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Implementation of A Mini Solar-Powered Car Experiment to Teach Renewable Energy Concepts in Junior High School

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ABSTRACT

The increasing global energy crisis and rising fuel prices highlight the need for effective renewable energy education at the school. However, science instruction in junior high schools often relies on theoretical explanations and limited hands-on activities, which can limit students' understanding of real-world energy issues. This study aims to implement a mini solar-powered car experiment to support students' understanding of renewable energy. The study was conducted in a junior high school using the Engineering Design Process (EDP) framework. Students worked in groups to assemble solar-powered cars and investigate the effect of light exposure duration on distance and speed. Data were collected through experimental measurements and students' answers in worksheets. The results showed that more prolonged light exposure generally increased the distance traveled, while speed fluctuated due to factors such as friction and mechanical inefficiencies. Student reflections indicated an improved awareness of the benefits and challenges of solar-powered transportation. In conclusion, the mini solar-powered car experiment is feasible for school implementation and effective in promoting conceptual understanding of renewable energy and real-world energy issues.

Keywords : Energy Crisis, Engineering Design Process, Solar-Powered Car, Renewable Energy, STEM

I. INTRODUCTION

The growing global demand for energy, combined with the rapid depletion of fossil fuel resources, has heightened the urgency of transitioning to renewable and sustainable energy solutions. Around the world, issues such as rising fuel prices, climate change, and reliance on non-renewable resources underscore the need for greater public understanding of alternative energy sources. Education plays a critical role in shaping environmental awareness, especially when introduced early to junior high school students [1]. Teaching renewable energy through hands-on learning helps students connect scientific concepts with real-world problems. Implementing a mini solar-powered car experiment provides an engaging way for learners to observe energy transformation and understand how solar power can serve as a clean and accessible energy source. This research is significant because it supports students' content knowledge about renewable energy while also fostering curiosity and scientific thinking in junior high school settings.

The global energy crisis has become an increasingly urgent issue, marked by rising fuel prices, depletion of non-renewable resources. The widening gap between energy production and energy consumption has led to a crisis in the energy sector [2]. One of the examples, the increase in global oil prices has become a serious challenge, as fluctuations in international oil prices have a significant impact on national economic stability [3]. Many countries are experiencing fluctuations in oil supply and demand, causing fuel costs to continue increasing and placing economic strain on communities. This situation highlights the importance of strengthening students' understanding of renewable energy from an early age, so they can recognize why societies must shift toward cleaner, more sustainable solutions.

Despite the importance of renewable energy education, many junior high school students still struggle to understand energy transformation concepts and often see science learning as disconnected from real-life applications. In schools, lessons on energy transformation are often taught in traditional teaching when the student is only taught theoretically through lectures. Unfortunately, in lecture-based classes, students often lose concentration early on, within the first ten minutes after the lecture begins, and only remember 20% of the material presented [4]. These issues show why students may struggle to grasp complex topics such as renewable energy when taught only through traditional explanations.

Research on renewable energy education has increasingly emphasized the importance of hands-on, inquiry-based learning to improve students' scientific understanding and awareness of global energy challenges. As demonstrated in [5], low-cost and practical solar-energy activities can significantly enhance students' science knowledge, experimental skills, and motivation toward sustainability. Their findings show that when students actively construct and test renewable-energy devices, they develop deeper conceptual understanding compared to conventional instruction. This highlights the value of practical solar-based experiments as a means to bridge classroom learning with real-world energy issues.

At the higher education level, hands-on renewable energy platforms have been shown to improve learning outcomes in engineering contexts. As presented in [6], a portable solar microgrid system was designed to teach photovoltaic, battery management, and cyber-physical concepts. Students who engaged with the system demonstrated higher awareness, stronger understanding of renewable energy systems, and increased interest in STEM fields compared to students taught using traditional methods. Similarly, problem-based learning (PBL) and design optimization in a solar car chassis project was integrated in previous research, enabling engineering students to collaboratively solve real design challenges and develop practical engineering judgment [7]. These studies emphasize solar-related projects, whether microgrids or solar vehicles which serve as effective vehicles for STEM learning.

Beyond education, environmental studies reinforce the importance of solar technologies in addressing global energy and climate challenges. A study [8] compared the environmental footprints of various vehicle types and found that solar-powered battery-electric vehicles have the smallest carbon, land, and water impacts per kilometer driven. This aligns with global efforts to reduce emissions and transition to sustainable transport. Likewise, as reported in [9], a comprehensive comparison of biofuel, electric, fuel-cell, and solar-powered vehicles, concluding that solar and electric vehicles offer the most promising near-term solutions for decarbonizing transportation. These findings illustrate the critical importance of educating younger generations about solar energy as a viable and environmentally responsible alternative.

Although the existing literature demonstrates strong evidence that hands-on renewable energy activities enhance science learning [5], [6], [10] and research about sustainability potential of solar as one of renewable energy [8], [9]. Educational studies tend to focus on learning outcomes within classroom or laboratory settings, while engineering studies emphasize the broader impacts of renewable energy technologies. Fewer studies have examined how hands-on experiments simultaneously support students' ability to relate these scientific concepts to real-world global energy issues.

Several gaps also remain in the existing literature. First, previous research has predominantly focused on evaluating students' general understanding of renewable energy concepts [11], learning motivation [12], and higher-order skills such as creative thinking and communication [13]. However, there is still limited investigation into how the Engineering Design Process (EDP) specifically influences students' conceptual understanding of science learning, particularly in relation to renewable energy topics. Beside that, none of the reviewed studies focus specifically on solar-car-based experiments as a tool for strengthening foundational energy transformation concepts or connecting them to the global energy crisis, such as rising fuel prices and the need for energy sustainability.

Therefore, there is a clear need for research that explores how a mini solar-powered car experiment can be implemented in a junior high to enhance students' content knowledge of renewable energy, while also making global energy issues more relevant and understandable for younger learners.

To ensure that this research is aligned with national education standards, an analysis of the Merdeka Curriculum used in Indonesia is conducted. Table 1. presents an analysis focusing on core competence, basic competence, and learning outcomes related to the concept of renewable energy in Grade 9 science lessons. Integrating curriculum analysis is crucial to demonstrate that the solar-powered mini car experiment not only supports students' conceptual understanding but also encourages the application of scientific skills.

Table 1. Merdeka Curriculum Analysis in Grade 9

Core Competence	Basic Competence	Learning Outcome
3. Understanding knowledge	3.10 Analyzing eco-friendly	Students understand the

(factual, conceptual, and procedural) based on curiosity about science, technology, art, culture-related phenomena, and eyesight events.	technology processes and products for sustainable living.	relationship between concepts and apply the use of renewable energy sources in everyday life.
4. Trying, processing, and serving in the concrete realm (using, parsing, composing, modifying, and creating) and abstract realm (writing, reading, counting, drawing, and composing) according to what was learned in schools and other sources same in point of view/theory.	4.10 Presenting simple products of eco-friendly technology processes.	Students are able to process data in the form of tables and graphs, then explain the results of their observations and the patterns of relationships in the data.

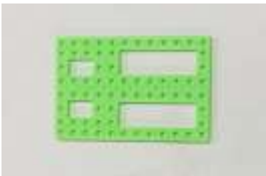
II. METHOD

This study is the development of an experiment-based practicum learning method to examine the implementation of a mini solar-powered car experiment as a STEM learning activity in a junior high school. The participants were members of the school's STEM Club, consisting of students who voluntarily enrolled in weekly sessions. The implementation took place during a scheduled club meeting, where students conducted a hands-on mini solar-powered car experiment. Overall, the method focused on observing the learning process, guiding students through the experiment, and collecting qualitative data through student responses in answering the worksheet.

The implementation is divided into two main sessions to ensure students have enough time to complete each stage effectively. The total estimated duration of the activity is 80–100 minutes, while each meeting lasts only 60 minutes. Therefore, the experiment was carried out across two meetings. In the first meeting, students focused on assembling the mini solar-powered car in small groups, learning about its components and how solar panels convert light into electrical energy. In the second meeting, the groups continued with the testing phase, where they directed a flashlight toward the car's solar panel and measured the distance traveled during each trial. By the end of the two sessions, every group successfully completed both the building and testing stages of the experiment.

This study used the materials and apparatuses to conduct the experiment. The materials and apparatuses required are presented in Figure 1.


a. Solar panel


b. Base frame (chassis)


c. Electric motor


d. Tin wire


e. Shaft bracket


f. Axle and gear


g. Wheel


h. Screw


i. Sleeve


j. Masking tape


k. Measuring tape


l. Pen

m. Flashlight n. Pliers o. Screwdriver p. Solder

Fig. 1. Example of an image

In this experiment, several variables were identified to ensure the investigation was conducted in a structured, measurable way. The variables are detailed in Table 2.

Table 2. Experiment Variable

Variable	Details
Independent	Duration of light exposure (s)
Dependent	Distance the car travels (cm)
Control	The type of solar-powered car used and the brightness level of the flashlight

The overall procedure for this activity follows a series of structured and straightforward steps to ensure the experiment runs smoothly and produces consistent results. The complete sequence of steps is outlined in the flowchart below.

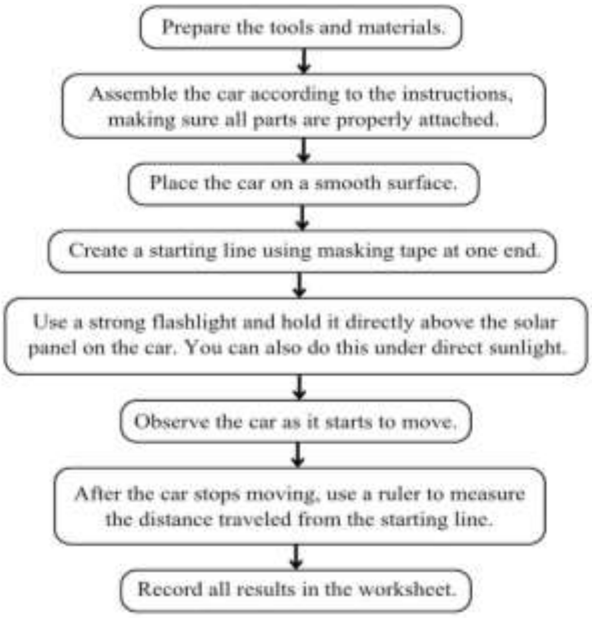


Fig. 2. Flowchart of the steps in the mini solar-powered car experiment

After completing the procedure, students record the results on the distributed worksheet (Figure 3). Worksheets play an important role in creating meaningful learning experiences by assisting and facilitating learning activities to foster effective interaction between students and teachers [14]. The worksheet is designed to guide them during the experiment, help them record observations, and support them in exploring how solar energy can power motion. This is supported by a study [15], who emphasize that student worksheets can help guide students' activities during science learning and support them in understanding the concepts presented. By following the worksheet tasks, students can work more independently, stay organized throughout the experiment, and prepare for the analysis and discussion that follow.

Fig. 3. Students' worksheet

The implementation was conducted using the Engineering Design Process (EDP) framework. The EDP stages as shown in Figure 4. adopted in this study include Ask, Imagine, Create, Test, and Improve [16]. This framework is used to structure student activities and to examine how students engage in problem-solving and design-based learning, making it well suited for STEM-based learning activities [17].

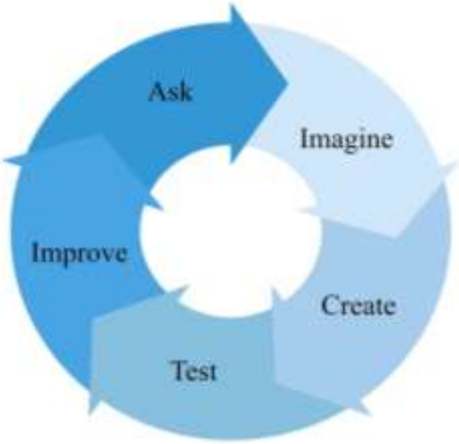


Fig. 4. The EDP stages during the implementation

It starts with the Ask stage. Students are introduced to real-world issues related to rising fuel prices and energy sustainability, which encourage them to identify the need for alternative energy sources. Students explore the basic concepts of solar energy, energy transformation, and renewable energy through the worksheet. It allows them to generate ideas and possible solutions. In the Image stage, students design and plan the assembly of a mini solar car, including composing hypotheses, identifying experimental variables, and preparing tools and materials for this experiment. Then, in the Create stage, students assemble a solar-powered car and make adjustments based on initial observations. The Try stage is carried out when students measure the distance and speed of the car under controlled light exposure conditions, after which they record the findings in tables and graphs. Finally, the Improve stage encourages students to reflect on their results and evaluate the effectiveness of their designs. If the results do not meet expectations, students are encouraged to revisit earlier stages, such as the Create stage or Try stage to modify their design, thereby repeating the cycle. This process continues until satisfactory results are achieved. After that, the activity ends with a reflection on the benefits and limitations of solar-powered vehicles in real-world applications.

III. RESULTS AND DISCUSSION

1) Ask Stage

At the beginning of the activity, an introduction was given on the global issue of rising fuel prices and its impact on energy consumption. Students were then presented with a guiding question to stimulate their problem-solving skills and encourage them to think about the use of alternative energy sources, such as solar power.

After that, students were divided into 3 groups and prepared to apply their understanding of renewable energy through a mini solar-powered car experiment. Using the worksheets provided, students were introduced to the function of solar panels and how light intensity can be converted into electricity to power the car.

2) Image Stage

Before experimenting, each group formulated a hypothesis to be tested, such as *"The longer the car is exposed to light, the farther it will travel" or "The car will move slower if the light is dim."* Based on these hypotheses, the independent variable was the duration of light exposure (in seconds), the dependent variable was the distance traveled by the car (in centimeters), and the controlled variables were light intensity and the type of car used. After that, students preparing the tools and materials needed for this experiment.

3) Create Stage

Students were instructed to assemble the solar-powered mini cars by first identifying and listing all the necessary tools and materials. They were then given time to work collaboratively in constructing the cars, with the results shown in Figure 5. Once the assembly was completed, each group briefly tested their car under direct sunlight to ensure that the motor and solar panel were functioning properly. This preliminary test allowed students to confirm that their cars could move and helped them identify any construction issues before proceeding to the data collection.

Fig. 5. The product of a mini-solar powered car

4) Try Stage

During the second meeting, students conducted the data collection by testing their cars one group at a time using a flashlight as the light source (Figure 6). To maintain consistency, the light intensity was kept constant at the average of 152.813 lux throughout the entire testing process. The duration of light exposure was varied at 5-second intervals, beginning at 5 seconds and increasing up to 25 seconds. For each trial, students recorded the distance y their car traveled during the duration of light exposure.

Fig. 6. Student testing their car to collect the data

The results obtained from the three groups shown in Figure 7. with a consistent pattern. As the duration of light exposure increased, the distance traveled by the mini solar-powered car also increased. This finding supports the hypothesis formulated earlier, which stated that longer exposure to light provides more energy to the solar panel, allowing the car to travel farther. Clear relationship between light characteristics and the electrical output performance of solar cells, showing that the amount and quality of light energy received by the panel influence its electrical generation [18].

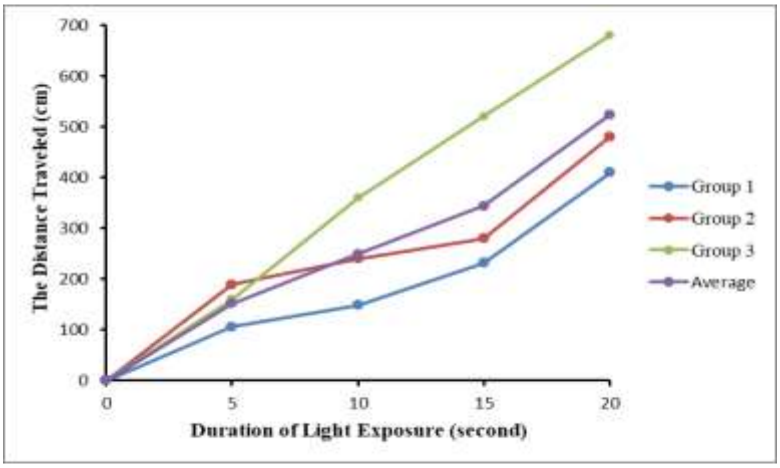


Fig. 7. Comparison Graph of Distance Traveled

From the graph, Group 1 had the lowest distance. This may indicate minor limitations in the assembly of the car or energy conversion efficiency. Group 2 showed better performance than Group 1, with consistently longer distances at each interval. Lastly, Group 3 achieved the longest distance at all exposure durations, indicating that their solar-powered cars were the most efficient at converting light energy into electrical and kinetic energy. All of the groups showed similar distances at the 5-second expostointerval, ranging between 100 and 200 cm. The differences became more apparent as the duration of light exposure increased. Starting at the 10-second interval, Group 3 consistently traveled farther than Groups 1 and 2.

After collecting the distance data, students calculated the speed of the solar-powered car using the basic kinematics formula:

$$v = \frac{s}{t} \tag{1}$$

Information:
v = speed (m/s)
s = distance traveled (m)
t = duration of light exposure (s).

This calculation allowed students to analyze not only how far the car moved but also how efficiently the car converted light energy into motion over time. The result shown in Figure 8.

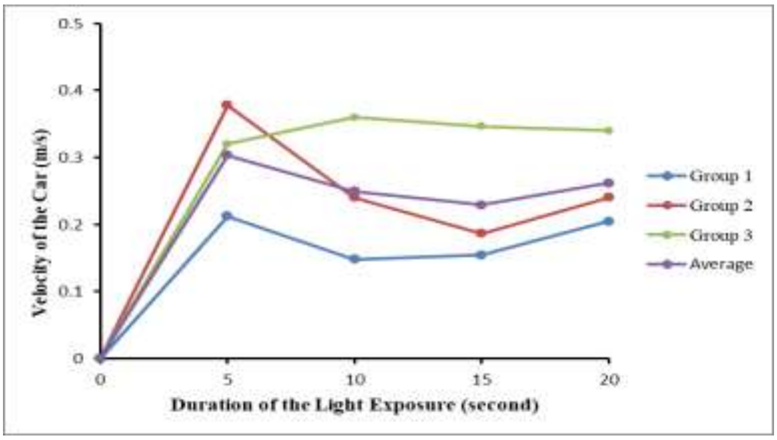


Fig. 8. Comparison Graph of the Speed

As seen in the comparison graph of the speed, all three groups showed fluctuating speeds rather than steady increases throughout the experiment. Brief initial speed increased during the short 5-second consistently exposure, but did not consistently increase with longer light exposure times. Group 1 showed a moderate increase followed by slight fluctuations, with a decrease in speed at the tenth second. Group 2 showed a sharp increase at 5 seconds before decreasing and increasing again. Meanwhile, Group 3 maintained a relatively higher speed but remained variable.

5) Improve Stage

The difference in distance traveled between these groups can be explained by several reasons. One of them is the variation in light intensity received by the solar panels. Although the intensity of the flashlight is controlled, small differences in the adjustment of the direction and position of the light source relative to the solar panels can affect the amount of light energy absorbed. Solar panels receive maximum energy when the light source is placed perpendicular to their surface, allowing more photons to be converted into electrical energy to power the motor. This is consistent with the previous findings [19], who reported that the electrical output of solar cells is greatly influenced by the amount and angle of light entering them, with better adjustments resulting in higher energy conversion efficiency.

Surface friction is another important factor contributing to the difference in mileage between these groups. Friction between the wheels of a solar car and the surface of the table can hinder movement, thereby reducing the distance the car can travel even though the motor has received sufficient electrical energy. Uneven surface conditions, such as small gaps caused by joints in floor tiles, can increase the actual contact area between the wheels and the surface. This can cause greater friction and hinder the movement of the vehicle. Friction is closely related to the actual contact area between two surfaces, meaning that rough or uneven surfaces can significantly increase resistance to movement [20]. In addition to affecting the total distance traveled, surface friction also plays an important role in causing fluctuations in the speed of solar-powered cars.

Additionally, even though the light source and exposure duration were controlled, the conversion of light energy into mechanical motion was not entirely efficient. Energy losses occur in the motor and gear system, and these losses can vary during operation, affecting the car's speed over time. This phenomenon is consistent with the findings of a study [21], which reported that maintaining stable motion in solar-powered systems is challenging due to the dynamic interaction between electrical output and mechanical resistance. Therefore, the fluctuating speed observed in this experiment reflects the application of solar energy in the real world, where constant energy input does not always result in continuous motion due to system inefficiencies. The conversion of electrical to mechanical energy is inherently inefficient, with losses arising from misbehaving vehicle configurations [22]. As a result, the observed speed fluctuations reflect realistic vehicle behavior, where constant power input does not guarantee continuous speed due to constantly changing resistance and system inefficiency. After analyzing the experimental results, students were asked a reflective question as shown below.

Question 1: How did the duration of flashlight exposure affect the distance traveled by the solar car?

All three groups gave similar answers: *“Because solar panels need light to operate, in this case to run the wheels. So the more light they get, the farther they can travel.”* Their explanation reflects the basic principle that solar panels require sufficient light energy to generate electrical power for movement. The output of a solar photovoltaic system depends on solar radiation, with higher levels producing greater power output [23]. When applied to the mini solar car experiment, more prolonged exposure to the flashlight simulates higher solar radiation, resulting in high electrical power. This is then translated into mechanical performance, with the electric motor driving the gears to enable the car to travel long distances.

Question 2: What are the limitations that might have affected the results of your experiment, and how could you improve the setup in future trials?

The three groups gave different answers. Group 1 answered, *"The floor is not flat, so it often gets stuck on the ceramic joints. The solution for the future is to conduct experiments indoors.“* Next, group 2 answered, *”The car did not move at all in the first experiment. Therefore, we rearranged the wheel joints so that they were not too tight.“* And group 3 answered, *”The light received by the car was inconsistent because the position of the flashlight was unstable."*

Students' responses to Question 2 show diversity in the obstacles they encountered in this experiment. Group 1 noted that surface irregularities increased friction and hindered movement. This explanation aligns with the findings of Liang et al. (2021), who reported that uneven contact significantly increases friction resistance, thereby reducing the efficiency of vehicle movement. Group 2 identified improper wheel alignment as the cause of the car's lack of movement in the first experiment and solved the problem by readjusting the wheel connections to reduce excessive tension. Wheel assembly directly affects motion performance, mechanical configuration and assembly quality greatly affect vehicle mobility and energy transfer efficiency [22]. Meanwhile, Group 3 highlighted inconsistent light reception due to the unstable position of the spotlight, which can cause fluctuating electrical output from the solar panel. Variations in the angle of illumination can significantly affect energy generation and system performance in solar panels [7].

Among the three groups, all of the student responses indicate that they were well engaged in the Improve stage by identifying errors in their first Try stage and repeating the early stages to refine their setup and achieve better experimental results.

Question 3: In your opinion, what are the benefits and challenges of using solar-powered vehicles for transportation in real life?

One group stated, *"In the future, the use of solar power will not cause air pollution and will not deplete fossil fuel resources, but there are challenges such as the need for constant sunlight."* Another group explained, *"When it is raining or the sky is cloudy, there is not enough energy. However, the benefits are excellent as it is an alternative energy source that will not run out."* These responses indicate that students were able to connect the experimental findings with real-world energy issues.

The students' responses reflect their understanding of the advantages and limitations of solar-powered transportation. Their statements that solar energy does not cause air pollution and helps conserve fossil fuel resources are in line with global findings that renewable energy sources such as solar power produce little or no greenhouse resources reduce dependence on fossil fuels, thereby contributing to a reduction in pollution and climate change. On the other hand, their observation that solar energy production can be disrupted by weather conditions such as thick clouds or rain is supported by research showing that the variability of weather patterns can significantly affect the intensity of sunlight, posing challenges to the stability of solar energy systems [24]. Furthermore, environmental reviews highlight that environmental factors such as temperature, clouds, and atmospheric conditions can affect the efficiency and output of solar photovoltaic systems, emphasizing that solar energy performance is not entirely independent of climatic conditions [25].

IV. CONCLUSION

The implementation of the mini solar-powered car experiment in a junior high school proved to be feasible and effective, as the activity used simple, affordable, and easily accessible materials. Through this study, students were able to explore the relationship between light exposure duration and the distance and speed of a solar-powered car. The results showed that increasing the duration of light exposure generally led to greater travel distances, although variations occurred due to factors such as light alignment, surface friction, and mechanical efficiency. In addition, the calculated speed values demonstrated fluctuating patterns rather than constant motion, reflecting realistic energy conversion processes in solar-powered systems.

The results of this study support the basic scientific concept of energy transformation, in which light energy is converted into electrical energy and then into motion. The changes in speed observed during the experiment show that friction and mechanical resistance can affect the way a car moves. Student reflections also show that they understand the real benefits of using solar energy, as well as the limitations that can be caused by weather conditions. Overall, this experiment helped students connect scientific concepts to real-world energy issues. Future research could explore similar activities with different designs or learning environments to further enhance renewable energy education in schools.

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