Session XXXX

Development of a Battery Powered Vehicle Model for Integration into Elementary School Science Curricula

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Abstract

The present article documents the development of a battery powered vehicle model suitable for integration into science related curricula in elementary schools. The build is motivated by the documented need to integrate engineering concepts into elementary school curricula. The objective is to create an activity that develops connections between real-world phenomena and engineering concepts and elicits intentional interactions from elementary school students. The work in this article is the outcome of collaboration between engineering undergraduate students and faculty with education faculty. The specific model is intended to teach concepts related to electric circuits, energy conversion, and, more broadly, transportation electrification. The design criteria are outlined next. (1) The design is low-cost and accessible; (2) the design must be safe and not include potentially hazardous items; (3) the kit is amenable for building without special tools; (4) the design integrates well with teaching of relevant electric circuits and energy conversion concepts; and (5) the build can be easily performed at scale, for instance, simultaneously by a cohort of 25 students. The selection of materials (including base, wheels, motor, and pulleys) and the process of ensuring proper fit is documented. The kit is approximately 10 cm by 9 cm. The development of build instructions and documentation of common issues and recommended fixes are presented as well. Experiences and feedback from implementation of the model in an elementary school in Texas during regular class time are thoroughly discussed. Pointers to further enhancements of the model are provided as well, where the objective would be to enable model modifications interpretable by engineering concepts.

Introduction

The present paper deals with the development of a small battery-powered vehicle model that is suitable for integration into elementary school curricula. The documentation of the process in this article is intended to contribute a hands-on activity that can promote engineering and scientific literacy and facilitate teaching of engineering and science concepts.[1]

The concept of battery powered vehicle is selected due to the increased significance that electric vehicles are expected to have in the future. Indeed, the sales of electric cars have experienced substantial growth over the last few years.[2] The electrification of the transportation sector is critical in meeting emission reduction goals set by various governments and other stakeholders across the world.[3] Furthermore, the adoption of electric vehicles poses significant challenges to the planning and operation of the electric power grid due to the increased demand for battery charging.[4,5] It is therefore anticipated that the proliferation of electric vehicles will have a significant impact across various aspects of our lives in the future. The aforementioned contextual issues serve as excellent motivation for innovative activities that promote STEM literacy.[6] In addition, introducing the topic of electric vehicles in elementary education offers an opportunity to leverage STEM literacy toward becoming a knowledgeable individual equipped with capacities to navigate a complex technological world.[7]

Recommendations for introducing concepts relevant to electric vehicles in the classroom have appeared in the literature. For instance, an activity that asks students to design the dashboard of an electric vehicle has been proposed.[8] The students may use drawings or 3D modeling software. A classroom challenge to imagine how a battery swap system might operate has been described.[9] Concerns related to standardization alongside a host of issues pertaining to the safe and effective operation of the service station are to be considered. Each of the aforementioned activities focuses on a single aspect of the vehicle (such as dash design or battery swap), offering the opportunity to delve deeper in the respective issue. The present work is concerned with the development and implementation of a hands-on activity that takes a more holistic view of the vehicle and emphasizes how various components come together towards a final design. Specifically, the students are asked to build a small battery powered vehicle from supplied parts. To render the activity suitable for upper elementary students, the individual parts and the overall design are simple yet effective in teaching concepts related to electric circuits and energy conversion.

The remainder of the article is organized as follows. The design specifications are analyzed next. The vehicle model development is thoroughly documented, and a short troubleshooting guide is provided. Feedback from implementing the model at an elementary school in Texas is presented, including specific pointers for model improvement.

Design Specifications

The design criteria for the electric vehicle model are outlined next.

1. The design must be low-cost and accessible. In particular, we have selected materials that can easily be procured from common retailers without significant costs. This makes the model widely available to any school that would want to adopt this lesson.
2. The design must be safe and not include potentially hazardous items.
3. The kit is amenable to building without special tools that schools may not have. Indeed, all steps of the proposed model can be performed by fifth graders by hand. Age-appropriate scissors can be used to cut tape for securing certain parts of the model.
4. The design integrates well with the teaching of relevant electric circuits and energy conversion concepts. Specifically, the model includes batteries and a motor, which lend themselves to basic electric circuit modeling. A sequence of energy conversion stages is involved, from chemical to electrical and kinetic energy.
5. The model can be efficiently built at scale. The design objective is for the model to be completed simultaneously by a cohort of 25 students within the time limit of the class.

In summary, the model must be cost-effective, safe, and practical while aligning with the curriculum to provide a fun and scalable learning experience. The ensuing section provides all the necessary steps to replicate the design.

Vehicle Model Development

The list of materials and design of the vehicle model are detailed next, followed by a useful troubleshooting guide.

List of Materials

The materials needed for the vehicle model are listed next and are shown in Fig. 1.

- Cardboard
- Plastic motor mount
- 2 axles
- 4 wheels
- 5V motor with wire and socket
- 2 pulley gears
- 4 AA batteries
- Battery case
- Rubber band
- Electrical tape
- Scissors

Design

A principal design decision is to settle on how the wheels and axles are attached to the vehicle base. The present design features a combination of a cardboard base and wheels separated from the axles. The axle has a diameter of 2 mm, and the wheel has a socket to accommodate the axle, as depicted in Fig. 2 (left).

Figure 1. Vehicle Model Parts

The cardboard is a sturdy and effective base considering the limited budget and the need for simplicity. The cardboard size is 9cm x 10cm. The cardboard features horizontal channels, as depicted in Fig. 2 (right), which are suitable for running the axles through and keeping them in place. Cardboard used for packaging typically has such channels.

Figure 2. Wheels and Side View of Cardboard Base

To accommodate the pulley, a 1cm x 3cm hole is cut through the cardboard, as depicted in Fig. 3 (left). After the hole is made, the axle is threaded through the cardboard, the pulley is joined, and the rubber band is secured around the pulley. The process continues by threading the axle the remaining distance through the cardboard. The result is shown in Fig. 3 (right).

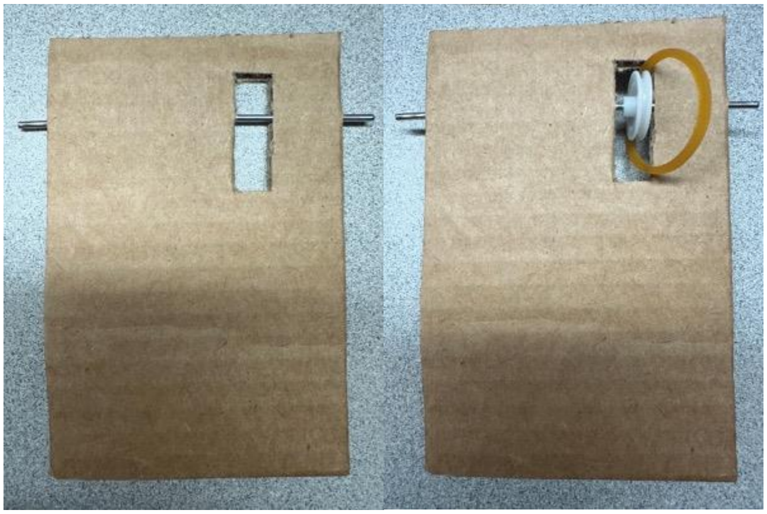


Figure 3. Cardboard Base with Pulley and Rubber Band

Having addressed the first challenge, the next issue is to secure the motor. The motor was originally mounted with popsicle sticks and glue. This option would not fit into Criterion #5, as the resulting design turned out rather intricate, while waiting for the glue to fully adhere was not tenable. Instead, prefabricated plastic motor mounts and electrical tape amount to a particularly fitting combination to hold the motor in place and manage the torque. The motor mount should be compatible in size with the motor. The mount selected has an inner circle size of 2 cm. The placement of the mount and motor must enable the connection to the pulley already secured on the cardboard base. The relevant procedure is explained next.

The axle and the motor must be joined together so that the car could move. Two combinations of pulleys are selected, matched with a rubber band of appropriate large or small size. The first combination includes a 1.8-cm pulley paired with a 1.6-cm pulley and connected with the small rubber band. The second combination features two 1.8-cm pulleys connected with the larger rubber band. The suitable pulley combinations are depicted in Fig. 4. The selection of matching pulleys and rubber band is left to the students so they can investigate how to set up the pulleys to fit each other.

Figure 4. Pulley and Rubber Band Combinations

Next is making sure the motor pulley is the right distance from the axle so that there is tension in the rubber band when it is linked. The average distance from pulley to pulley is around 2 cm for the smaller rubber band and 3 cm for the larger rubber band.

Following the test fit of the motor and pulley and upon ensuring the rubber band is taut and not touching with the cardboard, the placement of the mount is marked using a pencil. The motor mount is then secured in position by taping all four sides for additional support and preventing any potential movement. A single long piece of tape that spans over the hole and extends down the sides is placed. The remaining four sides are taped for more security. The steps are depicted in Fig. 5. It is worth mentioning that even though the students didn't use specific instructions about where to place the motor, the location of the cardboard cutout limits the placement of the motor. The model nevertheless allows for meaningful exploration. Upon determining the motor orientation, the students had to evaluate three design variables simultaneously, namely, the size of the second pulley, the size of the rubber band, and the precise distance of the motor from the affixed pulley.

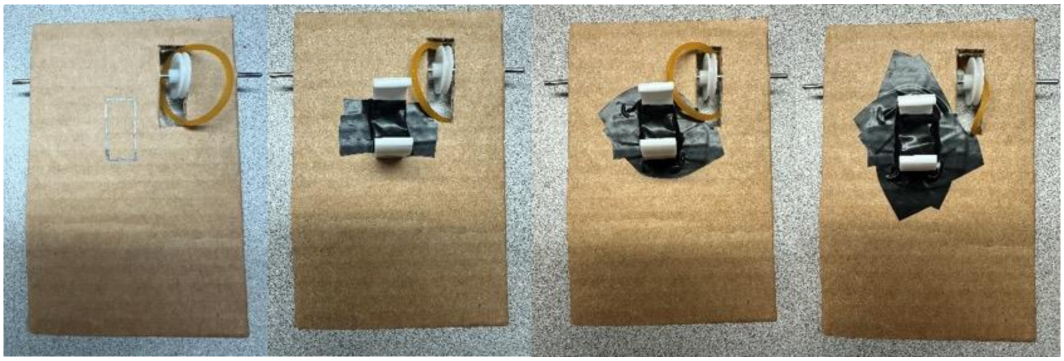


Figure 5. Timeline of Securing the Motor Mount

The next step is to place the motor onto the motor mount. Tape can be optionally applied across the top of the motor, securing it to the cardboard. The front wheels are then attached to the axle, as depicted in Fig. 6 (left and middle). The rear axle is connected afterward. Specifically, one wheel is attached to the axle, and the axle is threaded about 5-6 channels towards the back. Once the rear axle is through, the other rear wheel is attached. The build stage is shown in Fig. 6 (right).

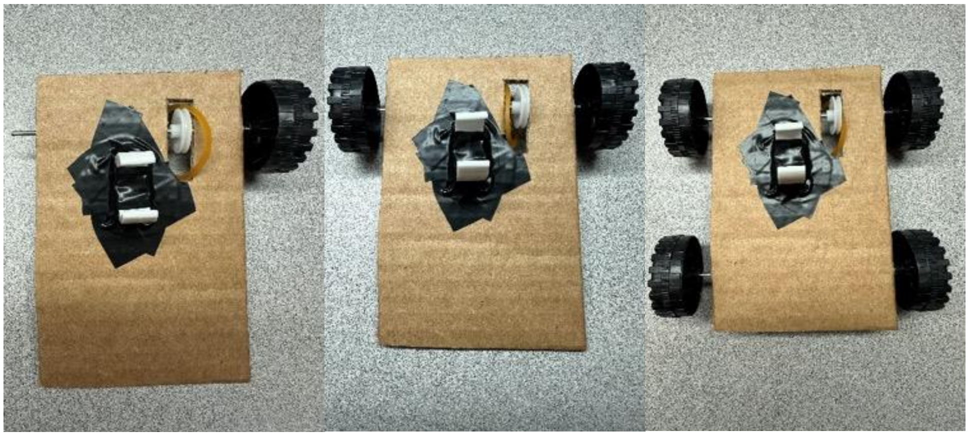


Figure 6. Wheel and Axle Assembly

The following step entails inserting the batteries into the battery pack and securing the pack onto the cardboard surface. The pack is placed on the cardboard using two pieces of electrical tape. To accomplish this, a loop is created with the electrical tape, effectively making it "double-sided." The tape is positioned onto the two black sections of the battery pack and placed at the rear of the car. Fig. 7 depicts the battery back taping and Fig. 8 shows the battery placement.

Figure 7. Battery Pack Taping

The final step in this model is connecting the wires together. The black wire from the motor is inserted into the black wire side of the battery pack outlet, and likewise for the red wire. The completed model is depicted in Fig. 8.

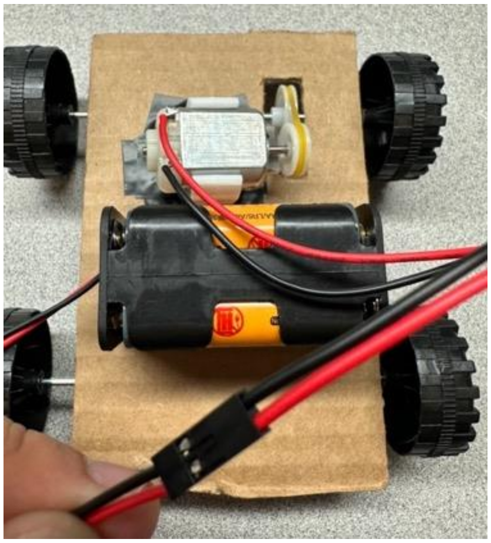
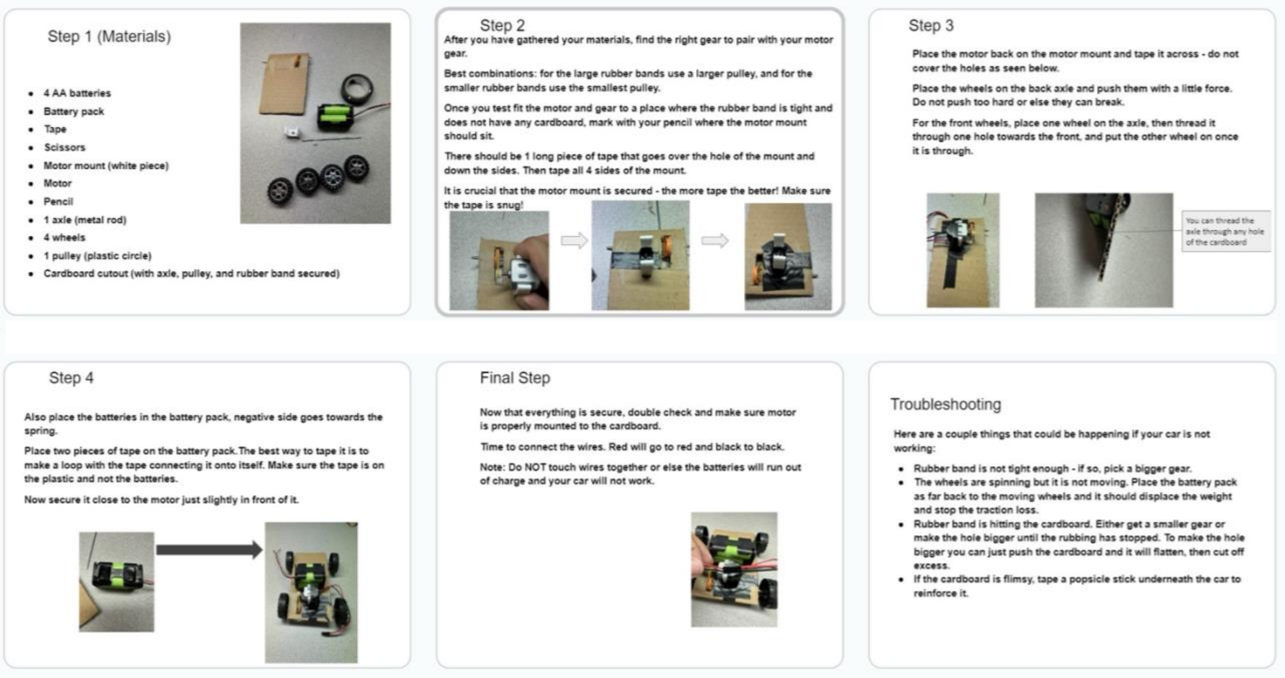


Figure 8. Completed Model

Building Instructions and Troubleshooting Steps

Clear and concise building instructions are made available to the teacher. It is up to the teacher whether they want to provide those to the students or create a more open-ended environment. Nevertheless, providing detailed instructions and troubleshooting provides teachers with an insight into how the car can be built and anticipate some of the scaffolds they can provide students. The instructions begin with a parts list helping the students gather everything they need to begin construction and they continue with building steps and a troubleshooting guide, as seen in Fig. 9.



Step 1 (Materials)

- 4 AA batteries
- Battery pack
- Tape
- Scissors
- Motor mount (white piece)
- Motor
- Pencil
- 1 axle (metal rod)
- 4 wheels
- 1 pulley (plastic circle)
- Cardboard cutout (with axle, pulley, and rubber band secured)

Step 2

After you have gathered your materials, find the right gear to pair with your motor gear.

Best combinations: for the large rubber bands use a larger pulley, and for the smaller rubber bands use the smallest pulley.

Once you test fit the motor and gear to a place where the rubber band is tight and does not have any cardboard, mark with your pencil where the motor mount should sit.

There should be 1 long piece of tape that goes over the hole of the mount and down the sides. Then tape all 4 sides of the mount.

It is crucial that the motor mount is secured - the more tape the better! Make sure the tape is snug!

Step 3

Place the motor back on the motor mount and tape it across - do not cover the holes as seen below.

Place the wheels on the back axle and push them with a little force. Do not push too hard or else they can break.

For the front wheels, place one wheel on the axle, then thread it through one hole towards the front, and put the other wheel on once it is through.

You can thread the axle through any hole of the cardboard

Step 4

Also place the batteries in the battery pack, negative side goes towards the spring.

Place two pieces of tape on the battery pack. The best way to tape it is to make a loop with the tape connecting it onto itself. Make sure the tape is on the plastic and not the batteries.

Now secure it close to the motor just slightly in front of it.

Final Step

Now that everything is secure, double check and make sure motor is properly mounted to the cardboard.

Time to connect the wires. Red will go to red and black to black.

Note: Do NOT touch wires together or else the batteries will run out of charge and your car will not work.

Troubleshooting

Here are a couple things that could be happening if your car is not working:

- Rubber band is not tight enough - if so, pick a bigger gear.
- The wheels are spinning but it is not moving. Place the battery pack as far back to the moving wheels and it should displace the weight and stop the traction loss.
- Rubber band is hitting the cardboard. Either get a smaller gear or make the hole bigger until the rubbing has stopped. To make the hole bigger you can just push the cardboard and it will flatten, then cut off excess.
- If the cardboard is flimsy, tape a popsicle stick underneath the car to reinforce it.

Figure 9. Building Instructions with Troubleshooting Guide

Several issues that may arise during construction are identified in the troubleshooting guide and addressed to optimize functionality:

- **Tensioned Rubber Band:** To address lack of tension in the rubber band, a recommendation is made to select a larger gear for improved performance. If that does not work, moving the motor mount further will also significantly improve tension in the band.
- **Wheel Spin Without Movement:** In the case where the wheels spin without moving the car, moving the battery pack to the rear of the vehicle will effectively redistribute weight, preventing traction loss.
- **Rubber Band Interference:** When encountering an issue with the rubber band rubbing the cardboard, there are two potential solutions, namely, opting for a smaller pulley or modifying the hole size. The latter can be achieved by gently pushing and flattening the cardboard with a pencil or scissors, followed by trimming excess material.
- **Reinforcing Flimsy Structure:** To improve the overall structural integrity of the cardboard, a suggestion is to reinforce it by affixing a popsicle stick underneath the car.

Implementation and Feedback

The model car kit was assembled by a group of 21 fifth-grade students, the majority Hispanic. They used a pre-packaged kit that included all the necessary materials. The goal was for the students to create an electric car model that could travel by itself. The cardboard bases provided to the students had the axle, pulley, and rubber band already attached, as depicted in Fig. 3 (right). The teacher supported the activity by projecting a list of materials on the screen (cf. the first slide in Fig. 9). At the beginning of the class, the students were asked to build the model without any guidance or instructions, but they could use the knowledge discussed during the lesson. After 8-10 minutes, the teacher showed the students a built model to help them refine their thinking and finalize their model. By limiting the time, the teacher made it a constraint of the design process.

The model car kit implementation was assessed using the design criteria previously articulated. Each kit was priced at approximately $7.60 at the time of writing, making it accessible (the figure excludes the cost of scissors, the cardboard—which was obtained from used shipping boxes—and the electrical tape—which can be shared by several students). The design did not include hazardous items for students; they could build the car without safety issues or using specialized equipment. The researchers were allowed to observe the implementation and collected qualitative feedback from the STEM teacher. The findings pertaining to student experience and possible implementation improvements are reported next.

The results from the implementation show that having a low-cost product benefited the students, as they could take the kit home, continue working on the design, and share it with family members, thus extending the learning experience from the school setting to their homes. Participating students manipulated the parts easily (Fig. 10). However, connecting the battery and motor was difficult for them due to the small size of the connector.

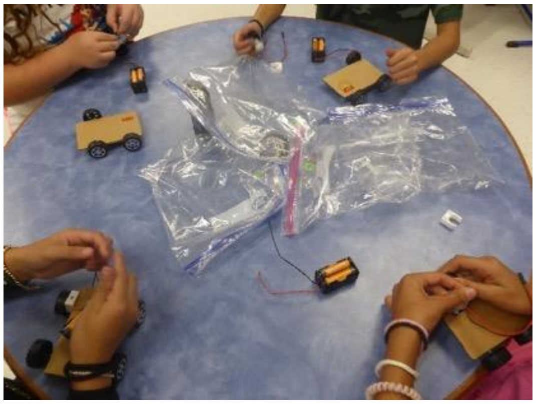


Figure 10. Elementary Students Using the Car Kit During the Lesson

The students established connections between the scientific knowledge and engineering practices addressed during the lesson. They were able to differentiate between electric and gasoline cars, but recognized that both used batteries and electric circuits, albeit within different engineering designs. As a result, the knowledge they developed in this lesson could apply to both types of cars and in particular, help the students differentiate between technologies. When prompted to explain why building the car the way they did allowed the car to move, some of the students based their explanations on energy conversion from the battery to the wheels.

The teacher's evaluation primarily emphasized the preparation time required for this lesson, and provided additional approaches to implementation. The teacher suggested that teachers must have a comprehensive understanding of how to construct the car before initiating the lesson to enable them to better assist the students. Moreover, the teacher recommended an alternative approach to hand out the materials, which resembles an assembly line, where materials are systematically arranged on a table, and students can form a line to choose their materials. The teacher further emphasized that preparing the materials and learning how to assemble the car might require up to an hour.

Although the initial criteria for the kit design were met, there is always room for improvement. Based on feedback from the elementary STEM teacher and observations conducted by the researchers during the lesson, possible changes were identified to enhance future implementations of the car kit. Areas of improvement include the physical kit components, design constraints, and packaging.

The car model used for this lesson can benefit from adding a switch. This switch would allow students to start and stop the car without disconnecting the battery and the motor. Some students had difficulty connecting the battery and the motor, given the small size of the cables and the connector. This caused delays during the building and testing process, which made the process more time-consuming. In a classroom setting, time is limited by the school schedule. Therefore, adding a switch could simplify the process, making better use of class time.

Design constraints are an essential part of the engineering design cycle as they encourage students to think deeply about the variables that describe the system and the relationships between them. During the implementation, the STEM teacher included time as a constraint. However, additional constraints might be added to prompt deeper thinking about how different components might affect the functioning of the electric vehicle. For instance, providing for the vehicle to move forward and backward and inquiring the students to achieve this goal expands the design space of the model. The latter can be combined with various switch types and exploring concepts related to source polarity in direct current circuits.

Most of the engineering kits are packaged individually so that each student or group of students receives all the materials they need at once. However, in this case, the researchers provided the materials without packaging them. The purpose was to prompt students to think about what they might need to build a car and choose the necessary parts. Although this approach has proven effective in science learning environments, it can be time-consuming, and it was not deemed feasible. Therefore, the STEM teacher pre-packaged the kits before the lesson, allowing the students to focus on building the model.

The possible areas of growth are influenced by contextual classroom and school factors, for instance, scheduled time for the STEM lesson or adjustments that can enhance student learning. The culture of the classroom and school plays a crucial role in instruction. In the case of the school where the lesson was implemented, the STEM class was scheduled every other week. Without additional time for any lesson, it had to be completed during the designated time. To keep the class on schedule, it was necessary to complete the first step of attaching the axle, pulley, and rubber band to the cardboard base as well as pre-package the remaining components of the kit before the class. Notwithstanding the extra load on the teacher outside of the class, the build time can potentially be further reduced by completing additional steps of the design before class. The trade-off between activity duration and allowing for meaningful exploration of the engineering concepts must be assessed in this case. On the other hand, adding a switch is an improvement that could allow students to establish more direct connections between the electric circuit lesson and the car's functioning. To more effectively assist with the teacher preparation, the researchers have identified that recording a video with the car build sequence would be pertinent.

Summary and Conclusions

There is a documented need for developing materials that promote STEM literacy and fulfill requirements on teaching engineering concepts in elementary schools. Motivated by the broader issue of transportation electrification, this article is concerned with the development of a hands-on activity for elementary school students to build a small battery-powered vehicle model. The materials include a 5-volt motor, bracket, wheels, axles, pulleys, rubber band, cardboard, and electrical tape. The design is documented in detail to facilitate the reproduction and adoption by other interested parties. The build is low-cost, safe, and effective. Experiences from implementation of the model in an elementary school indicate that connections to relevant electric circuit and energy conversion concepts were successful. The students benefited from the low-cost implementation, as they were able to take the model back home. Feedback from the teacher emphasized that adequate preparation for the lesson is necessary, especially understanding how to build the model before starting the lesson. Suggestions for model improvements include adding a switch, enriching the design to explore various design constraints, and pre-packaging the materials needed per student or small group of students before the lesson. Future implementations will be paired with strategies for collecting feedback to allow for quantitative analysis.

Acknowledgement

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