Quest for Speed

TechXcite Discover Engineering

Facilitator's Guide

Module Overview

In this TechXcite: Discover Engineering module, youth use math and engineering principles to design and test several different cars with various propulsion systems. They scientifically measure and evaluate the cars' performance—including speed, distance, and efficiency—and explore the concepts of thrust, torque, units of measure, and measurement conversion. They explore modifying their cars to best meet the design objectives and improve performance.

This curriculum is intended for use in informal settings, such as after-school programs and summer camps, for youth in the middle school grades. However, it has been successfully implemented in formal contexts, such as in-school activities including homeschool content, and youth older and younger than middle school grades.

Activity 1: Youth make a simple car from a spool, rubber band, and nail. Then they measure how far it can go, evaluate its performance, and explore design improvements.

Activity 2: Youth build a K'NEX® car that rolls down a ramp, then measure its speed. They evaluate its performance and explore design improvements.

Activity 3: Youth build a K'NEX® car that uses a rubber band for propulsion. They evaluate its performance and explore design improvements.

Activity 4: Youth build a K'NEX® car that uses a rubber band and propeller for propulsion. They evaluate its performance and explore design improvements.

Activity 5: Youth build a K'NEX® car that uses a balloon for propulsion. They evaluate its performance and explore design improvements.

*K'NEX® is a registered trademark of K'NEX Limited Partnership Group.

Table of Contents

TechXcite: Discover Engineering

TechXcite is an informal engineering program partnering 4-H Youth Development/Family and Consumer Sciences at North Carolina State University, National 4-H Council and the Engineering K-PhD Program at Duke University's Pratt School of Engineering. It was initially funded by a five-year grant from the National Science Foundation.

In 2000, Drs. Ybarra and Klenk created an informal after-school engineering program at Rogers-Herr Middle School in Durham called Techtronics, which spread to additional schools across North Carolina and other states. The TechXcite: Discover Engineering curriculum builds on the Techtronics foundation by implementing hands-on, exploratory, engineering learning modules in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school and home-school programs have chosen to use the TechXcite curriculum. TechXcite is an engaging, substantive, experiential and inquiry-based curriculum centered on engineering, while using technology, applied science and mathematics learned in school. TechXcite's mission is to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

TechXcite is the product of a collaboration of twelve 4-H leaders at land grant universities, two leaders at National 4-H Council and a team at Duke University.

Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

Training Videos

Each module comes with a set of training videos found on its curriculum page (techxcite.org/curriculum). These videos serve as a companion to the Facilitator's Guide. An introductory video provides an overview of the material and concepts. The corresponding video for each activity then covers basic setup, procedure, and helpful tips for facilitating that activity. It's recommended that instructors watch all of the videos before starting the module.

Using This Guide

The Facilitator's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will be given basic information about the activity. This includes:

- Time Required
- Group Size – Suggested number of students per group.
- Materials List
- Youth Handouts – These will need to be copied.
- Getting Ready– Includes what you need to do before the activity and approximately how much time it will take you.
- Education Standards
- Learner Outcomes
- Vocabulary

Introduction and Activity Closure

The Introduction and Activity Closure are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics.

Facilitating the Activity

This section is not scripted. It contains step-by-step instructions for facilitating the activity. Students have their own procedure in the Youth Handouts.

Exploration Questions

Provides possible answers to the Exploration Questions found at the end of each activity in the Youth Handouts. After the students have a chance to answer the questions individually, instructors should hold a class discussion. The main purpose of this section is to encourage critical thinking.

Activity 1: Spooling Around

Time Required: 45 Minutes **Group Size:** 1

Materials List

Each student needs:
- Wooden spool
- Nail
- Flat washer
- 3 Rubber bands
- Craft stick
- Nut

Each class needs:
- Tape measures
- Calculators
- Masking tape

Youth Handouts:
- "Spooling Around"

Getting Ready (5 minutes)

- Build a sample spool car to show students.

Education Standards

NGSS: MS-ETS1-2, MS-ETS1-3

Learner Outcomes

- Define unit of measure and provide some common examples.
- Measure distance with a tape measure.
- Explain the importance of design trade-offs in engineering.

Activity 1: Spooling Around

Vocabulary

Word	Definition
Design trade-off	When a change in the design improves one aspect of its performance but causes other things to get worse. The best design is usually a compromise that balances many different aspects of performance.
Efficiency	The amount of output produced for each unit of input.
Friction	Resistance or drag caused by two surfaces rubbing against each other.
Iterative design	The process of continuously improving upon a previous design using the results of testing.
Traction	Friction or grip between a wheel and the surface it is rolling on.
Unit of measure	An agreed-upon amount of something used as a standard for comparison.

Introduction

Taking measurements and recording data is critical to any scientific or engineering process. However, to understand and compare the collected data, scientists and engineers must have a commonly agreed upon way to measure things, or **unit of measure**.

A unit of measure is simply a standard for comparison. Hundreds of years ago, everyone grew barley for food. The kernels were all about the same size, making barley the perfect unit of measure. In fact, an inch in the current English System of Measurement is still equivalent to three dried barleycorns laid end-to-end. This simple system of measurement was built upon commonly available items so that everyone, including those who couldn't read or write, could agree upon and understand the units.

What are some other units of measure for distance that you can think of? [*mile, fathom, yard, kilometer, meter, millimeter, etc.*]

What are some units of measure for things other than distance? [*gallon of milk, pound of hamburger, acre of land, etc*.]

One of the great things about units of measure is that they can be mathematically combined together to create new units. An example you may already be familiar with is a car's fuel **efficiency**, measured in miles per gallon.

A mile is a measure of distance and a gallon is a measure of volume. If you divide "miles" by "gallons" you get "miles per gallon" or MPG. MPG is a unit of measure for the fuel efficiency of an automobile. If your car gets 40 MPG, then for each gallon of gasoline you pump into the fuel tank, you can expect the car to drive a distance of 40 miles. A car with a higher MPG rating uses gasoline more efficiently.

We will revisit the idea of combining units later, but for now let's build some cars! You are going to start by building possibly the world's simplest vehicle, made from just a spool, a rubber band, and a nail.

Activity 1: Spooling Around

Facilitating the Activity

1. Show students a completed spool car. Wind it up and let it go so they can see how it works.
2. Distribute the handouts and materials then have students follow the instructions to build the car exactly as shown below with no improvements yet.

Completed Spool Car

3. Ask students to scientifically test their cars. Make sure they take measurements of the car's distance and calculate the efficiency (inches/turns) of each run in the table on their handout.
4. Testing the cars on a variety of surfaces and comparing the measured results is a good idea. Make sure that at least one test location has a smooth surface with limited traction.
5. After students test the initial spool car design, ask them if they see any flaws in the design or ways in which they could improve its performance.

   Collaboration is critically important in engineering. Have the class discuss what they saw and discuss their ideas for improving the spool car design. Avoid giving students the answers below and instead encourage them to discover on their own.

6. One significant design flaw classroom collaboration should uncover is that the craft stick on the end of the spool will slip and spin limiting how much you can wind up the rubber band. One possible solution is to add tape, as shown, to prevent the craft stick from slipping.

7. Ask students to think about how fixing this design flaw will impact the performance of the spool car. You may choose to ask the questions below to provoke thought without giving them the answers. Let them discover through experimentation, measurement, and group collaboration.

Activity 1: Spooling Around

Will taping the craft stick to the spool increase the distance traveled? [*Yes. You can wind the rubber band up more and the car will travel farther.*]

Will it improve the efficiency of the car? [*Not necessarily. Winding the band up tightly will probably cause the spool to spin in place for a moment when first released before it starts to move forward. This wastes some of the energy stored in the rubber band.*]

8. Before making any other design changes, have the students measure the distance and calculate the efficiency of the spool car to see the effect of fixing the design flaw.
9. By now students will have noticed that on smooth surfaces with the band wound tight the spool will spin some before it begins to move forward. The spool car design can again be improved by increasing its **traction**. One possible solution is to add rubber bands around the spool, as shown. Encourage students to "do it their own way" and to experiment with their own ideas to improve traction.
10. Ask the students to predict what effect the traction improvement will have on the distance and efficiency of the spool car. [*Both distance and efficiency should improve on smooth surfaces.*]
11. After students make changes to the design to improve traction, have them measure the distance and recalculate the efficiency.
12. Encourage students to experiment with other ideas to improve the design. They should always attempt to predict the results before testing to see if their changes have a measurable effect on performance. Feel free to use other materials and experiment away!

Activity Closure

Efficiency is defined as the amount of output per input. In the case of your spool cars, the input was nail turns and the output was distance. Therefore, the farther your spool car went for every turn of the nail, the greater it's efficiency.

The goal of efficiency is to get the best performance (output) from something while consuming the least amount of resources (input). The input can be anything from time to money to energy. In most cases, engineers want the products they design to function as efficiently as possible.

As you discovered, the engineering design process also involves a lot of "trial and error". Often the first few attempts (trials) at creating a successful design have problems (errors) that must be addressed. Once the design is modified to fix those issues, it's tested and the results are analyzed again. This process, known as **iterative design**, is repeated over and over with the hope of yielding a better design each time through.

Activity 1: Spooling Around

Exploration Questions

1. If you could have any materials you wanted to make the spool car out of, what would you use and how would it improve the performance of the car?

   [*Allow a couple groups to respond.*]

2. What would be the benefits of using a stronger rubber band?

   [*With a stronger rubber band the car would go faster and travel farther.*]

3. Do you think a stronger rubber band could hurt the spool cars performance in any way?

   [*The stronger band will make the spool spin more at the starting line without moving forward when it is released, reducing the efficiency.*]

4. Even with access to any materials desired, is it possible to keep improving one type of performance without hurting the others?

   [*Unfortunately, no. This is a fundamental aspect of engineering. Eventually you reach a point where improving one thing will begin to degrade the others. This is what engineers call a* **design trade-off***. In order to gain improvement in one area you must be willing to trade away a reduction in performance elsewhere.*]

Activity 2: Ramp-Powered Car

Time Required: 45 Minutes **Group Size:** 2

Materials List

- K'NEX® Motion and Design Set
- Tape measures (One per two groups)
- Stopwatches (One per two groups)
- Calculators (One per two groups)

Youth Handouts:

- "Ramp-Powered Car"
- "Prototype Instructions" (Optional)

Getting Ready (15 minutes)

- Set up the K'NEX® parts in a central location where students can access them.
- Build a sample car to show students.
- Locate a sloped sidewalk near the classroom or make a sturdy ramp by leaning a board against a table, desk, or stack of books. Use masking tape or chalk to create start and finish lines that are 36-100 inches (91.5-254.0 cm) apart.

Education Standards

CCSS: 6.RP.A.1, 6.RP.A.2
NGSS: MS-ETS1-2, MS-ETS1-3

Learner Outcomes

- Use a stopwatch to measure time.
- Design and build a gravity-powered car.
- Explain that speed equals distance divided by time.

Vocabulary

Word	Definition
Acceleration	An increase in speed
Prototype	An initial version of a new device. Engineers use prototypes to test new devices prior to mass-producing them.
Ratio	The relationship between two amounts, normally expressed by dividing one number into the other.
Rolling resistance	Friction between the tire and the surface that slows down the wheel when it is rolling. Narrower tires normally have less rolling resistance.
Speed	Distance per unit of time. Distance divided by time.

Activity 2: Ramp-Powered Car

Introduction

Last time, you built a spool car that used energy from a rubber band to move the car across a surface. Today we're going to build a basic car using K'NEX® pieces. Then, we are going to measure the car's **speed** down a ramp.

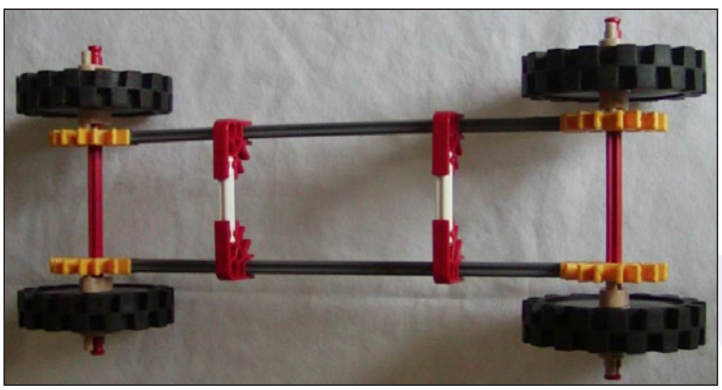
What does "speed" mean?

[*Let students volunteer a few definitions*.]

Speed is related to distance and time. A car's speed is determined by the distance it's traveling and the amount of time it will take to cover that distance. In testing your spool car, you learned how to use units of measure to determine distance. Your tool was a tape measure and the units were inches and feet. Today you'll also measure time, the other component of speed. Time is usually measured in seconds, minutes, or hours. In this activity, we will be counting seconds using a stopwatch.

Facilitating the Activity

Note: The Youth Handout "Prototype Instructions" for Activities 2-5 contains instructions for building the cars. Advanced students may complete the design challenges without the printed instructions, but many students—especially those unfamiliar with K'NEX®—might need them. In later activities, encourage students to try the engineering design challenges without using instructions. There are many ways to build cars that work, so it's okay if students make a version that looks different from the ones pictured. Always encourage students to improve on their **prototypes***.*



Prototype of Ramp-Powered Car

1. Show students the sample K'NEX® car and roll it on a smooth surface so they can see it move. Tell them that there are many other ways to construct the car and that it's OK to make a version that looks different.
2. Place students in pairs and distribute the handouts. If students are more advanced, you may decide not to give them the *Prototype Instructions*.
3. Tell students that their engineering design challenge is to build the fastest car possible.

Activity 2: Ramp-Powered Car

4. Direct students to the parts bins and give them these rules:
    - Don't crowd around the bins. Return to your table to assemble your car.
    - Don't hoard parts in your workspace. If you have parts you don't need, put them back in the bins for others to use.
5. Instruct students to build their cars, referring to the *Prototype Instructions*, if necessary.
6. Show students the test surface. Ask them to measure the distance between the lines with a tape measure and record the length on the handout.
7. Demonstrate how to use the stopwatch.
8. Instruct students to take turns testing their cars on the ramp. Tell them to record their test results in the table on their handout.
9. Encourage students to experiment with changes to the design and then test to see if their improvements had a measurable effect on performance. They should record their results in the table after each test-run.

Variations

- Use additional ramps with different surfaces and steepness to see what effects these changes have on speed. You could also move the same ramp so that it runs onto different surfaces, such as carpet, floor, concrete, etc. (This would be important only if the starting and finish lines are on the surface beyond the ramp and not on the ramp itself.)
- Change the distance between the starting and finish lines.
- Add another line between the starting and finish lines. Have students measure the car's speed along the first section and second section and evaluate the results. The car will be faster over the second interval since it is speeding up as it travels down the ramp.
- Have students time their cars as they decelerate on the flat surface. Ask students to make observations about how quickly the cars slow down.

Activity 2: Ramp-Powered Car

Activity Closure

Math is the language of engineers and scientists all over the world. A lot of powerful information can be contained in a concise mathematical equation. Speed has a simple mathematical definition: the ratio of distance over time. A ratio is a fraction made by dividing one number by another. [*Show the equations below or write them on the board.*]

$$\text{SPEED} = \frac{\text{DISTANCE}}{\text{TIME}}$$

$$60 \text{ MPH} = \frac{60 \text{ MILES}}{1 \text{ HOUR}}$$

$$30 \text{ MPH} = \frac{60 \text{ MILES}}{2 \text{ HOURS}}$$

To make sense of this equation, let's look at a familiar example. If you're driving to visit a friend who lives 60 miles away and it takes you 1 hour to get there, then your speed was 60 miles per hour (mph). If it took 2 hours to make the trip, then your speed was 30 mph. How did we get 30 mph? We took the distance, 60 miles, and divided it by the travel time, 2 hours, to get the ratio of the two numbers.

60 ÷ 2 = 30 or 60/2 = 30.

This mathematical ratio relates the two quantities—distance and speed—to each other. For every hour you drive at that speed, you will cover 60 miles of distance. Think about what the math is saying: 60 miles per hour. That's 60 miles in exchange for 1 hour of time.

You now have a scientist's view of what speed is and how it is calculated in an experiment.

Exploration Questions

1. What are some factors that affected your car's performance?

   [*Students may have noticed a smoother surface has less* rolling resistance*, so a car will go faster on a bare floor compared to a rug. They may have observed that a steeper ramp makes the car* accelerate *faster. They may also have noticed that in some designs, a wheel rubbing against the side of the car's body caused friction, slowing the car down.*]

2. Did the car run at a constant speed on the ramp? What about on the flat surface? Why?

   [*No. It accelerated while going down the ramp (due to gravity). But as soon as it reached the flat surface it began to decelerate (due to friction and air resistance).*]

3. If a car's speed is always changing, how are we able to calculate a single speed for a car trip?

   [*The calculated speed is the average speed of the car over the entire distance.*]

Activity 2: Ramp-Powered Car

Optional Extension

Have you ever heard of the Soap Box Derby? It's a race for kids similar to the ramp-powered car activity you just completed. Like your ramp-powered cars, these cars don't have an engine—they simply coast down a hill, two at a time, each racing to be first to the finish line.

The winning Derby cars typically have wheel hubs and tires specially made for this type of racing.

The hubs in Derby cars have ceramic wheel bearings instead of metal ones. Wheel bearings are a mechanical arrangement of several round balls that fit between the axle and hub. Ceramic wheel bearings are made of clay that has been fired in a super-hot oven called a kiln, so they are harder than metal ones. Hardness is a measure of how much something bends and deforms under pressure.

Can you guess why Soap Box Derby cars use ceramic wheel bearings instead of metal ones? [*It reduces friction between the hub and axle.*] Why is it desirable to reduce friction? [*Friction between the tire and the surface slows down the wheel when it is rolling.*] Since ceramic wheel bearings produce less friction, why wouldn't they be used in all wheel hubs? [*There is always a trade-off, and in this case the trade-off is price. Steel bearings are typically less expensive than ceramic ones.*]

The tires on Derby cars are also made of hard rubber and are narrower than typical wheels. If hardness determines how much something bends and deforms under pressure, how do tires made of hard rubber help a Derby car's performance? [*They don't press into any cracks or crevices in the racing track surface*.] Do the hard tires produce more friction or less? [*They produce less friction. They also have less rolling resistance, which reduces friction.*] Why are the tires narrower? [*Narrow tires have less rolling resistance because there is less tire surface in contact with the ground, which reduces friction*.]

Do you notice a trend? Making the car roll faster is all about reducing friction. The less friction produced, the faster the car will go.

In what situation would you like to have more friction? [*You'd want more friction to help the tires grip the road if you were steering the car, stopping the car using brakes, or accelerating quickly (like the spool cars in Activity 1)*.]

As you can see, the different physical properties of a tire (material, hardness, width, etc) are important to consider. Softer tires grip the little cracks and crevices in a surface such as asphalt, causing better traction and more friction. Hard tires function exactly the opposite as soft tires—they have less rolling resistance, reducing friction. Wide tires have more surface area, so they have more contact with the ground, increasing friction. The exact opposite is true of narrow tires.

The *best* kind of tire simply depends on the situation.

Activity 3: Rubber-Band-Powered Car

Time Required: 45 Minutes **Group Size:** 2

Materials List

- Size #16 rubber bands
- K'NEX® Motion and Design Set
- Tape measures (One per two groups)
- Stopwatches (One per two groups)
- Calculators (One per two groups)

Youth Handouts:

- "Rubber-Band-Powered Car"
- "Prototype Instructions" (Optional)

Getting Ready (15 minutes)

- Set up the K'NEX® parts in a central location where students can access them.
- Build a sample car to show students.
- Choose the design challenge you'll give students (see Facilitating the Activity, Step 4).
- Select a flat surface for testing the cars. For example, you could use a sidewalk, the floor of the classroom, or the floor of a hallway.

Education Standards

NGSS: MS-ETS1-2, MS-ETS1-3, MS-PS3-2, MS-PS3-5, 4-PS3-4

Learner Outcomes

- Explain that energy can only be converted from one form to another
- Explain that energy is stored in the rubber band and released to make the car move.
- Explain how tires help improve traction on drive wheels.
- Explain why changing the test distance affects the calculated speed.

Vocabulary

Word	Definition
Drive axle	An axle that has a twisting or turning force applied to it to propel the vehicle forward.
Drive wheel	A wheel attached to the drive axle.
Energy	The ability to do work. Can take many forms, including heat, light, electricity, mechanical, or chemical (ex: gasoline).
Kinetic energy	Energy due to an object's motion.
Potential energy	Energy due to an object's position or state.

Activity 3: Rubber-Band-Powered Car

Introduction

One of the most interesting and important concepts in science and engineering is **energy** transformation. This is the process of changing energy from one form to another. A light bulb, for example, converts electrical energy into radiant energy (light) and thermal energy (heat).

In today's activity, you will be designing a car that converts the **potential energy** stored in a rubber band into **kinetic energy**, or the energy of motion.

Facilitating the Activity

1. Show students the sample K'NEX® car and demonstrate how it moves. Stretch the free end of the rubber band and hold it tightly against the drive axle. Continuing to hold the rubber band and rotate the **drive axle** backward until the rubber band begins to overlap itself. Let go of the rubber band and continue rotating the axle. When the band is fully wound, set the car down and let it go.
2. Place students in pairs and distribute the handouts. If students are more advanced, you may decide not to give them the *Prototype Instructions*. The instructions assume that students have already built the ramp-powered car from Activity 2. If they don't have a car, they'll need to build one from scratch.
3. Give students one of the following design challenges. The level of difficulty increases a little for each one. You may decide to use more than one. Choose whatever is best suited to the class.
    a. **How Far Can It Go?** Let students modify their cars, any way they like, to make them travel farther. Have them measure and record the distance traveled on each test-run in the table on their handout.
    b. **How Fast Can It Go?** Let students modify their cars, any way they like, to attain the highest speed over a specified distance. Let them experiment to find the distance between the starting and finish lines that works best. Have them measure and record the speed for each test-run in the table on their handout.
    c. **How Does Moving the Cross-Brace Affect Performance?** Have students explore the relationship between the distance from the cross-brace to the drive axle and the maximum speed or distance their car travels. Instruct them to measure the distance from the cross-brace rod (white) to the drive-axle rod (red) and record it on their handout. Ask them to test the car to determine its maximum distance or maximum speed over a given interval. Then have them slide the cross-brace closer to the drive axle and repeat the tests. Ask them what happened and why.
4. Encourage students to modify their cars, any way they like, to improve performance. Remind them to record their test results after each modification.

Activity 3: Rubber-Band-Powered Car

Activity Closure

Although energy exists in many forms (mechanical, chemical, elastic, etc), all energy can generally be divided into two states: potential and kinetic. Additionally, energy cannot be created or destroyed—only transformed from one state to another.

Potential energy is stored energy. As you just found out in this activity, a stretched rubber band is a great source of potential energy. The more you twist the rubber band around the axle, the more elastic potential energy is stored. When you let go, the rubber band tries to snap back to its original size and shape, spinning the drive axle in the process. The potential energy of the stretched rubber band was converted into kinetic energy, or the energy of motion, propelling the car forward!

Your ramp-powered car from the previous activity also had potential energy that was transformed into kinetic energy. When an object is lifted off the ground it contains *gravitational* potential energy, because if it were dropped, it could do a lot of work. The higher the object, the more work it can do. For every inch of height the car drops down the ramp, a little bit of potential energy is converted into kinetic energy causing the car to go just a little faster. The farther it falls, the faster it goes.

Exploration Questions

1. What is the purpose of the tires and how do they work? What would happen if you didn't have tires on the **drive wheels**?

   [*The tires provide friction between the ground and the wheels to ensure that the wheels don't spin without moving the car. They transfer force to the ground. Without tires, the drive wheels might slip/spin on the surface.*]

2. Why does changing the test distance affect the speed calculated for the car?

   [*The car speeds up at first and then it slows down. The distance affects the average speed calculation.*]

3. Do you really need the axle clips between the wheels and the yellow connectors? What would happen if you took them out?

   [*The wheels would rub against the yellow connectors, slowing the car down.*]

4. What happened when you slid the rubber-band cross-brace closer to the drive axle (Challenge C)?

   [*Energy is stored only in the portion of the band that's being stretched. When the brace is moved closer to the drive axle, more of the rubber band's length is wrapped around the axle and less of it is available to be stretched. So less energy is stored and the car performs worse.*]

5. Imagine you were an engineer and could design this car any way you wanted. How might you redesign the car to improve its performance if you weren't limited to the parts you have on hand?

   [*Allow students time to respond and discuss.*]

Activity 4: Propeller-Powered Car

Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:
- 5-10 Size #16 rubber bands
- 2 Brass bushings
- Propeller
- J-hook
- Safety glasses

Each class needs:
- K'NEX® Motion and Design Set
- Tape measures (One per two groups)
- Stopwatches (One per two groups)
- Calculators (One per two groups)

Youth Handouts:
- "Propeller-Powered Car"
- "Prototype Instructions" (Optional)

Education Standards

NGSS: MS-ETS1-2, MS-ETS1-3

Learner Outcomes

- Describe how a propeller works to convert torque into thrust.
- Explain why some propellers work better in one direction than another.
- Explain why certain rubber-band arrangements work better than others.

Vocabulary

Word	Definition
Propeller	An arrangement of spinning blades used to generate thrust.
Thrust	Force used to propel something forward.
Torque	Rotational or twisting force that makes something turn or spin.

Activity 4: Propeller-Powered Car

Introduction

Today you will build another car driven by rubber bands. But instead of the rubber band directly driving the axle, like last time, it will spin a **propeller**. [*Hand out propellers so students can examine them while you talk*.]

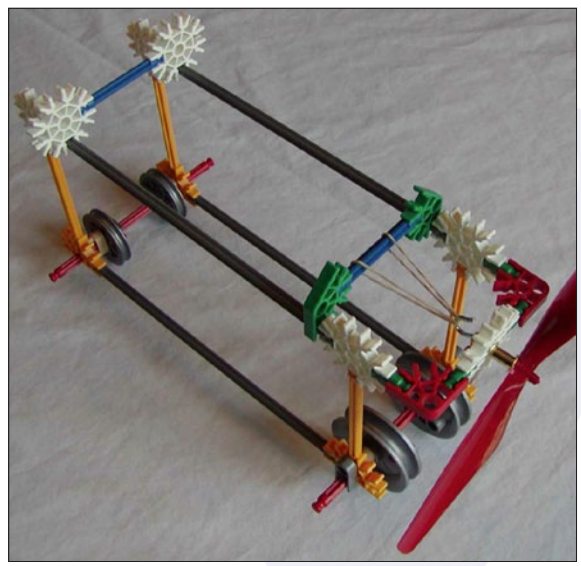
Where have you seen a propeller before? What types of devices have them?

[*Airplanes and boats have propellers. They might also say a fan, which is similar to a propeller in that it pushes air but different in that it does not create enough thrust to make a device move*.]

The inventor of the propeller was very clever, but no single person can take all of the credit for its design. The idea was developed over a long time, with each person making improvements. In fact, a key improvement actually happened when a propeller broke during testing. It ended up working better after it broke. Engineers learn a lot more from failure than success. So set aside your fear of failure!

Now let's build your propeller car and see what you can make it do.

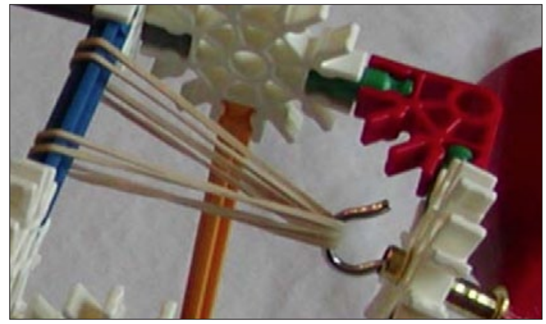
Facilitating the Activity



1. Show students the sample car and demonstrate how it moves. To wind up the car, turn the propeller. To start the car, let the propeller go. (The test car pictured to the right traveled more than 3 feet using two Size #13 rubber bands for power.)
2. Place students in pairs and distribute the handouts. If students are more advanced, you may decide not to give them the *Prototype Instructions*.
3. Before handing out materials, go over the following safety instructions:
    - Do not wind your car up so tightly that the pieces begin to bend.
    - Do not use more than two rubber bands.
    - Do not use rubber bands stronger than size #16.
    - Wear safety glasses when winding the propeller. The propellers are made of many small, metallic parts. If these parts are put under too much stress, they may come apart at high speeds.
4. Tell students their design challenge is to build the fastest car or build a car that travels farthest. You could also give them a more creative challenge. For example, you could challenge them to design a car that will travel farthest on 30 turns of the propeller. This would be a test of efficiency. If you'd like, you can have students define their own design challenge instead of assigning one.
5. Direct students to the parts bins and give them these rules:
    - Don't crowd around the bins. Return to your table to assemble your car.
    - Don't hoard parts in your workspace. If you have parts you don't need, put them back in the bins for others to use.

Activity 4: Propeller-Powered Car

6. Remind students they must not use more than two size #16 rubber bands. Too many bands will rip the J-hook out of the propeller, damaging it and sending parts flying. Also remind students to wear safety glasses when winding the bands and to keep their faces away from the engine area in case the bands break. The picture to the right shows what the car looks like with two rubber bands attached.



7. Instruct students to build their cars, referring to the *Prototype Instructions*, if necessary.
8. Tell students to test their cars and record the results in the table on the handout.
9. Encourage students to experiment to find the best configuration for the rubber bands. This might be challenging, as many configurations don't produce much power. Students should quickly discover that a single rubber band does not produce enough power to move the car very far, if at all. A smooth surface, tire-free hubs, and a lightweight design are key to getting good performance from the propeller-powered car. Students should eventually discover that configuring bands in a V-shape is the key to getting maximum torque.
10. Encourage students to modify their cars, any way they like, to improve performance. Remind them to record their results after each modification and test-run.
11. Have students test the car with the propeller spinning both ways. They should find that the propeller works much better in one direction than the other. A car made like the one pictured in the *Prototype Instructions* works best when the propeller pushes the car forward.

Activity Closure

What does a propeller do? It converts **torque** into **thrust**. That may sound simple, but to understand this definition we must first break it down.

Thrust is what happens when rushing air is used to push something forward. For example, if you blow up a balloon and let it go, the air rushing out will produce thrust, causing the balloon to fly around the room. What are some types of transportation that use thrust? [*Jet airplane, rocket, etc.*] A solid rocket-booster on the Space Shuttle produces 2.8 million pounds of thrust.

Torque is a turning or twisting force. When you turn a doorknob, your hand is applying twisting force called torque. What are some other everyday examples of torque? [T*urning a screwdriver, turning a water faucet on and off, opening a jar lid, etc*.] In Activity 3, the rubber band applied torque to the drive axle to propel the car.

So how does the propeller on your car work? [*Allow students chance to answer.*]

The wound rubber band creates torque, which is converted into thrust (rushing air) by the propeller.

Activity 4: Propeller-Powered Car

Exploration Questions

1. Why did your propeller work better spinning in one direction than the other?

   [*The blades of the propeller are slightly curved so that they cup the air a little bit in one direction.*]

2. Could you design a propeller that works equally well when spun in either direction? Explain.

   [*Yes. If the blades were flat, the propeller would work the same in both directions.*]

3. What makes some rubber-band arrangements work better than others?

   [*The angle of the rubber bands determines how stretched they are. If the rubber bands are more stretched, they unwind with greater force, causing the propeller to spin faster and produce more thrust.*]

4. What would be one way you would improve your design if you had more time?

   [*Give as many students as possible a chance to answer.*]

Activity 5: Balloon-Powered Car

Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:
- Punch balloon

Each class needs:
- K'NEX® Motion and Design Set
- Tape measures (One per two groups)
- Stopwatches (One per two groups)
- Calculators (One per two groups)
- Air pump (One per two groups)

Youth Handouts:
- "Balloon-Powered Car"
- "Prototype Instructions" (Optional)

Getting Ready (20 minutes)

- Set up the K'NEX® parts in a central location where students can access them.
- Build a sample car to show students.
- Choose the design challenge you'll give students (see Facilitating the Activity, Step 4).
- Select a flat surface for testing the cars. For example, you could use a sidewalk, the floor of the classroom, or the floor of a hallway.
- Write the formulas on the board.

Education Standards

CCSS: 5.MD.A.1, 6.RP.A.3d, 6.NS.A.1, 7.RP.A.1, 7.RP.A.2b, 7.RP.A.3
NGSS: MS-ETS1-2, MS-ETS1-3

Learner Outcomes

- Convert distance measurements from inches to centimeters.
- Convert speed measurements in inches per second to miles per hour.
- Describe how a balloon produces thrust.

Vocabulary

Word	Definition
Conversion factor	A ratio used to convert one unit of measure into another unit of measure.
Trial-and-error	A process in which you try different methods of doing something and see if they make things better or worse.

Activity 5: Balloon-Powered Car

Introduction

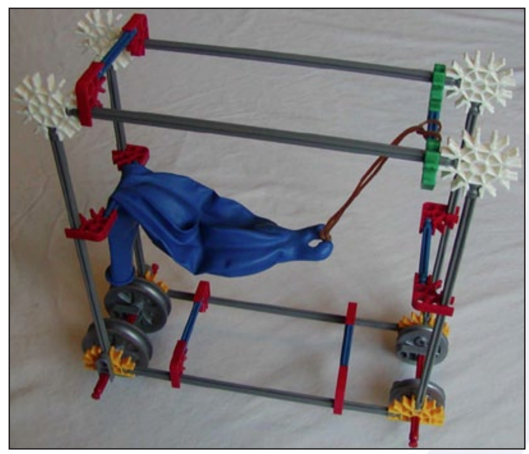
We've now made several different kinds of cars and learned how to scientifically measure their speed in different situations, just like a real engineer.

So what if you made a K'NEX® car that goes 968 inches per second, is that a fast car or a slow car? What if it went 55 miles per hour?

It's nice to be able to express the speed of the car in a scientific way that other engineers can understand, but it's also important to have a feel for what that number means and the ability to convert from one unit of measure to another.

But before we learn more about speed, you're first going to build a car powered by a balloon. Remember: the key to a successful balloon car design is to have a lot of room for the balloon to inflate. The more air you can fit into the balloon, the faster and farther your car will go.

Facilitating the Activity



1. Show students the sample car and demonstrate how it works. Using the air pump, inflate the balloon while it is confined inside the frame. Stop inflating when the balloon pushes against the frame. Pinch the balloon closed with your fingers. Release your fingers when you're ready for the car to start.
2. Place students in pairs and distribute the handouts. If students are more advanced, you may decide not to give them the *Prototype Instructions*.
3. Choose a design challenge for the students, such as to build the fastest car, to build one that travels farthest, or to build one that has the maximum efficiency (inches per pump). If you'd like, you can have students define their own design challenge instead of assigning one.
4. Direct students to the parts bins and give them these rules:
    - Don't crowd around the bins. Return to your table to assemble your car.
    - Don't hoard parts in your workspace. If you have parts you don't need, put them back in the bins for others to use.
5. Instruct students to build their cars, referring to the *Prototype Instructions*, if necessary.
6. Tell students to test their cars and record the results in the table on the handout.
7. Encourage students to be creative and modify their cars, any way they like, to improve performance. Remind them to record their test results after each modification. Also remind them that it's okay if a design does not work out exactly as they hoped. Engineering design involves lots of trial-and-error, no matter how experienced you are.

Activity 5: Balloon-Powered Car

Activity Closure

Before starting the activity, we asked if a car that goes 968 inches per second is a fast car or a slow car. How would you figure this out?

Even though specifying the speed of an object in inches per second is perfectly valid, that unit of measure is very uncommon and doesn't give you a good idea of how fast the car is actually going. Instead, we should convert the speed into a unit that is a little easier to comprehend, such as miles per hour (MPH).

We'll start with the basic structure of a conversion. There are three parts: (1) the original quantity, (2) the **conversion factor**, and (3) the answer.

The first part is easy. Our original quantity is 968 inches per second.

$$\underbrace{968\frac{\text{IN}}{\text{SEC}}}_{1} \times \underbrace{\boxed{}}_{2} = \underbrace{\frac{\text{MI}}{\text{HR}}}_{3}$$

Now we're going to skip the second part for just a moment and focus on the answer. What unit of measure do we want the answer to be in? [*Miles per hour*] This is how we determine part two of the equation, or our conversion factor.

A conversion factor is simply the relationship between original unit of measure and the final unit of measure. Since we don't know exactly how many inches per second equal one mile per hour, we're going to break this part down into more manageable pieces. Let's identify some related conversion factors that we do know.

We know that 1 foot = 12 inch, 60 seconds = 1 minute, 60 minutes = 1 hour, and 1 mile = 5280 feet. This is all we need.

Next, we're going to take each of these factors and turn them into a fraction. To decide which quantity goes on the top of the fraction, recall a common math rule: if the same factor is in the top and bottom of a fraction, you can cancel them out. This is the key to converting units.

Our goal in setting up the conversion factors will be to cancel out each unit until we end up with miles on top and hours on the bottom. If you don't get all the fractions arranged in the right order the first time, that's okay. They can easily be flipped later.

$$\underbrace{968\frac{\text{IN}}{\text{SEC}}}_{1} \times \underbrace{\frac{1\ \text{FT}}{12\ \text{IN}} \times \frac{60\ \text{SEC}}{1\ \text{MIN}} \times \frac{60\ \text{MIN}}{1\ \text{HR}} \times \frac{1\ \text{MI}}{5280\ \text{FT}}}_{2} = \underbrace{\frac{\text{MI}}{\text{HR}}}_{3}$$

The final step is canceling out all the unwanted units and multiplying the remaining numbers.

$$\frac{968\ \cancel{\text{IN}}}{1\ \cancel{\text{SEC}}} \times \frac{1\ \cancel{\text{FT}}}{12\ \cancel{\text{IN}}} \times \frac{60\ \cancel{\text{SEC}}}{1\ \cancel{\text{MIN}}} \times \frac{60\ \cancel{\text{MIN}}}{1\ \text{HR}} \times \frac{1\ \text{MI}}{5280\ \cancel{\text{FT}}} = 55\frac{\text{MI}}{\text{HR}}$$

Now we have our answer. A car that is going 968 inches per second is actually traveling 55 mph. How fast did *your* balloon car go in miles per hour?

Activity 5: Balloon-Powered Car

Exploration Questions

1. Describe how a balloon produces thrust.

   [*The rubber surface of the balloon is stretched when it is filled with air. When the balloon is released, the surface of the balloon squeezes air out of the opening, providing thrust.*]

2. Throughout this project, you've explored ways of making cars move using gravity, rubber-band power, and balloon power. Which ones worked best and why?

   [*Allow a couple groups to respond.*]

3. What differences did you notice between balloon power and propeller power? Which method would you prefer if you were to design another car? Explain.

   [*They likely noticed that the balloon car accelerated faster at first because there is more initial thrust from the balloon than from the propeller. The propeller may not provide as much thrust, but that thrust often lasts longer. Either could go faster or farther, depending on how many times the propeller is wound or how much the balloon is inflated. In both cases though the thrust was provided by air.*]

Glossary

Acceleration
An increase in speed

Conversion factor
A ratio used to convert one unit of measure into another unit of measure.

Design trade-off
When a change in the design improves one aspect of its performance but causes other things to get worse. The best design is usually a compromise that balances many different aspects of performance.

Drive axle
An axle that has a twisting or turning force applied to it to propel the vehicle forward.

Drive wheel
A wheel attached to the drive axle.

Efficiency
The amount of output produced for each unit of input.

Energy
The ability to do work. Can take many forms, including heat, light, electricity, mechanical, or chemical (ex: gasoline).

Friction
Resistance or drag caused by two surfaces rubbing against each other.

Iterative design
The process of continuously improving upon a previous design using the results of testing.

Kinetic energy
Energy due to an object's motion.

Potential energy
Energy due to an object's position or state.

Propeller
An arrangement of spinning blades used to generate thrust.

Prototype
An initial version of a new device. Engineers use prototypes to test new devices prior to mass-producing them.

Ratio
The relationship between two amounts, normally expressed by dividing one number into the other.

Rolling resistance
Friction between the tire and the surface that slows down the wheel when it is rolling. Narrower tires normally have less rolling resistance.

Speed
Distance per unit of time. Distance divided by time.

Thrust
Force used to propel something forward.

Torque
Rotational or twisting force that makes something turn or spin.

Traction
Friction or grip between a wheel and the surface it is rolling on.

Trial-and-error
A process in which you try different methods of doing something and see if they make things better or worse.

Unit of measure
An agreed-upon amount of something used as a standard for comparison.

Acknowledgments

Authorship Team

Dr. Ed Maxa, Associate Professor (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Kate Guerdat, Former 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Amy Chilcote, 4-H Extension Associate, Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Kristy Oosterhouse, 4-H Program Coordinator, Michigan State University Extension

Dr. Jacob DeDecker, Program Leader, Children and Youth Institute, Michigan State University Extension

Steven Worker, 4-H SET Coordinator, University of California Agriculture and Natural Resources, Youth, Family and Communities, 4-H Youth Development Program

Lynn Schmitt-McQuitty, County Director & Science Literacy Youth Development Advisor, University of California Agriculture and Natural Resources

Dr. Matthew T. Portillo, 4-H Youth Development Program Advisor, Academic Assembly Council President, University of California, Butte County

Amanda Meek, 4-H SET Educator, University of Missouri Extension

Dr. Jeff Sallee, Assistant Professor and Extension Specialist 4-H Youth Development, Oklahoma State University

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Paul Klenk, Research Scientist, Duke University

Wendy Candler, Curriculum Development / Graphic Design, Techsplorers

Curriculum Developers

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Paul Klenk, Research Scientist, Duke University

Nancy C. Shaw, NC Director of Project Lead The Way, Duke University

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

Wendy Candler, Curriculum Development / Graphic Design, Techsplorers

Collaborative Contributors

Donna Patton, Extension Specialist, West Virginia University Extension Service

Sherry Swint, Extension Agent, West Virginia University Extension Service

Lynna Lawson, 4-H Youth Development Specialist, University of Missouri Extension

Robert B. Furr, County Extension Director, North Carolina Cooperative Extension

Carla Burgess, Youth Curriculum Reviewer, Duke University

Acknowledgments

Layout, Graphics, & Design

Jenny McAllister, Adobe InDesign Layout, Techsplorers

Wendy Candler, Illustration / Graphic Design, Techsplorers

Illustration / Graphic Design / Website Design – Cuberis Design + Web Solutions

Leadership Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Allen O'Hara, Grant Manager, National 4-H Council

Gregg Tabbachow, Grant Manager, National 4-H Council

Dr. Gary A. Ybarra, Professor of Electrical and Computer Engineering, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Research Team

Dr. Ed Maxa, Professor Emeritus (retired 2010), Department of 4-H Youth Development and Family & Consumer Sciences, North Carolina State University.

Dr. Mitzi Downing, Department of 4-H Youth Development Cooperative Extension Service, North Carolina State University.

Dr. Eddie Locklear, Director of National 4-H Afterschool Program (retired 2012)

Dr. Gary A. Ybarra, TechXcite Principal Investigator, Duke University

Rodger Dalton, Research Associate, Duke University and President, Techsplorers

Dr. Anne D'Agostino, TechXcite Program Evaluator, Compass Evaluation and Research Inc.

Program Management

Rodger Dalton, TechXcite Program Manager (2012-2014), Duke University

Dr. Paul Klenk, TechXcite Program Manager (2007-2012), Duke University

Copyright

This Module was created with support from the National Science Foundation grant 0638970.