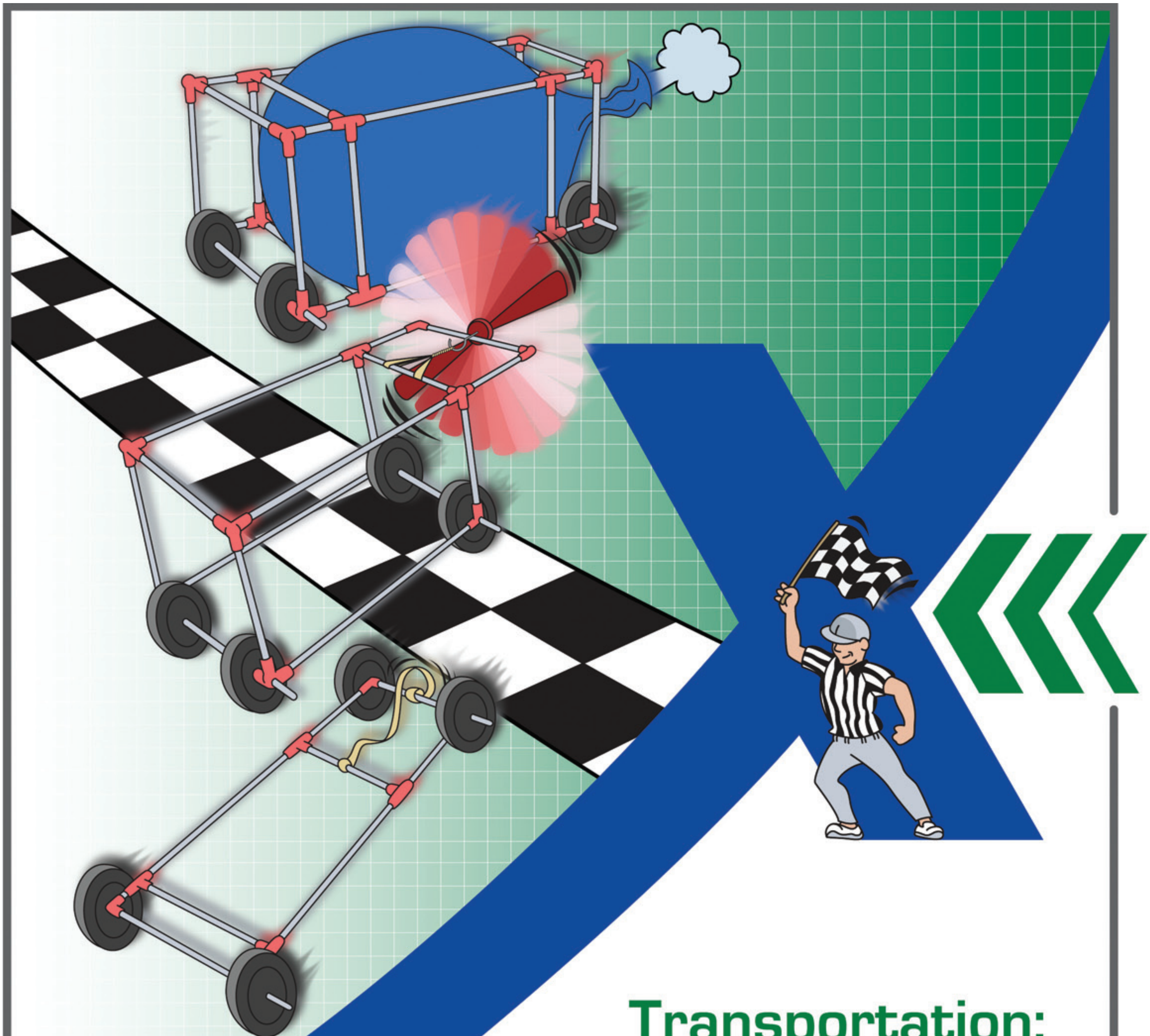

Transportation: Quest for Speed

Pratt School of Engineering, Duke University

techxcite.pratt.duke.edu

TechXcite

Discover Engineering

Instructor's Guide

Table of Contents

Module Overview

In this **TechXcite: Discover Engineering** module, youth use math and engineering principles to design and test several different cars that use 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 conversion of measurements. They explore modifying their cars to best meet the design objectives and improve performance.

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

Activity 2: Youth build a simple 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.

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TechXcite Program

TechXcite is a partnership between the Pratt School of Engineering at Duke University, the National 4-H Council/4-H Afterschool and North Carolina 4-H.

The program is directed by Drs. Gary Ybarra (PI) and Paul Klenk (Co-PI). Beginning in 2001, they co-created the successful Techtronics afterschool engineering program at Rogers-Herr Middle School and Lowes Grove Middle School in Durham, N.C. The TechXcite: Discover Engineering curriculum is building on this work by creating engineering learning modules in seven theme areas for use in afterschool programs nationwide. Together they have created an engaging, substantive, experiential and inquiry-based curriculum in engineering, technology and applied science for 4-H-supported middle school youth in afterschool programs across the nation. We hope to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

If your program is interested in adopting any of the TechXcite: Discover Engineering learning modules, please contact us at techxcite@duke.edu.

Online Support

The TechXcite Web site (techxcite.pratt.duke.edu) contains additional material to help you implement this module. There are videos to guide you through facilitating the activities with students. You can download copies of the Instructor's Guide and Youth Handouts. You'll also find a list of sources for any materials you'll need. Finally, there are links to additional resources.

E-mail and Phone Support

If you have questions about any of the material in this curriculum, please do not hesitate to ask. The Duke team is available to support you if you have questions about implementing the modules. Please contact our staff at techxcite@duke.edu. You may also call us anytime at the phone number listed on the Contact Us page on our web site: http://techxcite.pratt.duke.edu/contact/index.php.

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Using This Guide

The first portion of this handbook is the Instructor's Guide for all of the activities in the module. It includes this introductory section and also the Instructor's Guide for each activity. This introduction contains general information about the TechXcite curriculum, what to expect in each activity's Instructor's Guide and background on tools you will be using.

The Instructor'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 find basic information about the module. This includes:

- Time Required
- Materials
- Group Size – This is the suggested number of students per group.
- Youth Handouts – These will need to be copied.
- Instructor Preparation – This describes what you need to do before the activity and approximately how much time it will take you.
- Learning Objectives
- Vocabulary

Introduction, Procedure and Activity Closure

Three sections form the body of the activity: Introduction, Procedure and Activity Closure. The Introduction and Activity Closure sections 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. The Procedure section is not scripted. It contains step-by-step instructions for facilitating the activity with a group of students.

Cleanup

This section appears in activities in which cleaning up in a particular way will help reassemble the kit or prepare for the next activity. Following these instructions will keep the kit in proper order.

Assessment

This section tells you how to assess whether or not students understood the material presented to them in the activity. These assessments are generally based on students' answers to questions asked during the Activity Closure section.

Tools Used in the Module

Keeping the K'NEX® Set Organized

In Activities 2 through 5, students use the K'NEX® Motion and Design set to build their cars. We have found that even if the parts are laid out in perfectly organized containers, it is difficult to keep the parts sorted during the course of the activities. Sorting requires a lot of prep time. We recommend allowing the parts to become mixed up. Simply set out bins of assorted parts in front of the room or spread parts on a table. Students should be able to find and select the parts they need fairly easily. At the end of the class, you can put all of the mixed parts back into the same cardboard box in which they arrived.

Before starting, give students the following rules, which will help keep the workspace organized, eliminate crowding and give everyone access.

1. Don't crowd around the parts bins. Return to your table to assemble your car.
2. 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 1: Spooling Around

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

Materials List

Each student needs:
- Wooden spool
- Nail
- Flat washer
- Three rubber bands

Each class needs:
- Tape measures
- Calculators

Youth Handouts:
- "Spooling Around"

Instructor Preparation (5 minutes)

- Build a sample spool car to show students.

Learning Objectives

After this activity, students should be able to:

- Describe what a unit of measure is and provide some common examples.
- Measure distance with a tape measure.
- Explain that engineering often involves design trade-offs, meaning that changing one aspect of a design to improve it often causes other aspects to get worse.

VOCABULARY	Word	Definition
	Design trade-off	A compromise that balances many different aspects of performance.
	Efficiency	The amount of output you get for a given input.
	Propulsion	Force that causes motion.
	Traction	The 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 and/or measurement.

Activity 1: Spooling Around

Introduction

Over the next few sessions, we are going to build and test a variety of different cars, each with a unique method of propulsion. Like engineers, you'll make many small improvements to those cars over time. Automotive engineers are always exploring ways to make their products work better. Some of the ways they scientifically evaluate the performance include: measuring how far their cars can travel, how fast they can go and how efficient they are. Today we're going to explore the concepts of distance and efficiency. Next time, we'll talk about speed.

Transportation is all about getting from point A to point B in a certain amount of time. How can you figure out how long a trip will take? You must first answer the question: "How far are you going?" To find the solution, you need a method of measuring distance—what scientists call a "unit of measure."

What are some units of measure you can think of?

[Allow students to name a few. Possible answers: pounds, miles, feet, gallons, etc.]

How would you define a unit of measure?

[Allow students to brainstorm a few definitions.]

What units of measure do people use every day?

[A pound of butter, a gallon of milk, an 8-foot board, etc.]

A unit of measure is a standardized quantity that allows consistency, meaning that everyone using the measurement agrees on how much the quantity represents. For example, the units on a tape measure are defined by the English System of Measurement, which uses feet and inches. As you know, each foot contains 12 inches. What you may not know is that these units of measure date all the way back to medieval times. The base unit of measure in the English System is the "barleycorn." In the old days, everyone grew barley for food and the kernels were about the same size. Three dried kernels laid end-to-end measured 1 inch.

Units of measure can be combined to create new units of measure. This is a powerful scientific concept. Take, for example, the mile, which is a measure of distance, and the gallon, which is a measure of volume. With a little math, you can use these two units of measure to determine your car's "gas mileage". If you divide "miles" by "gallons" you get "miles per gallon" or MPG. MPG is a way of measuring the fuel efficiency of an automobile. If your car gets 40 miles per gallon, then for each gallon of gas you pump into the fuel tank, you can expect to achieve 40 miles of distance.

Efficiency is the amount of output you get for a given input. The goal of efficiency is to get the best performance (output) from something while using the lease amount of resources (input), such as time, money or energy. Engineers want the products they design to function as efficiently as possible.

We'll discuss the concept 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, rubber band and nail.

Activity 1: Spooling Around

Procedure:

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 and ask students to follow the instructions to build the car.

Completed Spool Car

3. Let students select their own test locations. These may be tables, the floor of the classroom, or the hallway. (You can vary the activity by having them experiment with different surfaces, such as a carpeted area. This will allow them to compare a variety of results.)
4. Before students begin testing the cars, ask them to predict what they think will happen to the distance and efficiency as the number of nail turns is increased.
5. Now instruct students to test their cars. Remind them to enter the test results in the table on their handout. People who lack the use of one hand can often do anything you or I can do. For example, typing on a computer is usually a two-handed activity, but if you had only one hand you might adapt to other methods of typing.
6. Now say to students, "What problems, if any, do you notice with your spool cars? Engineers are always improving their devices by identifying problems and designing solutions." Let students brainstorm some problems, then ask if they have any ideas about how they might solve those problems using their materials. You could walk around and discuss this while students are finishing up, or do it with the whole class.
7. Encourage them to experiment with changes to the design and then test to see if their improvements had a measurable effect on performance, such as greater distance or better efficiency. They should record their results after each test-run.

Activity 1: Spooling Around

Following are a couple of possible problems and solutions:

- **The craft stick begins to slip and spin while students are winding the nail. This limits how tightly the rubber band can be wound and hence how far the car will travel.** *[Possible solutions: add a small piece of masking tape, as pictured, to prevent the craft stick from spinning; glue the stick to the spool; use sandpaper to roughen the end face of the spool so that the stick doesn't slip.]* Discuss any benefits or drawbacks to these possible solutions. For example, suppose they added masking tape to keep the spool from slipping while winding. Did this improvement increase the maximum distance the car can travel? *[Yes, because the band can be wound tighter.]* Does this improve the car's efficiency? *[No. It may even decrease efficiency because the tighter winding may cause the spool to spin when the car is first released.]*

- **Upon release, the spool spins before moving forward. This is especially prone to happen if spools are tested on a smooth surface.** *[Possible solution: A #16 size rubber band can be doubled over and wrapped around the part of the spool that makes contact with the surface (see picture). This should improve traction.]* Ask students what effect they think this improvement in traction would have on efficiency? *[Increasing the friction between the spool and the ground can prevent the spool from slipping or spinning when it is first released. That will help to prevent wasting energy stored in the rubber band and thus could improve efficiency.]* Will this improve the maximum distance that the spool car can travel? *[Yes. By not wasting energy on spinning, more energy goes into moving the spool forward.]*

Activity Closure

[At the end of every activity, ask students the following questions to prompt them to think about which design modifications worked well and which didn't. Their responses will vary.]

1. Which designs worked best and why?
2. Which designs didn't work so well and why?
3. What would you do to improve your designs?

Activity 1: Spooling Around

[Below are some questions that are specific to this activity.]

What do you think a "design trade-off" is?

[Write a few of their responses on the board.]

Mechanical engineers designing a real automobile face many of the same design trade-offs as you made with your little spool car. A design trade-off means that changing one aspect of the design may cause other aspects to get worse. In engineering, there are always design trade-offs. The best design is the one that strikes a balance between trade-offs and attaining the objectives.

Let's look at a couple of examples of how you might try to improve the spool car and how you might end up making trade-offs.

1. How might you make the engine more powerful?

   You could use a stronger rubber band. The car might sprint off the starting line and travel much farther. But what would happen to the efficiency? [The band would eventually become so strong that the spool would spin without moving forward when it is released, severely reducing the efficiency.]

2. How might you make it faster?

   You could reduce the weight of the spool by substituting lighter parts. For example, you could use a pencil for the crank handle instead of the nail. The car's performance would improve. But if you continued to make it lighter, you would eventually reach a point where not enough weight bore down on the spool to help it maintain 100 percent traction on the surface. When you first let go of it, the car would spin a little before it began to move forward, wasting some of the energy stored in the rubber band and lowering the efficiency.

3. Could lower efficiency be OK?

   If your design objective is to attain the fastest speed possible, you might be willing to trade lower efficiency for higher speed.

Assessment

Discuss the following questions as part of Activity Closure, or have students write answers to these questions.

1. What makes this spool car move? Where does it get its power or energy?
   [From the winding of the rubber band.]

2. What does efficiency mean?
   [Efficiency is the amount of output you get for a given input.]
   Can you give an everyday example?
   [Miles per gallon, etc.]

3. Explain what traction is.
   [The friction or grip between a wheel and the surface it is rolling on.]
   If more weight pushes down on a tire, does traction get better or worse?
   [Better.]

4. What is a design trade-off?
   [A compromise that balances many different aspects of performance.]

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)

Instructor Preparation (15 minutes)

- Prepare the K'NEX® parts in a central location where students can access them (see Tools Used in the Module: Keeping the K'NEX® Kit Organized).
- Build a sample car to show students.
- Locate a sloped sidewalk near the classroom or make a sturdy ramp by leaning a board or piece of foam core, for instance, against a table, desk or stack of books. The ramp is too steep if cars move too fast to be timed. Use masking tape, chalk or marker to create starting and finish lines that are 36-100 inches (91.5-254.0 cm) apart. The starting and finish lines could be on the ramp or they could be on the flat surface beyond the ramp.

Learning Objectives

After this activity, students should be able to:

- Explain that speed equals distance divided by time.
- Use a stopwatch to measure time.
- Identify a wheel's axle, hub and tire.
- Explain how a wheel and axle work together to make something roll.
- Describe how friction can be good or bad depending on the situation.

Activity 2: Ramp-Powered Car

VOCABULARY	Word	Definition
	Axle	The shaft that passes through the center of one or more wheels. (The red plastic rod on the cars is the axle.)
	Friction	Resistance or drag caused by two surfaces rubbing against each other.
	Hub	The center part of a wheel where the axle passes through. (On K'NEX® wheels, the hub is the silver plastic part that the tire wraps around.)
	Prototype	An initial version of a new device. Engineers use prototypes to test new devices prior to mass-producing them.
	Ratio	A relationship between two quantities, normally expressed by dividing one number into the other. For example, speed is a ratio of distance divided by time.
	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.
	Tire	The black rubber part of a wheel that helps it grip the surface.

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. *[Show them the sample car.]*

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 is 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 has units of measure too, such as seconds, minutes and hours. In this case, we will be counting seconds using a stopwatch.

Activity 2: Ramp-Powered Car

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: it is the ratio of distance over time. A ratio is a fraction made by dividing one number by another, as shown below.

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

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

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

To make sense of this equation, let's look at a familiar example. If you are 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.

$60 \div 2 = 30$ 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: how much of one will give you how much of the other.

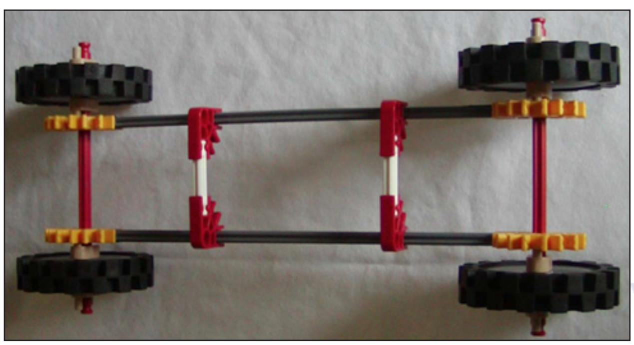
You'll use this information to calculate the speed of the vehicle you're about to create.

Activity 2: Ramp-Powered Car

Procedure

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 not familiar with K'NEX®, might need them, especially in Activities 2 and 3. 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 OK if students make a version that looks different from the ones pictured. Always encourage students to improve on their prototypes.

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.
3. Distribute the handouts. If students are more advanced, you may decide not to give them the Prototype Instructions.
4. Tell students that their engineering design challenge is to build the fastest car possible.
5. Direct students to the parts bins and give them these rules: (1) Don't crowd around the bins. Return to your table to assemble your car. (2) 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.



Prototype of Ramp-Powered Car

6. Instruct students to build their cars, referring to the Prototype Instructions, if necessary.
7. 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.
8. Demonstrate how to use the stopwatch.
9. Instruct students to take turns testing their cars on the ramp. Tell them to record their test results in the table on their handout.
10. 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.

Activity 2: Ramp-Powered Car

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 Closure

[At the end of every activity, ask students the following questions that will prompt them to think about which design modifications worked well and which didn't. Their responses will vary.]

1. Which designs worked best and why?
2. Which designs didn't work so well and why?
3. What would you do to improve your designs?

[Below are some questions that are specific to this activity.]

You now have a scientist's view of what speed is and how it is calculated in an experiment. Think about what factors affected your car's speed performance. What was the fastest speed observed during your experiments? What was it about your set-up that produced this result? What set-up resulted in the slowest speed? *[Students may have noticed that a smoother surface has less rolling friction, so a car will go faster on a bare floor than 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.]*

Did the car run at a constant speed on the ramp?
[No. It constantly accelerated while it continued down the ramp.]

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 distance interval used in the calculation.]

Do you think you could make a new unit of measure by multiplying instead of dividing?
[Everyday examples are less common, but some occur frequently in engineering and science. One of the more common examples is "foot pounds" of torque applied when you tighten a bolt or nut. See Activity 4 for a definition of torque.]

Activity 2: Ramp-Powered Car

Optional Closure Extension

Have you ever heard of the Soap Box Derby? It is a car race for kids that is conducted like the ramp-powered car activity you just did. Just 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 that are 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 made of hard rubber, and they 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 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, if you were stopping the car using brakes, or if you were accelerating quickly (like the spools in Activity 1).]

How do different physical properties of a tire (softness, hardness, wide width, narrow width) affect friction?
[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.]

Assessment

Discuss the following questions as part of Activity Closure, or have students write answers to these questions.

1. What unit of measure do you come up with when you divide feet by seconds? *[Feet per second]*
   Is this a measure of speed? *[Yes]*
2. Explain the scientific definition of speed. *[Distance divided by time.]*
3. Draw a wheel and axle, then explain how they allow a car to roll.
4. While the car is on the ramp, is its speed increasing? *[Yes]*
   What about when it is rolling on the flat surface? *[No]*

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)

Instructor Preparation (15 minutes)

- Prepare the K'NEX® parts in a central location where students can access them (see Tools Used in the Module: Keeping the K'NEX® Kit Organized).
- Build a sample car to show students.
- Choose the design challenge you'll give students (see Procedure, Step 4).
- Select a flat surface for testing the cars. You could use a sidewalk, the floor of the classroom or the floor of a hallway, for example.

Learning Objectives

After this activity, students should be able to:

- Identify that the drive axle is the one that makes the car move.
- 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.
- Discuss some alternative energy sources used for green transportation.
- Explain why changing the test distance affects the speed calculated for the car.

VOCABULARY	Word	Definition
	Carbon Dioxide (CO_2)	A chemical substance released from burning oil, coal, gasoline and other similar fuels. Most scientists believe that increased carbon dioxide in the atmosphere is causing the climate of the earth to become warmer, with potentially harmful results.
	Drive Axle	An axle that has twisting/turning force applied to it so that the car will be propelled forward.
	Drive Wheel	A wheel attached to a drive axle.
	Energy	The ability to do work, such as making an object move. Energy can take many forms, including heat, light, electricity, mechanical (such as turning an axle or wheel) or chemical (such as gasoline).
	Green	A description applied to technologies that are less harmful to the environment, often with the intent to reduce carbon dioxide emissions.

Activity 3: Rubber-Band-Powered Car

Introduction

What caused our cars to move during the test we did last time? *[The force of gravity.]*

Today we're going to modify the car you made last time so it will be propelled by a rubber band. *[Show students the sample car.]*

Since the invention of the wheel, humans have sought to make daily transportation faster. We have made outstanding technological progress. An impressive example is the Shanghai Maglev train, which connects Shanghai Pudong International Airport to the city's center. It has a top speed of 268 mph (431 km/h). Maglev functions using magnetic levitation—it is lifted onto a cushion of air by magnets. As it does not roll, the train has no rolling resistance. The only friction it encounters is from drag created by the air. *[More at **http://en.wikipedia.org/wiki/Shanghai_Maglev_Train**.]*

Planes are faster than trains, and rockets in space are faster still. The Space Shuttle Endeavor could go a whopping 17,320 mph!

But speed isn't everything. Engineers are working to develop forms of transportation that reduce air pollution and damage to the environment. The new hybrid cars have batteries to power an electric motor to drive the wheels. The advantage of this approach is that the electric motor can be used both as a motor and a brake. When braking, energy is transferred from the electric motor back to the batteries so it can be saved and reused later when the car accelerates. Hybrid cars do have a small gasoline engine that is used to recharge the batteries. That's why the car is called a hybrid—it uses a combination of two different energy sources, a battery and gasoline.

Another green transportation technology under development is a hydrogen-powered car. This car uses something called a fuel cell that takes hydrogen and oxygen gas coming in and combines them to form water. In the process, electrical energy is released. That energy can be used to power an electric motor to drive the wheels of the car. *[More at **http://en.wikipedia.org/wiki/Fuel_cell**.]* But the technology isn't perfect, so engineers have many challenges to meet to make the car practical and safe. Because fuel cells are made with rare metals, they are very expensive. The cells are prone to contamination by impurities that exist in the fuel supply. Also, hydrogen poses a similar but different set of dangers when compared to gasoline-powered cars. *[More at **http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/hydrogen-vehicle-danger.htm**.]*

We need a new generation of young engineers to dream up their own clever solutions for the problems of the 21st century world. Today you'll investigate various ways of making cars move, much like real engineers do. You've explored gravity power and the rubber-band-powered spool. Today you'll again be using rubber bands to power your car, but in a different way.

Activity 3: Rubber-Band-Powered Car

Procedure

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, 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.
3. 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.)
4. 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, whatever is best suited to the class.
    a. **How Far Can It Go?** Let students modify their cars, any way they like, to try to make them travel farther. Have them measure and record the distance traveled on each test-run.
    b. **How Fast Can It Go?** Let students modify their cars, any way they like, to try to attain the highest speed over a specified distance. Let them experiment to find out what distance between the starting and finish lines 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 white rubber-band cross-brace rod to the red drive-axle rod 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.
5. If students are starting with a completed car from Activity 2, ask them to modify it so it can be propelled with a rubber band. If they don't have a car, they'll need to build one from scratch.
6. Have students test their cars and record their results in the table on their handout.
7. 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

Prototype of Rubber-Band-Powered Car

Activity Closure

[At the end of every activity, ask students the following questions to prompt them to think about which design modifications worked well and which didn't. Their responses will vary.]

1. Which designs worked best and why?
2. Which designs didn't work so well and why?
3. What would you do to improve your designs?

[Below are some questions that are specific to this activity.]

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.]

Did you use wide tires or narrow ones? What difference does it make if you use narrow tires instead of wide tires? *[Narrow tires have less rolling resistance than wide ones.]*

What is the purpose of the tires? What would happen if you didn't have tires on the drive wheels? *[The tires improve traction between the surface and the wheel. Without tires, the drive wheels might slip/spin on the surface.]*

Do you really need the axle clips that are 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.]*

[If students worked on challenge C, ask them what happened when they slid the rubber-band cross-brace closer to the drive axle. Answer: 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.]

Activity 3: Rubber-Band-Powered Car

Assessment

Discuss the following questions as part of Activity Closure, or have them write answers to these questions.

- What is a drive axle?
  [The axle that the rubber band spins to make the car move.]
- Where does the car get its energy? What makes it go?
  [The rubber band.]
- What do the tires do and how do they work?
  [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.]
- Which part of the rubber band stores energy?
  [The part that is stretched, not the part wrapped around the axle.]
- 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.]
- What types of alternative energy sources are used for green transportation?
  [Battery-powered electric cars, fuel-cell-powered cars, etc.]

Activity 4: Propeller-Powered Car

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

Materials List

Each group needs:
- Five to 10 size #16 rubber bands
- Two 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)

Learning Objectives:

After this activity, students should be able to:

- Describe how a propeller works to convert torque into thrust.
- Explain that the faster a propeller turns, the more thrust it generates.
- Explain why some propellers work better in one direction than another.
- Describe why certain rubber-band arrangements work better than others.

VOCABULARY	Word	Definition
	Propeller	An arrangement of spinning blades used to generate thrust.
	Thrust	Rushing air that is 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 a propeller car driven by rubber bands. But instead of the rubber band directly driving the axle, like last time, it will spin a propeller, which will push air behind the car to make the car move.

[Hand out propellers so students can examine them while you talk.]

Whoever invented the propeller was very clever. But no single person can get all the credit for this invention. The idea was developed over a long time, with each person making improvements. *[More at **http://en.wikipedia.org/wiki/Propeller**.]* A key improvement 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!

"Torque" is the word that engineers and scientists use to describe turning or twisting force. When you turn a door knob, your hand is applying twisting force called torque. What are some other everyday examples of torque? *[Turning a screwdriver, turning a water faucet on and off, opening a jar lid, etc.]* In the car you made in Activity 3, the rubber band applied torque to the drive axle to propel the car.

Let's define some of the terms used in understanding torque. First is the term "convert", which means changing one thing into another. Another term is "thrust". 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.

So what does a propeller do?
[It converts torque into thrust.]

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.

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

Before you start building and testing, here are some words of caution:

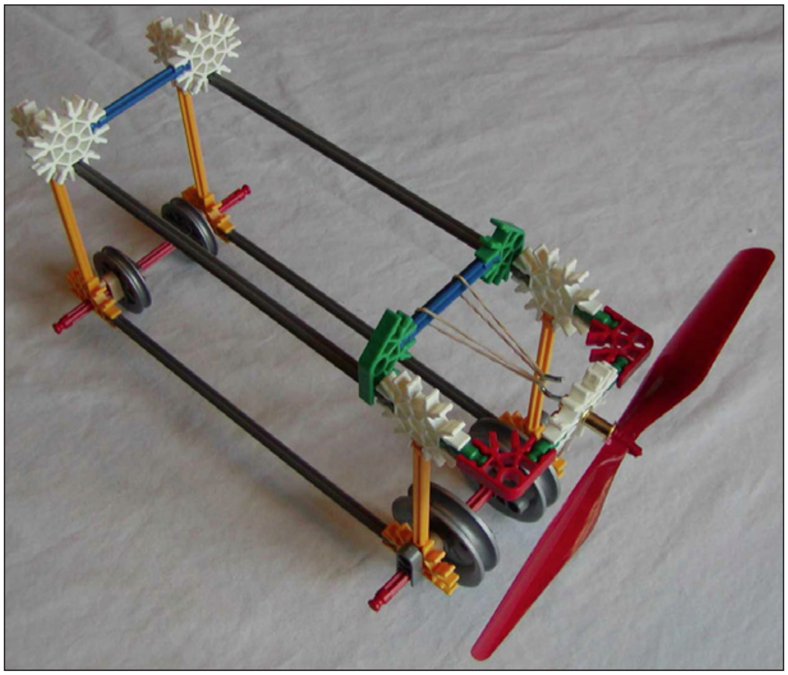
1) Do not wind your car up so tightly that the pieces begin to bend.
2) Do not use more than two rubber bands.
3) Do not use rubber bands that are stronger than the #16 size ones provided.
4) Wear safety glasses when winding the propeller. The propellers are made of many small, metallic parts. If these parts are put under too much stress, they may come apart at high speeds.

Activity 4: Propeller-Powered Car

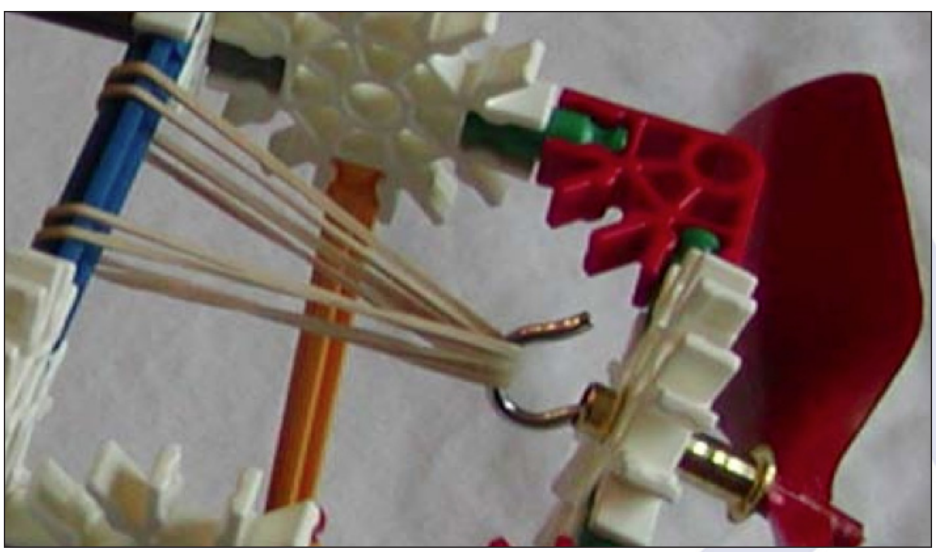
Procedure

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. (In a test of the car pictured, the car traveled more than 3 feet using two Size #13 rubber bands for power.)
2. Place students in pairs.
3. Distribute the handouts. If students are more advanced, you may decide not to give them the Prototype Instructions.
4. Tell students what 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 them one.
5. Direct students to the parts bins and give them these rules: (1) Don't crowd around the bins. Return to your table to assemble your car. (2) 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.
6. Tell 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. Instruct 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 below 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 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 4: Propeller-Powered Car



Prototype of Propeller-Powered Car



Activity 4: Propeller-Powered Car

Activity Closure

[At the end of every activity, ask students the following questions to prompt them to think about which design modifications worked well and which didn't. Their responses will vary.]

1. Which designs worked best and why?
2. Which designs didn't work so well and why?
3. What would you do to improve your designs?

[Below are some questions that are specific to this activity.]

Where have you seen a propeller before? What types of devices have them?
[Airplanes and boats have propellers. A student 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.]

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.]

How does a propeller work?
[It pushes air, which provides thrust.]

If a propeller spins faster, will it produce more, less or the same amount of thrust?
[Faster spinning will produce more thrust.]

Assessment

Ask students the following questions as part of Activity Closure, or have them write answers to these questions.

- What is torque? *[Rotational or twisting force that makes something turn or spin.]*
- 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.]
- Could you design a propeller that works equally well when spun in either direction? *[Yes.]*
  Explain. *[If the blades were flat, the propeller would work the same in both directions.]*
- 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.]

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 measure (one per two groups)
- Stopwatch (one per two groups)
- Calculator (one per two groups)
- Air pump (one per two groups)

Youth Handouts:

- "Balloon-Powered Car"
- "Prototype Instructions" (optional)

Instructor Preparation (20 minutes)

- Prepare the K'NEX® parts in a central location where students can access them (see Tools Used in the Module: Keeping the K'NEX® Kit Organized).
- Build a sample car to show students.
- Choose the design challenge you'll give students (see Procedure, Step 4).
- Select a flat surface for testing the cars. You could use a sidewalk, the floor of the classroom or the floor of a hallway, for example.
- Write the math formulas on the board.

Learning Objectives

After this activity, students should be able to:

- 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
	Centimeter	Unit of measure for length from the Metric System. 1 inch = 2.54 centimeters.
	Trial-and-error	A process for improving products or processes in which you make changes or try new ideas.

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 would. Today you're going to build a car that is powered by a balloon. But first we're going to explore more about speed.

If you made a K'NEX® car that goes 968 inches per second, is that a fast car or a slow car? Let's say you wanted to know how fast that is in miles per hour. How would you figure this out?

By specifying the speed of something, such as 55 mph, engineers and other scientists have a measurement that everyone can relate to and understand. It's a standard unit of measure that always means the same thing. Let's say we want to convert one unit of measure to another. Imagine that the length of one of our cars is 12.0 inches and we want to know what its length in feet is? [1 foot. There are 12 inches in 1 foot.] If someone is 120 inches tall, how tall is that person in feet? [10 feet.]

Let's look at some examples of the mathematics of conversion.

What did you do to convert inches to feet? You knew that there are 12 inches in 1 foot. So you divided the length in inches by 12, which gave you the length in feet. Easy. But let's break it down in a way that you may not have seen before. I'm going to show you how to make any type of unit conversion you want. *[Go over the first three math rules in the diagram below. The last rule about canceling out an equal factor is addressed in depth after the diagram.]*

Useful Math Rules

1. Anything multiplied by 1 = itself, example: 12 x 1 = 12.
2. Anything divided by 1 = itself, example: 12/1=12.
3. Order does not matter when multiplying, for example, 4x2x3 = 24 = 3x2x4.
4. If the same factor (number or unit of measure) is in the top and bottom of a fraction, you can cancel it out, as shown below (8/4=2).

$$\frac{8}{4} = \frac{\cancel{4} \times 2}{\cancel{4} \times 1} = \frac{2}{1} = 2$$

Unit of Measure Conversion Diagram 1

The key part of converting measurements is to cancel out a factor that is in both the top and bottom of a fraction. Here's a simple example using numbers only: 8 divided by 4 equals 2. You can think of the number 8 in the top of the fraction as being 4 times 2, and the bottom can be written as 4 times 1.

Activity 5: Balloon-Powered Car

You can cancel a factor that is on the top and bottom of a fraction even if it is a unit of measure. Check out the example in Diagram 2. Here, your 12-inch-long car is being converted into 1 foot (ft).

$$\frac{12\ \text{INCHES}}{1} \times \frac{1\ \ \text{FT}}{12\ \text{INCHES}} = \frac{12 \times 1 \times \text{INCHES} \times \text{FT}}{12 \times 1 \times \text{INCHES}}$$

$$\frac{\cancel{12} \times 1 \times \cancel{\text{INCHES}} \times \text{FT}}{\cancel{12} \times 1 \times \cancel{\text{INCHES}}} = \frac{1 \times \text{FT}}{1} = 1\ \ \text{FT}$$

Unit of Measure Conversion Diagram 2

As shown in Diagram 2, you measured the car and found that it was 12 inches long. That is the first measurement shown. I went ahead and indicated that 12 is divided by 1, which doesn't change any math. Then the next term says 1 foot per 12 inches. Of course it's also true the other way around, 12 inches per 1 foot. By putting "inches" in the bottom of the fraction, we're setting things up for canceling out.

Now here comes the magic. The 12's cancel out like the 4's did in Diagram 1. But we can also cancel out the word "inches" in the top and bottom. When we do that, all that's left is "feet". Sure enough, there sits the right answer, 1 divided by 1 is just 1. The car is 1 foot long.

Let's look at an example with numbers that aren't even. Check out Diagram 3.

$$\frac{12\ \text{INCHES}}{1} \times \frac{2.54\ \text{CM}}{1\ \text{INCHES}} = \frac{12 \times 2.54 \times \text{INCHES} \times \text{CM}}{1 \times 1 \times \text{INCHES}}$$

$$\frac{12 \times 2.54 \times \cancel{\text{INCHES}} \times \text{CM}}{1 \times 1 \times \cancel{\text{INCHES}}} = \frac{30.48 \times \text{CM}}{1} = 30.48\ \text{CM}$$

Unit of Measure Conversion Diagram 3

If your car is 12 inches long, what is its length in centimeters? Time to get out the calculators. There are 2.54 centimeters (cm) per inch. "Inches" goes on the bottom so that it will cancel out the first "inches" beside the 12. The only term left is "cm"—we want the answer to be in centimeters.

Finally, in Diagram 4, we're going to convert inches per second to miles per hour. Let's say our car goes 968 inches per second. We'll change one part at a time of the unit of measure, using the cancellation trick, then slowly work toward the unit of measure that we want.

Activity 5: Balloon-Powered Car

THERE ARE 5280 FEET IN A MILE, 12 INCHES IN A FOOT, 60 MINUTES IN AN HOUR, 60 SECONDS IN A MINUTE

$$\frac{968\ \text{INCHES}}{1\ \text{SECOND}} \times \frac{1\ \text{FT}}{12\ \text{INCHES}} = \frac{968 \times 1 \times \text{INCHES} \times \text{FT}}{1 \times 12 \times \text{INCHES} \times \text{SECOND}}$$

$$\frac{968 \times \cancel{\text{INCHES}} \times \text{FT}}{12 \times \cancel{\text{INCHES}} \times \text{SECOND}} = \frac{968 \times \text{FT}}{12 \times \text{SECOND}} = \frac{80.67\ \text{FT}}{1\ \text{SEC}}$$

$$\frac{80.67\ \text{FT}}{1\ \text{SEC}} \times \frac{60\ \text{SEC}}{1\ \text{MIN}} = \frac{80.67 \times 60 \times \text{FT} \times \cancel{\text{SEC}}}{1 \times 1 \times \text{MIN} \times \cancel{\text{SEC}}} = 4{,}840\ \frac{\text{FT}}{\text{MIN}}$$

$$\frac{4840\ \text{FT}}{\cancel{\text{MIN}}} \times \frac{60\ \cancel{\text{MIN}}}{1\ \text{HR}} = 4840 \times 60\ \frac{\text{FT}}{\text{HR}} = 290{,}400\ \frac{\text{FT}}{\text{HR}}$$

$$290{,}400\ \frac{\cancel{\text{FT}}}{\text{HR}} \times \frac{1\ \text{MILES}}{5{,}280\ \cancel{\text{FT}}} = \frac{290{,}400\ \text{MILES}}{5{,}280\ \text{HR}} = 55\ \frac{\text{MILES}}{\text{HR}}$$

Unit of Measure Conversion Diagram 4

We start by multiplying 968 inches per second by 1 foot per 12 inches. The word "inches" cancels out, leaving just "feet" (ft) in the top of the fraction. 968 divided by 12 equals 80.67 feet per second.

Now let's think about this answer—does it make sense? If we were traveling almost 1,000 inches per second, our speed in feet per second should be a smaller number. So it makes sense that if we divide 968 by 12, we'll get a smaller number. It's important that the math solution agrees with your common sense. If you get an answer that doesn't make sense, stop and check to see what went wrong.

Now let's convert the unit of measure for time, starting with the third row of calculations in Diagram 4. There are 60 seconds in 1 minute. We're looking at a longer amount of time, 1 minute instead of 1 second. The answer should be a bigger quantity of feet, so we multiply 80.67 by 60 and get 4,840 feet per minute.

We do the same thing to convert from minutes to hours. 4,840 x 60 = 290,400 feet per hour. Finally, there are 5,280 feet in 1 mile, so we'll come up with a much smaller number of miles in an hour than in feet. 290,400 ÷ 5,280 = 55 miles per hour. So now you have your answer: A car that is going 968 inches per second is traveling 55 miles per hour.

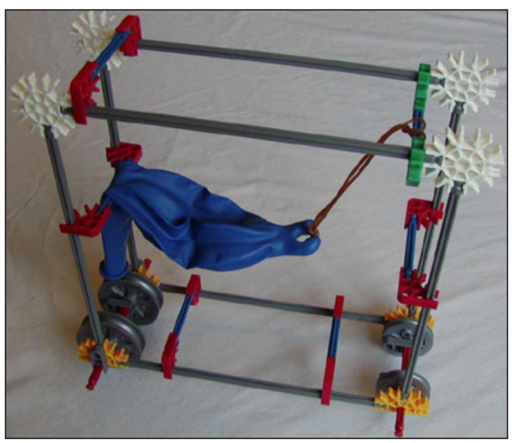
We're just using the cancellation rule of fractions so that we can change from one unit of measure to another. Convert one part of the units at a time, inches into feet, feet into miles, until you come up with the final version of units that you want. Remember, always keep in mind whether the new number should be bigger or smaller, so that you can catch mistakes.

Now let's get busy making our balloon-powered cars. 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.

Activity 5: Balloon-Powered Car

Procedure

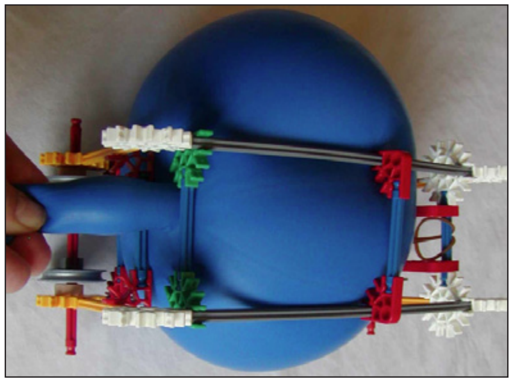
1. Show students the sample car and demonstrate how it works. Using the air pump, inflate the balloon while it is confined inside the frame. Stop inflating when the balloon pushes against the frame. Pinch the balloon closed with your fingers. Release your fingers when you're ready for the car to start.
2. Place students in pairs.
3. Distribute the handouts. If students are more advanced, you may decide not to give them the Prototype Instructions.
4. Choose the design challenge to assign to 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.
5. Direct students to the parts bins and give them these rules: (1) Don't crowd around the bins. Return to your table to assemble your car. (2) 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.
6. Instruct students to build their cars, referring to the Prototype Instructions, if necessary.



Prototype of Balloon-Powered Car

7. Tell students to test their cars and record the results in the table on the handout.
8. Encourage students to modify their cars, any way they like, to improve performance. Remind them to record their test results after each modification.
9. Encourage students to be creative in their designs, but urge them to be careful about confining the balloon into a space that is too small. Show them the photo below of one engineer's failed design. Ask them to notice how the balloon is putting a lot of stress on the gray frame rods, causing the frame to bend. The car had to be redesigned to use all gray rods in the frame so the balloon would have more room. The moral of the story: **Engineering design involves trial-and-error, no matter how experienced you are.**

Activity 5: Balloon-Powered Car



Failed Prototype of Balloon-Powered Car
Avoid designs that confine the balloon too much!

Activity Closure

[At the end of every activity, ask students the following questions to prompt them to think about which design modifications worked well and which didn't. Their responses will vary.]

1. Which designs worked best and why?
2. Which designs didn't work so well and why?
3. What would you do to improve your designs?

[Below are some questions that are specific to this activity.]

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 time for everyone to respond.]

What differences did you notice about using balloon power versus using a propeller with a rubber band? Which method would you prefer if you were to design another car? Explain why.

[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.]

What provides the thrust in each case? *[Air]*

Assessment

Ask students the following questions as part of Activity Closure, or have them write answers to these questions.

- Convert 25.4 inches into centimeters. [10 cm]
- Convert 176 inches per second into miles per hour. [10 mph]
- 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.]*