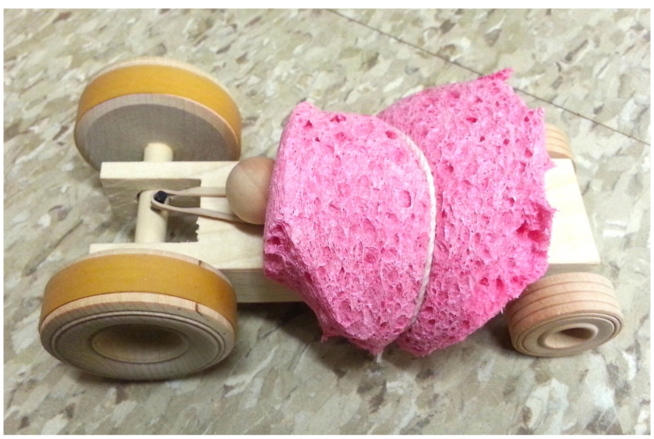
Focus on Energy

Preparing Elementary Teachers to Meet New Science Standards.

Engineering Design Challenge

Teacher's Guide



Investigation 1

Investigation 2

Appendix

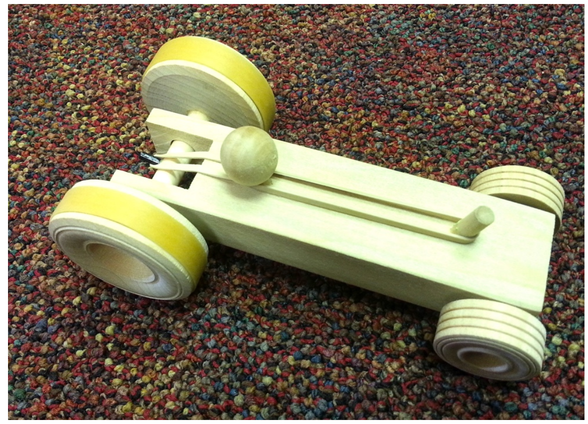
- Background Information
- Summary Sheet Instructions

Focus on Energy: Preparing Elementary Teachers to Meet New Science Standards.
Supported by the National Science Foundation

Engineering Design Challenge – Investigation 1

NOTE: Students should have completed the Focus on Energy curriculum prior to working on this challenge.

Plan Investigation 1



In this 2-class Investigation students work on solving a practical problem: How can you use simple materials (supplied kit) to modify a car so that it comes to a stop exactly where you want it to? Students start with a toy car that has enough stored elastic energy to propel itself 12 feet or more. They are challenged to modify to the car so that it comes to a stop between 3 feet and 6 feet beyond a starting line. The strategy they are asked to employ is to transform some of the car's motion energy into thermal energy.

Students are familiar with motion energy, thermal energy, and energy transformation, but have had only one brief experience—in Thermal Investigation 1—that highlighted the transformation of motion energy into thermal energy: they rubbed their hands together and sensed the resulting warmth. That transformation, however, is ubiquitous: all motion energy is accompanied by some degree of friction, and friction transforms motion energy into thermal energy. In Motion Investigation 1, a ball rolling along the track slowed down and stopped moving. The explanation is that while the ball was rolling, friction—between the ball and air, and between the ball and the track—continuously transformed some of the ball's motion energy into thermal energy until no motion energy remained. The term *friction* (a force), however, is not introduced in this investigation. Discussing friction can get complicated and may detract from the learning goals of this investigation. If students mention friction, that's fine. Explain that in this investigation we use the term "rubbing".

In previous Focus on Energy investigations, as students attempted to answer the question, "Where did the energy go?", they frequently concluded with, "…then energy went into the environment." That response was often correct, but one goal of this investigation is to help students move past that somewhat vague response to understand that often the "it" that moves into the environment is *thermal energy* transferring to the *air*. Another goal is to reinforce some of the key energy concepts that were highlighted previously—energy forms, energy transfer, and energy transformation—by having students analyze the flow of energy through a new system, one which they will have a role in designing.

In this investigation students work in pairs, using only the limited materials provided in a kit to modify their toy car so that it stops in the target area. As they work, they collect and record data in their Student Notebooks. And as they have done throughout much of the Focus on Energy curriculum, they also tell the energy story.

Allow two class periods for this engineering design challenge: one day for introducing the challenge, the associated concepts, and time for students to develop and test their designs; and a second day to develop and share energy stories. The two class periods should be as close together as possible.

Learning Targets

This engineering design challenge is a context for introducing some ideas about engineering design and reinforcing some important ideas that were introduced in the Focus on Energy units, and specifically some ideas that were introduced in the Thermal Energy unit:

- Motion energy can be transformed into thermal energy through rubbing.
- If an object's temperature increases or decreases, its thermal energy has increased or decreased.
- Thermal energy can be transferred between objects through contact.
- Some thermal energy of a warm object is transferred to its surrounding environment.

- When thermal energy is transferred to the environment, temperature changes in the environment may be too small to observe.
- Possible solutions to a problem are limited by available materials.
- Different possible solutions to a problem need to be tested in order to determine which of them best solves the problem.

Sequence of Experiences		
1. Introduce the Challenge	All Class	10 Minutes
2. Motion Energy, Brakes, and Thermal Energy	All Class	15 Minutes
3. Design Challenge and Clean-Up	Pairs	35 Minutes

Materials

For the class:

- One propeller-rubber band system (used in Motion 4)
- One bicycle. Either a child-size or adult size will work (not included in kit)
- One digital thermometer (used in Thermal 3)
- 1 tape measure that expands to 15 feet (not included in kit). Alternatively, use 2 yardsticks, or if you have 1-ft square tiles on the classroom floor you can use the tiles for measurement.

For each small group of 2 students:

- 1 wood car with rubber band
- 1 gallon-sized zip lock bag holding:
  - 1 4"x6" kitchen sponge
  - 2 6" paper plates
  - 1 piece of string (3 ft.)
  - 4 plastic straws
  - 1 roll Scotch tape
- Scissors (not included in kit)

For each student:

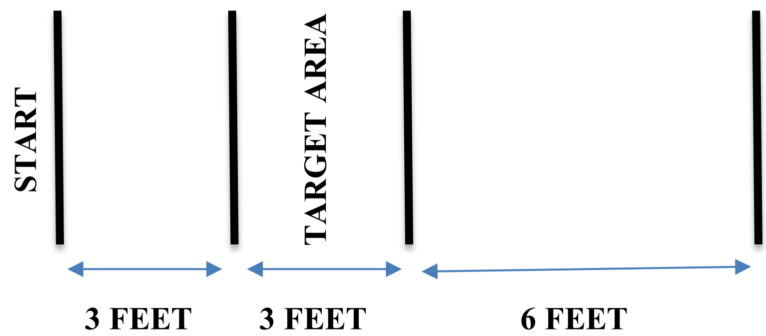
- Engineering Design Challenge student notebook (Available on web site)

Preparation:

- Read the document "Background Information" in the Appendix.
- Practice setting up, spinning, and stopping the bicycle wheel as described in Part 2. Use the FRONT wheel and spin it with your hand.
- Assign teams of two to work together on the challenge.
- (Optional) Prepare to take a photo of each design.
- Create 2 or 3 Test Tracks on the classroom floor or other available space. For each Test Track, use four 18-inch-long pieces of masking tape to establish four lines: 1) a Starting Line; 2) a line 3 feet from the starting line; 3) a line 3 feet after that line; and 4) a line 6 feet after that line. The area between 3 and 6 feet is the target destination for the redesigned cars. See Test Track Layout below.

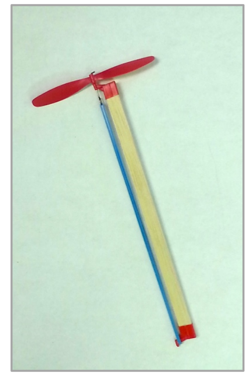
> **NOTE**: If you have a smooth (tile, etc.) floor in the area of the test tracks, be sure it is free of the sand and dirt that shoes may track into the classroom. Car wheels will just spin on a gritty floor! Smooth floors must be clean in order for the drive wheels of the cars to properly grip the floor surface.

TEST TRACK LAYOUT



1. Introduce the Challenge

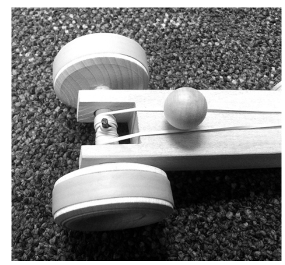
All class – 10 Minutes



Gather students in a circle. Ask if they remember using the propeller-rubber band system, and demonstrate by winding and releasing the propeller. Ask if they remember the energy story of that system. Students may recall the *transformation* from elastic energy to motion energy of the rubber band, the *transfer* of motion energy from the rubber band to the propeller, and possibly the *transfer* of motion energy from the propeller to the air.

Explain that today students will work like engineers, to solve a problem. Today's problem involves elastic energy and motion energy, and thermal energy as well. They will use their ideas about energy to help them solve the engineering problem. This time the object they will work with is not a propeller; it's a toy car.

Holding a wooden car vertically with one hand gripping the smaller front wheels, rotate the large rear wheels to wind the rubber band around the axle a few times. Then release the rear wheels so they spin in the air, mimicking the way the propeller spins when holding the balsa stick.



Ask if someone can tell the energy story of the rubber band beginning when it was tightly wound until it was no longer stretched.

Now show how to wind rotate the wheels six full times, winding or stretching (deforming) the rubber band. This time place the car on the floor and let it go. How far did the car travel?

> *If I rotate the big wheels six full times, the car will travel 12 feet or more.*

Introduce the challenge.

> *Your challenge is to make changes to the car so that even after winding the rubber band six times around the axle, the car will only travel between three and six feet instead of twelve (or more) feet.*
>
> *What are some of your ideas about how to stop or slow down a bike or sled or car or other moving vehicle?*

Listen for ideas. They might include brakes, speed bumps, or adding weights to the car.

Acknowledge students' ideas. It is likely someone has suggested some kind of brake.

> *Today we're going to talk about one of your suggestions: brakes.*

2. Motion Energy, Brakes, and Thermal Energy

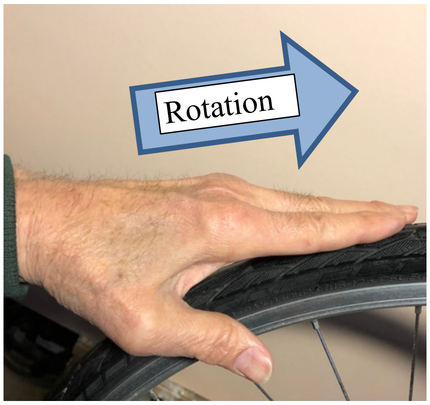
All class – 20 Minutes

Discussion about brakes

> *If you were small enough, and if you had brakes for this toy car, you could ride on it and use the brakes to make it stop somewhere between 3 feet and 6 feet.*
>
> *Does anyone know how brakes actually work?*
>
> *How do brakes cause a bicycle to stop?*

Listen to student ideas about how brakes work. Some will know that many bicycle brakes work by squeezing the wheels. If the topic comes up, agree that car brakes are more complicated but that rubbing against a moving part of the wheel is also what stops the car, the same approach as stopping a bicycle.

Demonstrations

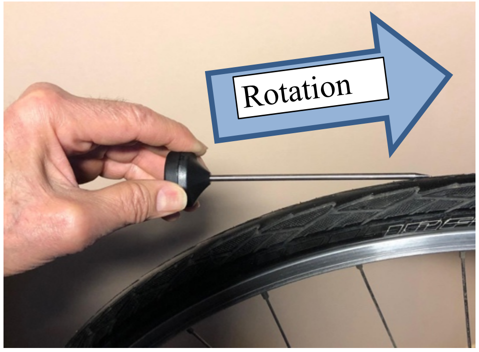


Have students assist you in holding the upside-down bicycle while you spin the wheel *away* from you. Then, demonstrate a simplified version of how bicycle brakes work by lightly pressing fingers against the rubber, causing the wheel to slow down and stop. (See image.)

> *Think about the energy story. What kind of energy did the spinning wheel have?*
> ➔ Motion energy.
>
> *Do you agree that the wheel lost motion energy after I made it rub against my finger?*
> ➔ Yes.
>
> *When the wheel lost motion energy, what gained energy?*

Listen to student ideas without making judgements, even though they may switch from a focus on energy to a focus on mechanism, explaining that it was your finger that made the wheel stop.

Move on to the next demonstration, which highlights the transformation of motion energy into thermal energy.



Have another student assistant come up to observe and report on the thermometer's temperature. Then spin the wheel again, this time using the shaft of the thermometer (in place of your finger) to apply gentle pressure against the rubber tire. (See image.) The temperature reading on the thermometer—which indicates the temperature of the shaft of the thermometer, which in turn indicates the temperature of its immediate environment—will increase by 5 degrees F or more. As the wheel stopped spinning, motion energy transformed into thermal energy.

Debrief the demonstration

Repeat the question:

> *When the wheel lost motion energy, what gained energy? What is the evidence?*

Students are likely to say the thermometer (casing) gained thermal energy (true). They may respond that the wheel also gained thermal energy and back up this claim by saying the wheel felt warmer as it slowed down.

The important point to highlight is: when something rubs against the wheel, *motion energy is transformed into thermal energy*. In general, when things rub against each other, motion energy gets transformed into thermal energy. That's what bicycle brakes do.

> *Can you think of another example from everyday life where motion energy transforms to thermal energy?*

Responses will provide insight into your students' experience. Examples might include:

A saw blade gets warm as you cut wood.
The kitchen mixer gets warm as the beaters spin.
A car's tires get hot as it skids to a stop.
You get a "floor burn" as you skid across a gym floor or down a slide.
An eraser gets warm as you rub it vigorously across a surface.

> *Do you remember rubbing your hands together in Thermal Investigation 1 and feeling your hands get warmer? That's another example of motion energy being transformed into thermal energy by rubbing.*

Note: If hands did not appear to lose motion energy as they gained thermal energy, it is because the body was continuously transferring (or losing) chemical energy to the hands to keep them moving.

> *Your challenge is to make changes to the car to transform enough motion energy of the car to thermal energy so that, even after winding the rubber band six times around the axle, the car only travels between three and six feet instead of twelve feet. There are different ways to do this, but everyone must use rubbing to transform motion energy into thermal energy.*

3. Design Challenge and Clean-Up

Pairs – 35 min

Instructions

Show students the packet of materials they have to work with. They should use nothing but the materials in the bag (or the bag itself) to make their braking system.

Emphasize that students should take time to discuss different ideas with their partner *before* they decide on a plan and start to change the car in some way. This is a challenge for <u>two people</u> to work on. Engineers often work in teams to discuss plans before they start working on a new design.

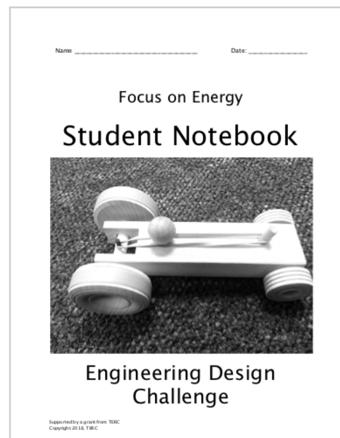
Their solution <u>must transform motion energy into thermal energy by rubbing</u>—even though the amount of thermal energy will be tiny and we will not be able to measure it with a thermometer.

Students should use one of the test tracks to test their design. The car's front wheels must stop in between the 3-foot line and the 6-foot line to be a successful design.

> *Your design should work more than once. If it can't stop the car in the target area two or three times in a row, it's not yet a reliable design.*
>
> *You probably will not solve the problem the first few times you try. That's OK, but you should write the results of each test in your student notebooks. Collecting and analyzing data is very important to engineers and scientists.*

Distribute student notebooks and review the pertinent pages with the class.
Contents includes:

- Page 2: The Energy Tracking Lens
- Page 3: How to properly wind up the wooden car
- Page 4: Completing, measuring, and recording results of a Test Run <u>before</u> working on the brakes
- Page 5: Places to record the result of every test with brakes. Students are unlikely to run 8 tests. There is also a place to *measure and record* the final test of the day.



Page 6 (and page 7 if needed) is for use in Day 2.

> *You will have the rest of the class to work on solving the problem.*
> *You will have time in the next science class—or later today if you finish early—to use energy cubes to tell the energy story.*

Distribute cars and a bag of materials to each pair.

Note: If a pair seems stuck, offer help. Solving the challenge independently is not the main goal; it is just the context for strengthening ideas about the transformation of motion energy to thermal energy, the transfer of that energy into the air, and the concept that change can be too small to sense.

If a team addresses the challenge quickly, suggest they tackle a new challenge: Make the car stop between 6 ft and 8 ft.

Engineering Design Challenge – Investigation 2

Plan Investigation 2

In Day 1, students were introduced or re-introduced to a set of concepts related to the transformation of motion energy to thermal energy, but once they started working on the redesign of their cars, their attention may well have switched to using a trial-and-error approach to addressing the design challenge. That's expected. Day 2 returns the focus to energy.

Today's class has three sections: 1) a short introduction; 2) time for pairs of students to "cube" the energy story of their altered car and to record that story; and 3) time for students to share their work with the class.

Hopefully all teams were able to successfully address the challenge on Day 1, but even if they weren't, they'll be ready to focus on energy today. Everyone is by now familiar with the Energy Tracking Lens questions and with using energy cubes to track the flow of energy through a system and should be poised to apply their understandings about energy to their car and its braking system, regardless of their success on Day 1.

Learning Targets

- Use the Energy Tracking Lens questions and energy cubes representation to tell the energy story of the rubber band propelled car and its braking system.

Sequence of Experiences		
1. Introduction	All Class	10 Minutes
2. Tell the Energy Story	Pairs	25 Minutes
3. Share and Make Meaning	All Class	15 Minutes
4. Add to the Model of Energy and Wrap-Up	All Class	10 Minutes

Materials

For the class:

- 6 class sized energy cubes with stickers that were added during the Focus on Energy units.

For each small group of 2 students:

- 6 student-sized energy cubes with stickers that were added during the Focus on Energy units.
- Large sheet of paper and markers, or a whiteboard and erasable markers.

For each student:

Engineering Design Challenge Student Notebook

Preparation

- Read the Summary Sheet Instructions in the Appendix.
- If students are working on large sheets of paper vs whiteboards, have extra sheets available in case a team really needs it, but also assure students that you can accept revisions on their sheets as long as the changes are clear. The goal is to use cubes to figure out the energy story of their car.
- Just a reminder: Unlike their work in the Focus on Energy curriculum, pairs will not be investigating the exact same system, so the range of system components identified (via circles) will reflect their different designs.

1. Introduction

All class – 10 Minutes

Remind students that in the previous class, each team worked on making changes to its car, changes that in different ways transformed some of the car's motion energy into thermal energy, so that the car traveled less than the 12 feet it would usually travel. And even if some teams did not make their car stop in the Target Area, most likely everyone was able to transform some of their car's motion energy into thermal energy by having components rub against one another.

Would someone volunteer to tell us what kind of energy the car's motion energy was transformed into?
➔ Thermal energy

Did anyone try to feel parts of the car or the braking system to see if they felt warmer?
➔ (Students may not be able to expand on this – that's OK. You may be able to return to this question later in the class, but an answer might be… For tiny amounts of thermal energy, the temperature change might be very small and we would not notice or perceive it.)

Explain that the class will continue to work on the car challenge, but today the focus will be on the energy story of the car.

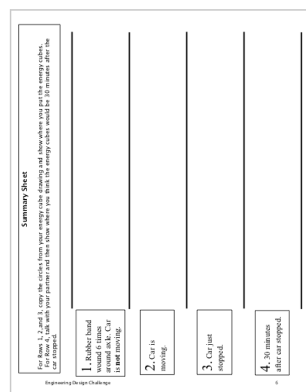
You have three main tasks today:
1. Use cubes, markers, and a whiteboard or paper to tell the energy story of your car. Remember to answer the Energy Tracking Lens questions as you "cube" the energy story.

Teams can do this even if the car did not stop in the Target Zone. If students decide that 6 cubes are not enough, they can imagine putting half-cubes in places.

2. Use the Summary Sheet in the Student Notebooks (Page 6, with an extra copy on Page 7 if you need it) to record where the cubes would be for 4 different points in time. Draw half-cubes if you need to.

Review the Summary Sheet with students. The circles (system components) they draw for each of the four points in time should be the same circles they used on the large sheet or whiteboard when they were moving the cubes. They are just copying information from the large sheet to the Notebook page.

The 4th point in time—30 minutes after the car has stopped—is a new idea and something students will have to think about. Where would they put the cubes 30 minutes after the car has stopped?



Student Notebook – Pg. 6

3. We will save 15 minutes of class time for sharing energy stories with one another.

Teams should bring their whiteboards or large sheets of paper with the circles as well as their notebooks to the meeting and be prepared to share their energy story with the rest of the class.

2. Tell the Energy Story

Pairs – 25 Minutes

Distribute whiteboards or large sheets of paper, six energy cubes, and markers to each team.

After 15 minutes, make sure students have at least begun to summarize their energy story in their Student Notebooks and encourage them to use the final ten minutes to do that.

As students work, ask them to explain their decisions: what circles did they include? How did they decide how to distribute the cubes? if there was a transformation, where did it occur? Were there energy transfers? What was the evidence?

Think about two or three examples of cube stories that differ in some interesting way. Ask these groups to kick off the sharing.

3. Sharing and Make Meaning

All class – 15 Minutes

The focus of the discussion today is on the energy story, but the one performance question that is pertinent for each team that shares is, "What does your evidence (data) tell you about the success of your braking system?"

Have students bring their whiteboards or papers and Student Notebooks to the discussion circle.

Select a team to tell their energy story, moving cubes through their system components. Once the team has finished moving cubes, have the team share their Summary Sheet.

Ask the observers to notice:

1. How this story is the same or different from theirs?
2. *Were there any big differences in how you moved the cubes or how you recorded things on your Summary Sheet?*
3. Have the presenters addressed all of the Energy Tracking Lens question?

Is there a team that used a very different type of braking system?

Repeat as time permits.

4. Add to the Model of Energy and Wrap-Up

All class – 10 Minutes

Although the key concepts that are highlighted in this investigation are not new, they may not have been identified by students as they constructed their Model of Energy. This is an opportunity to add some or all of the key ideas, or just as importantly, to go back and underline them if they are already included in the Model of Energy.

Let students know that the Engineering Design Challenge gave them a chance to apply their understandings about energy to a completely new system, and that they can now continue to do that for other new systems…maybe not always with the cubes, but by asking the Energy Tracking Lens questions and remembering the ideas that are part of the Model of Energy they have developed.

APPENDIX

Background Information

1. Notes About Engineering

In this Investigation, students do what engineers are asked to do: solve a problem. The iterative process that students utilize to solve the problem includes generating an idea for how to solve the problem, implementing and testing the idea, collecting data, applying critical thinking as they evaluate the results, refining the design, and stepping through the process again until they have solved the problem. These and other practices are fundamental to design.

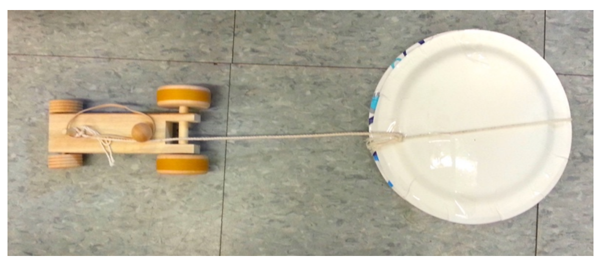
A key to successful design is to approach the process outlined above in a systematic way, but in their enthusiasm and sometimes impatience to address the challenge, students can miss the "systematic" part and possibly lose track of where they have been or where they need to go next. One purpose of the Student Notebook, in which students document their steps and their results throughout the challenge, is to help them be more systematic, hopefully reducing or preventing the inefficiency or chaos that can result from an undisciplined "trial and error" process.

2. Design Types

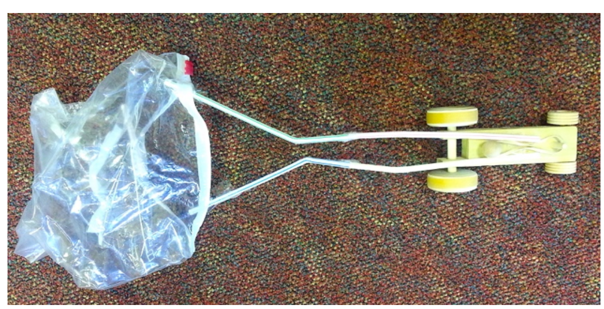
The examples below show some of the popular approaches students used to reduce the travel of the car during early classroom trials. You will undoubtedly see additional approaches. These examples are for your information only. The demonstration at the start of class along with the general design guidelines and materials will be more than adequate to get students started.

A. Increased Wheel Friction Attaching something to the body of the car that rubs against the wheels as they turn is a popular approach. It is the approach used in the demonstration at the start of class: pressing the shaft of the digital thermometer against a wheel to bring it to a stop sooner than it would otherwise have stopped.

B. Increased Floor Friction Using string to have the car drag a sponge or paper plates carrying various amounts of weight was another popular approach.



C. Air Resistance The friction between a moving object and the surrounding air (or water) is commonly referred to as *drag*, and is another approach to transforming motion energy into thermal energy via friction. (Students made a special request to use the bag that the materials came in, and were granted permission.)



"Wasted Motion" This is NOT a design that relies mainly on using friction and so should *not be an acceptable solution*. It is included here only to give you an example of what some students may propose, and to help you explain why it does NOT meet the design constraints of today's challenge. In this case, some of the elastic energy causes the car to have an up-down motion in addition to forward motion, so the result was less forward motion.

3. Science Standards

Next Generation Science Standard Performance Expectation 4-PS3-4 reads, *Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.* In this challenge, the *device* that students design, test, and refine is the mechanism they add to the car that brings the car to a stop within the target zone. The *scientific idea* that students apply is that motion energy can be converted to thermal energy via friction.

4. Energy Transformation and Imperceptible Change

In this design challenge, the approach students use—transforming motion energy to thermal energy via friction—is exactly the same approach engineers use to help us control our cars, trucks, trains, bicycles, and more. It is the same approach a child uses to bring a scooter to a stop by dragging a shoe along the ground. In all of these examples, motion energy is transformed into thermal energy via friction, and that thermal energy—of the brakes, or the child's shoe—is eventually transferred to the air.

Yes, the braking mechanism students design for the wooden cars will gain thermal energy (become slightly warmer than room temperature) once the car is in motion, but it will be a very tiny gain, with an imperceptible increase in temperature. And that tiny increase in thermal energy will eventually transfer to the atmosphere, because thermal energy always flows from a warmer (brakes) to a cooler (room temperature air) object. The concept of *imperceptible change* is a challenging one for students, but accepting the idea that change can happen even when one can't perceive it is key to understanding the flow of energy in the case of the wooden car, or to understanding why the car ever stops once it is moving, or to understanding thousands of other situations we encounter in the world around us.

True, students have probably accepted the idea that whenever there is an energy loss in one place there must be a gain in another place. This is obvious when one ball collides with another. But when an obvious loss (motion energy) is paired with an imperceptible gain (thermal energy), the concept of balanced gains and losses is not so clear. Hopefully, the combination of students' prior experiences in the curriculum, the demonstration with the wheel and the thermometer at the start of class, the hands-on work in this engineering design challenge, and the debriefing, will help students strengthen their understanding of this important gain-loss energy concept.

5. The "Friction" Word

Although the term *friction* has been used several times in the notes above it is not introduced to students in the curriculum unit. Defining friction leads to a whole new set of ideas in an investigation that already has some challenging ideas. If students suggest the word and are using it appropriately, agree that friction is involved, but leave it at that. The key goals of the investigation can be met simply by focusing on the concept that *when objects rub together* the result is that motion energy is transformed into thermal energy. Those are terms with which students are already familiar.

Summary Sheet Instructions

Students use the Summary Sheet in their Student Notebooks to record information at three specific points of time (see notes at the left end of each row), <u>based entirely on the energy cube diagrams they created</u>.

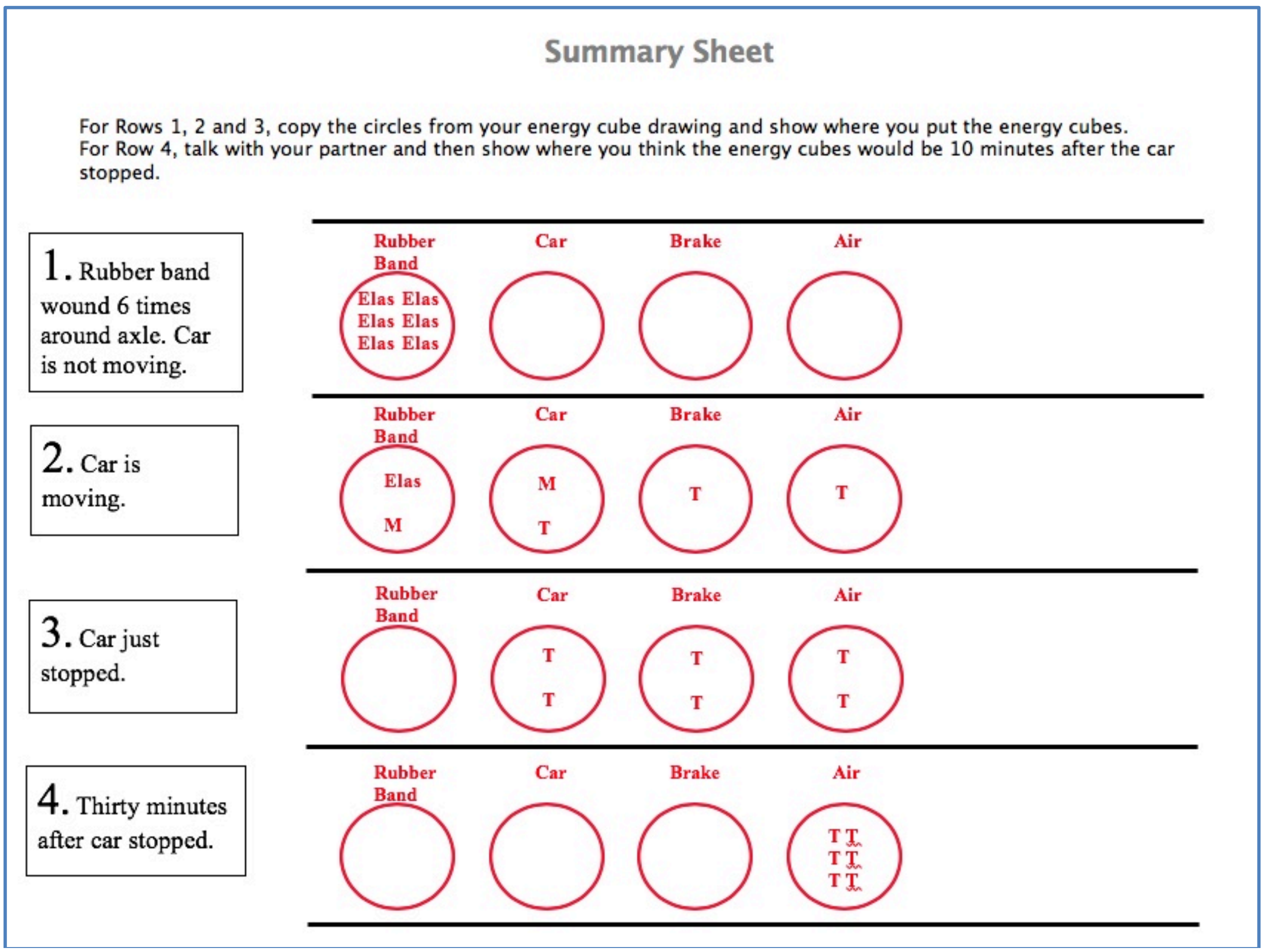
For Row 4, they are asked to discuss with their partner where they think the energy cubes would be 30 minutes after the car has stopped.

There is a second copy of the Summary Sheet in each notebook, just in case students need it.

For Your Eyes Only!

The text in **red** is just one example of how a student might complete the Summary Sheet, but this will give you some sense of how the sheet should be used.

KEY: Elas = elastic energy; M = motion energy; T =thermal energy



Please use the **blank** Summary Sheet on the next page or a page from the Student Notebook as you explain how students should use the Summary Sheet.

Summary Sheet

For Rows 1, 2 and 3, copy the circles from your energy cube drawing and show where you put the energy cubes.
For Row 4, talk with your partner and then show where you think the energy cubes would be 30 minutes after the car stopped.

1. Rubber band wound 6 times around axle. Car is **not** moving.

2. Car is moving.

3. Car just stopped.

4. 30 minutes after car stopped.