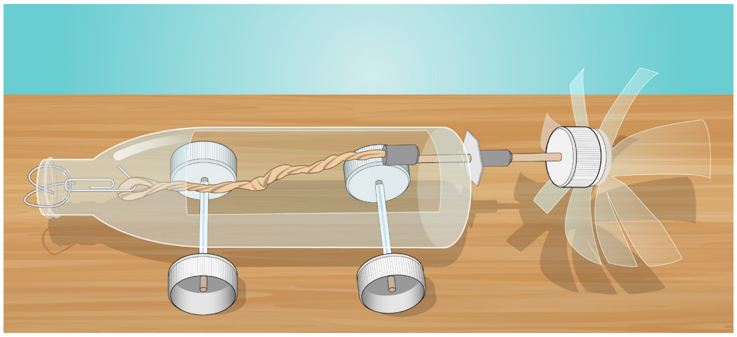
Activity Two: Propelling the Payload With Electric Propulsion

Educator Notes

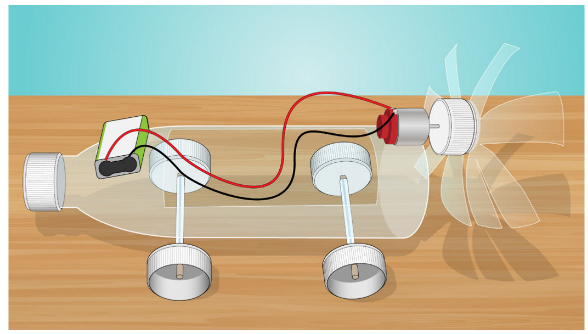
Learning Objectives

Students will

- Investigate the impact of varying mass on the average speed of a propeller car (either of the designs below).



or



Investigation Overview

Students will explore the compromises engineers have to make when designing an electric vehicle with batteries. Specifically, students will use a propeller car (premade or by design) to investigate the effect of varying mass on average speed. This investigation will highlight the tradeoff of higher capacity batteries being heavier.

Suggested Pacing

45 to 90 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. • MS-PS3-1 Energy: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.	*Crosscutting Concepts* • Stability and Change: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others.	*Standards for Students (continued)* • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.
Mathematics (CCSS)	
Mathematical Practices • MP.2: Reason abstractly and quantitatively. *Content Standards* • 6.EE.A.2: Write, read, and evaluate expressions in which letters stand for numbers. • 7.EE.B.3: Solve multistep real-life and mathematical problems posed with positive and negative rational numbers in any form, using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate. and assess the reasonableness of answers using mental computation and estimation strategies.	*Content Standards (continued)* • 7.EE.B.4: Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. • 8.F.A.3: Interpret the equation y = mx + b as defining a linear function whose graph is a straight line; give examples of functions that are not linear.

Investigation Preparation

- Read the introduction and background information, Educator Notes, and Student Handout to become familiar with the activity.
- Determine teams and roles prior to the investigation. See team role suggestions in the front of this educator guide.
- Prepare materials ahead of time in the materials area for team assembly.
- Make copies ahead of time of the Student Handout, Propeller Car Instructions (Appendix C), and optional Basic Propeller Template (Appendix C).

Materials (per team unless noted)

- ☐ 1 balance (one per whole group)
- ☐ 1 ruler or measurement tape
- ☐ 1 timer
- ☐ Various items representing mass (washers, coins, etc.)
  Tip: Pennies weigh approximately 2.5 to 3.1 grams for an easy unit of measure.
- ☐ Graph paper
- ☐ Calculators

Building Supplies for Propeller Car

- ☐ See Propeller Car Instructions in Appendix C for list of materials.

  Note: For data comparison purposes, each car should be made with the same materials to eliminate extra variables.

Safety

Review all safety tips before building the propeller car. Adult supervision is required for building and testing the propeller car.

Introduce the Investigation

- Before providing information to students, begin with a graphic organizer and simply write the word "drone." See how much information students already know and what they want to learn. Return to the graphic organizer at the conclusion of the investigation to follow up with students about what was learned through the activity.
- Show one or both of these introductory videos:
  - What Is AAM? https://youtu.be/Vu1VWEvgd24
  - NASA LEAPTech: Distributed Electrical Propulsion. https://youtu.be/hhL2-Lykl9s
- Explain the details of the investigation, including criteria and constraints.

Criteria	Constraints
Students may utilize a commercially available propeller car or use the provided instructions to build a motorized or rubberband-powered propeller car.	Students may not deviate from the propeller car design or use a different design than other teams.
Students must design an investigation that demonstrates how mass affects the speed of a propeller car.	

Facilitate the Investigation

? Pose Question

- After watching the introductory videos, ask students guiding questions such as these:
  - What are some challenges of electric propulsion for unmanned aircraft systems (UAS)?
  - In what ways are electric propulsion and propulsion on traditional aircraft similar or different?
  - Why is the battery such an important part of a UAS?
  - Is a bigger battery always better? What are the benefits and drawbacks of a bigger battery?

Brain Booster

We often confuse the terms "mass" and "weight" and use them interchangeably even though they have very different meanings. Mass does not change whether it is measured on Earth, the International Space Station, or Mars. Weight can change depending upon the gravitational pull, such as on the Moon, where weight is reduced to one-sixth that of on Earth. Follow the link below and see how much you weigh on the other planets in our solar system.

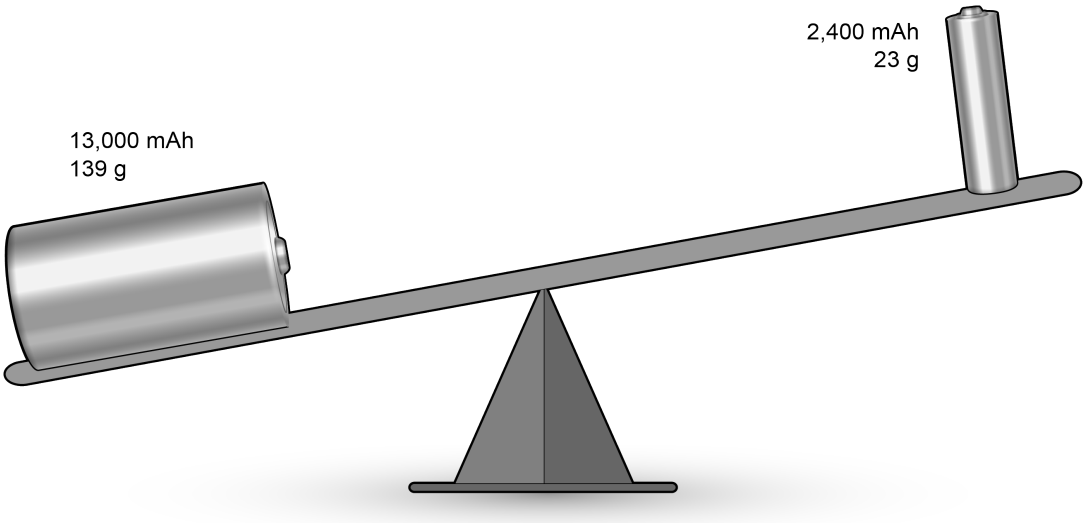
Learn more:
https://www.nasa.gov/specials/kidsclub/games/astro-matic-3000/index.html

On Location

Katherine Johnson worked for NASA from 1953 to 1986 as a mathematician. She made her mark in history at a time when women and African Americans were regularly marginalized. NASA's Langley Research Center has named a 40,000-square-foot Computational Research Facility in her honor. Johnson calculated the trajectory of the first American in space in 1961. She verified the calculations of the 1962 launch into orbit and the calculation for the Apollo 11 trajectory to the Moon. Johnson has been recognized throughout the years, and Hollywood told Johnson's story in the film "Hidden Figures."

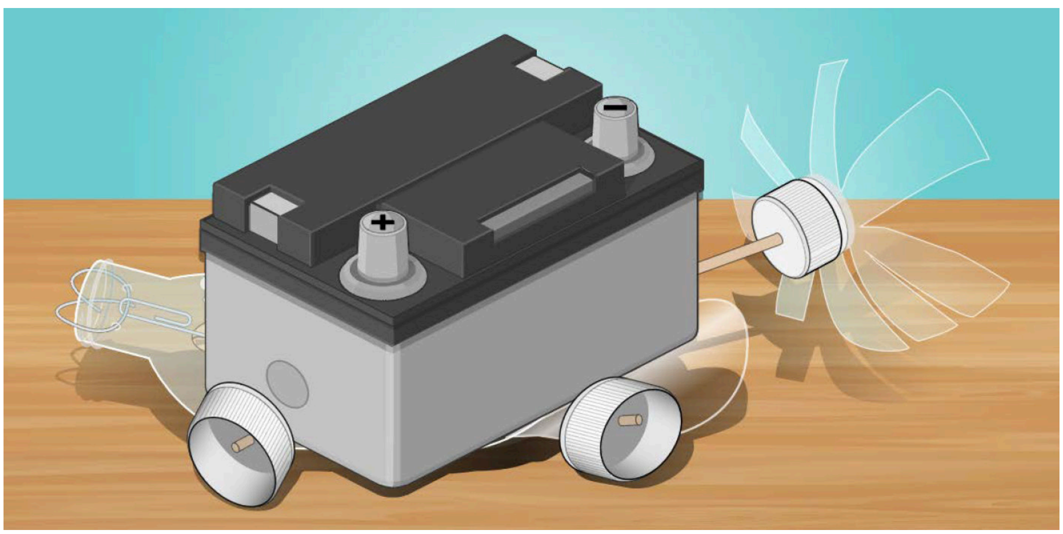
Learn more:
https://www.nasa.gov/feature/langley/computational-facility-named-in-tribute-to-nasa-langley-math-master-katherine-johnson

- Explain to students that they will be investigating the tradeoffs between the capacity of a battery and its mass with respect to how that might affect the speed of a UAV. The following diagram captures the essence of the problem.



The D battery can store more power than the AA battery but weighs a lot more.

- If students do not immediately grasp why the illustrated tradeoff is not always worthwhile, show them a propeller car with a battery that is so big the car cannot possibly move and might even be crushed.



There is such a thing as "too much power."

Develop Hypothesis

Electric propulsion, while beneficial to our overall environmental impact, does present challenges for scientists and researchers. One of the main challenges is that batteries are heavy, and the heavier the object, the greater the force that is needed to move the object, according to Newton's second law.

- Teams will use a propeller car (representing a UAV) to investigate how mass (representing batteries) can affect average speed. Students are free to choose the object they will use to increase the mass added to the car and the increments by which they will increase the mass.
- If students are having difficulty formulating a testable hypothesis, provide them with the following prompt: "If mass is __________, then the average speed of the propeller car will _________________________."

Plan Investigation

- Teams will construct an electric motor propeller car or a rubberband-powered propeller car to test their hypothesis.

  Note: As a time-saving alternative, educators may choose to construct or purchase enough commercial propellers for everyone in advance. However, if a commercial propeller is not available, students may use the Basic Propeller Template in Appendix C to build their propeller.
- Teams will brainstorm suitable objects to use for mass and develop a testable hypothesis along with a plan for investigation.
- Once the team has a working propeller car, they will need to prepare for data collection. A sample data table is provided here:

Amount of mass added to test car, g *Payload*	Time to travel length of course, s				Average speed, m/s
	Test 1	Test 2	Test 3	Average time	
0	5	5	5	5	2 m/5 s = 0.4 m/s
5	7	10	10	9	2 m/9 s = 0.22 m/s

- Students should pick a standard course length for all of their tests. A 2-m course length is typically long enough, but longer or shorter courses are fine if there is enough space to test safely. The starting and ending points of the course should be clearly marked. Student-made cars may not always travel in a straight line, so the finish line may need to be a semicircle centered on the starting point.
- In order to mitigate random error, students will be using the average (mean) time of three tests per chosen mass.
- To find the average speed, take the length of the course and divide it by the seconds taken on average; for example, if a propeller car travels 3 m at an average time of 10 s, the speed = 3 m/10 s, and the average speed = 0.3 m/s.
- Optional: If students have access to video tracking software, a tachometer, or a high-speed camera, they may be able to find peak speed (the fastest the car travelled during tests) or even several points of instantaneous speed (how fast the car is going at any given moment) instead of, or in addition to, the average speed.

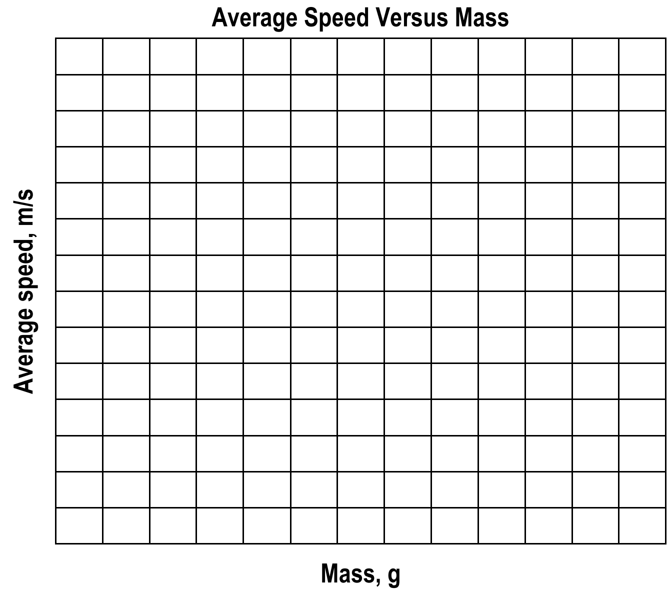
Assemble Data

- Have teams run the trials, adjusting the variable of mass the team agreed upon initially in the plan. Reminder: Always use the same amount of propeller twists if using the rubberband propeller cars; if using the motorized car, be sure the battery is fully charged.

  Note: If not using rechargeable batteries, have extras on hand, because the motor will drain the battery. If using rechargeable batteries, keep extras on the charger.
- Teams will measure the length of time the car travels a given distance for each mass.
- After the information is added to the table, teams will calculate the average time and speed for each payload trial.

Analyze and Document Conclusions

- Students should plot their data points on a graph.
- Students will use average speed (dependent variable) and the mass (independent variable) to make a graph of their results for all trials conducted.
- Students will determine if their hypothesis was supported or not supported by their data.



Present Findings

Post student graphs around the room so all students can easily compare the data.

Engage students with the following discussion questions:

- What can you infer from the data regarding the effect of mass on average speed of an object?
- What were some obstacles your team faced during the investigation process, and how did you overcome them?
- Were your predictions about your team's propeller car accurate? Explain.
- How would you take what you learned about your propeller car to make a better UAV?
- Based on your findings, what is something you would like to investigate further?
- Compare your graph to the graphs of other teams and answer the following questions:
  - How is your graph similar to the other graphs?
  - How is your graph different from the other graphs?
  - What are possible reasons for these similarities and differences?
  - Were there any trials performed by your team or another team with unexpected outcomes? If so, why do you think that was?

Extensions

- Measurement extension: Students can use a smartphone and/or a computer for digital video analysis of instantaneous speed. Examples of video analysis tools are Tracker (Open Source Physics), Logger Pro® (Vernier Software & Technology), and Vernier Video Physics (Vernier Software & Technology).
- Ask students to design their own controlled investigation with the propeller car and brainstorm other independent variables they could change besides mass.
- Students could draw a line or curve of best fit for the data. In addition, ask students to find the equation of the line or curve of best fit. Spreadsheets can make this easier and can also be used to quickly measure the fit (r^2 value) of the formula.

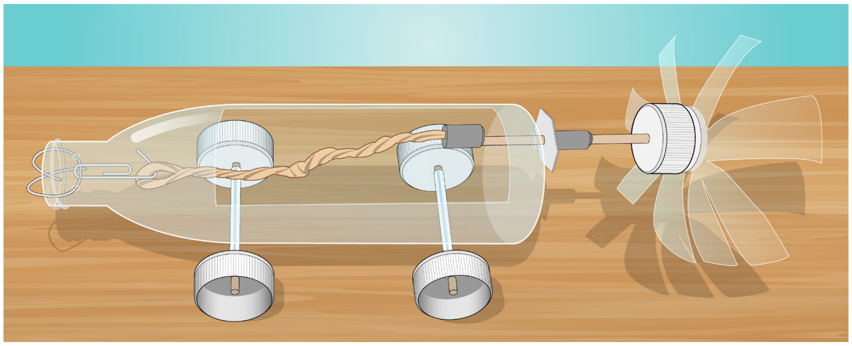
Resources

Mass vs. Weight
https://www.nasa.gov/pdf/591747main_MVW_Intro.pdf

NASA STEMonstration Classroom Connection: Newton's Second Law
https://www.nasa.gov/sites/default/files/atoms/files/stemonstrations_newtons-second-law.pdf

Activity Two: Propelling the Payload With Electric Propulsion

Student Handout



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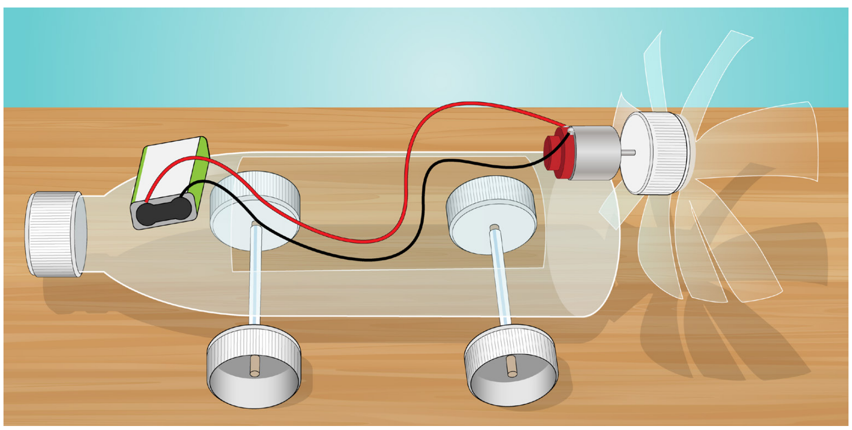

Your Challenge

Your team will explore the challenges of electric propulsion in flight. You will use a propeller car to represent an unmanned aerial vehicle (UAV) as you investigate the effect of varying mass on average speed. In this experiment, the mass represents the weight of the battery.

Note: The car and means of propulsion must remain constant.

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? Pose Question

NASA is exploring the benefits and challenges of unmanned aircraft systems (UAS) for future travel and delivery systems. After watching the introductory videos about UAS and electric propulsion, answer the following questions:

- What are some challenges of electric propulsion for UAS?

Fun Fact

The X–57 Maxwell is NASA's first all-electric X-plane. The X–57 will have 14 motors that are run by 16 batteries weighing a total of 360 kg (800 lb). This X-plane is being developed to demonstrate that electric propulsion can significantly increase efficiency at high-speed cruise compared with aircraft propelled by traditional systems. Electric propulsion will result in lower operating costs and lower carbon emissions.

Learn more:
https://www.nasa.gov/centers/armstrong/feature/X-57_battery_major_milestone.html

NASA's X–57 all-electric X-plane is shown here in its Mod II configuration. (NASA AFRC TV/ Steve Parcel)

Career Corner

Timothy Williams is a research test pilot at NASA's Armstrong Flight Research Center, and he will pilot the X–57 Maxwell. Timothy is qualified to fly a diverse array of science, research, and mission support aircraft for NASA.

Learn more:
https://www.nasa.gov/centers/armstrong/about/biographies/pilots/timothy-williams.html

- In what ways are electric propulsion and propulsion on traditional aircraft similar or different?
- Why is the battery such an important part of a UAS?
- Is a bigger battery always better? What are the benefits and drawbacks of a bigger battery?

Develop Hypothesis

Electric propulsion, while beneficial to our overall environmental impact, does present challenges for scientist and researchers. One of the main challenges is that batteries are heavy, and the heavier the object, the greater the force that is needed to move the object, according to Newton's second law.

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- If you are having difficulty formulating a testable hypothesis, use the following prompt: "If mass is __________, then the average speed of the propeller car will ________________________ ."

Plan Investigation

- Construct an electric motor propeller car or a rubberband-powered propeller car.
- Your team will brainstorm suitable objects to use for mass and develop a testable hypothesis along with a plan for investigation.
- Once your team has a working propeller car, you will need to prepare for data collection. A sample data table is provided below:

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- Your team will be using the average (mean) time of three tests per chosen mass.
- To find the average speed, take the length of the course and divide it by the seconds taken on average; for example, if a propeller car travels 3 m in the average time of 10 s, the speed = 3 m/10 s, and the average speed = 0.3 m/s.

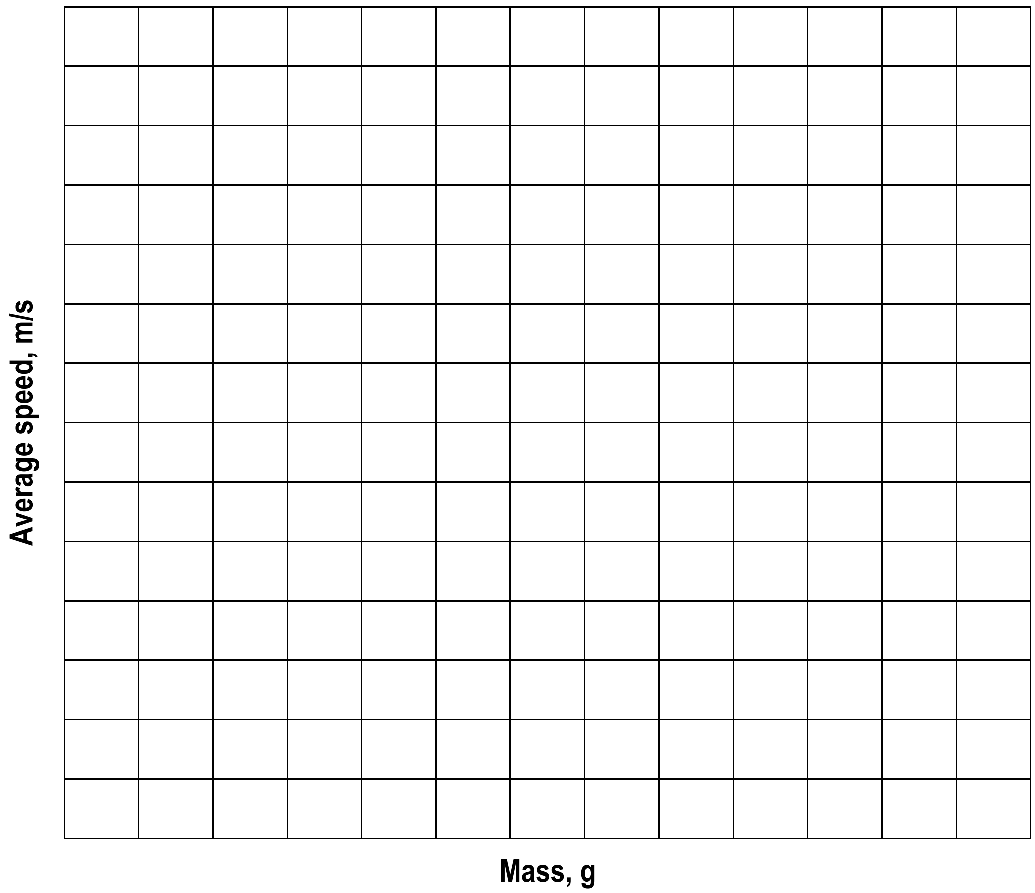
Assemble Data

- Your team will run the tests, adjusting the variable of mass the team agreed upon initially in your team's plan. Reminder: always use the same number of propeller twists if using the rubberband car; if using the motorized car, be sure that the battery is fully charged.
- Your team will measure the length of time the car travels a given distance for each mass. Add the data to your data table, and then calculate the average time and speed for each payload trial.

Analyze and Document Conclusions

- Use average speed values (dependent variable) and the mass values (independent variable) to make a line graph of your results for all trials conducted.

Average Speed Versus Mass



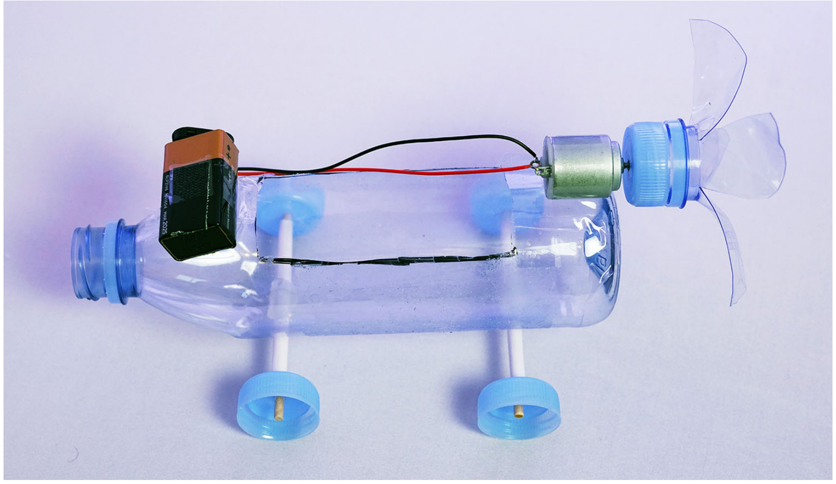
Present Findings

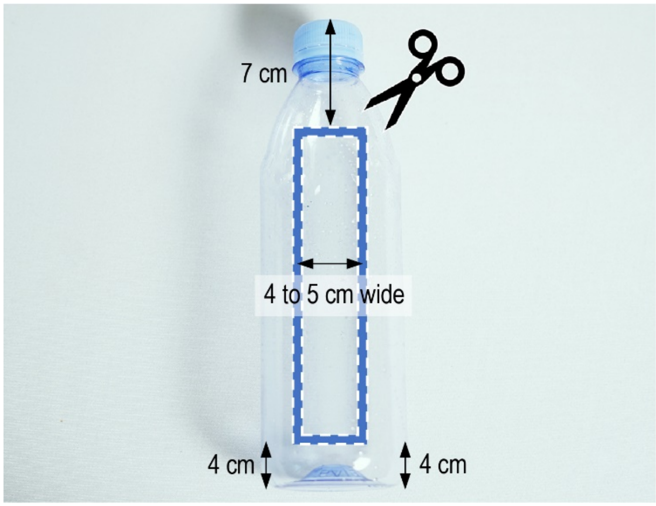
Be prepared to answer the following discussion questions with the whole group:

- What can you infer from the data regarding the effect of mass on average speed of an object?
- What were some obstacles your team faced during the investigation process, and how did you overcome them?
- Were your predictions about your team's propeller car accurate? Explain.
- How would you take what you learned about your propeller car to make a better UAV?
- Based on your findings, what is something you would like to investigate further?
- Compare your graph to the graphs of other teams and answer the following questions:
  - How is your graph similar to the other graphs?
  - How is your graph different from the other graphs?
  - What are possible reasons for these similarities and differences?
  - Were there any trials performed by your team or another team with unexpected outcomes? If so, why do you think that was?

C.2 Electric Motor Propeller Car Instructions

Gather all needed materials and review the Motorized Propeller Car Tutorial video: https://youtu.be/uPxmCzMyBII.

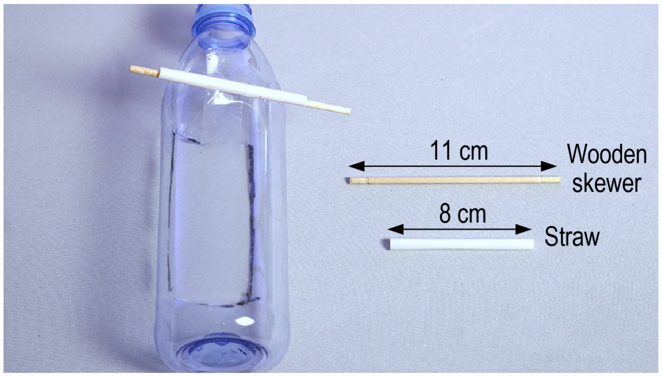




Step 1: Create the cargo bay access window.

Lay one of the bottles on its side and cut a rectangular hole that extends approximately 4 cm from the bottom of the bottle to approximately 7 cm from the top of the bottle.

The rectangle should be between 4 and 5 cm wide.

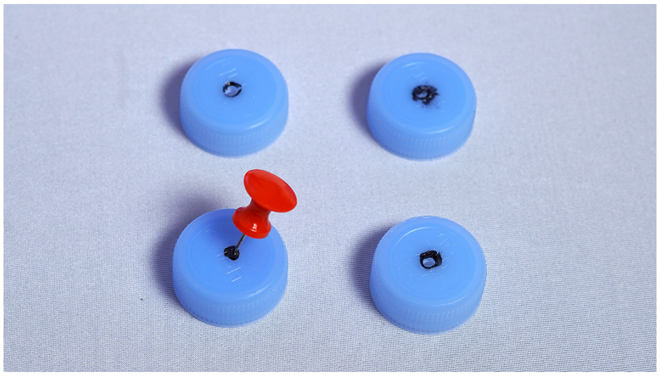


Step 2: Mount the axles.

Cut a straw into two 8-cm pieces. Each straw should be wider than the water bottle.

Use low-temperature hot glue or other adhesive to attach the straws to the water bottle on the opposite side of the rectangular hole that was cut in Step 1. Place the straws (axles) far enough apart so the weight is distributed evenly.

Cut a wooden skewer into two 11-cm pieces and slide the wooden skewers through the straws.



Step 3: Create the wheels.

Mark the center of each bottle-cap wheel with a marker. Use a pen or pushpin to make a small hole in the center of the marking. Make sure the hole is a little smaller than the wooden skewer (axle) diameter so it is a tight fit.

When using thick plastics, use a nail or a craft knife to make the holes larger.

Step 4: Mount the wheels.

Gently push a skewer through the center of a bottle-cap wheel.

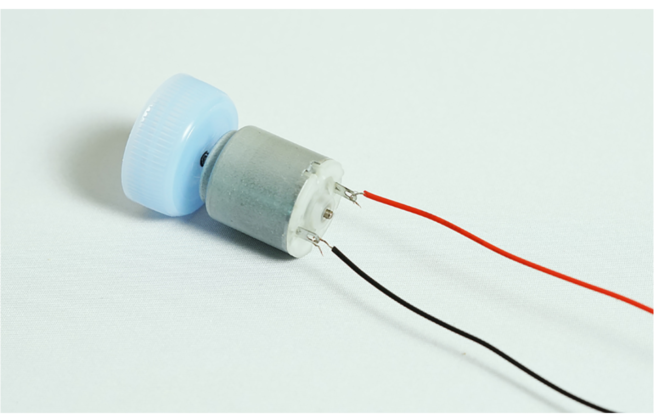
Slide the skewer through a straw and push into the center of a second bottle-cap wheel.

Repeat with the other two wheels and skewer.

Make sure the wheels are as straight as possible.

Note: Wobbly wheels make it difficult for propeller cars to move forward.

Step 5: Wire the motor to the 9-V battery clip.



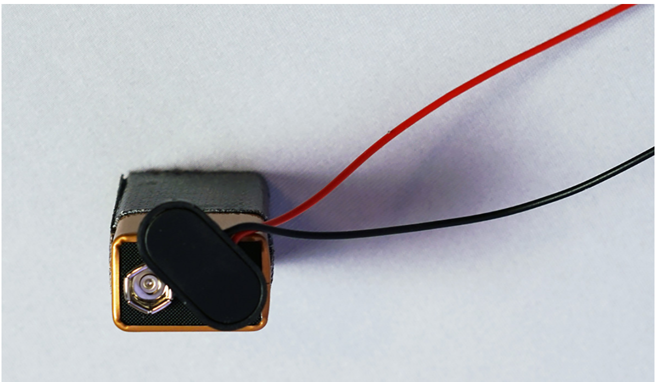
Strip the wires connected to the 9-V battery clip.

Connect the wires from the 9-V clip to the proper terminals on the motor.

- The **negative** terminal is designated by a "–" sign. Connect the **black wire** to the negative (–) terminal on the motor.
- The **positive** terminal is designated by a "+" sign. This is where the **red wire** will connect to the motor.

If the wires are too short, simply add additional cabling to extend the wires from the 9-V battery clip to the motor.

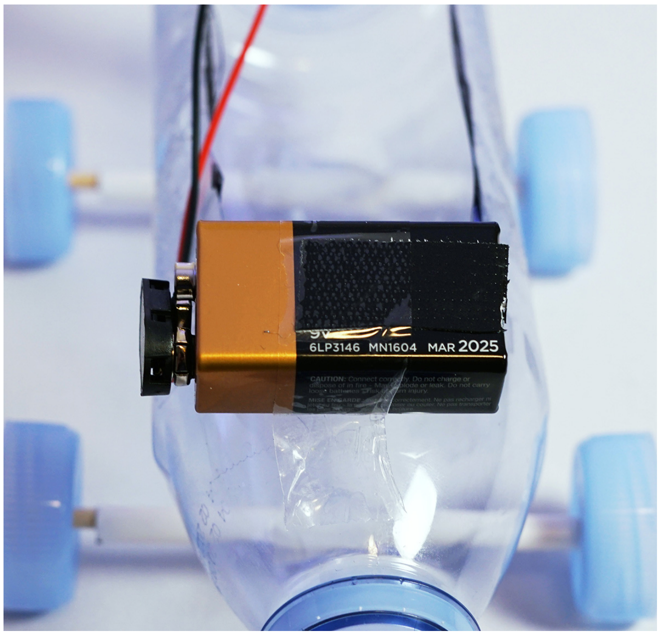
Note: Some DC motors do not designate a positive and negative terminal. If this is the case, simply wire each cable from the 9-V battery clip to a terminal on the motor.



Step 6: Connect the battery.

Attach the battery to the connectors on the 9-V battery clip. Your motor should run. If not, your battery may be dead, or wires may be touching. Troubleshoot the issue.

Now detach **one** of the battery connectors to turn off the power to the motor.

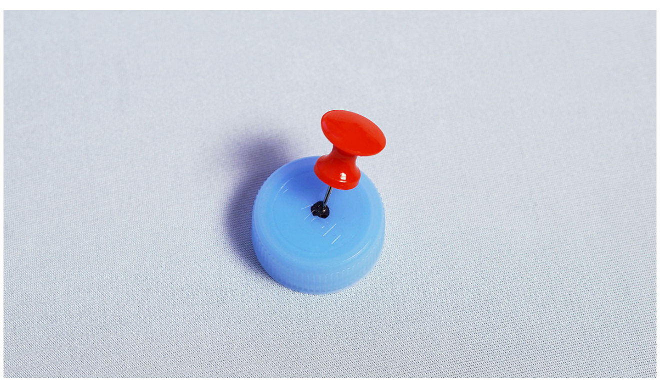


Step 7: Tape the 9-V battery to the car.

Neatly organize the cables inside or along the side of the test car.

Place and center the 9-V battery near the front of the car. It should be taped perpendicular to the body of the car.

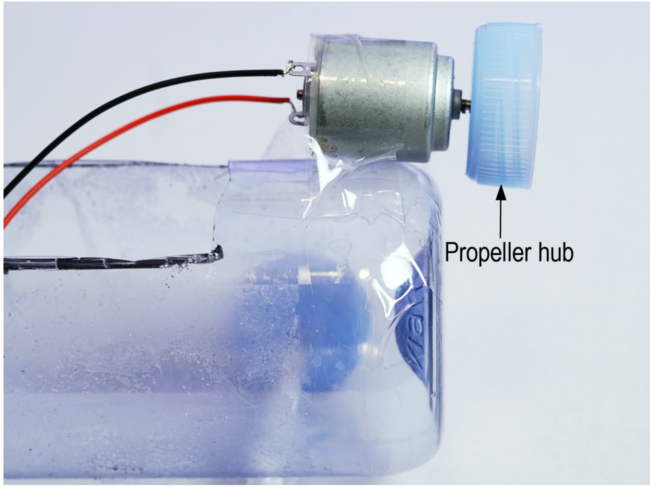
Note: Before moving to the next step, ensure that the propeller car is balanced.



Step 8: Connect the hub to the motor.

Mark the center of the top of a bottle cap with a marker.

Using the marking as a center point, use a pen to create a small hole through the **top** of the bottle cap.

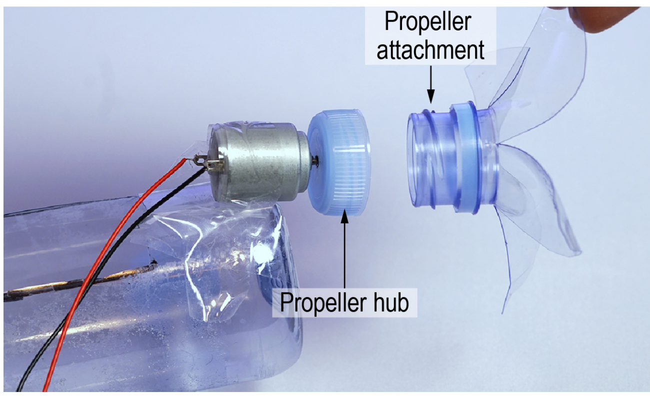


With the bottom of the bottle cap facing toward you, secure the bottle cap to the shaft of the motor.

The bottle cap should be placed about halfway between the tip of the motor shaft and the motor.

Use a moderate amount of low-temperature hot glue or adhesive on the inside of the bottle cap to ensure a tight fit.

Note: The bottle cap (propeller hub) should ***not*** *sag or rub against the motor or the bottom of the water bottle.*



Step 9: Connect the propeller attachment to the propeller hub.

The purpose of the propeller attachment (see photo) is for you to attach and reattach the propellers you design or redesign to the propeller hub.

Do not use glue to connect the propeller attachment to the propeller hub, because you will need to attach and reattach your propeller designs to it.

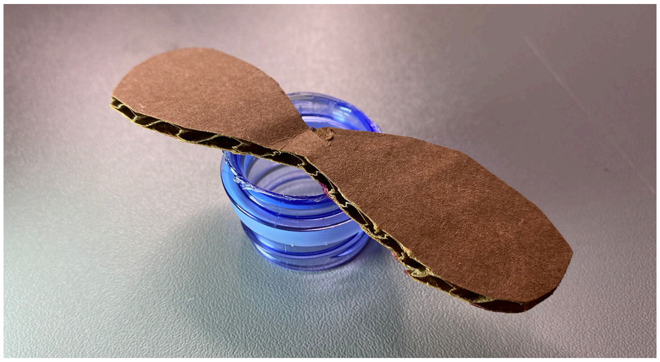
C.2.1 Propeller Attachment Instructions for Activity One, Propeller Design Challenge

After building either the rubberband-powered or electric motor propeller car, choose one of the options below for attaching propeller designs to the propeller car for Activity One: Propeller Design Challenge.

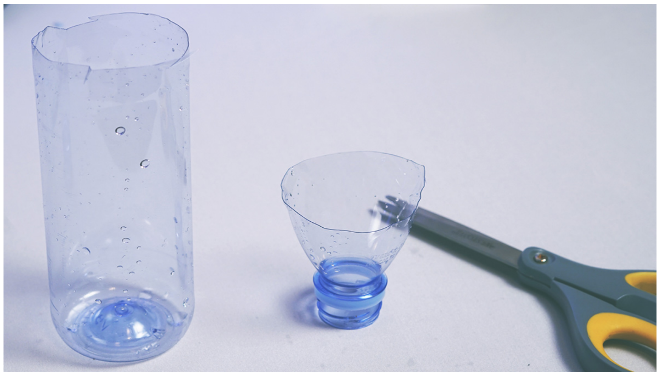
You have two options when using the propeller attachment.

Option 1:

Safely cut the threading off of a water bottle. You can use the base of this threading to attach your propeller designs to the system.



Option 1 example



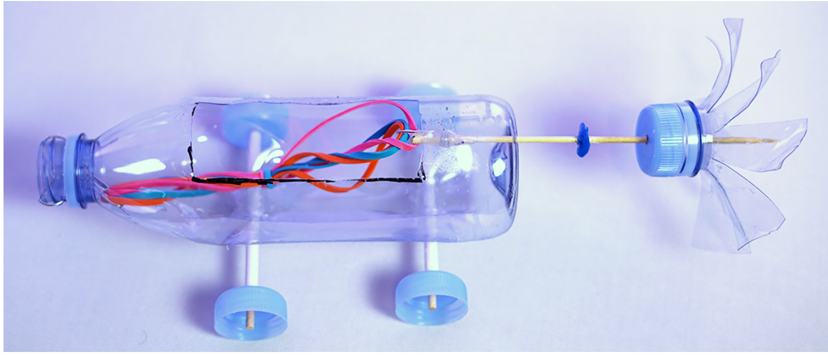
Option 2:

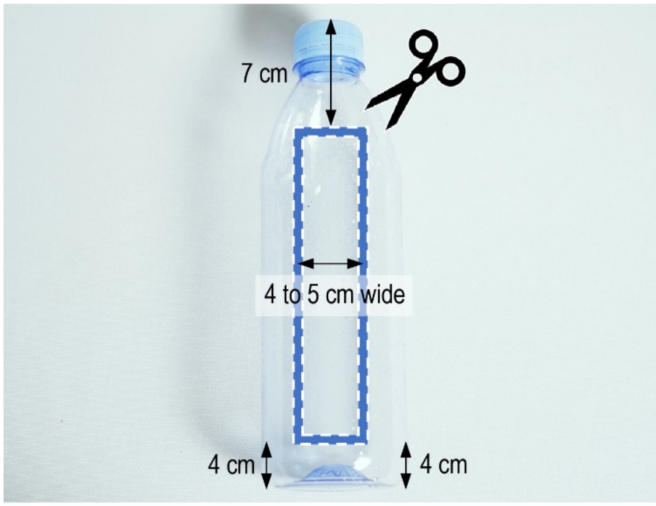
Safely cut the threading off of the second water bottle, but use some of the plastic from the neck of the second water bottle to create your propeller design.

Option 2 example

C.3 Rubberband-Powered Propeller Car Instructions

Gather all needed materials and review the Rubberband-Powered Propeller Car Tutorial video: https://youtu.be/1INd5Q8Cb2w





Step 1: Create the cargo bay access window.

Lay one of the bottles on its side and cut a rectangular hole that extends approximately 4 cm from the bottom of the bottle to approximately 7 cm from the top of the bottle.

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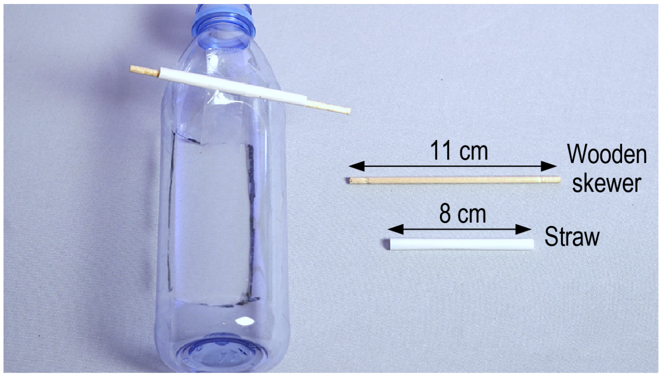
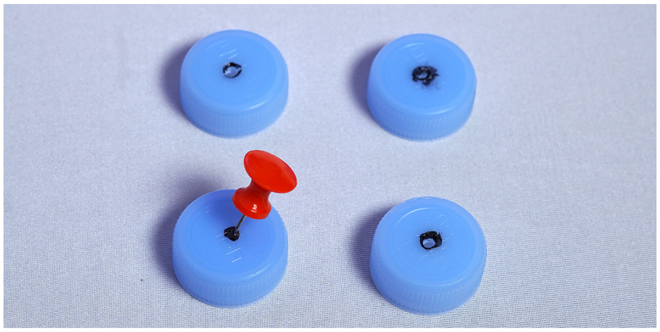


Step 2: Mount the axles.

Cut a straw into two 8-cm pieces. Each straw should be wider than the water bottle.

Use low-temperature hot glue or other adhesive to attach the straws to the water bottle on the opposite side of the rectangular hole that was cut in Step 1. Place the straws (axles) far enough apart so the weight is distributed evenly.

Cut a wooden skewer into two 11-cm pieces and slide the wooden skewers through the straws.



Step 3: Create the wheels.

Mark the center of each bottle-cap wheel with a marker. Use a pen or pushpin to make a small hole in the center of the marking. Make sure the hole is a little smaller than the wooden skewer (axle) diameter so it is a tight fit.

When using thick plastics, use a nail or a craft knife to make the holes larger.

Step 4: Mount the wheels.

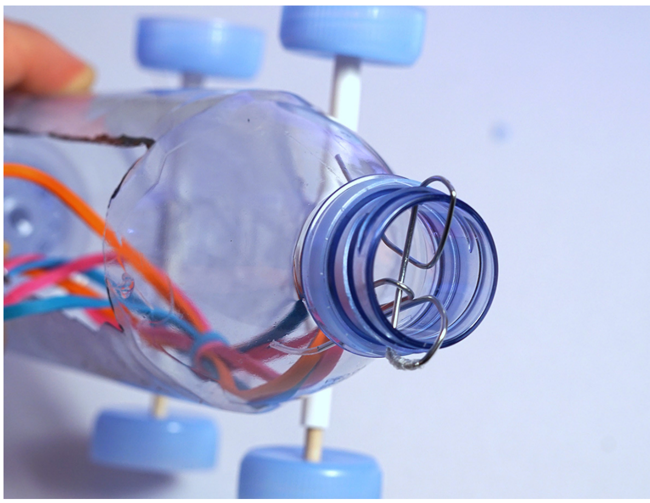
Gently push a skewer through the center of a bottle-cap wheel.

Slide the skewer through a straw and push into the center of a second bottle-cap wheel.

Repeat with the other two wheels and skewer.

Make sure the wheels are as straight as possible.

Note: Wobbly wheels make it difficult for propeller cars to move forward.



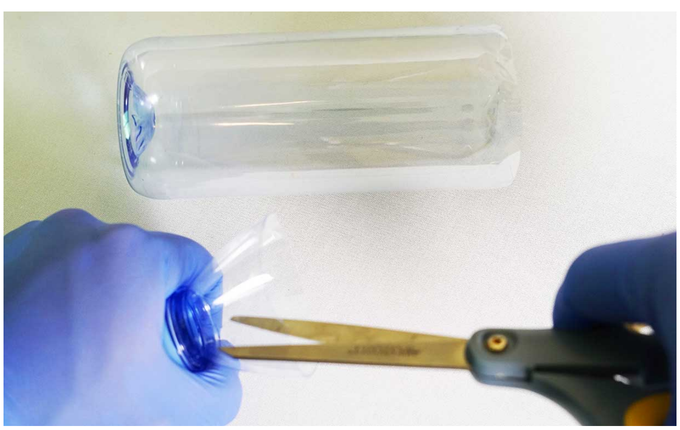
Step 5: Create the anchor for the rubberbands.

Use the pushpin and the nail to create two holes on opposite sides on the mouth of the bottle. Ensure the holes are large enough so the straightened paperclip will be able to slide through both sides.

Put the straightened paperclip through one hole, then slide it through the center of another paperclip that will be used as an anchor, and then out the other hole in the neck of the bottle. Bend the ends of the paperclip up and in, locking the paperclip in place.

Step 6: Make the propeller.

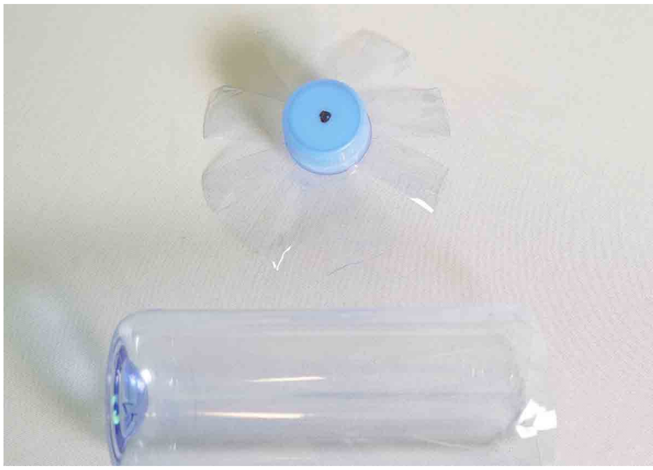
Note: This is an example of a basic propeller that can be used for the Propelling Your Payload With Electric Propulsion activity. Students will design their own propellers for the Propeller Design Challenge.



Cut off the top portion of the second water bottle. Make a horizontal cut on the side of the bottle right before the plastic starts to angle toward the neck of the bottle.

Safety reminder: Hold the bottle top firmly by its cap so the scissors do not accidentally contact your supporting hand.

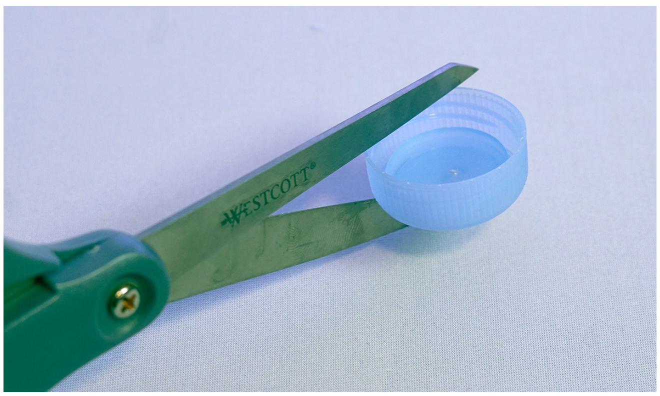
Starting at the cut edge of the bottle, make two cuts directly across from each other, cutting straight down and as close to the bottle cap as you can.



Repeat until you have four to eight equal sections or propeller blades. Gently fold them back to a roughly 90° angle (as shown in the picture).

Mark the center of the bottle cap (propeller hub) on the propeller with a marker. Use a pushpin to make a small hole in the center of the marking**.**

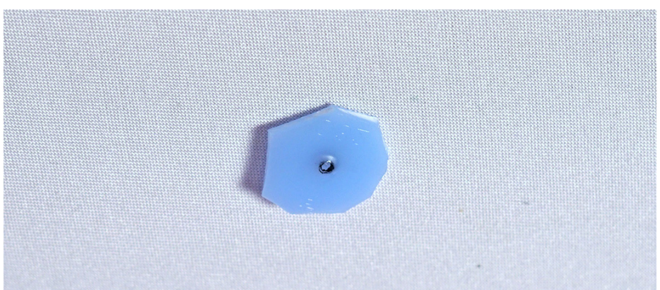
Make sure the hole in the bottle cap is a little smaller than the wooden skewer (axle) diameter, so it is a tight fit. **Do not** put the skewer in yet.



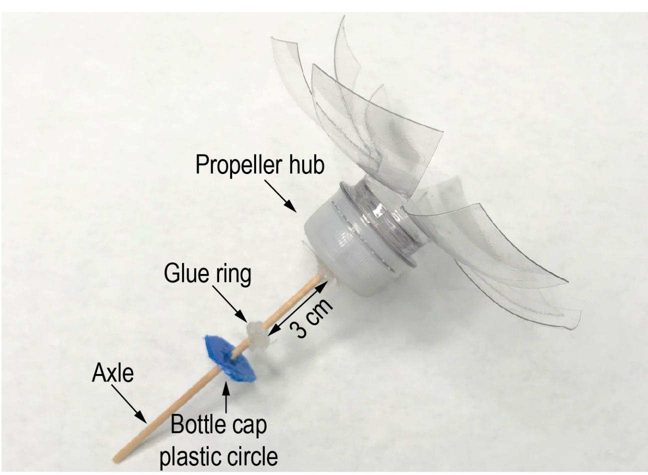
Step 7: Prepare your propeller.

Use the pushpin to poke a hole in the extra bottle cap.

Use the steel nail to widen the hole a little more.



Cut a circle out of the bottle cap. It does not have to be perfect.



Place the skewer in from the top side of the propeller bottle cap (propeller hub) and push it in about 4 cm. Put hot glue on the underside of the propeller hub to help hold the propeller hub onto the axle.

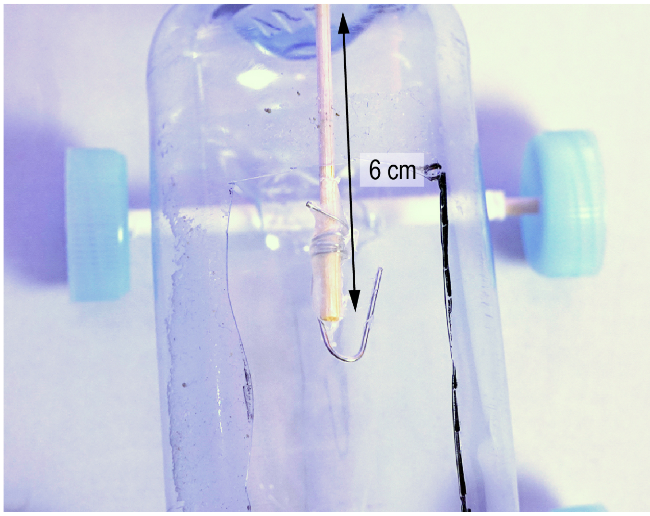
*Note***:** *The purpose of the propeller hub (see photo) is for you to attach and reattach the propellers you design or redesign to the propeller car, so it is important you **do not** use glue to connect the propeller itself to the propeller hub (bottle cap).*

Make a thick ring of hot glue, 3 cm away from the propeller hub on the skewer. Let it cool, then put the plastic circle you just cut out onto the skewer.

Step 8: Attach the propeller.

Use the pushpin to make a hole for the propeller's axle. Make the hole at the bottom (base) of the bottle on the same side as the cargo bay opening.

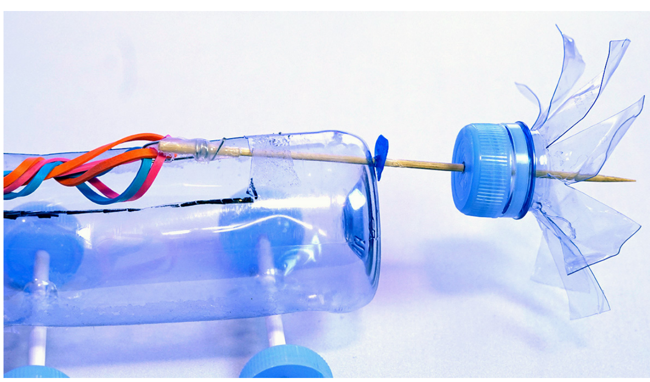
Use the nail to make the opening big enough for the skewer to go in and spin freely. Place the axle through the opening.



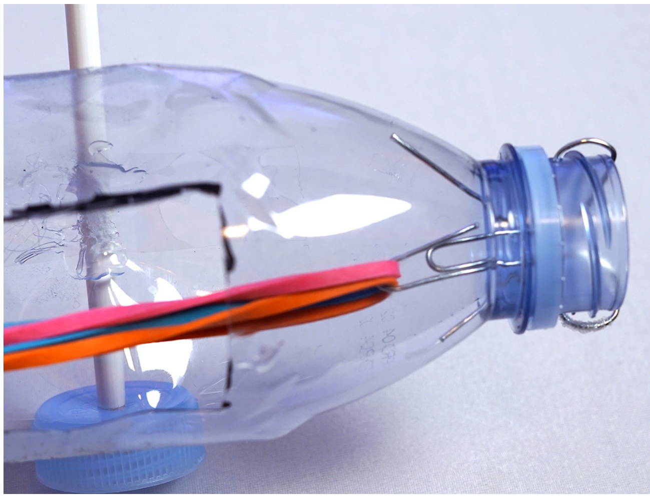
Shorten the skewer so there is about 6 cm inside the cargo bay.

Pull one end of a small paperclip and open it slightly. Hot glue the other end of the paperclip onto the skewer that is on the inside of the cargo bay opening. Glue the paperclip so that it will not come off the skewer (propeller).

Weave together two sets of three rubberbands into a loose knot, as shown.



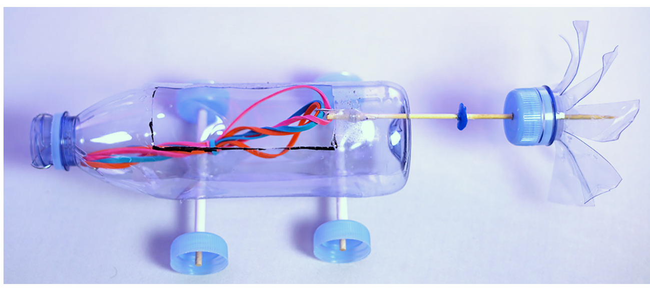
Connect one end of the rubberband knot to the paperclip attached to the propeller skewer.



Connect the other end of the rubberband knot to the paperclip attached to the mouth of the bottle.

Your propeller will be loose at this point; this is to be expected.

Safety reminder: Be sure you are wearing eye protection when stretching the rubberbands.



Step 9: Twist the propeller.

Twist the propeller by its axle—**do not** put your finger between the blades to spin it. Propellers will usually need to be twisted in a clockwise direction, but if your propeller spins backward or not at all, try turning the other direction.

Twist until the rubberbands double over on themselves. Usually this will be more than 100 twists. Keep hands and fingers clear of the propeller.

When you are ready, place the propeller car in the designated test area and release the propeller!

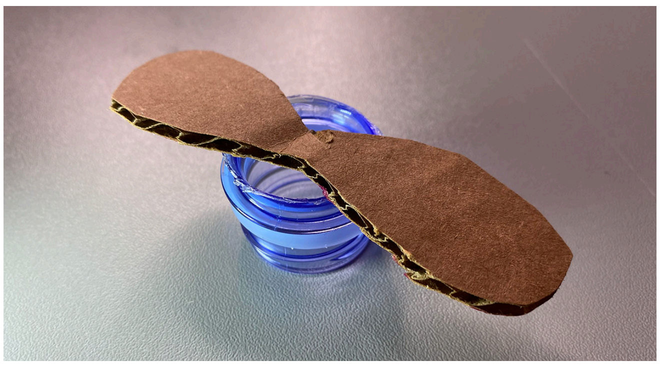
C.3.1 Propeller Attachment Instructions for Activity One: Propeller Design Challenge

After building either the rubberband-powered or electric motor propeller car, choose one of the options below for attaching propeller designs to the propeller car for Activity One: Propeller Design Challenge.

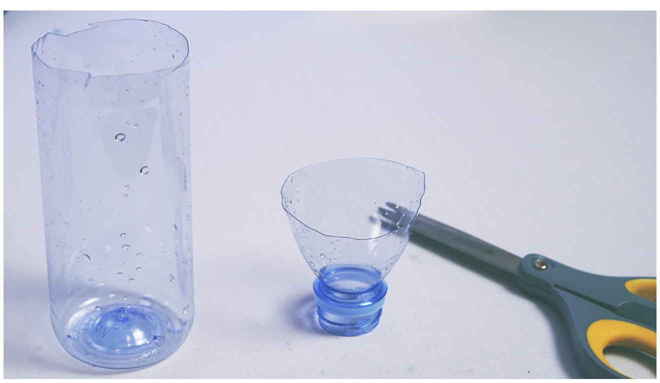
You have two options when using the propeller attachment:

Option 1:

Safely cut the threading off of a water bottle. You can use the base of this threading to attach your propeller designs to the system.

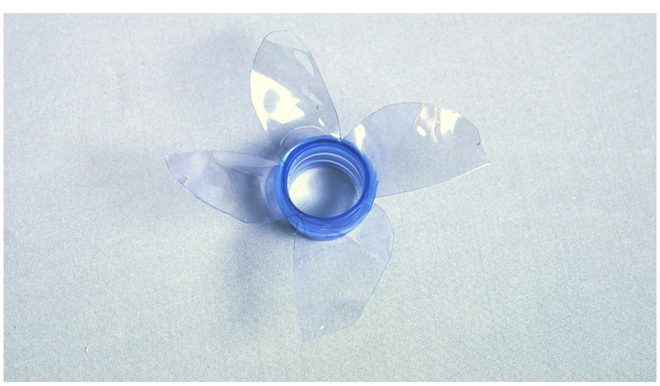


Option 1 example



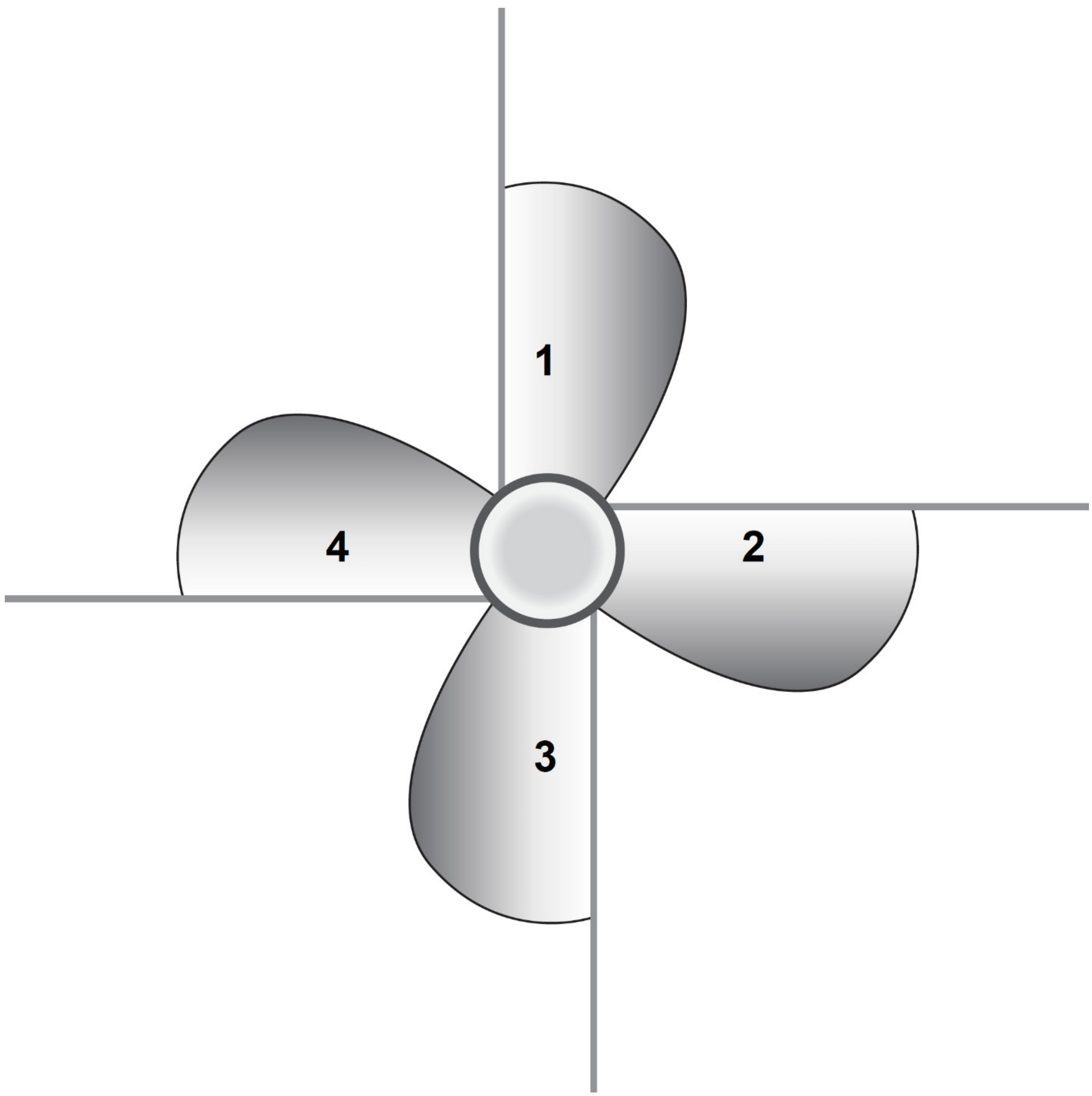
Option 2:

Safely cut the threading off of the second water bottle, but use some of the plastic from the neck of the second water bottle to create your propeller design.



Option 2 example

C.4 Basic Propeller Template



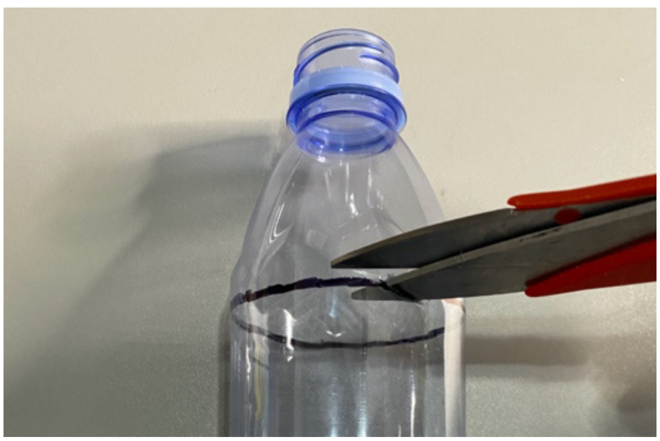
C.5 Basic Propeller Template Instructions for Activity Two: Propelling the Payload With Electric Propulsion

After building either the electric motor propeller car or the rubberband-powered propeller car, you will need a basic propeller to provide thrust for the car.

Step 1

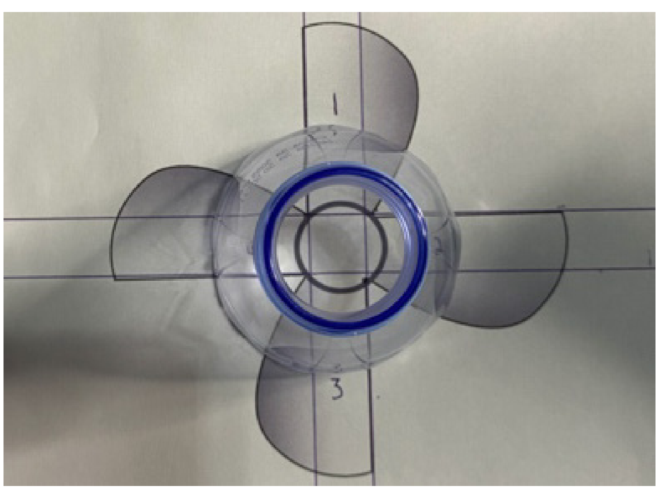
Have your Propeller Template ready.

Measure 7.5 cm from the top mouth of a plastic water bottle, and use a marker to carefully draw a line around its circumference.



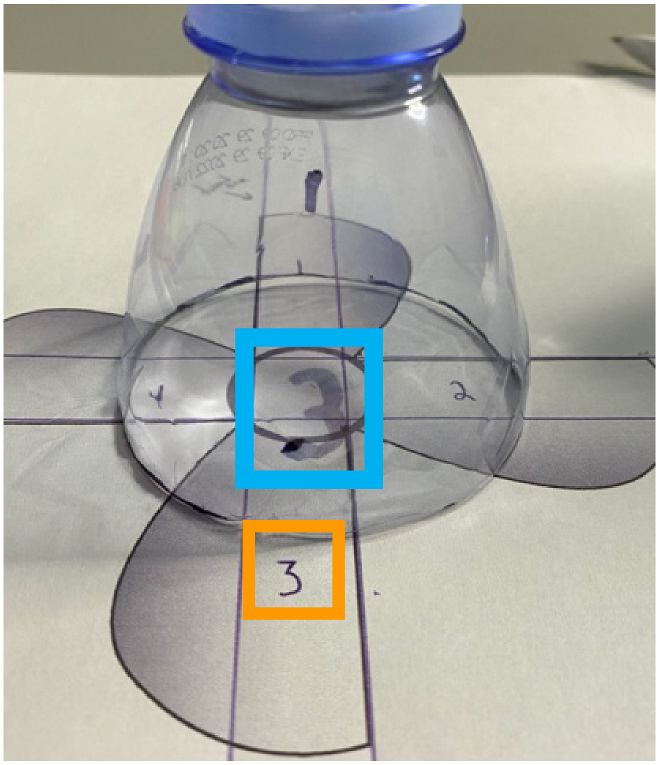
Step 2

Neatly cut along the line around the bottle.



Step 3

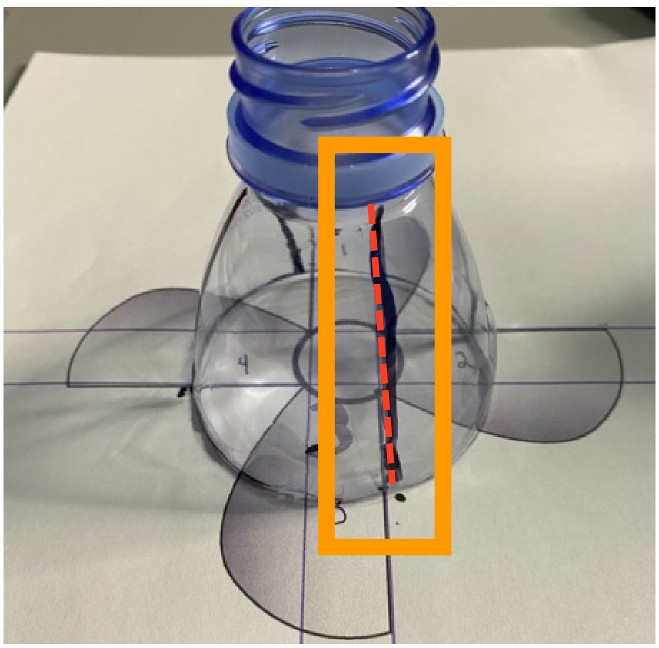
Place the bottle top you just cut out on top of the Propeller Template. Looking from the top, align the mouth of the water bottle with the center of the template.



Step 4

Each propeller on the template has a number.

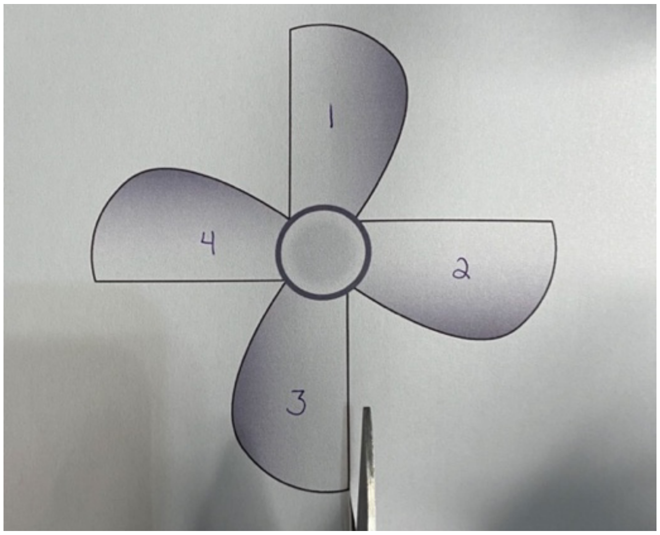
With a marker, write each number on the corresponding plastic bottle as shown.



Step 5

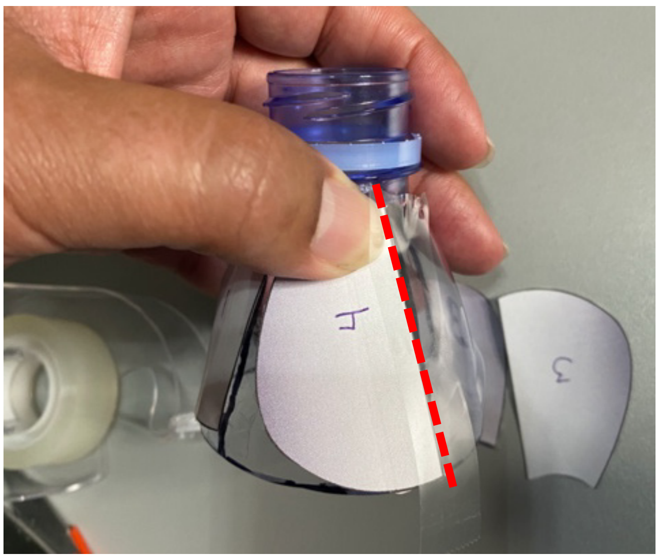
On the Propeller Template, you will notice four straight lines. Draw a line from the neck of the water bottle to each of the straight lines.

Do not cut the plastic yet.



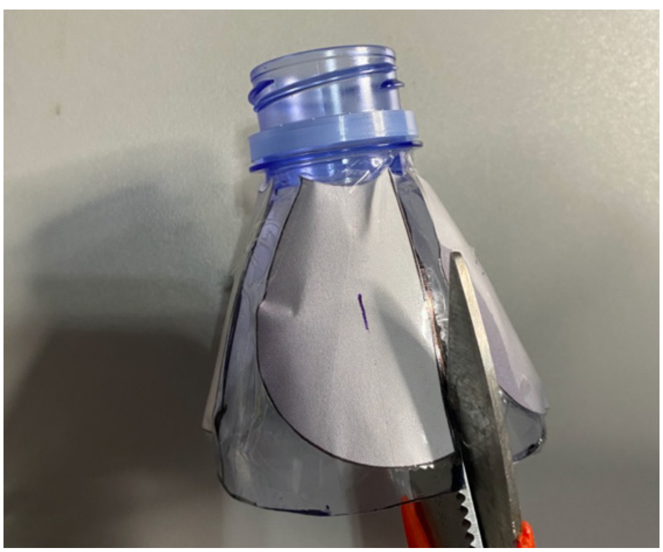
Step 6

Remove the bottle from the template and cut out all four of the template's paper propeller blades.



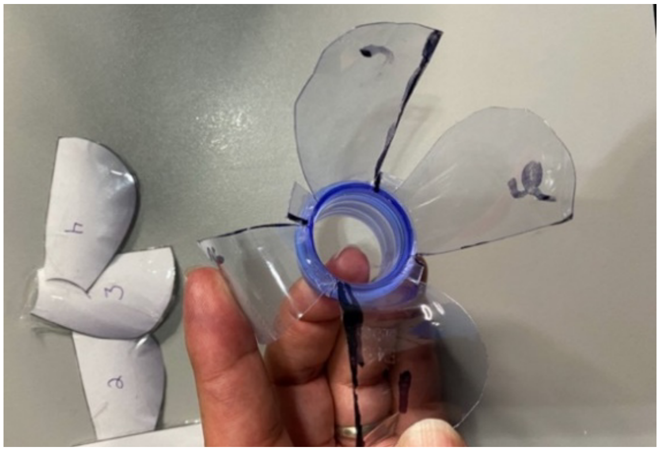
Step 7

Starting with the propeller blade labeled "1," align the straight edge of each paper propeller with the line you sketched earlier. Use clear tape to attach each propeller to the plastic bottle.



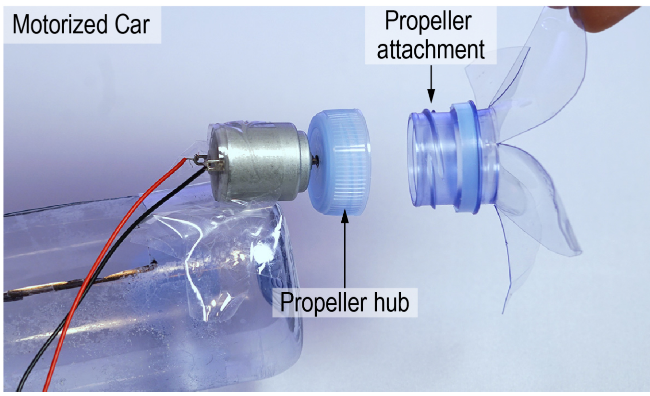
Step 8

Inspect the taped propellers to ensure they are neatly secured to the bottle. Cut along the lines slowly. When you are done, remove the paper.



Step 9

Gently pull open the propeller blades.



Step 10

Finally, screw the propeller attachment onto the propeller hub.

A.2 Scientific Research Process (SRP)

SRP Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Level of student knowledge (Score)
Observe	Student does not describe observations	Student generates a description that is either unclear or not based on observation	Student generates an observation-based description that is clearly stated	Student generates an observation-based description that is stated using scientific terms and identifies patterns	
Pose questions	Student does not identify the question	Student incorrectly identifies the question	Student identifies part of the question	Student identifies the question completely	
Develop hypothesis	Student does not state hypothesis	Student generates a hypothesis that is not clearly stated or well thought out and is not testable	Student generates a hypothesis that is clearly stated and testable	Student generates a hypothesis that is formulated using appropriate terms and is testable	
Plan the investigation	Student does not plan investigation	Student does plan the investigation, but it is largely incomplete (no testing of hypothesis)	Student does plan the investigation but does not adequately test the hypothesis previously stated	Student does plan the investigation and adequately tests the hypothesis previously stated	
Assemble data	Student does not present data	Student does present data but uses inappropriate presentation for the type of data	Student does present data and uses the appropriate presentation for the type of data	Student presents data that show trends or patterns (insight) and uses the appropriate presentation for the type of data	
Document conclusions	Student does not document conclusions	Student does document conclusions, but the conclusions are incomplete or suggest student does not understand the conclusion	Student does document conclusions and shows an understanding of evidence interpretation	Student does document conclusions and shows understanding of evidence interpretations as well as any limitations	
Analyze data	Student does not analyze data	Student makes an inaccurate analysis of data or does not provide justification	Student makes an accurate analysis of data using appropriate mathematical methods for justification	Student makes an accurate analysis of data and makes an appropriate prediction or projection based on that data	
Present findings	Student does not communicate results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with group	
Pose new questions	Student does not identify a followup question	Student poses an unrelated followup question	Student poses an appropriate followup question based on findings	Student poses multiple followup questions based on findings using scientific terms	
				Total	