, made data-based decisions, and refined their prototypes.

Furthermore, the solar oven activity connected science learning with environmental awareness. Students realized that sunlight—commonly perceived as ordinary—can be harnessed as a renewable energy source. Such experiences fostered not only conceptual understanding but also eco-ethical awareness, resonating with the goals of education for sustainable development (UNESCO, 2020). The combination of practical exploration and reflective discussion positioned students as active creators of knowledge rather than passive recipients.

The teacher's role as facilitator was also crucial. By guiding rather than directing, the teacher encouraged students to question, test, and take ownership of their learning. This supports the constructivist premise that knowledge is best developed through active engagement and social collaboration (Duschl, 2008; Vygotsky, 1978). The EDP–STEM environment thus served as a “mini-laboratory” where students could practice scientific thinking, teamwork, and iterative improvement skills essential for 21st-century learning.

Overall, the findings illustrate that integrating the EDP–STEM model meaningfully bridges scientific theory and engineering practice. It enhances cognitive engagement, creativity, and sustainability awareness-three pillars that support the vision of transformative science education in the era of Industry 4.0 and Society 5.0.

4 CONCLUSION

This study demonstrated that integrating the Engineering Design Process (EDP) within STEM learning offers an effective and engaging approach for developing elementary students’ problem-solving skills and scientific reasoning. Through a solar oven project based on light and heat energy, students were able to connect theoretical science concepts with hands-on experimentation, creativity, and environmental awareness.

The iterative nature of EDP encouraged students to think systematically by identifying problems, generating ideas, testing designs, and improving solutions while fostering collaboration and resilience. The findings affirm that EDP–STEM learning not only enhances conceptual understanding but also nurtures twenty-first-century competencies such as critical thinking, creativity, and teamwork.

Implementing EDP–STEM in primary classrooms can therefore serve as a practical pathway to bridge science education with sustainable innovation. Future applications may explore broader topics and include teacher capacity-building to ensure that engineering-based inquiry becomes a consistent part of science learning in Indonesian elementary schools.

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