Learning Set 1

The Coaster-Car Challenge: Design and Build a Coaster Car That Goes Straight and Far

Your *Big Challenge* is to design and build a vehicle that, will go straight, far, and fast, and carry a load. You are not expected to build this vehicle right away. You will begin with a smaller challenge: designing and building a vehicle that can go straight and far. You have already made some observations about what makes things move if they are at rest. In this *Learning Set,* you will learn about motion and forces, and apply what you learn to make a coaster car travel in a straight line as far as possible.

coast: to move without being continuously pushed or pulled.

Coaster cars are simple vehicles without a system to make them move if they are at rest. A coaster car moves when it is able to roll down a hill. Because it moves freely, it is said to **coast** along. When an object coasts, it moves without being continuously pushed or pulled. The coaster car is a simple frame with wheels that you will build, and hardware to hold it together. As you build your coaster car, you will also design a performance test and use it to measure your car's performance. This is your first step toward succeeding with the *Big Challenge.*

A soapbox car is a type of coaster car. The car that wins a soapbox derby travels faster and straighter than the others. Well-designed soapbox cars can reach speeds up to 56 km/h (35 mi/h).

1.1 Understand the Challenge

Think About How to Make Your Coaster Car Go Straight and Far

chassis: the frame and wheels of a vehicle.

The frame and wheels you will build make up the **chassis** of a vehicle. The chassis of a vehicle supports its engine and whatever load the vehicle carries. Your coaster car will be the chassis of the vehicle you eventually build to achieve the *Big Challenge.* By making a coaster car that can go straight and far, you will have a basic structure in place to which you can add other parts.

Most vehicles are built on a basic chassis. Other parts are then added on, depending on the vehicle's purpose. Adding a sleek body to the car, leather seats, and a powerful motor can turn a simple chassis into a high-performance sports car.

Identify Criteria and Constraints

Your class has already listed the criteria and constraints for this Unit's design challenge. Before starting on your coaster car, identify the criteria and constraints that apply to your car. Think about what you want the car to do and the factors that will limit how you complete this part of the challenge.

Criteria	Constraints

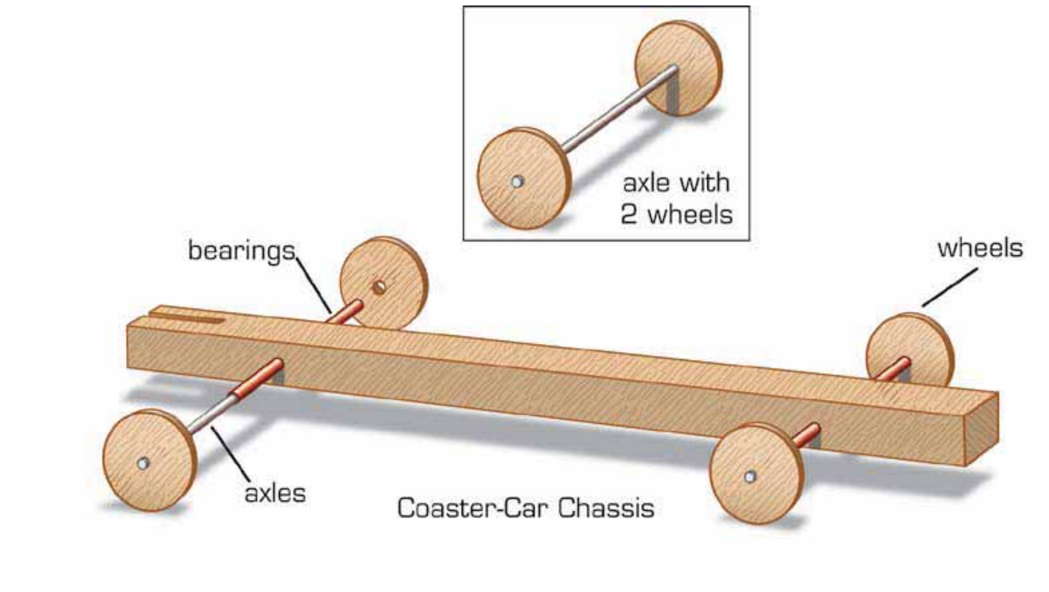
Build Your Coaster Car

The wheels of your coaster car will be connected by **axles**. An axle is a round shaft that can rotate. One wheel is attached to each end of an axle. The coaster car will also have **bearings**, structures that help the wheels move freely. Objects with parts that rotate or spin usually have some type of bearings. A well-built coaster car will roll smoothly when let go at the top of a ramp or when given a slight push.

You will be making a coaster car that has three basic parts:

- axles
- wheels
- bearings

You can put your coaster car together by hand, without using any tools.



Attaching the Bearings

In this design, the bearings hold the wheels on the axles while allowing them to move freely. Push each of the bearings—the hollow, straw-like pieces—into the pre-drilled holes in the front and back of the chassis. Slide them in and center them in the holes in the chassis.

axles: round shafts that connect the opposing wheels of a car.

bearings: structures that help parts move freely.

Material

- **coaster-car chassis, including:**
  - **2 axles**
  - **2 bearings**
  - **4 wheels**
- **ramp**
- **ramp support**

Connecting the Wheel-and-Axle Systems to the Bearings

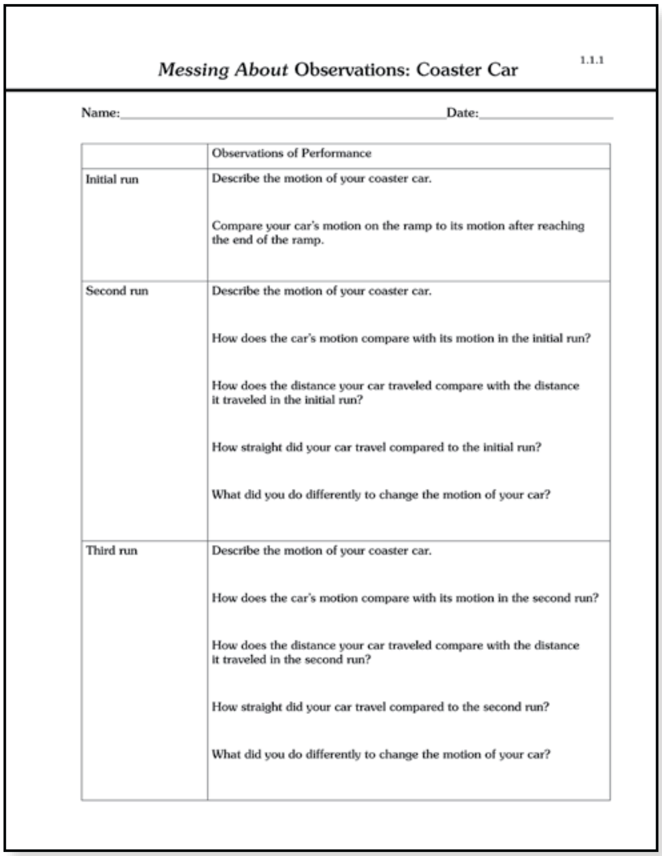
Push one axle into the hole in the center of one wheel and slide the axle into the bearing. Once the axle is through the bearing, push the second wheel into the axle and secure the wheels.

Repeat with the other wheel, bearing, and axle. Check that all the wheels are attached securely and the bearings are centered.

Mess About With Your Coaster Car

Now that you have built your coaster car, you can see how it moves. Let your car roll down a ramp once. Check to see that it can roll, and that the wheels are securely fastened. If you have any problems with your car, adjust the wheels, axles, or bearings until the car moves smoothly.

Once you have made the adjustments, let your coaster car roll down a ramp several more times. As you do this, observe the movement of your car and describe it on a *Messing About Observations: Coaster Car* page.



Messing About Observations: Coaster Car 1.1.1

Name:________________ Date:________

	Observations of Performance
Initial run	Describe the motion of your coaster car. Compare your car's motion on the ramp to its motion after reaching the end of the ramp.
Second run	Describe the motion of your coaster car. How does the car's motion compare with its motion in the initial run? How does the distance your car traveled compare with the distance it traveled in the initial run? How straight did your car travel compared to the initial run? What did you do differently to change the motion of your car?
Third run	Describe the motion of your coaster car. How does the car's motion compare with its motion in the second run? How does the distance your car traveled compare with the distance it traveled in the second run? How straight did your car travel compared to the second run? What did you do differently to change the motion of your car?

What changes each time you let your car run down the ramp? Does it move the same way every time you let it run down the ramp? What happens after it reaches the end of the ramp? Does it travel the same distance each time? Does it travel straight going down the ramp? Think about how to describe the way your car moves. What words can you use to describe its movement?

Coaster-Car Motion

When you describe how your coaster car moves, you are describing its **motion**. An object is in motion if its distance from some other object is changing. Your coaster car is in motion when its distance from the top of the ramp changes. The **speed** of the car describes how fast or slowly the distance changes.

A **force** is a push or pull. For a vehicle to move, it must have some **propulsion force.** A propulsion force is a push or pull that causes an object to move. For a gasoline-powered car, the propulsion force is produced by the burning of fuel in the engine. The propulsion force for your coaster car has a different source—**gravity**. Gravity is the force of attraction exerted between all pairs of objects in the universe. Objects on Earth experience gravity as a downward pull toward Earth's center. Earth's gravity is the force that keeps you and other objects on the surface of Earth and not flying off into space. The downward force of gravity pulls your coaster car down a ramp. In other words, gravity is the propulsion force for your coaster car.

motion: a change in the position of an object over time.

speed: a measure of how fast an object is traveling.

force: a push or pull.

propulsion force: a push or pull that causes an object to move.

gravity: the force of attraction between objects. On Earth, gravity pulls objects downward toward Earth's center.

Communicate

Share Your Coaster Car's Performance

Each group will demonstrate the performance of its coaster car and share its observations and descriptions of the car's motion. When it is your turn, place your car at the top of the ramp and release it. Share your description of its motion, including how far and straight it moves and how its speed changes.

As other groups let their coaster cars roll down the ramp and describe their motion, make your own observations. Listen carefully to the words they use to describe the motion of their car. Record what you see and hear in each group's presentation. This may help you better understand what motion is and how to describe it.

Reflect

Work in small groups to answer the following questions based on what you observed and heard in the presentations.

1. How does the performance of your coaster car compare to the performance of other cars? Be specific about the criteria you used for your comparisons.
2. What about a coaster car's motion do you think you can measure to allow you to compare the motion of one coaster car to another?
3. What needs to be improved about your car's performance?
4. What do you need to learn more about to improve your car's performance?

Update the *Project Board*

By observing the motion of your coaster car and that of the other groups, you were able to bring together your thoughts about motion. You recognized what you think you know about motion as well as what you do not know and need to learn. These things should be added to the class *Project Board.*

Suggest all of the things you now think you know about motion for the *What do we think we know?* column. Remember that no idea is too simple for the *Project Board* at this point. For example, you may want to suggest that you observed the coaster car starting from rest at the top of the ramp and moving downward.

Competitors in a soapbox derby compare the performances of their cars by seeing who crosses the finish line first.

Your discussions most likely revealed several things you do not know, especially when you tried to measure and compare the performance of different coaster cars. You may also be wondering how you can improve the performance of your car. These things should be added now to the *What do we need to investigate?* column.

1.2 Investigate

Design a Test Procedure for Measuring Vehicle Performance

You allowed your coaster car to roll down the ramp and you observed its motion. When you described its motion in words, you gave **qualitative data** about its performance. You may have said the coaster car moved fast, slowly, or straight. As a design engineer, you will need to describe the motion of the car using **quantitative data**. Quantitative data uses measurements in numbers to describe performance. If you can measure the way it performs, you will be able to compare the performance of your car to that of others. Measuring its performance before you make a design change will also enable you to determine how that design change affects its performance.

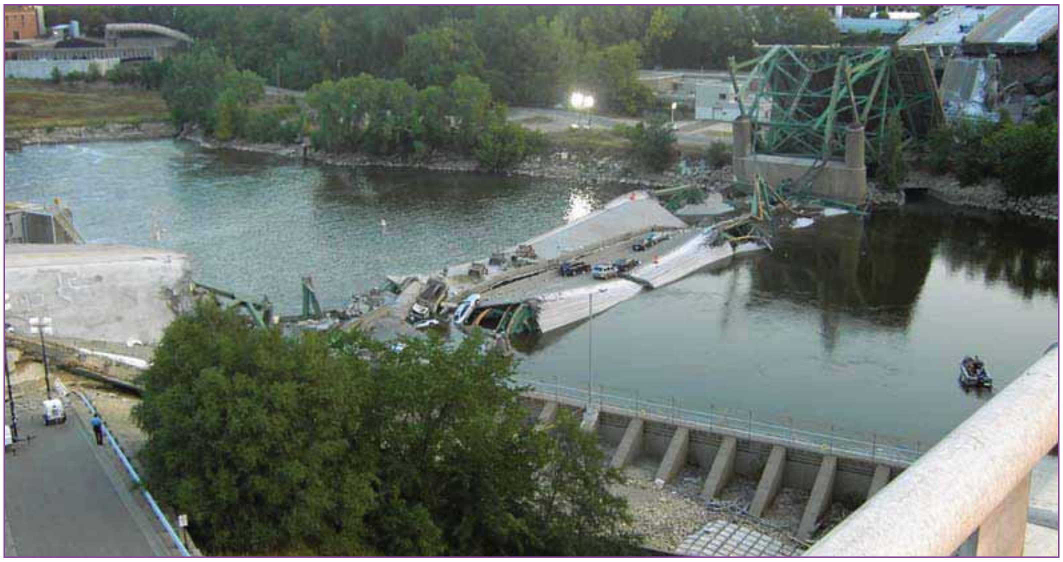
qualitative data: information describing the qualities of objects observed, but not measured.

quantitative data: information based on measurements or counting.

During this Unit, you will be comparing coaster cars to one another. You will also be making design changes, and you will want to know how each of those design changes affects the performance of the vehicle. To make sure your comparisons are fair tests, you will need to design a performance-test procedure that you can use to measure the performance of a car. You will perform the same test again after each change is made. This way, you will know how each change you make to your car's design affects its performance.

The first thing you need to decide in designing a performance test is what factors to measure. Your criteria for this part of the challenge are to make your coaster car go straight and far. Your performance-test procedure must therefore measure both how straight your car travels and the distance it travels. You will have to decide how to measure each of these factors.

You will also need to plan several trials for each measurement. You conduct a trial each time you repeat part of your performance-test procedure. For example, suppose you let the coaster car go at the top of the ramp and measure the distance it travels. If you repeat the same exact steps three different times, you have conducted three trials. The reason for conducting more than one trial is to avoid errors. Perhaps you made a mistake in measuring the distance. If you conduct only one trial, you may never realize the mistake. If you conduct several trials, however, you will see that one measurement is different from the others. This will help you recognize that you probably made a mistake while measuring.



This bridge in Minnesota collapsed during rush hour on August 1, 2007. More than 140 people were injured and 13 were killed. Investigators found that several design flaws may have caused the collapse. Safety experts agreed that better performance testing by the bridge's design engineers and inspectors could have avoided the disaster.

How a test is performed is as important as *what* it measures. If a test procedure is not performed the same way each time, you will not be able to compare the results. For example, suppose when you measure the distance your coaster car travels you sometimes measure from the bottom of the ramp to its stopping point and other times you measure from the top of the ramp to its stopping point. You will not be able to compare the distances because they were not measured in the same way. To draw accurate conclusions from your data, you need to make measurements the same way each time.

Reflect

Answering these questions will help you identify what you need to measure in your performance test.

1. How did you know that one car went farther than another? Describe what you observed to make this comparison.
2. How did you know that one car went straighter than another? Describe what you observed to make this comparison.
3. How can you compare the performance of the cars quantitatively? What factors can you measure to make fair comparisons?

Relative Motion

You have compared the performance of different coaster cars by describing their motion. Motion was defined as a change in the car's distance from the starting point. In other words, you compared the position of the car with the starting point. You assumed the starting point to be fixed, or unchanging. A location or object that you use for comparison to determine if an object is moving is called a **reference point**, or point of reference. Motion, then, is a change in an object's position when compared with a reference point. If an object is in motion when compared with a reference point, the object is said to be moving *relative* to that reference point. The coaster car is moving relative to the ramp when its distance from the ramp is changing.

reference point: an object or location with which the position of a second object is compared over time to determine if the second object is moving.

frame of reference: the view from which you judge the motion of another object.

A reference point can be described relative to a larger frame of reference. The **frame of reference** is the view from which you observe motion. If you are on the sidewalk watching a bus travel down the street, the sidewalk and the street are your frame of reference. If you are riding in the bus, your frame of reference is the bus itself.

How you describe motion depends on your frame of reference. Suppose you are on the sidewalk as a bus pulls away from a stop. The sidewalk is your frame of reference. If you stand at a bus stop and wave goodbye to a friend getting on the bus, your friend's position changes relative to the bus stop. The distance between your friend and the bus stop increases over time. You conclude that your friend is in motion.

Now suppose you are on the bus with your friend. Your frame of reference becomes the bus. As the bus pulls out of the station, you and your friend remain in seats next to each other. The distance between you and your friend does not change. You conclude that your friend is not moving relative to you or relative to the bus.

Objects on Earth are not the only reference points that can be used. Other objects in the universe, such as the Sun and the stars, can be used as reference points as well. Think about how this changes the perception of motion. Are you moving right now as you read these words? You would probably say that you were not moving if you are sitting at your desk. That is because you used the desk or other objects in your classroom as reference points. If you use the Sun, you are actually moving quite fast. That is because Earth moves around the Sun at approximately 30 km/s (18.6 mi/s). When you use the Sun as your reference point, everything on Earth is moving at a high rate of speed.

Remember that motion is relative whenever you describe the performance of your coaster car. Make sure you describe how far it travels relative to a reference point, and use the same reference point in each of your trials. The same is true when you describe how straight your coaster car travels. You must compare its path with some reference point. Also, you need to know what reference point other groups have chosen so you can fairly compare the performance of different coaster cars.

Stop and Think

1. Describe the movement of the coaster cars you observed using the terms *motion, position, reference point,* and *frame of reference.* Use these terms to describe how you knew one car went straighter or farther than another.

2. Using what you just read about motion, describe the observations you used to compare the motion of the different coaster cars.

3. How do you think you can measure the distance that a coaster car travels? How can you measure the direction in which it travels? Use the terms *motion, position,* and *reference point* to describe how you would measure distance and direction.

4. What reference points would work well when measuring the distance and direction of your coaster car?

Design a Procedure for Measuring Coaster-Car Performance

Each group will now design a procedure for measuring a coaster car's performance. Designing a performance-test procedure always begins by deciding what you want to test, how to measure it, and what tools and units of measurement you will use. For example, to measure how far your friend can jump from a standing position, you might use a ruler to measure from the tips of her toes at the starting point to the tips of her toes at her landing point. Designing a performance-test procedure also includes deciding how to keep all the test factors the same each time you conduct the test.

Remember that the goal of the *Coaster-Car Challenge* is to make your coaster car go straight and far. To get the results you need to improve your car's performance, you will need to find ways to measure both of these factors. The decisions you need to make include:

- how to test a coaster car to evaluate its performance
- what reference point you will use
- what factors you will measure
- what tools you will use to make the measurements
- what units of measurement you will use
- what factors you will need to keep the same for each trial

You might want to let your coaster car roll down the ramp as you are trying to determine how to measure its performance. Pay attention to what you can measure about its motion and how you can take measurements. If you cannot accurately measure what you intended, you might be able to try a different measuring tool or unit of measurement. You will need to justify your choice of measurement tools and units to others. Record your procedure so you will remember it and be able to share it with others.

Determine a way to measure how straight your coaster car travels and the distance it has traveled. If your car does not go straight, you need to measure how far it moves away from a straight path. You need to decide exactly how you will measure that distance.

Make sure you describe the performance-test procedure so it can be repeated. For example, describe where the car must be set on the ramp. Is it in the center or off to the side? Describe the height of the car as well. Is it at the very top of the ramp or is it down farther? Check if you described your performance-test procedure well enough so that someone else could follow the same steps and make the same measurements as you did. Revise your procedure if it does not meet all of these requirements.

Communicate

Plan Briefing

You will now share the procedure you have developed. Spend some time preparing for this presentation. Organize the information about your procedure on a small poster so that others can walk around and look at each group's ideas. Your poster should include all of the following:

- what you are measuring
- the materials and tools needed for your performance test
- the setup, including all reference points
- the performance-test procedure
- why you think your performance-test procedure can be used for a fair test

Be prepared to answer the following questions about your performance-test procedure:

- Why do you think your procedure is repeatable?
- How does your procedure keep all test factors the same?
- How can you be sure you will get reliable measurements during testing?

- What factors are the most difficult to keep the same each time you conduct the procedure?
- How can the procedure help you evaluate a coaster car's performance?
- How can the results of using your procedure be used to improve a coaster car's performance?

Walk around the classroom, and look at each poster. As you look at each poster, look for procedures that are similar to yours and those that are different. If other groups have different ideas, think about whether you agree or disagree with their ideas. Take notes about procedures that are different from yours.

When everyone has finished looking at the posters, two groups will present their procedures to the class. Listen carefully to what they have to say. Make sure you can answer the questions above about each procedure that is presented. If you have any questions or do not understand something, ask questions. Remember to be respectful.

To make any kind of race fair, the starting line, or reference point, must be the same for all participants.

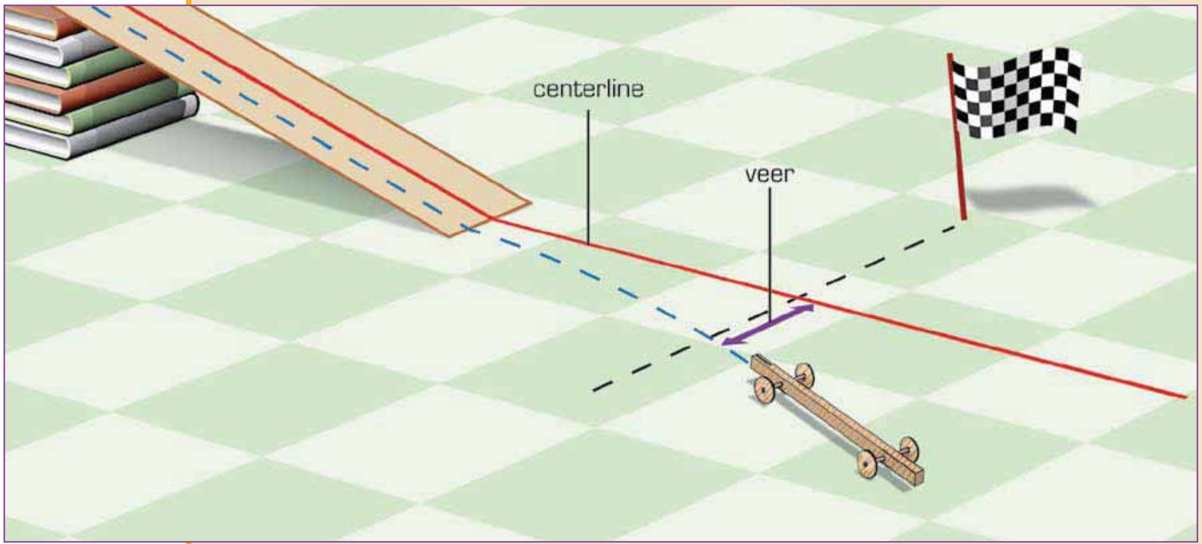
veer: (noun) a change of direction or course.

veer: (verb) to change direction or course.

Measuring Direction and Distance

Think about the factors you want to measure. The first factor you want to measure is how straight your coaster car travels. To make this measurement, you need to choose a reference point. The difference in direction between the reference point and the place where your coaster car stopped moving can be described as the **veer**. Veer can also be used as a verb, referring to the act of changing direction or course.

To measure the veer, you can mark a straight line from the center of the ramp across the floor. Then you can use this line, called the centerline, to measure the difference between your car and this line. The centerline is your reference point.



The second factor you want to measure is how far your car travels. Again, you need to choose a reference point. For example, you might choose the bottom of the ramp. Then you can measure the distance between the bottom of the ramp and your car after your car has stopped moving.

For both measurements, you must choose the correct unit of measurement. Distance can be measured in customary units, such as inches, feet, yards, and miles. It can also be measured in metric units, such as centimeters, meters, and kilometers. Choose the unit of measurement that makes the most sense for your procedure and can be determined using the tools you have available.

Reflect

The class will need to develop one procedure that everybody will use to measure their coaster cars' performance. Answering these questions will help you participate in developing that procedure.

1. What do you think you did well in your procedure?
2. What differences did you see in other procedures that you can use to make improvements to your procedure?
3. What will be important to include in the procedure the class develops?

Revise Procedure for Measuring Coaster-Car Performance

With your class, agree on a performance-test procedure that everyone will use to measure how straight and how far each coaster car moves. Take into account the procedures everyone presented in the *Plan Briefing.*

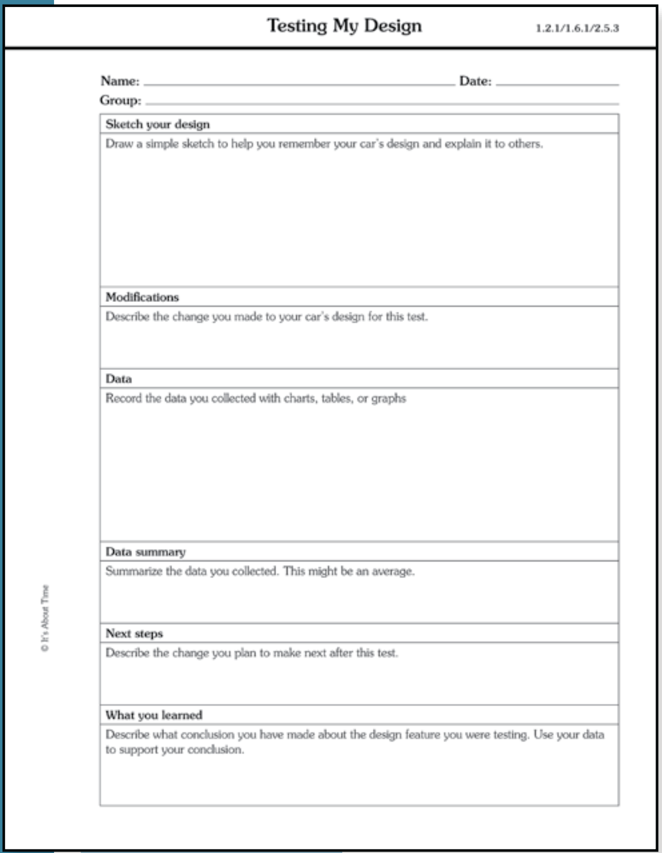
As in any scientific investigation, the procedure must be repeatable by others. The procedure must be written precisely, particularly when it involves measurement. A person following your procedure must know exactly where to place the car to begin the test, what tools and units to use for measuring, and how to measure to the end point.

Good design engineers redesign and retest designs many times to come up with a good product. They conduct the same performance test many times as they work on improving their designs.

If the same testing procedures are not followed exactly each time, you cannot tell if the differences in your results were caused by changes in the testing procedure or in the performance of your coaster car.

Your test should also give clear results to help you evaluate your car's design. It is important to know exactly what you want to find out before writing a procedure. Record the procedure for everyone to use after your class is satisfied that it has a well-designed performance test.

Conduct Your Procedure


Testing My Design 1.2.1/1.6.1/2.5.3

Name: Date:

Group:

Sketch your design

Draw a simple sketch to help you remember your car's design and explain it to others.

Modifications

Describe the change you made to your car's design for this test.

Data

Record the data you collected with charts, tables, or graphs

Data summary

Summarize the data you collected. This might be an average.

Next steps

Describe the change you plan to make next after this test.

What you learned

Describe what conclusion you have made about the design feature you were testing. Use your data to support your conclusion.

You will soon conduct the performance-test procedure your class designed to measure the performance of your coaster car. Your results will allow you to compare the performance of your car to the performance of other cars. The measurements you make will also be useful when you work to improve your car's performance. You will use the measurements you record now as the **baseline** for the performance of your car. Baseline measurements are the standard of comparison against which the effects of design changes are judged. When you change the design of your coaster car, you will conduct the performance-test procedure again to measure the performance of the redesigned car against this standard. Comparing the performance of your redesigned car to the baseline will allow you to identify any changes in performance.

Follow the procedure your class designed to measure the performance of your coaster car. Measure results for at least four trials. Record your results on a *Testing My Design* page. Be prepared to share your results with your class.

baseline: a specific value or values that can serve as a basis for comparison.

iteration: a repetition that attempts to improve on a process or product.

iterate: to perform repetitions to improve on a process or product.

Be a Scientist

Keeping Good Records

Design processes that involve repeating a series of procedures to make something better over time are called **iterations.** Design engineers always **iterate** (perform iterations) toward successful designs. They plan a design, build it, test it, redesign it, retest it, and so on. They might do this dozens of times. When involved in iterative design, keep good records of what you have tried, tested, and learned along the way. Such records enable you to keep track of your progress in completing a design challenge. You will use *Testing My Design* pages to keep track of your tests and results.

Communicate

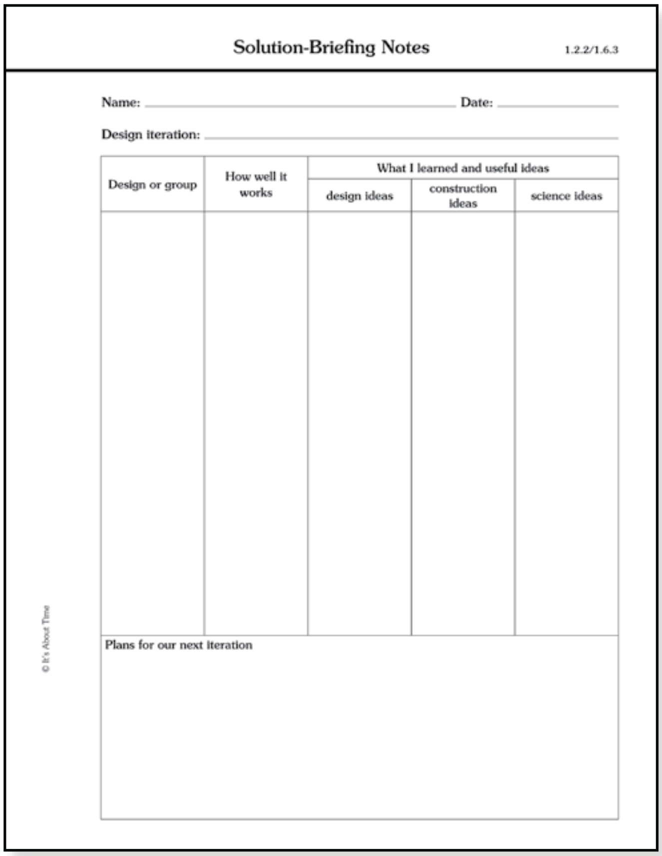
Solution Briefing

As you iterate toward a better design, you will occasionally present your work in progress to the class in a *Solution Briefing.* You will give a short presentation of your car's design. You will also describe the reasoning behind your design and tell about car's performance. A *Solution Briefing* provides a chance for you to report on your successes and to get advice from your classmates about any problems you might be having. Your classmates can also learn from your presentation. This can work successfully only if you present information in a clear and logical way.

For this *Solution Briefing,* make sure you include the following:

- your design and what you expected about its performance (include a sketch)
- data from your test trials, displayed so that others can understand what happened
- a description of the performance of your coaster car compared to your expectations
- your best explanation of why you think your car performed the way it did

You can learn a lot from designs that were not as successful as you, or others, expected. Pay careful attention as other groups present their findings. You may find you want to give others advice about design, construction, and testing. You may also appreciate the advice others can give you. Keep track of ideas you get from others on a *Solution-Briefing Notes* page.



Solution-Briefing Notes 1.2.2/1.6.3

Name: Date:

Design iteration:

Design or group	How well it works	What I learned and useful ideas		
		design ideas	construction ideas	science ideas

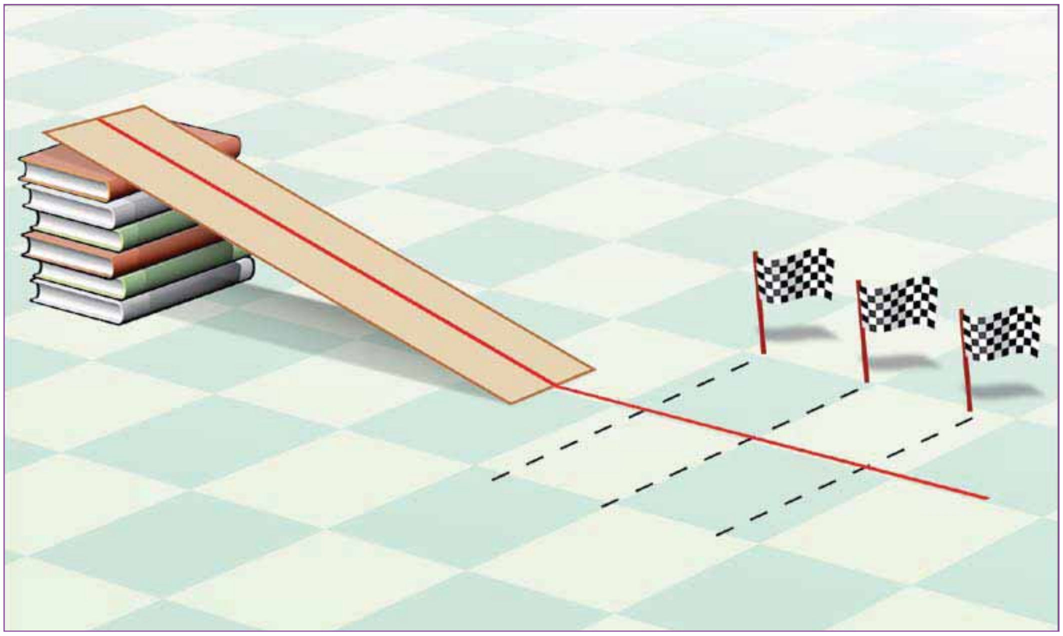
Plans for our next iteration

Reflect

1. Compared to the other coaster cars, how well did your coaster car perform? How straight did it go compared to the car that traveled straightest? How far did it go compared to the car that traveled the farthest? What needs to be improved?

2. Describe how you would like your car to perform.

3. How well do you think you could predict the motion of your car in another trial? Look at the diagram. Suppose you had to predict where your car would cross one of the finish lines? How would you do that?



What's the Point?

The challenge for this *Learning Set* is to design and build a vehicle that travels straight and far. To tell how well you are achieving the challenge, you must have a way to determine how straight and far your vehicle travels. Your performance test was designed to determine the distance your coaster car travels and how far it turns away from a straight path. To make valid comparisons of the performance of different coaster cars, they all must be tested in the same way. To determine the effect of a design change on vehicle performance, you must know how it performed before the design change was made. Understanding how motion can be described and measured relative to a reference point enabled you to develop procedures for measuring your coaster car's performance. Now that you have measured the performance of your coaster car, you have a standard of comparison that you will be able to use later to see how much better your coaster car performs as you iteratively refine its design.

1.3 Explore

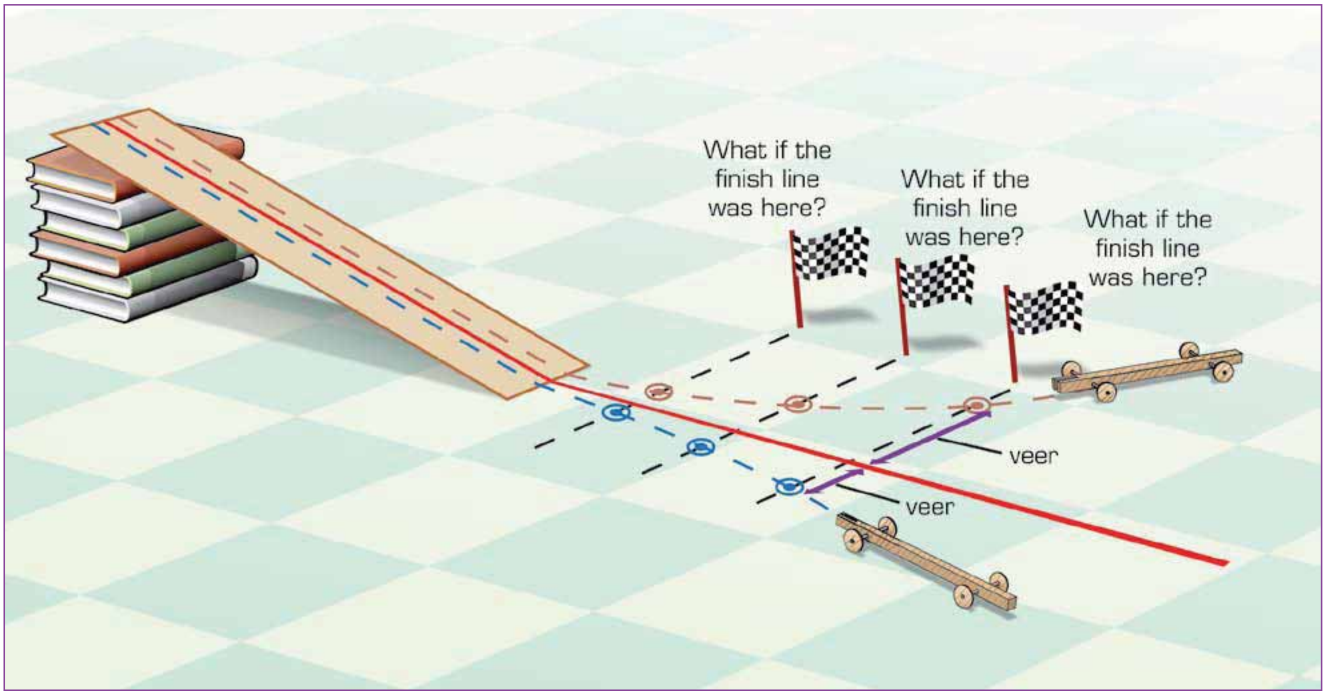
How Straight Is Your Coaster Car Traveling?

As a designer, you are beginning to know your coaster car and how it performs. You have seen how its performance compared to that of other coaster cars. But how straight is your coaster car traveling, and how well can you predict its path? This section offers you a small challenge that will help you achieve the *Big Challenge.* Given a specific finish line, you will need to predict where your coaster car will cross it. Will your coaster car cross on the centerline? Will it turn to the right or to the left? How much will it turn?

For this challenge, you will need to predict where your coaster car will cross a finish line. However, you will not yet be told how far the finish line will be from the bottom of the ramp. Will your coaster car cross on the centerline? Will it turn away from the centerline? If so, how much will it turn? How can you answer these questions if you do not know where the finish line is?

Materials

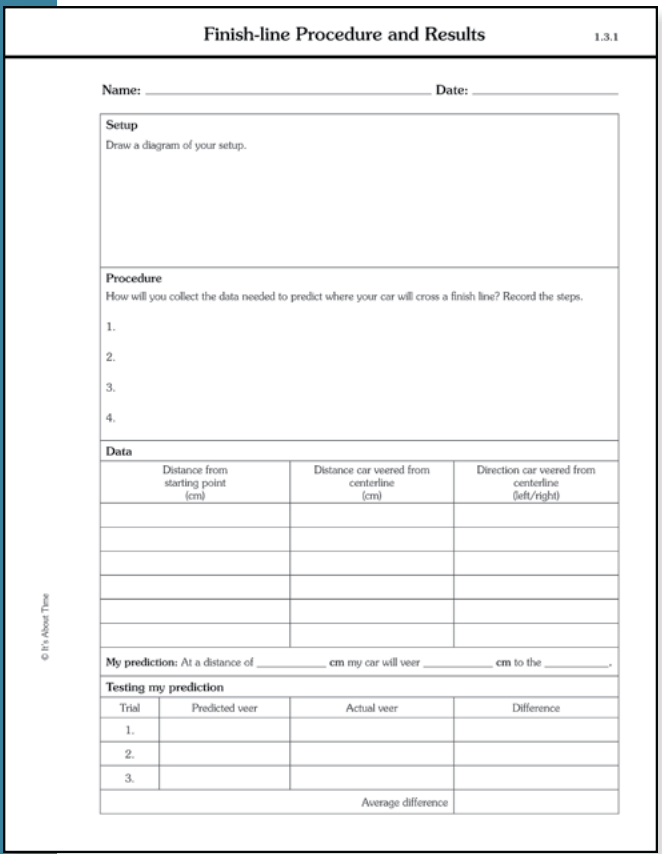
- **ramp**
- **coaster car**
- **tape for finish line**
- **finish-line flags**
- **tape measure**



Reflect

The following questions will start you thinking about predicting how straight your coaster car will travel. Answer these with your group. You will then discuss the answers with the class.

1. What information do you need to predict how far from the centerline your coaster car will cross a finish line? Remember that you do not know where the finish line will be.
2. How can you modify the performance-test procedure you developed to help you make your prediction?
3. How can you organize your data to help you make a prediction?
4. Why would performing repeated trials make you confident about your prediction?



Finish-line Procedure and Results 1.3.1

Name: ______ **Date:** ______

Setup
Draw a diagram of your setup.

Procedure
How will you collect the data needed to predict where your car will cross a finish line? Record the steps.

1.
2.
3.
4.

Data

Distance from starting point (cm)	Distance car veered from centerline (cm)	Direction car veered from centerline (left/right)

My prediction: At a distance of ______ cm my car will veer ______ cm to the ______.

Testing my prediction

Trial	Predicted veer	Actual veer	Difference
1.			
2.			
3.			
		Average difference	

Design Your Procedure

Meet with your group, and develop a way to modify the class performance-test procedure for measuring straightness so that you can use it to answer the question: How far from the centerline will your coaster car cross a finish line? You will have only a short time to modify the procedure. Your procedure may require the materials shown on the list on the previous page. Record your setup and procedure on a *Finish-line Procedure and Results* page. Later, you will present your procedure to the rest of the class.

Conduct the Performance Test

When you think you have a logical procedure, conduct the performance test, and collect and record your data on your *Finish-line Procedure and Results* page. You may want to make a table or a graph to show the relationship between distance from the starting point and distance left or right of the centerline.

Predict

After everyone has finished conducting their test and collecting their data, a strip of tape will be placed on the floor indicating the finish line. Use your data to predict where your car will cross the line. Record your prediction on your *Finish-line Procedure and Results* page. Then, mark a finish-line flag with your team's name, and place it on the strip of tape where you predict your coaster car will cross the finish line.

Test Your Prediction

Take turns letting your cars roll down the ramp. As the class watches, all groups should conduct three trials and mark where their cars cross the finish line each time.

Analyze Your Data

After all groups have run their trials, measure how far each of your trials was from your prediction. Record your results on your *Finish-line Procedure and Results* page. Choose your best trial, compute the average of all the trials, and record both. How did your prediction compare to your coaster car's performance? Why do you think your prediction was so close or so far from your coaster car's performance? Record your answers. Be prepared to report your results to the class. You may also need to report the procedure you used to collect data for your prediction.

Communicate

Solution Briefing

As you listen, notice which groups' predictions were closest to their cars' performance. Which predictions were most accurate? Remember, a value is said to be accurate if it is close to the actual result. Look carefully at the graphs they used, and how they collected their data to make their predictions.

Reflect

1. Which groups made the most accurate predictions? Why? How did their procedures and tables or graphs allow them to make their predictions?
2. Which groups' predictions were not as accurate? Why? What might have been wrong with their procedures or graphs?
3. How accurate were your predictions? How could you have made them more accurate?
4. Earlier, you considered how far your coaster car traveled. Then you considered how straight your car traveled. What factors might be causing your car to slow down or change direction?
5. What do you think you can do, based on these trials, to make your coaster car perform better?

What's the Point?

By observing and measuring a car's performance over a number of trials, you can predict how it will perform under different circumstances. When making observations and measurements, keep accurate records of each iteration. This important step will help you make comparisons and improve your results.

1.4 Read

What Is Keeping Your Coaster Car From Going Straight and Far?

Now you will look closely at your coaster car to determine what may be affecting its performance. This will help you identify how to change your car's design to help you meet the *Big Challenge*. You will be part scientist, part detective, and part car mechanic as you figure out why your coaster car may not be moving as straight and as far as you want it to.

Conference

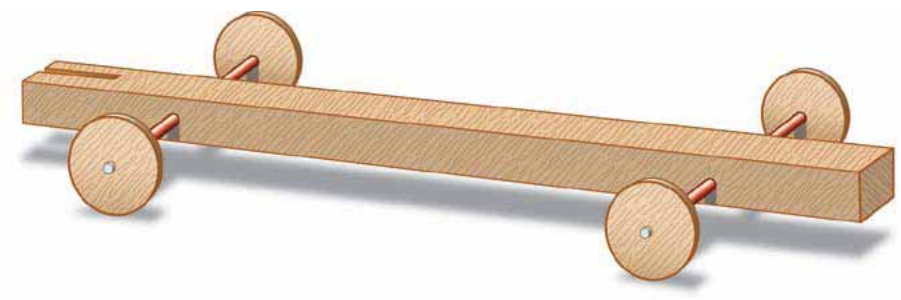
At the end of *Section 1.2,* you measured your coaster car's performance. Your car most likely did not go as straight or as far as you wanted. As a group, examine your car. Look at the way it is constructed. Observe the ways the parts fit and work together. What could be causing the car to change direction? What could be causing it to slow down? Record your answers to share with the class.

Communicate

Share Your Ideas

Share your ideas about what is making your car turn away from the centerline and what is making it slow down.

As you listen, notice which parts of the coaster cars your classmates think are affecting the car's motion. What do you think those parts are doing to cause the coaster cars to turn or slow down?



acceleration: a change over time in the speed, the direction, or the speed *and* direction, of motion.

Forces Change Motion

In your groups, you may have discussed that a pull or a push by some part of the coaster car is causing the car to slow down or change direction. That is exactly what is happening. Remember that a push or a pull is a force. A force can change the motion of an object. To scientists, a change in motion is called **acceleration**. When an object accelerates, it experiences a change in speed, or a change in direction, or a change in speed *and* direction.

The skier is accelerating as she speeds down the hill. Gravity is the force causing her to accelerate.

When an airplane speeds up to take off on a runway, it is accelerating. When a train slows down to pull into a station, it is accelerating. A satellite in orbit around Earth is also accelerating. Even though the satellite's speed may be constant, its direction is constantly changing. Acceleration is described as *positive* when an object's speed is increasing. When speed is decreasing, acceleration is described as *negative*.

Any time you observe a change in the motion of an object, you know that a force must be involved. Without a force, the motion of an object will stay the same whether the object is at rest or in motion.

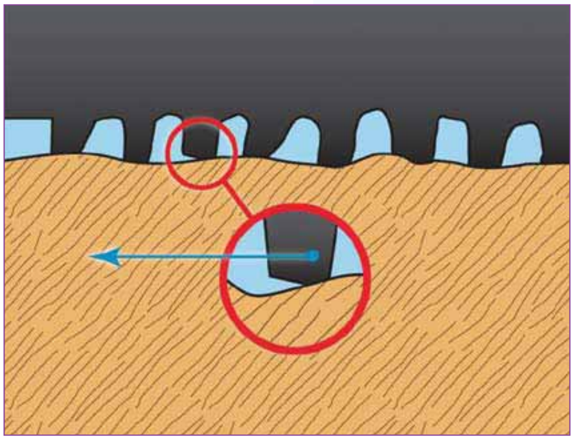
Cars on a track change motion because of forces exerted by the car's engine, brakes, and steering system. If the car changes its speed, its direction, or both its speed and direction, it is accelerating.

The Force of Friction

Now you know that to cause a soccer ball to start moving from a rest position, you need to exert a force on it. You might exert a force by kicking the ball. As a result, the ball accelerates. The ball might then roll across a field. You probably know from experience that the ball eventually comes to a stop. When the ball slows down and stops, its motion changes. If motion changes, you know one thing—a force was exerted on the ball. What force was exerted on the rolling soccer ball if no one touched it? The answer is **friction**, a force that opposes motion.

friction: a force that opposes motion.

Friction is produced whenever two surfaces are in contact. Even if two surfaces appear to be smooth, they are actually quite bumpy if you look at them under a microscope. As the two bumpy surfaces slide across each other, the bumps push against each other. In other words, the bumps exert forces on each other. Although, there are more complicated ways that scientist use to describe friction, this is a good way to describe friction for everyday situations.



Notice how the two surfaces are quite bumpy when viewed under a microscope. The bumps exert forces on each other which causes friction.

Friction causes moving objects, such as the soccer ball, to slow down and come to a stop. It is also the force that can make it difficult for you to push a heavy object across a floor.

Friction can be a nuisance when you are trying to pull a wagon full of rocks. But sometimes friction is so useful that people try to increase it.

Consider what happens when you walk across a floor. Friction between your back foot and the floor keeps that foot from slipping while you move your other foot forward. If you have ever walked on a surface with very little friction, such as ice, you know that it is easier if you are wearing boots with rough soles rather than boots with smoother soles. Boots with rough soles produce more friction when they come in contact with the ice. In this case, friction is actually helping you and pushing you forward. This is the same reason people put sand on icy roads and walkways. The sand increases the friction between the ice and objects traveling on the ice.

Stop and Think

1. What force do you think is making your coaster car move?
2. What force is making your coaster car slow down? Where is this force coming from?
3. What forces are making your coaster car turn off to the side? Where are these forces coming from?

The Amount of Friction

Basketball players depend on the friction between the rubber soles of their shoes and the polished wood floor to run fast and to make quick turns. If the soles of their shoes were not rubber, the players would slide and fall a lot.

The amount of friction between surfaces varies. The friction produced by sliding down a metal pole is less than the friction produced by sliding down a bumpy rope. The amount of friction between the tires of a heavy truck and the road is greater than the friction between the tires of a bicycle and the road.

The amount of friction produced between two surfaces is affected by two main factors. First, the more tightly two surfaces are pressed together, the greater the force of friction between them. That is why an empty box slides across a floor more easily than a box filled with something heavy.

Second, different materials have different levels of friction. Some materials are smoother than others and create less friction than rough materials. The friction between rubber and wood is about four times greater than the friction between leather and wood. This is why you are required to wear rubber-soled shoes instead of leather-soled dress shoes in gym class. The greater friction between the sole of a rubber-soled shoe and the floor keeps you from slipping and falling.

The amount of friction produced by a surface can change if the surface changes. When rough surfaces slide past each other over time, pieces can break off. When that happens, a surface becomes smoother.

The new tire in the picture on the left has deep treads and will not slide on the road as much as the old tire in the picture on the right. The treads on the old tire have worn away and the surface of the tire is almost smooth.

The amount of friction can also be affected by how two surfaces move past each other. Sliding friction occurs when two surfaces slide past each other. You have experienced sliding friction if you have ever tried to slide a piece of furniture across a floor. If the furniture is on wheels, however, it is easier to move. That is because rolling friction is less than sliding friction for similar materials. Rolling friction occurs when an object rolls across a surface.

Stop and Think

1. Describe two situations from your everyday life that involve friction. How could you increase or decrease the amount of friction in each of these situations?
2. Imagine sliding a heavy crate across a carpeted floor. What could you do to reduce the amount of friction and slide the crate more easily?
3. How do you think friction affects the performance of your coaster car?
4. How would you describe the type of surfaces involved in the motion of your car?

What's the Point?

Friction is a force that resists motion between the surfaces of objects or substances that are in contact with each other. Friction exists between all surfaces in contact with each other. Even the smoothest surfaces have some degree of friction between them. The amount of friction created between surfaces depends on the nature of the materials involved and the forces pressing the two surfaces together. The amount of friction tends to be higher between some substances, such as rubber and wood, than between others, such as leather and wood. It also tends to be higher between surfaces with rough, irregular features than between smooth surfaces. These rougher types of surfaces slow down motion more quickly than smoother surfaces because they exert a larger friction force. If the amount of friction is low, as between smoother surfaces, objects tend to move past each other more easily.

Friction can be desirable or undesirable. It can often work to your advantage, as when you walk, play certain sports, or try to grip something. Other times, friction can be undesirable. Sometimes it slows things down that you really want to move faster. This is the case with your coaster car. Your next step is to determine how to find the sources of friction that affect your car, and learn how to reduce friction.

Pushing a car is always a good lesson in the force of friction, especially when the surface is sandy, muddy, or snowy.

1.5 Investigate

Finding Friction: Coaster-Car Inspections

Now you will use what you just read to work on reducing friction that affects your coaster car. First, you will identify sources of friction in your car. Then, you will develop ideas for revising its design or construction to reduce the friction.

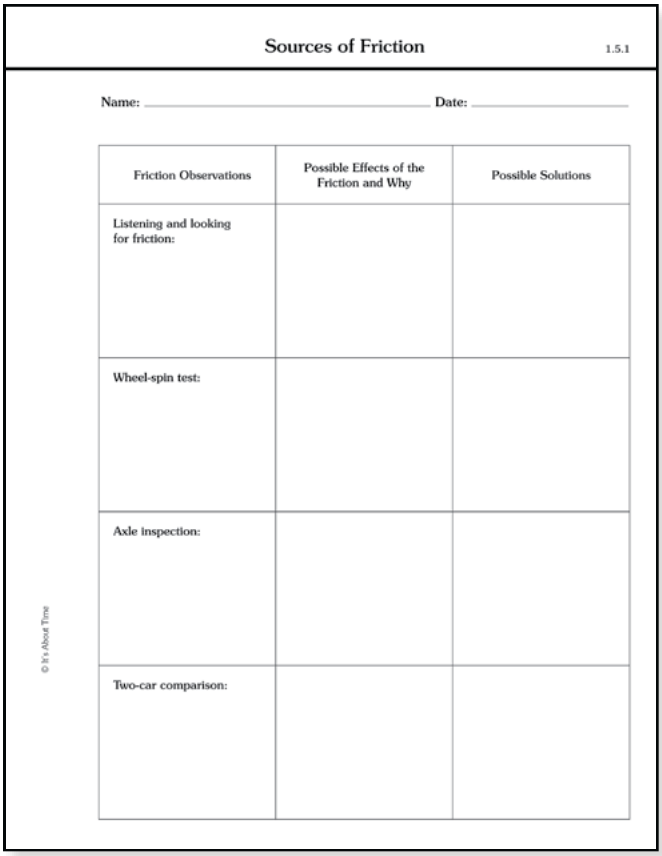
There are at least four ways to examine your coaster car for friction. As you use each technique, record your observations and evidence on a *Sources of Friction* page.

Procedure

1. **Looking and listening for friction:** While your coaster car is in motion, any friction may be hard to notice. Sometimes you can detect friction by listening for sounds produced because of friction. For example, when the surfaces in a door hinge rub together, they begin to vibrate. When a material vibrates, it produces a sound. The sound produced by vibrations in a door hinge might sound like a high-pitched squeak or creak.

   As your coaster car moves, some of its parts might rub together. This might cause parts to vibrate and make sounds. Listen for any sounds such as rubbing or squeaking as your car moves. If parts of your car are rubbing together, they may wear out faster.

   In the *Observations* column of your *Sources of Friction* page, describe any sounds you hear. Also, describe any wear and tear, or other design or construction problems you observe in that column. In the middle column, record what you think are the effects of the


Sources of Friction 1.5.1

Name: ______ Date: ______

Friction Observations	Possible Effects of the Friction and Why	Possible Solutions
Listening and looking for friction:		
Wheel-spin test:		
Axle inspection:		
Two-car comparison:		

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friction you found. A source of friction might slow down the car, it might exert a force that pushes it off to the side, or it may do both. Include in this column the reasons you think the friction is having this effect. If you have any suggestions about fixing the problem, record those in the third column of the chart.

2. **Wheel-spin test:** A wheel-spin test is a quick way to see how well the wheels and bearings perform. Turn your car upside down and hold the chassis with one hand. With the other hand, spin one wheel. Notice if it spins, and if it does, for how long. Observe any sounds made by the spinning wheel. Observe how smoothly the wheels spin. Sound and bumpiness may be due to friction. Try to identify what is causing the sound or bumpiness. Perform the same test on the other wheels. Compare the performance of the front and rear wheels.

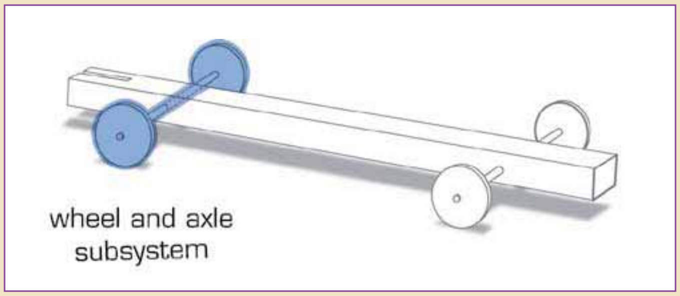
   Record your observations in the first column of your chart. In the middle column, record how you think any friction you identified is affecting your coaster car's performance. Is it slowing the car down, making it turn to the side, or both? Why do you think that? If you have an idea about how to reduce this source of friction, record it in the third column.

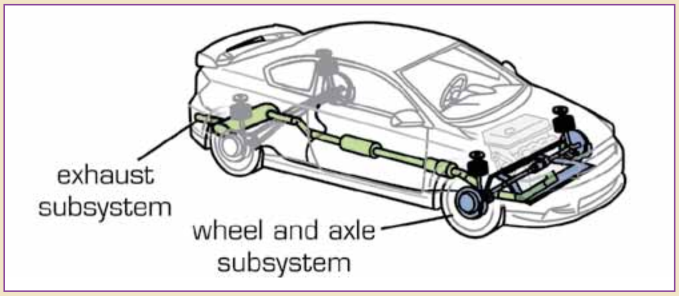
3. **Axle inspection:** With your car turned upside down, inspect the car's bearings to see if they are centered on the chassis. Take measurements to confirm your observations. Use a ruler to check that the distances between the ends of the bearings on each axle and the chassis are equal. You want to make sure that the bearings are lined up correctly, or aligned. If the bearings are not aligned, the back wheels will not move along the same path as the front wheels. This can cause wheels to be dragged across the ground rather than rolling over it, increasing the friction between the wheels and the ground. Check how far the axles extend beyond the bearings. If the distance is too great, the axles can move from side to side and get out of alignment with each other. On your *Sources of Friction* page, record your observations, the effects you think friction in the axles and bearings has on your car, and your ideas about how to fix the axles.

4. **Two-car comparison:** Meet with another group whose coaster car performs differently than yours. Observe the path and distance that each car travels for a number of downhill tests. Examine both cars side by side, looking for what is different about their design or construction that might explain why they perform differently. Record your observations, the effects on your car, and any ideas you have about fixing any friction you identified.

Systems and Systems Within Systems

In the coaster car you built, the wheels, axles, and bearings work together to allow the car to move. The whole coaster car is called a **system**, and the wheels and axles make up a **subsystem.** A subsystem is a system within a system with its own function. The wheel-axle-bearing subsystems in your car have the function of enabling your car to travel. The coaster car has two wheel-axle-bearing subsystems in it. A system or subsystem is a set of parts so related or interconnected that they work as a whole.





The coaster car has only one subsystem, the wheel and axle subsystem, one for each set of wheels. An actual car has many different subsystems, such as steering and exhaust, in addition to the wheels and axles.

system: a set of parts so related or interconnected that they work as a whole.

subsystem: a system within a system that has its own function.

5. **New ideas:** Try to think of other ways you can inspect your cars. Record your ideas, and suggest them to the class when you review your findings.

Communicate

Share Your Ideas

Different groups probably found different sources of friction in their cars. When your group makes its presentation, share each of your observations and the effects you think each source of friction is producing. For example, you might describe a rubbing sound you heard coming from the wheels and show which two parts are rubbing together. You may think that friction is making the wheels turn more slowly than they should, and is slowing down the car. Use your coaster car as part of your presentation, showing exactly where you found each source of friction. If you came up with any ideas about reducing the friction you found, share them as well. Use your *Sources of Friction* page as a guide during your presentation.

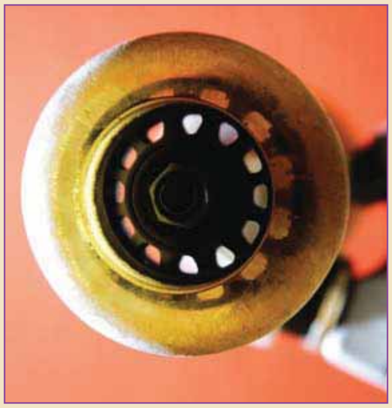
As each group presents its findings, make a class list of the sources of friction, along with the evidence for each and ideas people have about the effects of each. When the class is finished, discuss ideas about how to reduce each source of friction. Make sure you keep clear, organized records of what is discussed so you can use the suggestions when you redesign your car.

Reducing Friction

Many devices have moving parts that rub against each other. The rubbing of one surface against another results in friction that causes the parts to slow down and wear out. There are several different methods for reducing the amount of friction between parts and increasing their performance and lifespan. The friction between two surfaces depends on two factors: the amount of force pressing them together and the nature of the two surfaces—what they are made of and their smoothness. Friction can be reduced by preventing surfaces from coming into contact, decreasing the force pressing the surfaces together, changing the substances that come in contact, or making it easier for surfaces to move past each other.

Designers sometimes use bearings to control motion and reduce friction. Bearings support and guide the motion of moving parts. Bearings that guide moving parts can prevent unwanted contact. For example, the bearings on your coaster car's axles can keep the edges of the wheels from coming into contact with the car chassis. Bearings can also be used to change the substances that come into contact. Putting a plastic bearing between two metal surfaces can greatly decrease friction. For example, the amount of friction between a steel surface and an artificial non-stick coating is more than 100 times less than the friction between two steel surfaces. Some bearings decrease friction by providing smooth surfaces where parts slide or rotate past one another. You might find this type of bearing in a sliding switch or a hinge on a cell phone.

Balls and rollers (cylinders) are also widely used to reduce friction. They replace sliding friction with rolling friction. Recall that rolling friction is less than sliding friction for similar materials. A ball bearing is a common kind of bearing that uses small metal spheres. They are found in products such as roller skates and bicycles. With ball bearings, rolling balls are put between two rotating surfaces so the surfaces will roll instead of sliding against each other.



Most skateboards, in-line skates, and bicycles use ball bearings to improve wheel performance.

lubrication: a substance (such as oil or grease) between two surfaces to reduce friction.

To increase speed, skiers and snowboarders often lubricate the bottom of their skis or boards with wax to reduce the friction between bottom surfaces and the surface of the snow.

Lubrication

Another way to reduce friction is through the introduction of **lubrication**. When a lubricant, such as oil or grease, is introduced between two surfaces, the surfaces rub against the lubricant instead of rubbing against each other. In most cases, the amount of friction between a surface and a lubricant is less than the friction between the two surfaces. Oil is used to lubricate the moving parts in cars so they slide and move easier. Oil is also used on objects such as squeaky door hinges or rusty bicycle chains to help them move freely.

Reflect

Meet with your group again and review your *Sources of Friction* page, making sure your chart is complete. Then use what you just read about reducing friction to come up with ideas about how to reduce the friction in your coaster car. Record your ideas in the *Possible Solutions* column of your chart.

What's the Point?

You have just applied what you know about friction to your coaster car. Using several different methods, you were able to examine your car and identify the sources of friction. This task was made easier by identifying a subsystem, consisting of the wheels, axles, and bearings, and focusing on that. A subsystem is a system within a system. By identifying friction in different parts of the wheel-axle-bearing subsystem and taking steps to reduce it, the performance of the whole system, the vehicle itself, will improve.

Friction can be reduced in several ways. It can be reduced by preventing the materials from coming in contact, reducing the force squeezing the materials together, changing the materials that come in contact, or making it easier for materials to move past each other.

1.6 Design and Build

Revise Your Design

Using your analysis of the sources of friction in your coaster car and your ideas about how to reduce the amount of friction, you will now work to improve your car's performance. Some key parts that you may want to revise include:

- **bearings:** the materials, shape, and size
- **wheels:** the diameter, material, surface, treads
- **axle:** the material
- **wheel-and-axle system:** if the axle should spin freely with wheels attached or if the wheels should spin freely on a fixed axle

Materials

- ***Redesigning My Vehicle* page**
- ***Testing My Design* pages**

Some changes you will want to make to your coaster car will be design changes. Others will be construction changes. A design change is a change in the materials used or the structure of a design. A construction change is an adjustment to the way you build something, such as tightening a screw or attaching a bearing more securely.

You may consider both types of changes as you revise your coaster car. To determine the changes that will allow your car to travel farther or straighter, you will need to carefully examine your *Sources of Friction* page. For each source of friction, you will need to decide if you should make a design change, or if a simple construction change will reduce that source of friction.

Some sources of friction are due to the design of your coaster car. You may want to change the distance between the wheels and bearings. Or, you may reduce some sources of friction by changing the size or type of materials used.

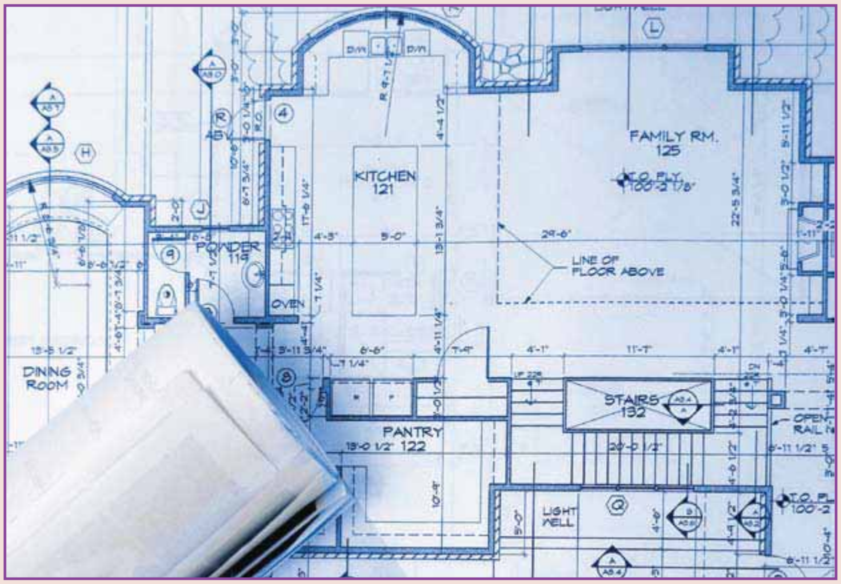
Other sources of friction are due to problems in the construction of your coaster car. For example, your axles might not be aligned.

You may make any design improvements allowed by time and materials available, but you must be able to justify your design changes using what you have read about friction and motion. You will also need to test every change you make so that you will know whether it is improving your coaster car's performance, and if so, how well it is improving performance. Testing your coaster car's performance after some changes might show you that those changes do not improve your car's performance. Some changes might even make its performance worse.

Be a Scientist

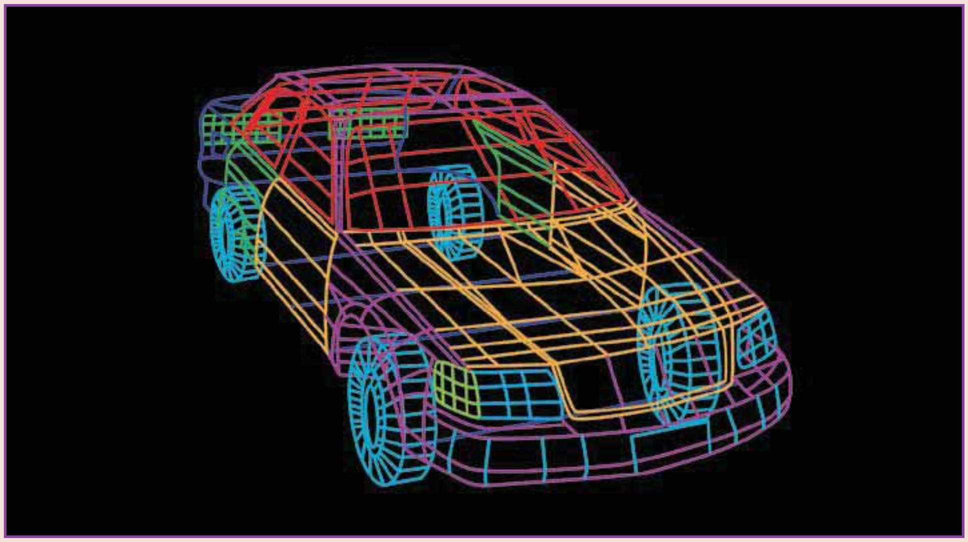
Construction Changes and Design Changes

When a product is developed, it begins with a plan. For example, a house begins with a blueprint developed by an architect—another type of design engineer. This blueprint shows the design of the house, including exact measurements of every detail of the house, and construction notes on how to assemble the house. A construction crew follows the plan, putting the wood beams and other materials together as directed. If something in the plan does not work out, they might go back to the plan to make revisions. People use the expression, "we're going back to the drawing board," because design engineers often use large drawing boards to sketch their designs. To revise or redesign a project is known as "going back to the drawing board."



A flaw in the product may not be in the design, but in the actual construction. The builders may have followed the plans exactly, but a screw that was not tight enough may cause other pieces to loosen. The builder must go back and correct the problem in the actual construction of the house.

A car also begins with a design and set of plans. Design engineers show what the car will look like and how it will be built using a sketch or computer drawing. They determine how the car should perform based on science knowledge. They record the expected performance on their drawings. If something does not work as expected, the engineers go back to the design drawings to find problems in the original design. They do this by looking at how each subsystem was supposed to perform and comparing the performance of the real subsystem to what they expected. This process helps determine what changes are needed to correct the problem. Sometimes, problems are a result of construction—something that happens on the assembly line, where the car is put together. Examining the design sketch can help the designers figure that out, too. If a bolt is loose or a subsystem looks different from the design sketch, a construction change is necessary. Other times, problems are due to the design itself, and engineers have to change the design.



Using computer models, design engineers can tell what the car will look like, predict how well it will perform, and determine its fuel needs.

fair test: a test in which only one factor (variable) is changed and all other conditions are kept the same.

Designers determine how design changes affect product performance by using **fair tests.** In a fair test, you change only one factor at a time and keep all other factors constant. You then measure the change in performance. Changing more than one factor at a time would not be a fair test because you would not be able to tell which of the changes affected the outcome.

Redesigning Your Vehicle

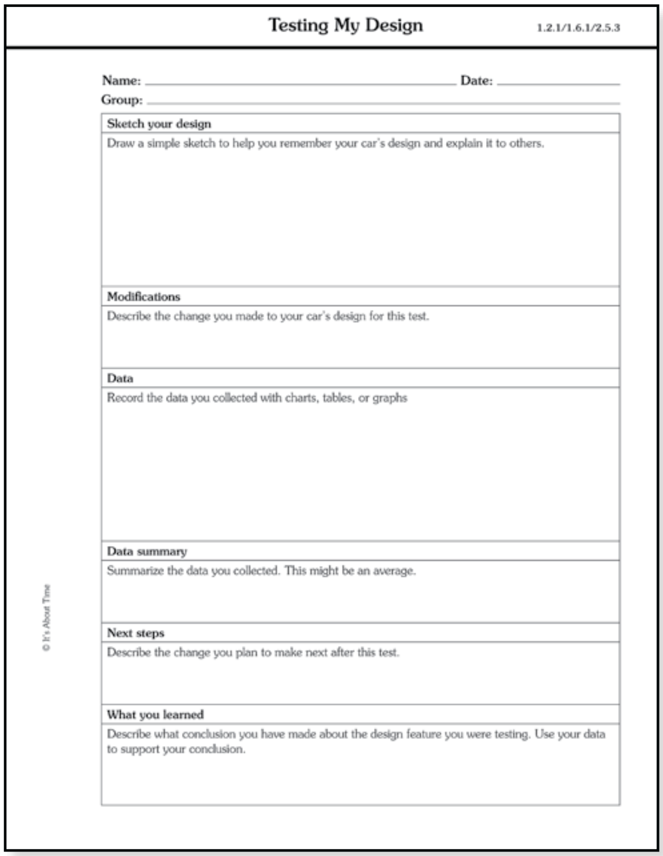
You will need to keep clear, organized records of your design changes as you modify your coaster car's design. Use a *Testing My Design* page to keep track of each of your design iterations. You already know how to use these pages. Remember to sketch your coaster car's design for each iteration.

scale: the ratio of the measurements in a representation or model of an object to the actual object.

Your drawings should include the dimensions, or measurements, and be as close to **scale** as possible. Scale is the ratio of the measurements in a representation or model of an object to the actual object. For example, on a map, 1 cm may represent 1 m. This would be a scale of 1 to 100, since a centimeter is $\frac{1}{100}$ of a meter. If you are specifying how close the axles are to the edge of the chassis, try to draw them to scale. Be sure to include a key to your scale, showing what ratios you used.

Mark these measurements on your drawing. Use the drawing in the instructions for constructing the coaster car as your guide.

You will use a *Redesigning My Vehicle* page to keep track of the order in which you are making changes in your coaster car's design and the effects of each change.



Testing My Design 1.2.1/1.6.1/2.5.3

Name: Date:
Group:

Sketch your design
Draw a simple sketch to help you remember your car's design and explain it to others.

Modifications
Describe the change you made to your car's design for this test.

Data
Record the data you collected with charts, tables, or graphs

Data summary
Summarize the data you collected. This might be an average.

Next steps
Describe the change you plan to make next after this test.

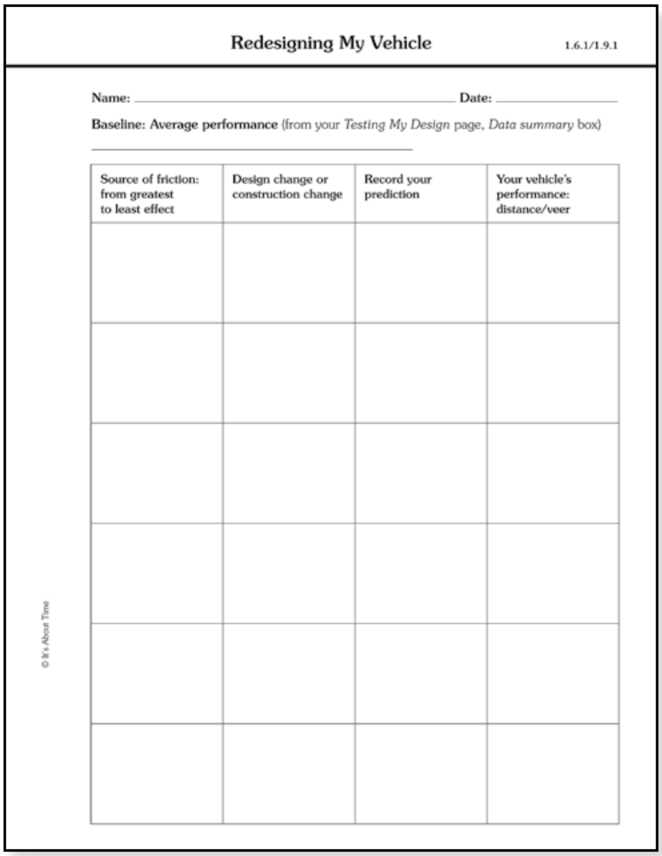
What you learned
Describe what conclusion you have made about the design feature you were testing. Use your data to support your conclusion.

Procedure

1. Review the sources of friction you have identified. Put them in order in the left column of your *Redesigning My Vehicle* page according to the importance of the effects you think they have. List the source of friction that you think is having the greatest effect on your coaster car's performance in the top row. In the next row, list the source of friction you think has the second-greatest effect on your car's performance. Keep adding to the list in the same way.

2. For each source of friction, decide how to reduce it. Record what you will do to reduce it in the second column of your *Redesigning My Vehicle* page. You might identify several different changes you want to make to reduce some sources of friction. List the changes

separately and in a way that leaves space for you to record the effects of each change. For each change, indicate whether it is a design change or a construction change.


Redesigning My Vehicle 1.6.1/1.9.1

Name: ______ Date: ______

Baseline: Average performance (from your *Testing My Design* page, *Data summary* box)

Source of friction: from greatest to least effect	Design change or construction change	Record your prediction	Your vehicle's performance: distance/veer

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You can make changes only to the coaster car itself. You cannot change the environment in which it is running. If you think a change in the test environment would help, see if you can apply a similar change to your car. For example, instead of making the surface of the floor smoother, you may try to make the wheels smoother.

3. Before making any changes to your coaster car, you must determine its baseline performance—how your car performs before any changes are made. You measured its baseline performance earlier, but you have been using it since then, and it may be performing differently now. Measure the performance of your car using the procedure you developed in *Section 1.2.* Record the results of these trials on a *Testing My Design* page. Average the results of your trials, and record the average performance at the top of your *Redesigning My Vehicle* page.

4. You will now make one change at a time to your vehicle and record the effects of each change. If you make all of the changes at one time, you will not be able to determine which changes actually affected the performance of your car. Identify the first change you listed in the second column of your chart. Revise your vehicle and test its performance. For each change, you will compare the resulting performance to the way the car performed before the change. If it performed better, you will move on to the next change and again compare the car's performance before and after the change.

   If your car performed worse, you will undo the change and make other changes to address that source of friction. Continue until you are out of changes you want to make, or until you are out of time. You may not have time to fix every friction problem, but this is why you put the problems in order of greatest effect to least effect.

Follow these steps for each change you investigate:

a. Record the change you are making to your coaster car on a *Testing My Design* page. Be sure to sketch your coaster car to scale and label it accurately.

b. Make the change in your coaster car.

c. Use the performance test you designed in *Section 1.2* to measure your coaster car's performance. Make sure you conduct enough trials so that you have a high level of confidence about confirming the effects of the change you made. Record the results of each trial on your *Testing My Design* page. Remember to record both the distance the coaster car travels and its veer from the centerline. Average both the distance measurement and the measurement of your car's veer from the centerline.

d. Record the average distance your car traveled and its average deviation from the centerline in the right-most column of your *Redesigning My Vehicle* page.

e. Compare your coaster car's performance to its performance before you made the most recent change. If the car's performance has improved, continue on to your next source of friction. If the coaster car performs worse than before the change, you have two choices: (1) undo the change and conduct your performance test on the car to make sure it is back to its previous performance, or (2) figure out how to better implement the design change, and conduct the performance test again.

5. Make a poster to show the class. The poster should include

- each source of friction you reduced, or tried to reduce
- what you did to reduce each source of friction. Identify each change as a design change or a construction change.
- data from each test, displayed clearly so others can understand the effects of each of your changes
- a drawing of your final design. Make it as close to scale as you can. Include measurements and construction notes.

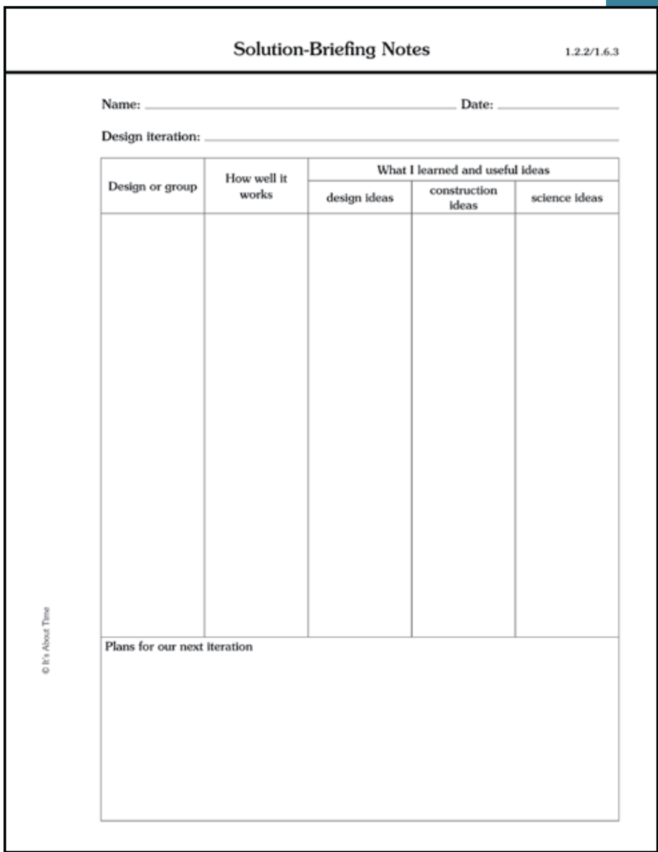
- reasons why the car performed as it did
- a statement about the role you think friction is playing in the motion of your vehicle

Communicate

Share Your Ideas

Each group will present its redesigned coaster car to the class. When it is your turn, use your poster to help you organize your presentation. Tell the class which sources of friction you reduced or tried to reduce, how you reduced each, and how your car's performance changed as a result of each change you made. If your car performed differently than you predicted, tell the class what your car did that you had not expected.

Be sure to use your data when describing tests and results. Then, let your car roll down the ramp to show the class how your vehicle performs. Finish your presentation by reporting to the class why you think your car is now performing better than it did earlier and the role you think friction is playing in the motion of your vehicle.


Solution-Briefing Notes 1.2.2/1.6.3

Name: ______ Date: ______

Design iteration: ______

Design or group	How well it works	What I learned and useful ideas		
		design ideas	construction ideas	science ideas

Plans for our next iteration

As you listen to other groups present, take notes on a *Solution-Briefing Notes* page. You may see or hear something that will help you design your car better the next time.

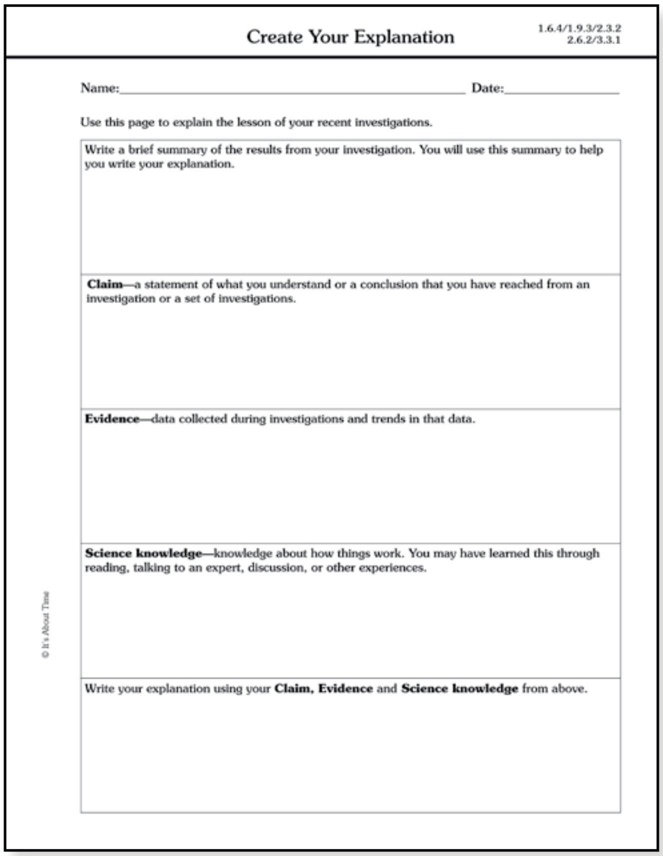
After every group has presented its car, identify which three coaster cars are the best performers. As a class, answer these questions:

- What is unique about the design of each of these cars that allows them to travel so far?
- What is unique about the design of each of these cars that allows them to travel so straight?
- What is unique about the construction of each of these cars that allows them to travel so far?

- What is unique about the construction of each of these cars that allows them to travel so straight?
- What did the designers of these cars do to reduce the friction in the subsystems of their cars?
- What, if anything, did the designers of these cars do to reduce the friction between the wheels of their cars and the ground?

Recommend

You have a lot of experience now with reducing friction in the subsystems of your vehicle. You have also seen how others in the class have reduced friction, and the effects of reducing friction. Working by yourself, identify the two coaster-car design and construction features that you think have the most impact on the performance of a coaster car. For each, identify the evidence and science knowledge that support your idea. Evidence might come from your group's experience designing your coaster car or from the experiences of other groups.



Create Your Explanation

1.6.4/1.9.3/2.3.2
2.6.2/3.3.1

Name:______________________ Date:__________

Use this page to explain the lesson of your recent investigations.

Write a brief summary of the results from your investigation. You will use this summary to help you write your explanation.

Claim—a statement of what you understand or a conclusion that you have reached from an investigation or a set of investigations.

Evidence—data collected during investigations and trends in that data.

Science knowledge—knowledge about how things work. You may have learned this through reading, talking to an expert, discussion, or other experiences.

Write your explanation using your **Claim, Evidence** and **Science knowledge** from above.

© It's About Time

Share your ideas along with the evidence and science knowledge that support them with your group members. As a group, choose three ideas that the group agrees are the best guidelines for making a coaster car go very far or very straight. The best ideas will be the ones that have evidence to back them up.

You will develop recommendations about these three ideas. Your recommendations will tell others about how to make their coaster car travel straight or far.

A recommendation is a statement or claim about how to accomplish some function. The best recommendations are clear statements of how to accomplish the function and are supported by evidence and science knowledge.

Use a *Create Your Explanation* page for each of your recommendations. For each, your recommendation will be your claim.

Your recommendations should have one of these forms:

- To make a coaster car travel very far, …
- To make a coaster car travel in a straight line, …
- To make a coaster car travel very straight and very far, …

After recording your claim, record the evidence you have to support your recommendation. Record in the *Science knowledge* box what you know about forces and motion to support your recommendation.

Finally, write a statement that connects your recommendation with the evidence and science knowledge that supports it. This statement should be written well enough to provide advice to others who are designing a coaster car. It should tell them something about how to construct or design the coaster car and include enough evidence or science knowledge so that they know why it is a good recommendation.

Communicate

Share Your Recommendations

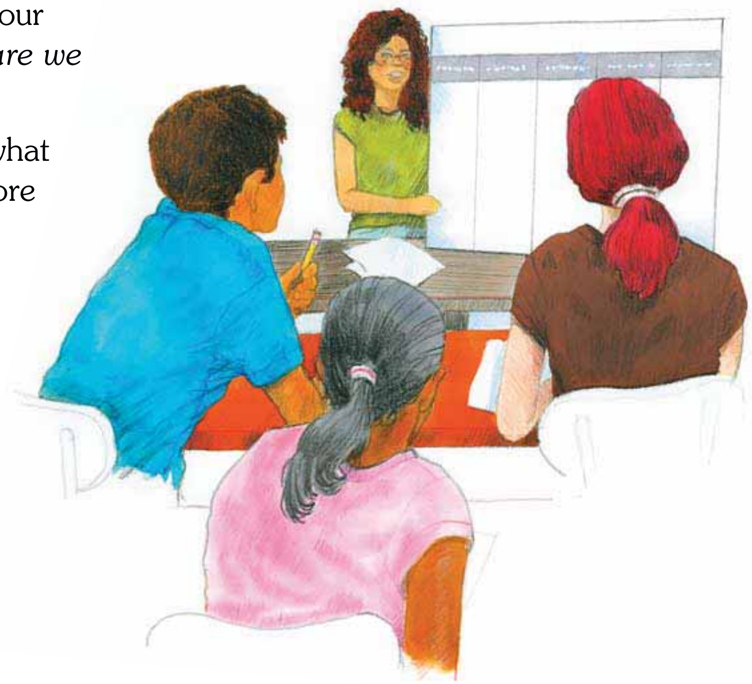
Share your recommendations, along with explanations and supporting evidence for each one, with the class. As each group shares recommendations, develop and record a class list.

Reflect

1. Choose one class recommendation that you think is most complete. Describe what makes this recommendation complete.
2. Choose one class recommendation that you think is most convincing. Describe what makes this recommendation convincing.
3. Choose one recommendation that is not as convincing. What else would have to be added to it to make it more convincing?
4. If you want your car to go still straighter or farther, what else do you need to know?
5. You have focused on making your car travel straight and far. Suppose you want to make your car go faster. What things would you need to know?

Update the *Project Board*

Update the class *Project Board* with what you now know about changing the motion of a coaster car. Add what you know to the *What are we learning?* column of the *Project Board*. Do not forget to add evidence to the *What is our evidence?* column for each of your entries in the *What are we learning?* column.



You have identified what you need to learn more about to make your recommendations more convincing or to make your car go straighter, farther, or faster. Add these as questions to the *What do we need to investigate?* column.

What's the Point?

You are using many of the same processes and skills as a professional design engineer. Using your analysis of friction on your coaster car, you made decisions about design changes and construction changes that could improve the performance of your car. A design change modifies a design plan, and a construction change modifies the assembly of a product. Both types of change can result in a better performing product.

You also had the opportunity to redesign and test the performance of your car. Testing the effects of one change at a time allowed you to determine which changes affected the performance of your vehicle. Using this data as evidence, you were able to make recommendations about how to design and build a coaster car that can travel straight and far.

1.7 Design a Procedure

Speed Trials

The cars your class designed look a lot alike. They have similar parts and subsystems. But some travel straighter than others, and some travel farther than others. Probably, some travel faster than others, or with greater speed. Recall that speed is a measure of how fast something is traveling.

You have measured the distance your coaster cars travel and how straight they travel (their direction), but you have not yet measured their speed. In this section, you will explore ways to determine the speed of the cars. As you have done in the past, groups will develop a procedure and share it with the class. Then, the class will consider all of the contributions and develop a performance test for measuring speed that will be used later by all groups.

Speedometers, such as this one, measure speed, not velocity.

Velocity

Speed describes how fast an object is moving. To describe an object's motion more completely, scientists use the term **velocity**. The velocity of an object describes its speed and its direction. The speed of an object might be 5 m/s (meters per second), but its velocity is 5 m/s east.

Remember what you read about acceleration. An object accelerates when its speed changes, when its direction changes, or when its speed *and* direction change. An easier way to define acceleration, then, is as a change in velocity since velocity includes both speed and direction.

velocity: an object's speed and direction.

Conference

With your group, discuss and answer the following questions. Be prepared to share your answers and ideas with the class.

- What is speed? What are some examples of things that commonly have their speed measured?
- How is the speed of an object usually measured? How is the speed of a car measured? A runner in a race? An airplane? A ship at sea?
- What are the two values that are always part of the units used to describe speed? What mathematical relationship between these two values is expressed as speed? Write out a mathematical sentence describing the relationship between speed and these two values. Write out a mathematical equation that shows the relationship between speed and these two values.

Communicate

Share Your Ideas

Take turns sharing your answers to the questions. As a class, keep a record of the answers. Try to come to agreement about what you need to measure to determine speed, how you will measure these values, and a mathematical expression that describes the relationship between the values you chose.

Average Speed

Speed is a measure of the distance something travels over a period of time. The higher an object's speed, the greater the distance it travels in a given amount of time. The speed limit on many highways is 88 km/h or about 55 mi/h. You will probably want to measure the speed of your coaster car in meters per second. An object moving at a speed of 5 m/s means that the object will travel 5 m in one second of time.

Most objects do not move at a constant speed throughout their motion. Instead, their speed may change many times. Rather than calculating the exact speed at any given time, you can calculate the average speed of the object throughout its motion. To calculate the average speed of a vehicle, you need to know the distance between the starting and ending points. You also need to know the time taken to travel that distance, or the **elapsed time**.

elapsed time: the time it takes to travel between a starting point and an ending point.

The relationship between speed, elapsed time, and distance traveled can be expressed as *speed equals distance divided by time.* This can be expressed as the mathematical equation:

$$\text{average speed} = \frac{\text{distance traveled}}{\text{elapsed time}}$$

As an example, if a car travels 6 m in 12 s, what is the average speed of the car?

Step 1 Substitute the values you know into the equation:

$$\text{average speed} = \frac{\text{6 m (meters)}}{\text{12 s (seconds)}}$$

Step 2 Calculate

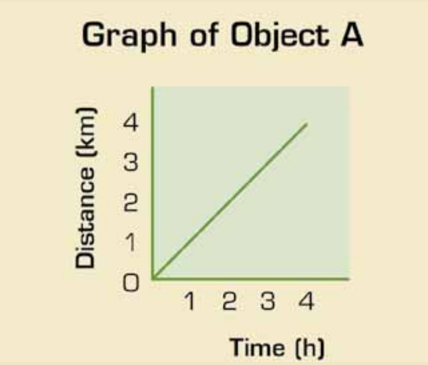
6 divided by 12 = 0.5

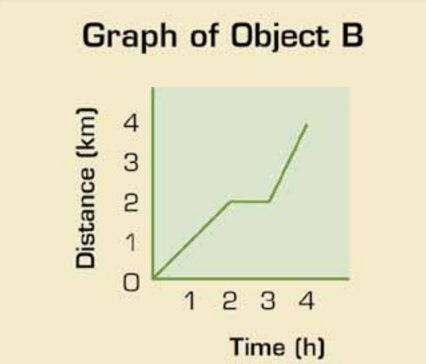
Step 3 You use the units that were in the top (numerator) and bottom (denominator) for speed. These were (6) meters over (12) seconds, so the final answer is:

average speed = 0.5 m/s

Graphing Motion

You can describe the motion of your car in different ways. You can use words to tell if it moved faster in one trial than in another. You could draw a diagram of its motion. Or, you can use a graph to represent any changes in its motion. A distance-time graph relates the distance an object travels to the time during which it travels that distance. Time is plotted on the horizontal axis, or *x*-axis. Distance is plotted on the vertical axis, or *y*-axis. Each point on the graph relates the distance traveled by the car at a specific time.





Look at the two distance-time graphs. Graph of Object A on the left represents an object that travels 4 km in 4 h. The straight line indicates that its speed is constant. Because speed equals the distance traveled by the elapsed time, the speed of Object A is 1 km/h.

Graph of Object B on the right represents an object with a speed that changes throughout its motion. During the first 2 hours, it travels 2 km so its speed is 1 km/h. Between hours 2 and 3, its distance from the reference point does not change. What does this tell you about its motion? If its distance does not change, the object is not moving. The speed is 0 km/h. During the fourth hour, the object is moving again. It travels 2 km in 1 hour so its speed is 2 km/h. The steepness, or slope, of the graph is related to the speed of the object. You can see that the graph is steeper during the last hour than it was during the first 2 hours because the speed of the object was greater during that period of time.

Even though the speed of the objects is not the same at every point throughout their motion, their average speed is the same. They traveled the same overall distance, 4 km, in the same amount of time, 4 s.

Plan

Design a Procedure That Measures Speed

Now that you know more about the relationship between speed, distance traveled, and elapsed time, work with your group to design a performance test to determine the speed of your coaster car. You will be able to use the materials shown in the list on the following page. Keep in mind what you have learned about designing a reliable performance test. It will need to be specific enough so that every time you conduct it, you will make the same measurements. Keep these questions in mind as you design your procedure.

- How will you measure the distance your car traveled? Where should you begin measuring the distance your car traveled? Where should you stop measuring?
- What tools will you need to measure distance? In what units will you measure the distance your car has traveled?

- How will you measure elapsed time? When should you begin and end your time measurements? What tools will you need to measure time? In what units will you measure time?

- Why are the units used to measure the speed of a car (miles per hour) not useful for measuring the speed of your group's coaster car? What units should be used?

Record your procedure for measuring speed, and prepare to present it to the class.

Communicate

Share Your Plan

Now it is time to share the performance-test procedure you have developed for measuring speed. Organize the information about your procedure on a small poster. This way, others can walk around and look at each group's ideas. Your poster should include all of the following:

- what you are measuring
- the materials and tools needed for your test
- the setup, including all reference points
- the procedure
- why you think it can be used in a fair test

Be prepared to answer the following questions about your procedure:

- Why do you think your procedure is repeatable?
- How does your procedure keep all test factors the same?
- How can you be sure you will get reliable measurements during testing?
- What factors are the most difficult to keep the same each time you conduct the procedure?
- How can the procedure help you evaluate a coaster car's performance?

- How can the results of using your procedure be used to increase a coaster car's speed?

Walk around the classroom, and look at each poster. As you look at each poster, look for procedures that are similar to yours and those that are different. If other groups have different ideas, think about whether you agree or disagree with their ideas. Take notes about the procedures that are different from yours.

When everyone has finished looking at the posters, two groups will present their plans to the class. Listen carefully to what they have to say. Make sure you can answer the questions above about each procedure that is presented. If you have any questions or do not understand something, ask questions. Remember to be respectful.

Revise Your Plan

As a class, discuss the strengths and weaknesses of each group's procedure for measuring speed. Work together to develop one procedure to be used by everyone. Try to describe each step in detail so everyone will know how to conduct it, and so that every group will make all of their measurements in the same way. Record your new class procedure.

Reflect

1. Why is it important that all groups make the same measurements in the same way? Why is it important that all of the groups use the same units for each measurement?
2. What parts of the procedure did all of the groups agree upon in order to design a repeatable test to measure speed? Why was each important?
3. How many trials of the performance test do you think each group needs to conduct to get the most accurate results. Why?

Conduct Your Speed Trials

Use the procedure designed by the class to measure the speed of your car. Record your data for each trial that you conduct. Average your results, and be prepared to share them with the class in a *Solution Briefing.*

Communicate

Solution Briefing

When you present, show the class your coaster car, and present the results of your speed trials.

After everyone has presented, examine the cars with the greatest speeds. Discuss the features of these cars that may have helped them travel faster than the others.

As a class, discuss the relationship between friction and speed, and the relationship between speed and velocity.

Reflect

1. Why is it important to perform several trials?
2. Why is it important to use the same tools and units of measurement for each trial?
3. If you had the chance to change your car to make it go faster, what would you do?
4. Describe the relationship between friction and speed.
5. Describe the relationship between speed and velocity.

What's the Point?

Speed is the distance something moves in a given time. Velocity is its speed and direction. The relationship between speed, distance, and time can be expressed mathematically as $speed = \frac{distance}{time}$. When measuring and comparing different speeds, it is important to use a repeatable procedure. This means that the same tools and units must be used for making measurements during each trial. That means that measurements for distance and time must be taken exactly the same way for every trial.

Time and distance in high-speed competitions, like this bicycle race, are measured to the smallest possible units for accuracy.

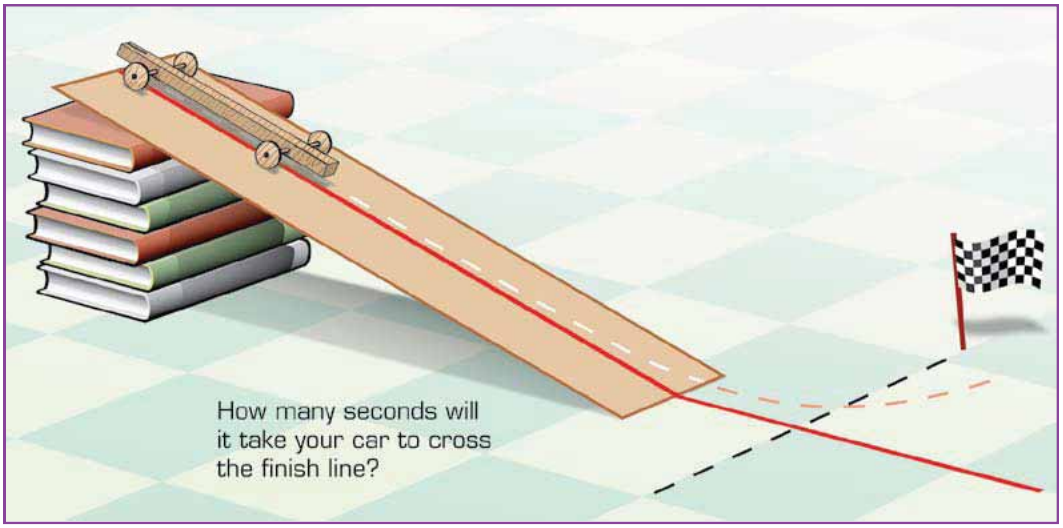
1.8 Explore

The Physics Triple Play

Now that your coaster car performs well and you know about speed, you are ready to participate in a variety of competitions with your car. These are not races. They are prediction competitions. You will use what you have learned so far to predict your coaster car's motion. Your group will choose to participate in one of three activities. The winners will be the groups that make the best predictions.

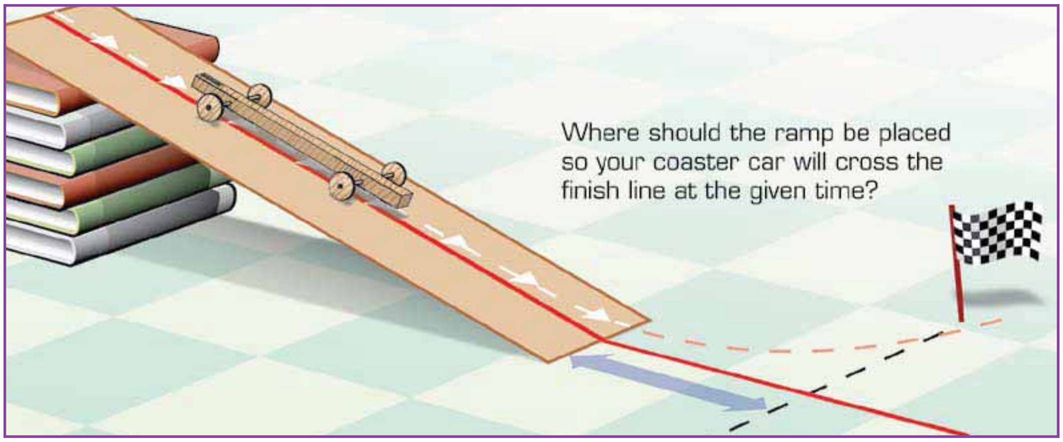
Race to the Finish

In the *Race to the Finish,* your group will work with two or three other groups. You will be given a distance, and you will have to predict elapsed time. The goal of the *Race to the Finish* is to predict how much time it will take each coaster car to finish a race and the order in which the cars will cross the finish line. To make the best prediction, you must observe and collect data about each car's speed. You will learn the distance to the finish line of the race only after you have collected your data.



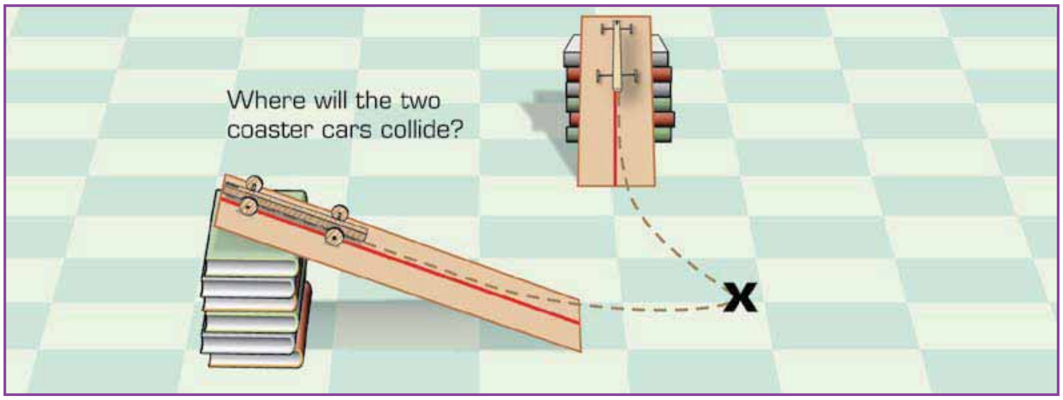
Road Rally

In the *Road Rally,* you will be given a specific elapsed time and you will have to predict distance. The goal of the *Road Rally* is to choose a starting position for your coaster car that will cause it to reach a finish line at a given time after its release. You must predict how far from the finish line your ramp must be positioned for your car to cross the finish line at exactly the right time, for example, in exactly 5.2 seconds.



Demolition Derby

In the *Demolition Derby,* you will be given a collision point. You will have to predict both distance and direction, so that both coaster cars arrive at the same point at the same time. Because the *Demolition Derby* involves two cars, you must work with another group. Your groups must arrange for the two coaster cars to collide at a particular point. If one car travels at a different speed or veers by a different amount than the other, you should consider that as you position the starting point for each car.



Conference

Choose Your Competition

Meet with your group and read the descriptions of each activity together. Decide which activity your group wants to compete in and discuss the reasons for your decision.

Communicate

Share Your Decision

Quickly share with the class the activity your group wants to compete in and why. Groups that choose the same activity will be assigned to work together. Once you know which other groups have chosen the same activity as your group, meet with them to go over the procedures for the activity.

Plan Your *Race to the Finish*

Groups that choose to compete in the *Race to the Finish* are challenged to predict the elapsed time it will take each coaster car to cross a finish line, as well as the order in which the cars will cross the finish line. You will need to determine the average speed of each coaster car over different distances before making your predictions. Think about what you know about the relationship among speed, distance traveled, and elapsed time. If you know speed and the distance traveled, how could you predict elapsed time?

- Plan a procedure for collecting the data you will need in order to predict the exact amount of time it will take for each car to reach the finish line at different distances and the order in which the cars will finish. You may want to conduct trials in which you measure the time it takes each coaster car to travel different distances so that you can calculate average speed. Record the results on a data table of distance vs. time. For each distance from the starting point to the finish line you choose, record the time it takes the car to travel that distance. Remember that you will not know the distance of the race until the actual race. You will not be allowed to conduct any trials after you are told the exact distance to the finish line, so you will need data that will enable you to make a prediction for any given distance. Use what you know about the relationship between speed, distance traveled, and elapsed time to determine the best plan.

- Decide how to organize your data so that you will be able to make a prediction. You might want to use your data to create a line graph showing distance vs. time that will help you make accurate predictions. Or, you might substitute a known speed and a given distance into the speed equation and solve for elapsed time.

Distance	Time	Amount of veer (to left or to right)

- Collect data about your coaster car. Using one of the ramps set up in your classroom, test your coaster car to determine its average speed at different distances. The more trials you conduct, the better you will be able to predict the outcomes. Keep accurate records of each trial you conduct.
- Meet with the other groups that selected the *Race to the Finish,* and exchange cars. Collect data about each of the cars that will participate in the *Race to the Finish.*
- Complete your charts or graphs so that you are ready to predict the first, second, and third place finishers when your teacher tells you the distance to the finish line.

Plan Your *Road Rally*

In the *Road Rally,* every coaster car needs to reach the finish line at the same time. Your challenge for this *Road Rally* is to predict the distance from the finish line that your ramp must be positioned for your car to cross at exactly the right time. To achieve this challenge, you will have to calculate how far from the finish line the ramp must be placed so that your coaster car crosses at the set time.

- Plan a procedure for predicting the distance from the finish line that the starting point (the ramp) should be positioned so that the coaster car will cross the finish line at a specific time. Use what you know about the relationship between speed, distance traveled, and elapsed time to determine the best plan. You will probably want to conduct several trials, measuring the distance your coaster car travels in different amount of times. Record the results on a data table of distance vs. time like the one below. For each time you choose, record the distance the car will travel from the starting point to the finish line.

Distance	Time

- Decide how to organize your data so that you will be able to make a prediction. You might want to use your data to create a line graph showing distance vs. time that will help you make accurate predictions.
- Remember that you will not be able to perform any trials after you are given the exact time at which your coaster cars should cross the finish line.

Plan Your *Demolition Derby*

The *Demolition Derby* challenges you to position your ramp **perpendicular**, or at right angles, to another group's ramp. Then, when the two cars are released at the same time they will collide at a given point. You will not be told exactly where the cars need to collide, and you will have to decide where to put the ramps for any given collision point. Prior to making your predictions, you will need to measure the time it takes each car to travel different distances and how much each one turns away from a straight line. You will need to work with another group to collect data for this competition.

perpendicular: at right angles.

- To collide, the two coaster cars must reach the collision point at the same time. Begin by agreeing upon a time at which both groups' cars will reach the collision point.
- Work together with another group to predict the positions of each ramp that will result in a collision of the two coaster cars at any given point marked on the floor. Each group will need to run multiple trials, measuring the travel time and veer of their car over different distances and share that data with the other group. Record the results on data tables set up for distance vs. time and distance vs. veer.
- Decide how to organize your data so that you will be able to make a prediction. You might want to use your data to create line graphs that will help you make accurate predictions.
- Use what you know about the relationship between speed, distance traveled, and elapsed time as you record and graph data for each car.

Predict

Now that you have collected the data you need for your competition, place your coaster cars in storage so that no more trials can be run. Your teacher will give you the information you need to make your prediction—the distance to the finish line for the *Race to the Finish,* the specific time at which a coaster car must reach the rallying point for the *Road Rally,* and the collision point for the *Demolition Derby.* Work with your coaster car competition group, and use this information to make your prediction.

- Each *Race to the Finish* group should predict the time it will take each car to reach the finish line and indicate the cars that will come in first, second, and third place in a race.
- Each *Road Rally* group should predict where it needs to place the ramp so that its car reaches the rallying point at the right time.
- Each *Demolition Derby* group should predict where it needs to place the two ramps so that its cars will collide at the given collision point.

Record your predictions on a sheet of paper.

Communicate

Share Your Predictions

When it is your group's turn to share your prediction with the class, support your prediction with evidence from the data collected. Give reasons why you collected the data you did and how you used it to develop your prediction.

Make sure to report how the relationship between speed, elapsed time, and distance traveled helped you make your prediction. Using the equation for speed, point out which values were known and which were unknown in your activity. Show how you used the equation to make your predictions.

After you have shared your predictions with the class, place the paper on which you recorded them in an envelope. Write your names on the envelope, and seal it.

Procedure

Hold the *Race to the Finish*

1. Decide how many trials you will conduct for each car and how you will calculate its performance. You may use the best finish time for each car or the average of its finish times. It is important to decide this before running the race.
2. Let each car roll down the ramp, and record the finish time for each. The finish time is the length of time it took for the car to reach the finish line. You may conduct a maximum of three trials for each car, depending on what you decided and the time available.
3. Determine the order in which the cars would cross the finish line—the first, second, and third place finishers.
4. Each group's sealed envelope will be opened to reveal its predictions. Compare the predictions of each group to the actual race results, and choose your winner. The winner is the group that best predicted the exact finish times of the first, second, and third place finishers.

Procedure

Hold the *Road Rally*

1. Decide how many trials you will conduct for each car and how you will calculate its performance. You may use the finish time closest to the predicted time as its performance, or you may average its finish times. It is important to decide this before running the race.
2. When it is time to test your car, position the ramp at the calculated distance from the finish line. Let your coaster car roll down the ramp, and record the finish time for each trial. The finish time is the length of time it took for each car to reach the finish line. You may conduct a maximum of three trials for each car, depending on what you decided and the time available.
3. Calculate the average finish time of each car.
4. Compare the predictions of each group's finish-time results, and choose your winner. The winner is the group that best predicted the ramp position that would allow its car to finish at the right time.

Procedure

Hold the *Demolition Derby*

1. Decide how many trials you will conduct for each prediction and how you will determine the accuracy of the predictions. You may choose the collision closest to the mark on the floor or average the distances from the mark for several trials.
2. Position the two ramps as predicted by one of the groups. Position both cars at the top of each ramp, and release them both at exactly the same time. Mark where they collide, and measure the distance from the mark on the floor. You may conduct a maximum of three trials for each prediction, depending on what you decided and the time available.
3. Repeat for each group's predictions.
4. Compare the accuracy of each group's predictions. The winner is the group that set up the two ramps so that the collision occurred closest to the given collision point.

Reflect

1. Describe how well your prediction matched the outcomes of your event.
2. How could you have improved your prediction? Are there other factors you should have taken into account?
3. What else do you need to learn about motion or forces to be able to better predict a car's performance?

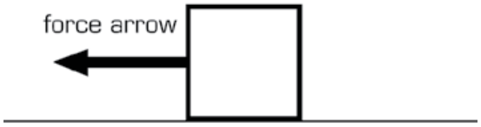
Update the *Project Board*

You have used the relationship of distance traveled, speed, and elapsed time to make predictions about your car's motion. Perhaps you have gained some new understanding of the relationship among distance traveled, speed, and elapsed time. If so, add what you now know to the *What are we learning?* column of the *Project Board.* For each idea you add to the *What are we learning?* column, remember to add evidence to the *What is our evidence?* column of the *Project Board.*

1.9 Read

Combining Forces

So far in this *Learning Set,* you have been talking about forces as pulls or pushes that act on objects. You have discussed the idea that these pulls and pushes can cause objects to speed up, slow down, stop moving, or change direction. Often, there is more than one force acting on an object at one time. In this section, you are going to look at the effect of a combination of forces acting on an object, all at the same time. To understand these concepts, you will learn how to represent forces by drawing arrows.



A force always acts in some direction. Force-arrow diagrams help you see and describe the forces acting on an object. You can show the direction of the force by drawing a picture of the object with a labeled arrow pointing in the direction the force is pushing or pulling.

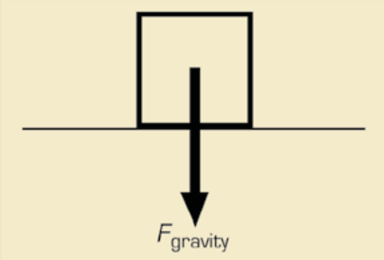
As the boy pushes the shopping cart, a combination of forces, or pushes and pulls, works together.

Forces can be of different sizes or **magnitudes**. You can also show the size of the force by drawing an arrow. The length of the arrow indicates the magnitude of the force. Use a long arrow for a large force and use a short arrow for a smaller force. A force arrow is drawn outward in the direction the force is acting.

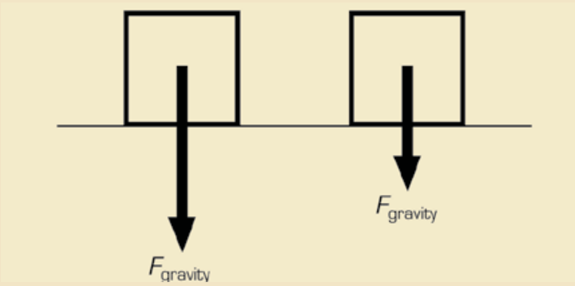
magnitude: greatness or extent of size.

Drawing Force Diagrams

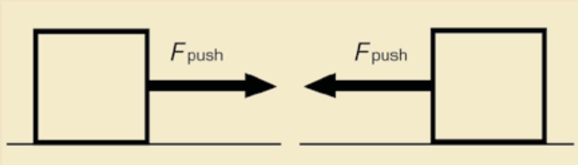
In a force diagram, the object can be represented by a box or a small image of the object itself, such as a bicycle or a coaster car. In the diagrams below, the box represents the shopping cart shown in the picture on the previous page.



In the diagram above, the shopping cart is represented by a box. The line under the box represents the floor. The force in the diagram is downward as a result of the action of the force of gravity. Notice that the arrow in the diagrams is labeled $F_{gravity}$. The F in force diagrams always stands for force. The small word or symbol to the right of the F, called a subscript, describes the type of force. The diagrams below show the magnitude, or size, of the force due to gravity when the shopping cart is full of groceries, and when it is empty.

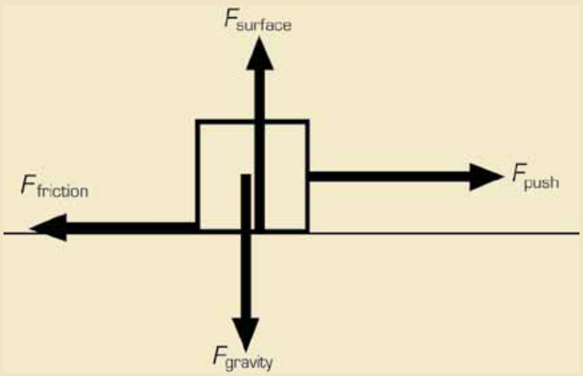


The diagram above on the left represents the force due to gravity on the cart when the cart has groceries in it. In the diagram above on the right, the cart is empty and the force due to gravity is smaller. Remember when an object has less mass, the force due to gravity on the object is smaller.



The direction of the arrow indicates the direction in which the force is acting. In the diagram above on the left, the person is pushing the cart to the right. The arrow is pointing to the right because that is the direction of the force. If the person turned the cart around and began pushing it in the opposite direction, as in the diagram above on the right, the force arrow would point to the left.

Think about four of the forces acting on the shopping cart. The cart, pushed by the person, is moving to the right on a flat surface. The person is exerting a forward force, to the right. Friction is opposing that force, exerting a force to the left. Gravity is pulling the cart down toward the center of Earth. While gravity pulls an object, the surface on which it is located pushes back. This is why the cart does not fall through the surface.



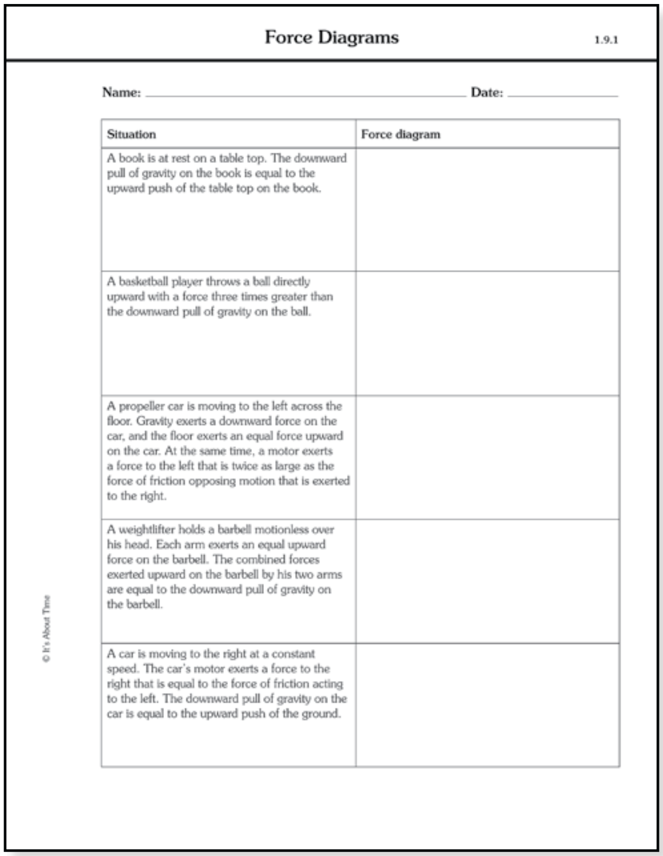
Objects do not always have four forces acting upon them. The number of forces depicted by a force diagram can be one, two, three, or more. There is no set rule about the number of force arrows that must be drawn in a force diagram. The only rule for drawing force diagrams is to show the magnitude and direction of all the forces that are acting on that object. Knowing the types of forces acting on an object can help you predict its motion.

You can follow these simple rules for drawing force diagrams:

- Each arrow points in the direction in which the force is acting on the object.
- The length of each arrow indicates the magnitude of the force (the longer the arrow, the greater the force).
- Each arrow should be labeled in a way that identifies that force as different from the others in the diagram.

Stop and Think

Apply what you learned to construct force diagrams for the various situations described in your *Force Diagrams* page.


Force Diagrams 1.9.1

Name: ______________________ Date: __________

Situation	Force diagram
A book is at rest on a table top. The downward pull of gravity on the book is equal to the upward push of the table top on the book.	
A basketball player throws a ball directly upward with a force three times greater than the downward pull of gravity on the ball.	
A propeller car is moving to the left across the floor. Gravity exerts a downward force on the car, and the floor exerts an equal force upward on the car. At the same time, a motor exerts a force to the left that is twice as large as the force of friction opposing motion that is exerted to the right.	
A weightlifter holds a barbell motionless over his head. Each arm exerts an equal upward force on the barbell. The combined forces exerted upward on the barbell by his two arms are equal to the downward pull of gravity on the barbell.	
A car is moving to the right at a constant speed. The car's motor exerts a force to the right that is equal to the force of friction acting to the left. The downward pull of gravity on the car is equal to the upward push of the ground.	

Combining Forces and Net Forces

In most situations, combinations of forces are exerted on an object at the same time. This combination of all forces results in an overall force, called the **net force**. Understanding how forces combine to produce the net force will help you understand how forces affect motion.

Forces that act in the same direction combine by adding together. The net force is greater than either of the individual forces, and acts in the same direction as both forces. You can see that the arrow for the net force is longer than the arrows for the individual forces.

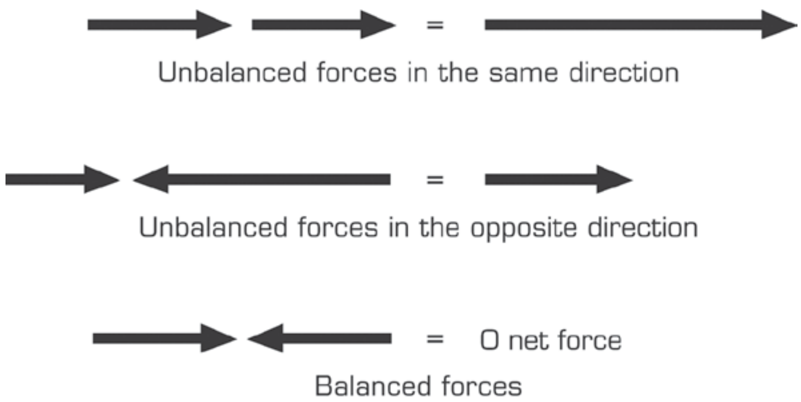
Forces that act in opposite directions combine by subtraction. The force with the lesser magnitude subtracts from the force with greater magnitude. The net force acts in the direction of the greater force.

If the forces acting in opposite directions are equal in magnitude, they are said to be **balanced**. When balanced forces combine, they result in a net force of zero. Forces that are **unbalanced** result in a net force.

net force: the overall force acting on an object, when all the individual forces acting on the object are added together.

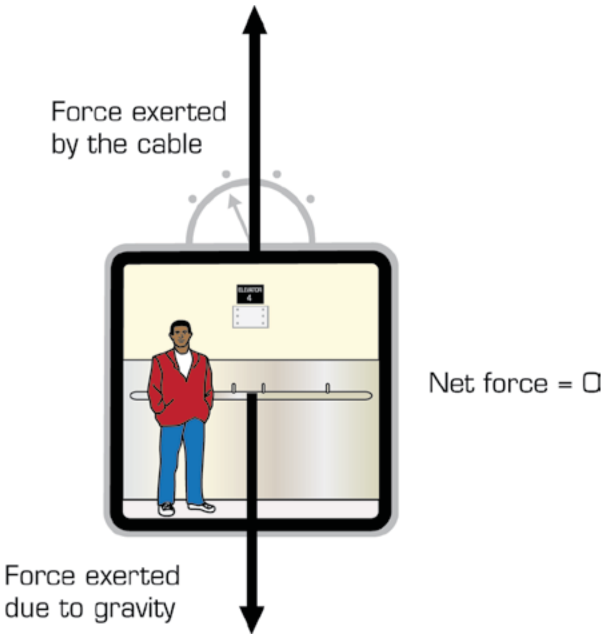
balanced forces: forces opposite in direction and equal in magnitude; balanced forces have a net force of zero.

unbalanced forces: forces that do not produce a net force of zero.



Net Force and Motion

All of the moving objects you encounter in a day are being acted upon by forces. Whether or not there is a net force acting on an object determines if the motion of the object will change. Consider the motion of an elevator car. One force on an elevator car is the downward force due to gravity. This force, known as weight, depends on the mass of the elevator car and any people or objects in the elevator. Another force acting on the elevator car is an upward force exerted by a strong cable attached to its top. The two forces act in opposite directions.

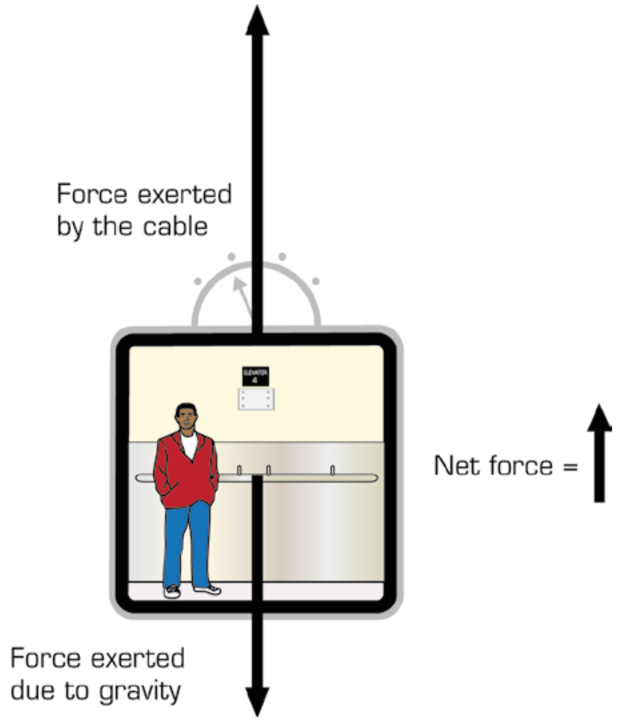


Balanced forces

When the elevator car is stopped at a floor in a building, its motion is not changing. If its motion is not changing, you know that the net force on the elevator car must be zero. The upward force exerted by the cable is exactly equal in magnitude to the downward force due to gravity. In other words, the forces are balanced.

Even if the net force on an object is zero, the object is not necessarily at rest. Suppose the elevator is moving downward. This happens when the upward force exerted by the cable is decreased so the elevator car can move downward. At some point, the upward force on the moving elevator car may exactly balance the downward force due to gravity. When this happens the net force is again zero. The elevator car continues to move in the same direction, downward, and at the same speed.

A net force of zero means that the forces on the elevator car are balanced so the motion does not change. It does not mean that the elevator car must be at rest. This is important to understand when thinking about the design of your coaster car.



Unbalanced Forces

Suppose the elevator car needs to go up several floors. The force exerted by the cable will increase. When the upward force becomes greater than the downward force due to gravity, the forces become unbalanced. The net force will be in the upward direction. If the elevator car was at rest, the net force would cause the elevator to move upward, at an increasing speed. The speed of the elevator car will increase in the upward direction. If the elevator car was already moving in the upward direction, its upward speed would increase.

If two unbalanced forces are in *opposite* directions, the net force is equal to the difference between the two forces, and is in the direction of the larger force. If two unbalanced forces are in the *same* direction, the net force is equal to the sum of the two forces and is in the direction of the two forces.

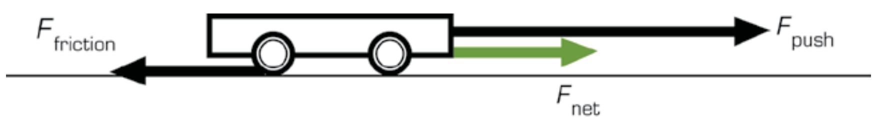
The opposite is true when the elevator car needs to go down several floors. The upward force exerted by the cable is decreased. When the downward force of gravity becomes greater than the upward force exerted by the cable, the net force will be in the downward direction. If the elevator car was at rest, the net force would cause the elevator car to move downward, at an ever increasing speed. If the elevator car were already moving in the downward direction, its downward speed would increase.

Understanding how unbalanced forces combine can help you to predict the motion of your coaster car. Suppose you put the coaster car on a flat surface and give it a push. Your push is a force on the car. It is represented by the arrow pointing toward the right in the following diagram. The force pointing in the opposite direction is due to friction.

You can determine the net force on the coaster car by subtracting the lesser force from the greater force.

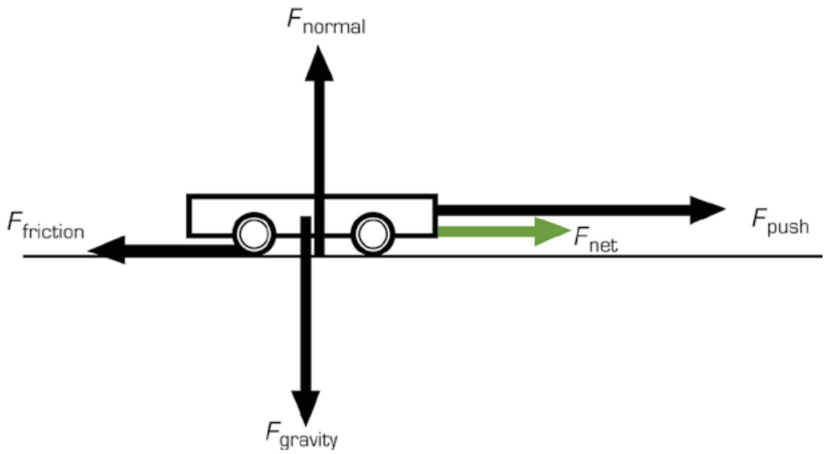
$F_{net} = F_{push} - F_{friction}$

In the diagram below, the force of friction is the lesser force. As a result, the net force points in the direction of the push. This means that the car will move toward the right.



Forces in Different Directions

You have read that forces occur in more than two directions. The diagram below shows forces acting on your coaster car in four different directions.

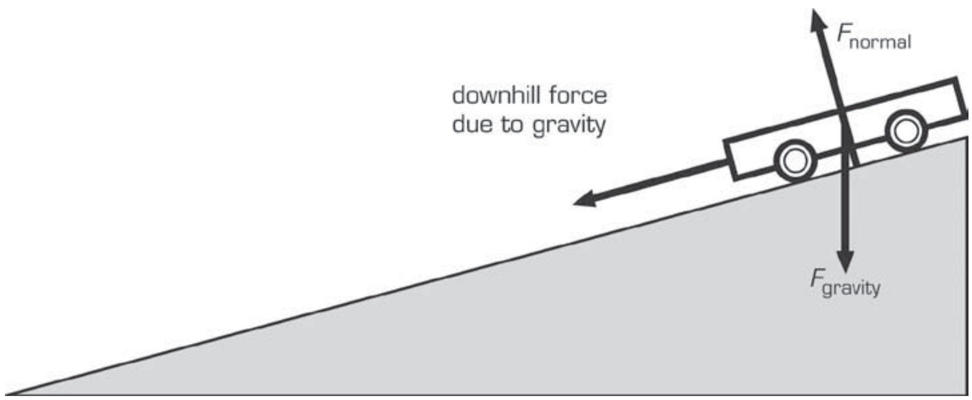


normal force: the force that comes from the surface on which an object is located.

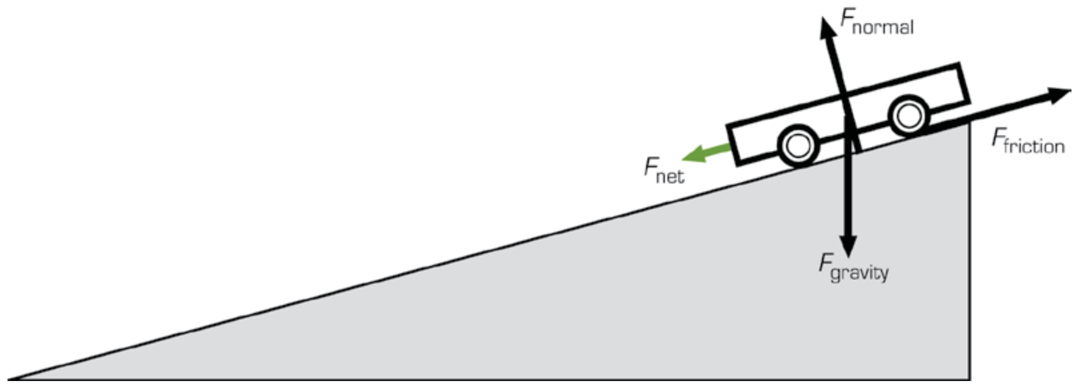
The forces include the push you give it *plus* friction. There is also a downward force exerted on the car due to gravity and an upward force, called the **normal force**. The word normal does not have the meaning in science as it does in everyday conversation. The normal force comes from the surface on which an object is located. If your coaster car is on the floor, the normal force comes from the floor. The normal force is always exerted at a right angle to the surface. When your car is resting on a flat surface, the normal force is equal in magnitude and opposite in direction to the downward force due to gravity. If the forces are equal and opposite, you know they are balanced. As a result, there is no net force in either the upward or downward direction. This is why the car does not rise off the surface or fall through it.

Forces at Angles

When your coaster car is on a ramp, the force diagram changes. The force due to gravity is still in the downward direction. The normal force, however, is no longer in the upward direction. Remember that it is exerted at a right angle to the surface. If the surface is tilted, so is the normal force. The force of friction is also tilted with the surface in the upward direction.



The combination of forces that act at an angle to each other is more complex than simply adding or subtracting. You do not need to know how to calculate the resulting net force. What you do need to know is that the upward and downward forces are no longer balanced so there is a net force. The net force acting on the car is in a direction between that of the two forces. The net force on the coaster car causes it to move down the ramp when you let go of it.



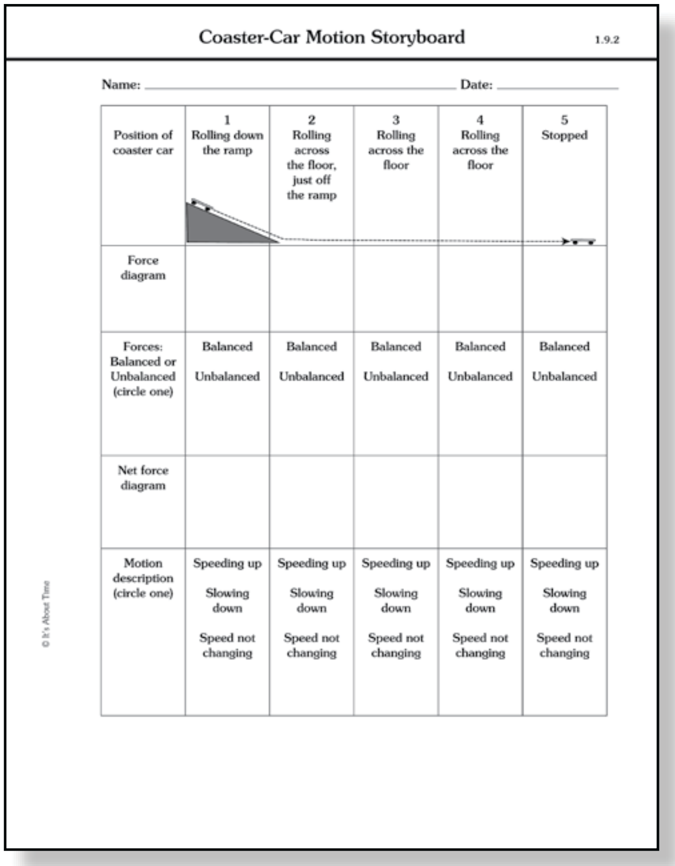
Stop and Think

Draw a force diagram and net force diagram for a skateboarder accelerating to the right along a flat surface. Then draw diagrams for a skateboarder moving at a constant speed to the right along a flat surface. Remember to include the force of gravity and the force pushing up from the ground.

Draw a *Motion Storyboard*

You have seen several examples now of diagrams showing combinations of forces. You have used force diagrams to find the net force. Now you can identify the forces acting on your coaster car. The *Coaster-Car Motion Storyboard* page shows a side view of the ramp and floor upon which your coaster car has been rolling. Below that, it is divided into four rows and four columns. Each column shows a *snapshot* of your car frozen in time during a segment of the car's motion. Assume that the car is at rest at the top of the ramp in column 1, traveling down the ramp in column 2, traveling across the floor in column 3, and at a complete stop in column 4. You will work with your group to fill in the forces and net forces acting on a coaster car during each segment of the *Coaster-Car Motion Storyboard* page. The following instructions will help you.

1. Look at the first row of the *Coaster-Car Motion Storyboard* page. It is labeled *Force diagram.* Along this row, for each segment, draw the force arrows that match the forces acting on a coaster car. If forces repeat from box to box, be sure to draw them the same length and in the same direction as you move from one box to another box. Draw the force pulling the car down the ramp and the friction when the car is on the ramp as force arrows parallel to the ramp.



Coaster-Car Motion Storyboard 1.9.2

Name: ______ Date: ______

Position of coaster car	1 Rolling down the ramp	2 Rolling across the floor, just off the ramp	3 Rolling across the floor	4 Rolling across the floor	5 Stopped
Force diagram					
Forces: Balanced or Unbalanced (circle one)	Balanced Unbalanced	Balanced Unbalanced	Balanced Unbalanced	Balanced Unbalanced	Balanced Unbalanced
Net force diagram					
Motion description (circle one)	Speeding up Slowing down Speed not changing	Speeding up Slowing down Speed not changing	Speeding up Slowing down Speed not changing	Speeding up Slowing down Speed not changing	Speeding up Slowing down Speed not changing

© It's About Time

The length of the force arrow pulling the car down the ramp can be determined by drawing a line perpendicular to the inclined plane that passes through the tip of the gravity arrow as shown on the previous page.

2. In the second row, decide whether the forces acting on a coaster car during each segment are *Balanced* or *Unbalanced.*

3. In the third row, labeled *Net force,* use your force arrows from the first row to determine the net force arrows for each segment. Try to make the net force arrow's length and direction accurate for each segment.

4. Now think about your coaster car and how it moved during its trials. In the fourth row, indicate for each segment whether the car was *speeding up, slowing down,* or *staying the same speed.*

Reflect

Use the *Coaster-Car Motion Storyboard* page to answer these questions. Be prepared to discuss your answers with the class.

1. In what direction is the net force when your coaster car is speeding up? What about when it is slowing down?

2. In which columns, or segments of time, do you see the car accelerating?

3. What happens to the coaster car's motion when the forces are balanced (when there is no net force)? What happens to the car's motion when the forces are unbalanced (when there is a net force)?

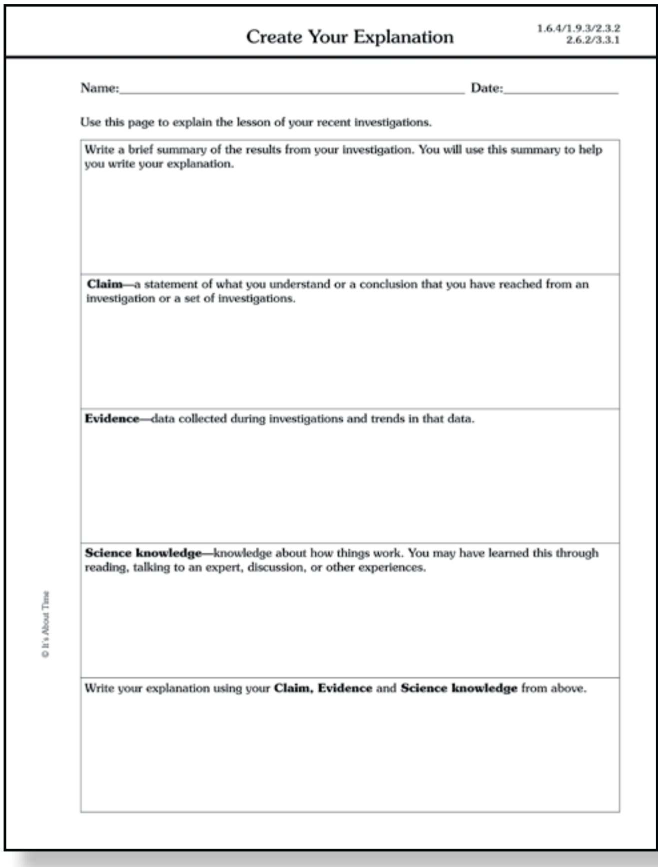
4. Describe the net forces when the coaster car's motion is changing (speeding up, slowing down, or turning).

5. Imagine that the motion storyboard shows the forces on your current coaster car. Now suppose you had to create a motion storyboard for your original coaster car. How would that motion storyboard be different?

Explain

Create Your Explanation

Your challenge has been to make a coaster car that will go straight and far. You have also measured how fast your coaster car travels. You have learned that to design the best coaster car, you need to understand the different forces acting on it as it moves. You know enough about forces now to explain scientifically why your current coaster car performs better than the ones that came before it. Draw a motion storyboard for your current coaster car and one for your original coaster car. Use the motion storyboard to create an explanation of why your current coaster car travels farther than your first one did.



Create Your Explanation 1.6.4/1.9.3/2.3.2 2.6.2/3.3.1

Name:__________ Date:__________

Use this page to explain the lesson of your recent investigations.

Write a brief summary of the results from your investigation. You will use this summary to help you write your explanation.

Claim—a statement of what you understand or a conclusion that you have reached from an investigation or a set of investigations.

Evidence—data collected during investigations and trends in that data.

Science knowledge—knowledge about how things work. You may have learned this through reading, talking to an expert, discussion, or other experiences.

Write your explanation using your **Claim, Evidence** and **Science knowledge** from above.

Use a *Create Your Explanation* page to record your explanation. Remember that a good explanation has four parts to it:

- your claim
- your evidence
- your science knowledge
- a statement connecting your claim to your evidence and the science you know

A claim is a statement of what you understand or a conclusion you have reached based on data from an investigation or fair test. Your claim will be about the design changes you have made that have resulted in your current coaster car traveling farther than the first one you built. You might word it like this: *Now that I <<list the changes here>>, my coaster car travels farther than my original coaster car.*

Revisit the data on your *Redesigning My Vehicle* page, and record the evidence you collected now that your car is performing better.

Next, record the science knowledge that explains why your current coaster car travels farther than your first one. Use force diagrams from your *Motion Storyboard* pages to show the differences in the forces. Use the language of forces to state why the motion is different in the two cars. Use the terms *friction* and *net force* in your statement.

Pull together your claim, evidence, and science knowledge into a full explanation. Begin the statement with your claim. Use the word *because,* and make a statement about the way your changes to the design changed the forces and net forces acting on your coaster car. Do not worry if your statement is not perfect. Do the best you can. A good explanation statement will A good explanation statement will describe why the forces acting on your car are different now than they were originally, and what the effects are of combining those forces.

Communicate

Share Your Explanation

When it is your turn to present your explanation, read your claim to the class, show the class your *Coaster-Car Motion Storyboard* pages, and present your explanation statement. As you listen to your classmates' explanations, make sure their explanation statements match the force diagrams on their motion storyboard pages. If you think a group has not explained well enough or that their explanation is wrong, offer your advice respectfully. If someone disagrees with your explanation, show your evidence and describe again how your science knowledge supports your claim. Try to come to agreement. You can help one another better understand how forces combine during this discussion.

Reflect

1. Your current coaster car also travels straighter than your original one did. Sketch two force diagrams: one that shows the forces that pushed your original coaster car to the right or left, and one that shows the forces that affect the direction of your current coaster car.

2. Using a *Create Your Explanation* page, make a claim about why your car now travels straighter. Add evidence and science knowledge. Do your best to develop an explanation.

Update the *Project Board*

You have learned a lot about the nature of forces in this *Learning Set,* including how to sketch their relative magnitude and direction in a force diagram. Add what you now know about forces and net force to the *What are we learning?* column of the *Project Board.* Don't forget to add what you now know about how net force causes changes in motion. For each idea you add to the *What are we learning?* column, remember to add evidence to the *What is our evidence?* column of the *Project Board.*

If you have remaining questions or feel the need to learn more about something to improve your car, suggest questions for the *What do we need to investigate?* column.

What's the Point?

Forces can be described by their magnitude and the specific direction in which they act. Force diagrams use arrows to show the magnitude and direction of the forces acting on an object. Arrow length represents the magnitude of the force. The direction of the arrow indicates the direction in which the force acts. When several forces act on an object at the same time, their effect on the object depends on the net force acting on the object.

The net force on an object is the sum of all of the forces acting on the object. When the forces on an object are unbalanced, there is a net force, and the object's motion will change (it will accelerate—speed up, slow down, or change direction). When the forces on an object are balanced, there is no net force, and the motion of the object does not change. The object remains at rest if it was at rest, or it continues to move at a constant speed in a straight line if it was already moving.

Understanding the forces that are acting on a car can help you explain how the design changes you made affected your car's motion. Understanding forces on your car will also help you design a propulsion system to add to your car that will exert a force to help it meet the *Big Challenge.*

Learning Set 1

Back to the Big Challenge

Design and build a vehicle that will go straight, far, and fast, and carry a load.

The *Big Challenge* for this Unit is to design a vehicle that will go straight, far, and fast, and carry a load. In this *Learning Set,* you addressed a smaller, simpler challenge— to build a coaster car that could go straight and far. Learning about how forces affect motion helped you redesign your coaster car so that it now travels straighter and farther than when you first built it. You found that by reducing friction acting on the coaster car, you increased the net force acting on the car, and the car traveled farther. You also found that by reducing friction acting on the coaster car, you changed the direction of the net force, and your car traveled straighter.

Now you will think again about the *Big Challenge.* You will begin by revising the recommendations you made earlier. The better your recommendations about designing a coaster car are, the better you will be able to redesign and rebuild your coaster car later when you address the *Big Challenge.* You know more science now than you did when you developed your recommendations, so you should be able to make your recommendations more complete. After you improve your recommendations, you will think about what else you need your car to do to achieve the *Big Challenge.*

Revise Your Recommendations

With your group, review the recommendations you created earlier in this *Learning Set.* Those recommendations were about designing or constructing a coaster car so it will travel straight and far. You supported your recommendations with evidence from your fair tests and science knowledge. You wrote an explanation statement connecting your recommendation to your evidence and science knowledge.

Now that you know more about how forces combine and affect motion, you may find that you can state your recommendations better. You should be able to state the science knowledge that supports each recommendation.

You should also be able to compose a better explanation statement for each. Add sketches to the science knowledge that supports your recommendations and to your explanation statement showing the forces that would be changed if somebody followed your recommendations. When you are finished, you will share your recommendations with the class.

Communicate

Share Your Recommendations

Share your recommendations, along with science knowledge and explanations for each one, with the class. As each group shares its revised recommendations, revise the class recommendation list and the science knowledge that supports each recommendation. For each recommendation on the class list, sketch the forces that would be changed if somebody followed the recommendation.

Reflect

When it is time to address the *Big Challenge,* you will design and build a coaster car that will hold a propulsion system and carry a load. There is more you still need to investigate before you can address the *Big Challenge.* Examine the *Big Challenge* and its criteria and constraints, and answer these questions.

1. Which elements of the *Big Challenge* have you already addressed?
2. What other issues do you need to address to achieve the *Big Challenge?*
3. What do you need to investigate to address each of those issues?

Update the *Project Board*

Examine the *What do we need to investigate?* column of the *Project Board.* See if there are questions in that column that you now know answers to. If so, make sure those answers are in the *What are we learning?* column. If the answers are not yet recorded on the *Project Board,* record them in the *What are we learning?* column. Record the evidence that supports your answers in the *What is our evidence?* column.

The last column on the *Project Board* helps you pull together everything you have learned in a Unit. It is the place to record recommendations for addressing the *Big Challenge.* Add your recommendations to the last column of the *Project Board.* Make sure there is evidence for each of your recommendations in the *What is our evidence?* column or in the *What are we learning?* column.

Then add the new questions you just generated to the *What do we need to investigate?* column.

Finally, examine the *What do we think we know?* column again. Identify the ideas you recorded in that column earlier in the Unit that you now know more about. Notice what you know now that you did not know when you began working on this Unit.