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Design Interactive Coal Mining Layout Pop-up Book: An Educational Tool for Introducing Environmental Awareness to Children

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Abstract

Understanding the balance between energy production and environmental sustainability remains a challenge for young learners, particularly when addressing complex topics such as coal mining. This community service initiative aims to design, implement, and evaluate an interactive coal mining pop-up book as a developmentally appropriate learning medium to enhance elementary students' environmental awareness. The activity was conducted using a Participatory Action Research (PAR) approach, involving stages of engagement, co-development, implementation, evaluation, and feedback. It included the design of 3D pop-up media, implementation through an interactive storytelling and demonstration session at Nido Primary School, and evaluation through Likert-scale questionnaires and observations. The findings indicate a notable improvement in students' environmental awareness, with 87.0% of students expressing agreement on eco-centric and nature-responsibility aspects. Moderate levels of agreement were also observed in students' understanding of coal-related concepts, indicating the development of conceptual comprehension. The pop-up book effectively supports learning through its visual and tactile features, which help students concretize abstract concepts in line with their cognitive development. Overall, this activity demonstrates that interactive and hands-on learning media can serve as an effective approach to introducing energy concepts while fostering early environmental awareness among elementary students.

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INTRODUCTION

Environmental awareness is a core element of environmental education, especially in schools that aim to instill sustainable behavior in younger generations (Hermawan et al., 2025). Environmental awareness is the fundamental building block of a sustainable future because it transforms our relationship with the planet from one of consumption to one of stewardship. At its core, this awareness serves as a survival manual; it helps us recognize that our economy, health, and food security are entirely dependent on finite natural resources that must be managed like a limited savings account rather (Velenturf & Purnell, 2021). By understanding the intricate links between human activity and ecosystem health, we can move away from "eco-anxiety" and toward "environmental literacy," which empowers individuals to make informed choices as consumers and citizens.

Among many environmental challenges, East Borneo province faces the complex trade-off between the need for coal and environmental preservation (Sundari et al., 2025). Coal mining, while a cornerstone of global energy production, often remains a "hidden" industry to the younger generation—a misunderstood or entirely overlooked (Friederich & van Leeuwen, 2017). However, as the future stewards of the planet, children require a foundational understanding of how resources are sourced and of the environmental responsibilities that accompany them. Furthermore, fostering this mindset in children creates a powerful ripple effect that extends far beyond the individual.

Nido Primary School is a national plus school that blends an international approach with the Montessori philosophy, adapted to the Indonesian context. It incorporates English-language exposure to facilitate learning in mathematics, sensorial studies, practical life exercises, cultural studies, and language arts. At each level of Montessori education, the difference in developmental needs is honored through the preparation of the classroom environment. Therefore, the classroom environment plays a crucial role and is designed carefully by teachers. The environment is prepared in every way for optimal development: physically, cognitively, socially, and emotionally, by aligning the activities in the environment with what each child needs at any moment (Ogbemudia et al., 2024). These prepared environments enhance children's energy for learning and enable them to learn at their own pace. From our early observations in the classroom, Montessori apparatus is organized by subject areas (mathematics, sensorial studies, practical life exercises, cultural studies, and language arts) and displayed on trays or in baskets to promote independence, accessibility, and focus. The shelf is arranged on low, open shelves, ordered logically from the easiest to the most difficult (Amalia et al., 2020).

Despite the growing emphasis on environmental education and sustainability, there remains a significant gap in the availability of developmentally appropriate instructional media for elementary school students. Existing learning approaches often rely on abstract explanations or textbook-based materials that are not aligned with young learners' cognitive characteristics, particularly when addressing complex and technical topics such as coal mining and its environmental implications (Mutiarasari et al., 2025). Moreover, instructional tools that explicitly integrate industrial processes with environmental sustainability concepts in a tangible and engaging format are still limited (Sofiasyari et al., 2025). This gap highlights the need for innovative, hands-on, and visual learning media that can effectively bridge students' understanding of energy production processes with environmental responsibility from an early age.

Therefore, this study aims to design, implement, and evaluate an interactive coal mining pop-up book as a developmentally appropriate learning medium to enhance elementary students' environmental awareness. By simplifying the coal mining life cycle—from initial extraction to final site greening—this book aims to instill environmental stewardship in children. It doesn't just show them how a mine works; it shows them how a mine can be

closed responsibly, ensuring that the next generation values both the energy that powers their world and the nature that sustains it. We propose that STEM activity could facilitate this process. STEM education indicates young learners' potential for early engineering (Sulaeman et al., 2023). Students can engage in design and redesign processes, applying their STEM disciplinary knowledge (English & King, 2015). Although many teachers have participated in STEM-related activities, their implementation requires greater support (Efwinda et al., 2025; Sulaeman et al., 2024). Therefore, our activity aims to support primary school students' environmental awareness through a STEM unit.

METHODS

The community service activity was conducted using a Participatory Action Research (PAR) approach, which emphasizes collaboration between researchers and community members to identify problems and develop solutions to improve educational practices (Edirmanasinghe, 2020). The activity consisted of four main stages, as illustrated in Figure 1. First, the engagement stage involved meetings with teachers to discuss science learning topics and identify the need for a contextual learning project related to coal mining and environmental issues. Second, during the co-development stage, the facilitators and teachers collaboratively adapted student worksheets and designed a lesson plan to support the project-based activity. Third, during the implementation stage, students carried out the learning activity by designing a coal-mining layout using a pop-up book model. Finally, the evaluation stage was conducted through post-questionnaires and teacher feedback to assess students' environmental awareness and gather reflections on the learning activity. Data were collected using two main instruments: (1) a post-activity questionnaire employing a Likert-scale format to assess students' environmental awareness across several dimensions, and (2) an observation sheet used by facilitators to record students' engagement and participation during the learning activities. The questionnaire items were adapted from established environmental awareness frameworks to ensure content relevance.

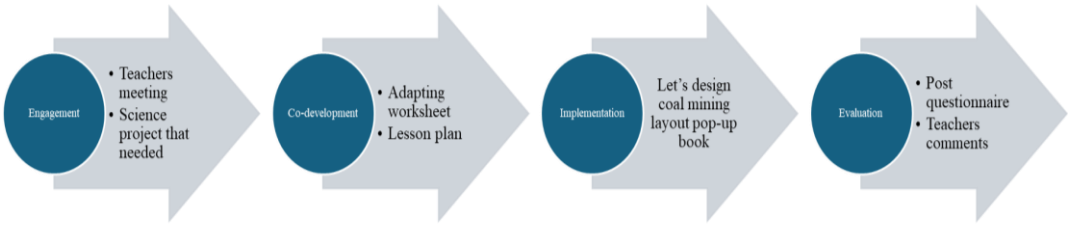


Figure 1 Activity steps

To assess students' energy and environmental awareness, a questionnaire was administered after the activity. The instrument consisted of several statements representing different aspects of environmental awareness, including eco-centric, nature responsibility, anthropocentric, environmental knowledge, and hedonistic perspectives (Gagnon Thompson & Barton, 1994; Gül & Özdemir, 2022; Wibowo et al., 2023), as presented in Table 1. Students responded to each statement to reflect their perceptions following the learning activity. The collected data were analyzed using descriptive statistics. Students' responses from the Likert-scale questionnaire were converted into percentages to identify the level of agreement for each aspect of environmental awareness. Observational data were analyzed qualitatively to support and interpret the quantitative findings.

Table 1 Energy and environmental questionnaire

Aspect	Statement
Eco-centric	The activity of designing a coal mining pop-up made me realize that we must collectively protect the environment.
Nature Responsibility	A clean surrounding environment makes me feel happy.
Anthropocentric	Humans derive many benefits from the existence of coal.
Environmental knowledge	Coal is a type of rock that originates from ancient dead plants.
Hedonistic	Coal mining should be conducted in moderation to meet electricity needs.

RESULT AND DISCUSSION

Engagement

As the initial stage of the activity, lecturers, teachers, and student teachers participated in workshops and community meetings to discuss energy and environmental issues relevant to the school context and to identify potential learning activities. These discussions aimed to explore the school's needs and collaboratively design preliminary lesson plans for the project. Engaging stakeholders at this stage ensured that the perspectives and needs of the school community informed the direction and implementation of the learning activity (Stevenson et al., 2025).

Co-development

Collaboration in designing the lesson plan is essential. This phase would involve creating prototypes and conducting trials based on the teacher's feedback. The co-development phase is rooted in the principle that collaboration is indispensable to effective lesson design (Voogt et al., 2015). By actively engaging stakeholders, this stage moves beyond theoretical planning into the creation of tangible prototypes and the execution of iterative trials. These trials are guided by direct community feedback, ensuring that the final instructional materials are both culturally relevant and pedagogically sound. The discussion begins with a draft of the STEM worksheet and its adaptation for primary school students, as shown in Figure 2.

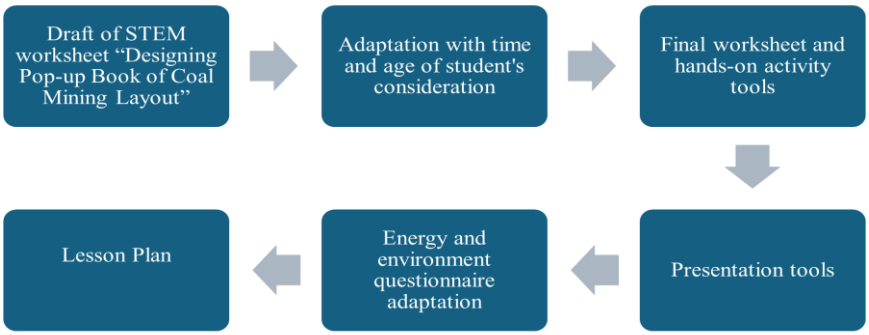


Figure 2 Co-development of the lesson plan

STEM worksheets adapt to be a structured roadmap for the active participation of primary students. Its primary value lies in its ability to break down overwhelming information into bite-sized, actionable steps, ensuring that the user moves from passive consumption to hands-on mastery (Anugrah et al., 2023). We use a simplified engineering design process (EDP) model to clarify the steps of learning. Figure 3 is an example of our worksheet that facilitates the entire learning process. Two professional primary school

teachers were involved in co-designing this worksheet. All the worksheets and presentation slides are designed in English to be in line with the students' daily learning process at this school.

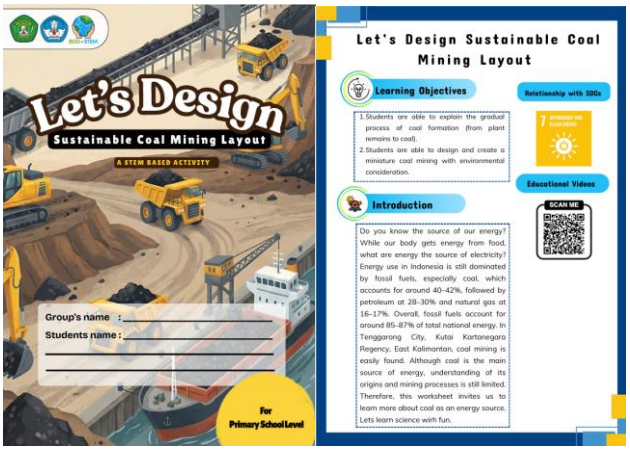
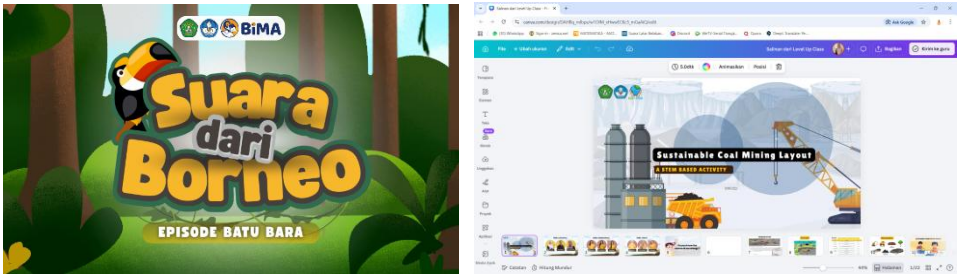


Figure 3 Student worksheet

To complement the worksheet, we also provide an animation video (Figure 4a) and presentation slides (Figure 4b) as a dynamic narrative tool designed to simplify the abstract and engage the senses in the opening part of the lesson. Because it uses a combination of movement, color, and sound, it can visualize concepts that are impossible to capture. When explaining an animation, focus on its ability to tell a story quickly and memorably, serving as a "hook" that captures attention and understanding of complex ideas in an easily digestible visual format for primary students (Kleftodimos, 2024; Lina et al., 2021).



(a) (b)

Figure 4 (a) Animation video and (b) Presentation slides

Implementation

Table 2 presents the implementation schedule of the STEM activity, which follows a simplified EDP consisting of five stages: Define, Learn, Plan, Test–Try, and Decide. All activities are conducted by teams and supported by teachers at the school. The collaboration ensures that all the aims of the activity are delivered to the children (Prastawa et al., 2024). The activity began with the Define stage (10 minutes), where students were introduced to different energy sources and a problem letter to stimulate curiosity about energy use. In the Learn stage (20 minutes), the science component was emphasized as students explored basic concepts about coal, including its origin, formation process, and physical characteristics through observation. The plan stage (30 minutes) engaged students in designing the layout of their coal mining pop-up book, integrating engineering and technology elements. This was followed by the Test–Try stage (60 minutes), where

students constructed their pop-up models while considering the constraints and criteria of the project. Finally, in the Decide stage (60 minutes), students presented their pop-up books and explained the function of each element in their design. Overall, the 180-minute activity provided a structured learning process that guided students from conceptual understanding to hands-on design and communication of their ideas.

Table 2 Implementation schedule

Syntax	STEM Element	Activity	Duration (min)
Define	Engineering	Introduction to the source of energy Problem letter	10
Learn	Science	Let's know more about coal (source, how it is made, observing coal)	20
Plan	Engineering Technology	Plan your pop-up book Let's design a coal mining layout	30
Test-Try	Engineering Technology	Make the design Check constraints and criteria of this project	60
Decide	Engineering Science	Pop-up book presentation	60
Total			180

Evaluation

The evaluation stage is the last stage of the PAR cycle. We evaluate the students' activity and environmental awareness. Figure 5 captures the final results of the students' active journey in these STEM activities. Figure 5a showcases the completed coal mining layout pop-up book, proudly designed by the students. This creation is the culmination of the Plan and Test-Try stages, where they brought their ideas to life by building a miniature coal mine that carefully followed the problem-orientation criteria. Meanwhile, Figure 5b highlights the final "Decide" stage during the presentation session. Here, the students practiced sharing the story behind their designs, confidently explaining each attached element and its function in their own simple words (Porter et al., 2019).

(a) (b)

Figure 5 (a) Final pop-up book design, (b) Pop-up presentation

Figure 6 presents students' responses across five aspects of environmental awareness following the activity. The results show a high level of agreement in the eco-centric and nature responsibility aspects, with 87.0% of students selecting "agree" for both categories. Only a small proportion of students responded neutrally (8.7% and 13.0%, respectively), and almost no students disagreed, indicating strong positive attitudes toward environmental protection and responsibility. For the anthropocentric and environmental knowledge aspects, 60.9% of students selected "agree," while 21.7% and 13.0% responded neutrally, and 17.4% and 26.1% selected "disagree," respectively. These findings suggest that while

students have begun to understand the role of coal in human life and its scientific origins, their conceptual understanding is still developing. In the hedonistic aspect, 52.2% of students agreed that coal mining should be conducted in moderation, while a relatively high proportion (43.5%) selected neutral responses. This indicates that students are still in the early stages of understanding the balance between energy needs and environmental sustainability. Overall, these results demonstrate a notable improvement in students' understanding of coal extraction processes, environmental impacts, and land restoration, particularly in aspects related to environmental values and responsibility. The pop-up book activity effectively supported students in connecting abstract industrial concepts with tangible environmental awareness (Ardoin et al., 2020; Monroe et al., 2019; Raudah et al., 2025).

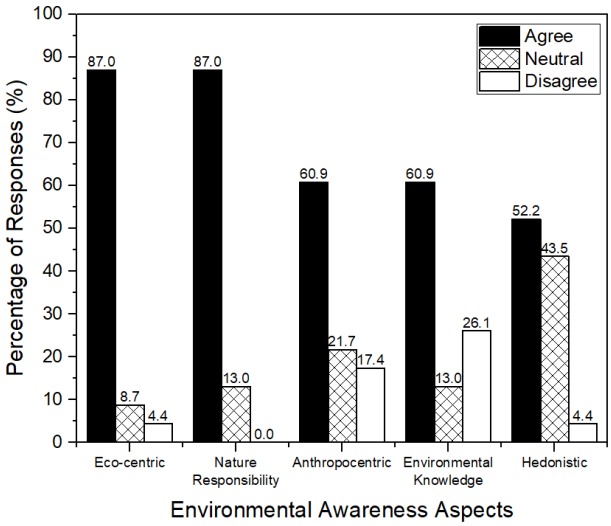


Figure 6 Students' environmental awareness

Meanwhile, responses to the anthropocentric, environmental knowledge, and hedonistic statements also indicate that the majority of students agreed, although with a higher proportion of neutral responses compared to the previous aspects. Students generally recognized that coal provides benefits for human life and demonstrated basic knowledge that coal originates from ancient plant materials. However, their responses regarding coal mining moderation indicate that their understanding of energy alternatives and sustainable energy transitions remains limited. This is reasonable considering that the participants are primary school students whose exposure to complex energy systems and renewable energy concepts is still developing (Suratmi et al., 2025). At this stage, their awareness tends to focus on immediate environmental responsibility rather than broader considerations of alternative energy solutions. Therefore, future learning activities could gradually introduce renewable energy concepts to strengthen students' long-term environmental literacy and sustainability awareness.

CONCLUSION

This community service activity successfully engaged teachers in co-designing a STEM-based learning unit on coal mining for elementary school students. By shifting the learning process from passive instruction to active construction, students were able to visualize the lifecycle of coal mining in a more concrete and meaningful way. The interactive pop-up book functioned as an innovative learning medium that effectively supports students' environmental awareness and early energy literacy. This result contributes to primary

science education by demonstrating how developmentally appropriate, hands-on learning media can facilitate young learners' understanding of complex industrial and environmental concepts. Furthermore, it supports the principles of education for sustainable development by fostering students' awareness of the relationship between energy production and environmental responsibility from an early age. The findings suggest that integrating tactile and visual learning media into STEM activities can be an effective way to enhance environmental literacy in primary education contexts. This approach also has the potential to be adapted and implemented in other educational settings, particularly in regions closely related to natural resource utilization.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

NFS conceived and designed the study; ES, IAADP, and ARW contributed to the development of learning materials; NFS, K.K., and AN supervised the research and contributed to manuscript writing; KK, ES, IAADP, and ARW assisted in data collection and product development; AWW and AMCR supported implementation at the school level; and IAADP and AN contributed to data analysis and manuscript revision. All authors contributed to the implementation of learning materials, reviewed, and approved the final manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT (OpenAI) during the preparation of this work for brainstorming, language refinement, and improving the manuscript's clarity. After using the tool/service, the authors thoroughly reviewed and edited the content as needed and take full responsibility for the publication's content.

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