Braking Investigation Setup Instructions

Note: See the *Cart Construction Instructions* for how to build the carts for investigating the three independent variables.

Safety Protocols

When working with the lab materials, the following safety precautions are necessary.

- Students must conduct the experiment under the supervision of qualified personnel who can respond quickly to any unforeseen circumstances.
- Students involved in setting up the equipment and conducting the experiment must be properly trained in handling the sensor carts and understand the experimental procedures.
- Wear appropriate personal protective equipment (PPE) including sanitized safety glasses with side shields during the setup, experimentation, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- Use caution when using sharps (tools, bolts, hinge, etc.), which can cut or puncture skin.
- Use caution when working with glue guns, which can get hot and burn skin!
- Clear the workspace of any obstacles or hazards that could interfere with the experiment or cause accidents during the collision.
- Make sure that all parts of the carts are properly secured and stabilized before conducting the collision test. Follow manufacturer guidelines for setup and operation.
- Immediately clean up anything that falls on the floor, so it does not become a slip or fall hazard.
- Maintain a safe distance from the collision area during the activity to avoid injury from flying debris or malfunctioning equipment.
- Following the activity, inspect all equipment for any damage or wear and tear. Repair or replace any damaged components before further use.
- Wash hands with soap and water once all equipment is put in appropriate storage areas.

Suggested Constant Values and Variable Ranges for Cart Setup

Prepare the variable carts by providing pea gravel/sand and fender washers (called braking washers on the student protocol sheets) to create initial conditions for the constants for each group. To adjust mass, add gravel/sand to the deli container on the mass cart. To adjust braking force, add washers to the bolt on the brake on the force cart. To set a starting point height for the speed cart, tape a starting line on the built ramp (see Ramp Setup below).

The following table lists values for the constant values and variable ranges for each group. These were determined to create the best anticipated stopping time ranges. Although you do not need to use these exact values (and may not be able to, based on specific washer masses), using similar values should optimize the time ranges that students can measure, increasing lab success.

	Force Group	Mass Group	Speed Group
Total cart mass	1,100 g	475-2,250 g	2,080 g

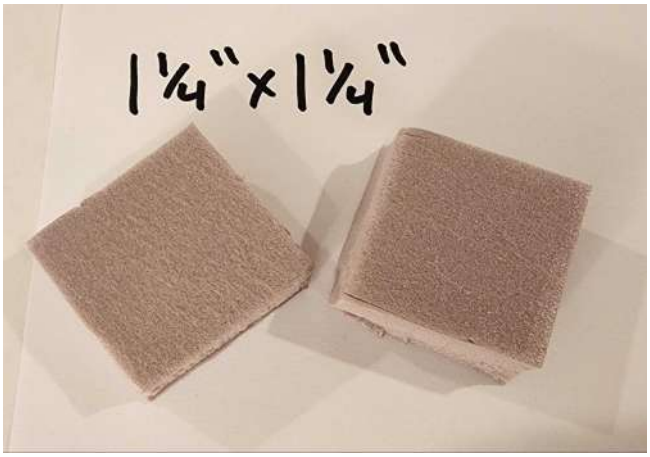
Starting point height (ramp height at front of cart when released)	3”	3”	0.5”-4”
Mass of washers placed on brake bolt	0-330 g	115 grams	170 g
Anticipated stopping time range	1.2-4.1 sec	1.1-4 sec	1.2-3.5 sec

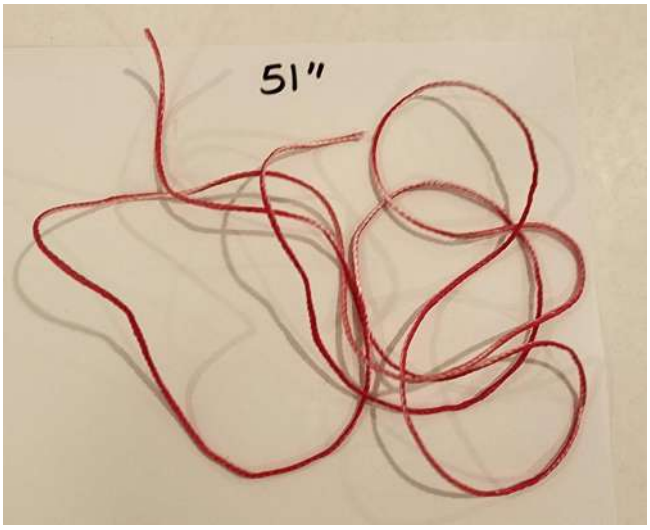
Ramp Setup

Build the following setup for each group in your class. See the last image in the table for the resulting assembly.

Materials for **each** ramp:

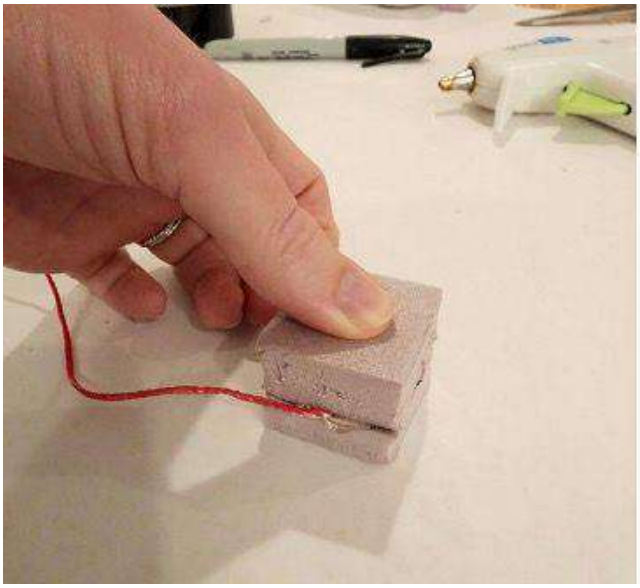
- 4 laminate flooring panels with a very smooth face on either the front or back
- 1 piece of ½” thick pink insulation foam cut into 2 pieces, each 1 ¼” x 1 ¼”
- 1 piece of string, 51” long
- 1 piece of 1” duct tape, about 1 ½” long
- 1 ruler
- painter’s tape or masking tape
- hot glue
- at least 3 books or cardboard boxes for angling and supporting the ramp





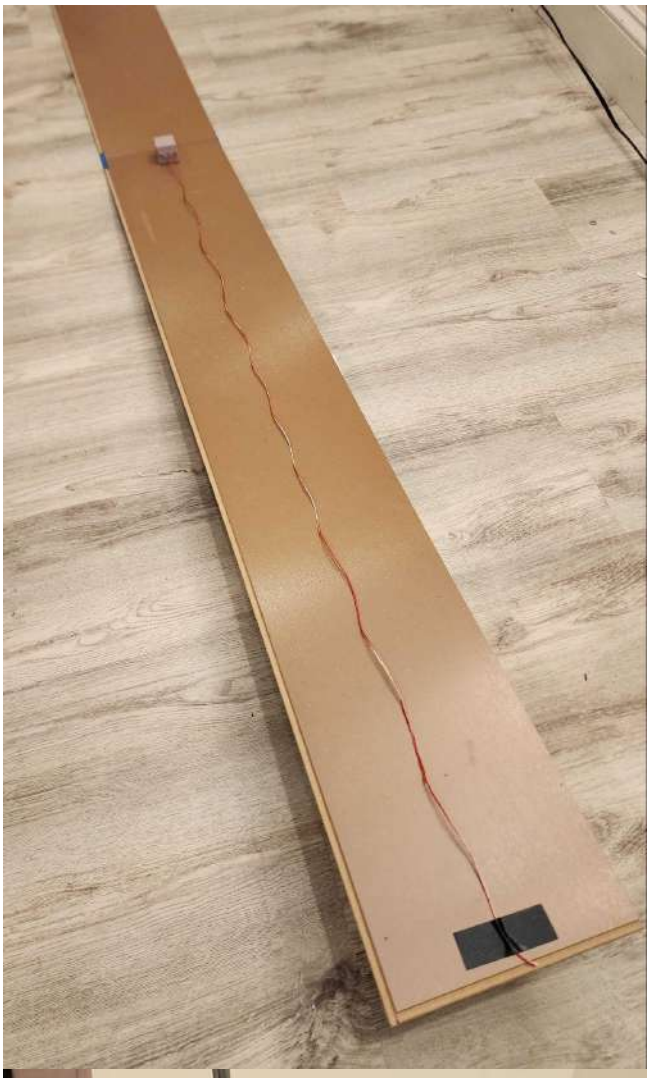
Position 2 of the floor panels side by side, rough faces up and smooth faces down. Make sure each side has an interlocking edge; if not, flip one around. To snap them together, angle the edge of one panel upward by about 20 degrees as you push it hard against the other. Lower it gently downward and push both panels tightly together to minimize the seam.	
Attach a piece of painter's or masking tape along the seam.	
Attach a piece of painter's or masking tape along the shorter edge of the attached panels so half its width is on the panels and half extends over the edge.	
Hold both long edges of the attached panels and push them together (to ensure they do not bend at the seam) as you carefully flip them over. Lay the attached panels on the floor, smooth faces up.	 

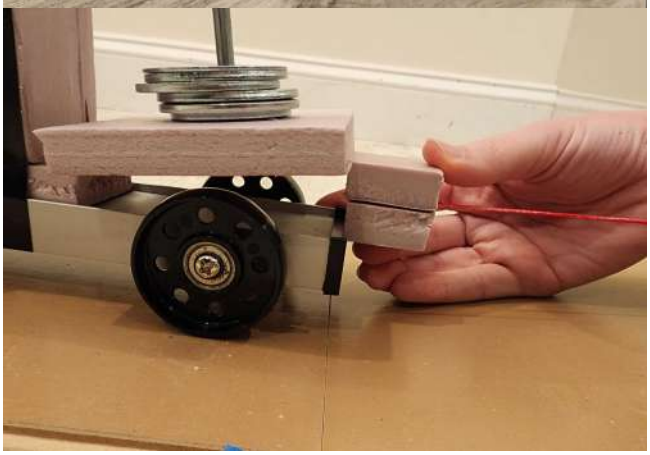
Lay a third panel on the floor, smooth face up. Position its short side against the center of the end of the attached panels. Make sure each side has an interlocking edge; if not, flip the third panel around. To snap them together, angle the edge of the third panel upward by about 20 degrees as you push it hard against the others. Lower it gently downward and push the panels tightly together to minimize the seam.	
Tear the exposed tape so you can fold it back over onto the smooth faces. Cut off any excess tape extending from the edge of the third panel.	
Attach a piece of painter's or masking tape, sticky side up, to the other edge of the third panel. Position the fourth panel at that edge, smooth face up. Make sure each side has an interlocking edge; if not, flip the fourth panel around.	
To snap them together, angle the edge of the fourth panel upward by about 20 degrees as you push it hard against the third panel. Lower it gently downward and push both panels tightly together to minimize the visible seam.	
Cut off any excess exposed tape.	

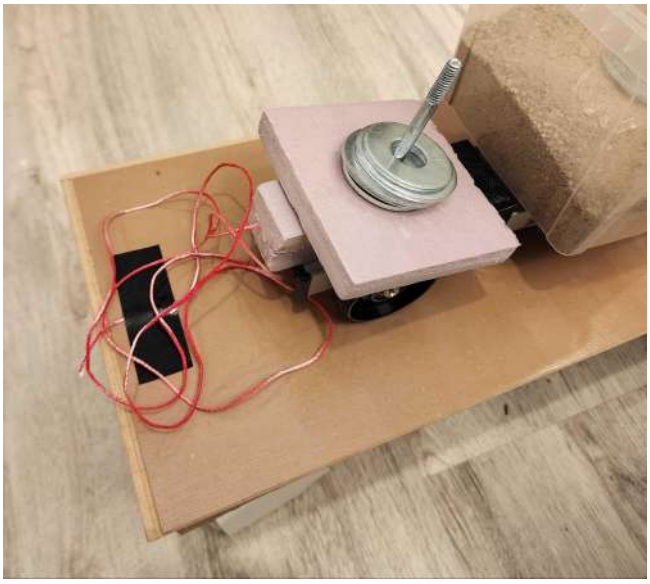
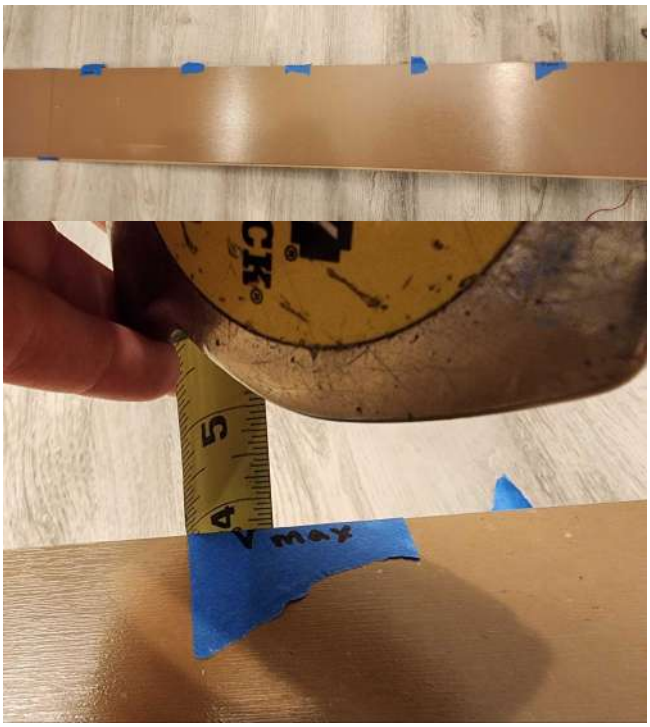
The seam between the third and fourth panels is now flexible, allowing you to angle the fourth panel upward a bit to make a ramp.	
Angle the end of the fourth panel upward and prop it up with multiple supports to prevent bending; at least 3 supports at different heights are recommended. Use the ruler to check the height of the ramp. Avoid elevating the ramp too high, as the machined edges of the third and fourth panels may break off, making it difficult to achieve a tight seam.	
The approximately 12' ramp and braking surface should now look like this.	
Assemble the brake release block: Hot glue the 2 pieces of foam together, with one end of the string between them and the rest coming out from the middle of one side.	

Lay the brake release block and string on the ramp so the block aligns with the bottom of the ramp.

Duct tape the free end of the string to the top of the ramp so it will pull out from the cart's brake when the cart reaches the bottom of the ramp.





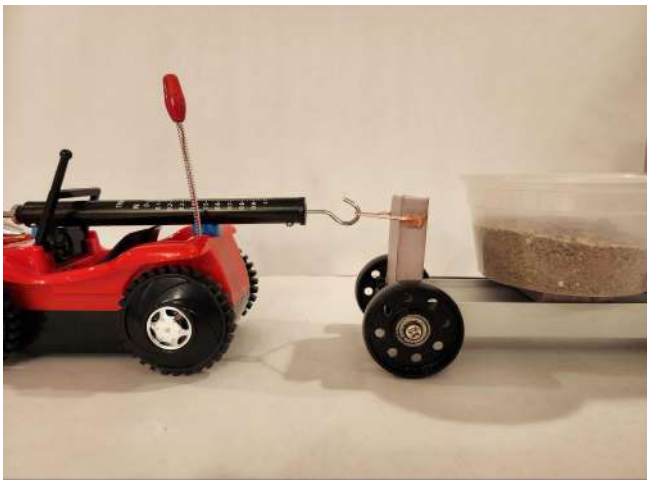
Note: A common mishap in data collection is for the brake string to get caught on something, like the corner of the ramp. To prevent that, we suggest bunching the string on the ramp behind the cart each time the cart is positioned, rather than letting it dangle over the end.	
Use painter's or masking tape to indicate where on the ramp the front of the cart should be when it is released. For the force and mass groups, this starting point should be about 3" off the floor. For the speed groups, mark the maximum and minimum heights (about ½" and 4"; see the Example Data below for value ranges). You can either pre-tape the other starting points or have students tape them.	

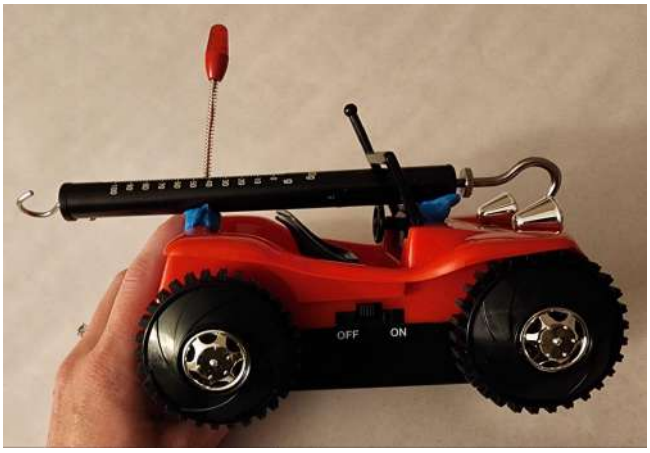
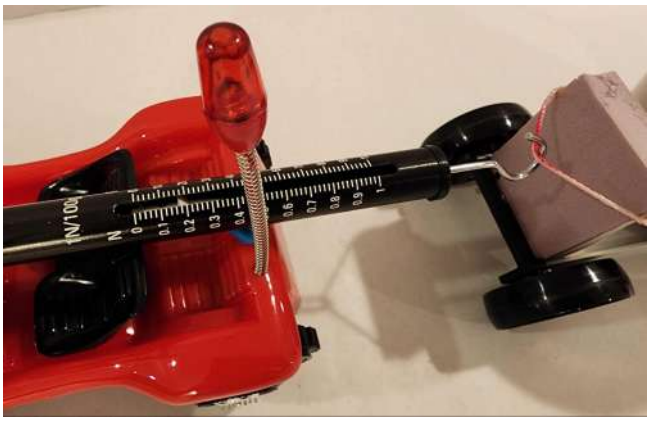
Measuring Braking Force Setup

Each group investigating braking force needs a tumble buggy (car) and a spring scale to measure the friction with the brake engaged. For instructions on calibrating the scales for the buggies, see *Zeroing Spring Scales Horizontally* from the *Earth's Interior Unit*, Lesson 11. If you used this process for that lesson, you may reuse the scales without further alteration.

Materials for **each** cart for measuring braking force:

- 1 tumble buggy
- 1 C-cell battery
- 1 piece of ½" thick pink insulation foam (or cardboard) cut to the size of a C-cell battery
- 1 aluminum spring scale (1 N), calibrated for

horizontal use (see note above) • 1 small Phillips screwdriver • aluminum foil • sticky tack	
Wrap the foam in foil. Use the screwdriver to open the buggy's battery compartment. Install the battery and the foil-wrapped foam. Make sure that the buggy runs. If it doesn't run, adjust the foil to ensure contact with both the battery and the compartment. If it runs, use the screwdriver to close the compartment.	 
Use sticky tack to attach the scale horizontally across the top of the buggy through the windshield. Make sure it lines up with the pull loops at the front of the force cart.	

	
The braking force can now be measured by dragging the cart with the buggy while the brake is engaged, and reading the force on the scale.	

Measuring Mass Setup

One mass measuring setup per class should be sufficient.

Materials for measuring mass: • 1 digital scale (3 kg) • 1 small (24-oz) deli container Place the container on the scale and tare it. By elevating the cart, the container allows the cart to be placed with its whole weight on the scale.	

Measuring Initial Speed Setup

The groups varying the initial speed (the speed of the cart at the bottom of the ramp, when the brake engages) need to take turns using the smart cart and computer. The groups that don't start with the smart cart can begin collecting time trial data using the set starting points on their ramps; when it is their turn to use the smart cart, they can then collect the initial speed values with it.

Materials for measuring initial speed: ● 1 smart cart ● 1 computer with smart cart software ● sticky tack	
Apply a few pieces of sticky tack to the side of the smart cart. Students will use this to attach the smart cart to the side of the speed cart, between the wheels.	 
Software setup Watch the video about how to set up your software to measure the speed of the cart upon reaching the bottom of the ramp: ● Pasco cart and software (SparkVue), https://youtu.be/4qr0LGT4K6A ● Vernier cart and software (Graphical Analysis), https://youtu.be/kErZa9ZzgBA	

Alternatively, you can premeasure the initial speeds corresponding to the marked starting points on the ramps for the speed groups. This simplifies data collection so students only need to record the given speed

and measure the stopping time. However, it reduces the opportunity for students to make sense of where the data are coming from, and the data may be inaccurate if the ramp shifts over the course of the day.

Example Data

The following example data sets were collected using the setups described above. These are provided as a teacher resource. Many of the graphs in the lesson materials were made using this data.

Some of the initial conditions are not within the suggested values. However, it is strongly recommended to use the suggested values with students, as these have been determined to provide the widest range of stopping times with clear data. Please note that these data also include reference initial conditions beyond what students will collect, and do not fit F = ma because of the many potential sources of error in the lab.

Starting height: 4.7"
Braking force: 0.42 N

Cart Mass (kg)	Stopping Time (sec)
1.844	3.97
1.844	4.05
1.844	3.91
1.459	3.27
1.459	3.09
1.459	3.05
0.912	2.32
0.912	2.2
0.912	2.3
0.62	1.66
0.62	1.46
0.62	1.46

Cart mass: 0.817 kg
Braking force: 0.38 N

Initial Speed (m/s)	Stopping Time (sec)
0.906	1.33
0.906	1.48
0.906	1.26
1.14	1.53
1.14	1.61
1.14	1.72
1.36	2.34

1.36	2.28
1.36	2.2
1.53	2.46
1.53	2.41
1.53	2.52
1.69	2.77
1.69	2.6
1.69	2.65

Cart mass: 1.094 kg
Initial speed: 1.025 m/s

Braking Force (N)	Stopping Time (sec)
0.18	4.3
0.18	3.98
0.18	4.18
0.18	4.3
0.32	2.73
0.32	2.66
0.32	2.8
0.35	2.2
0.35	2.39
0.35	2.42
0.45	1.59
0.45	1.86
0.45	1.99
0.45	1.99
0.5	1.68
0.5	1.33
0.5	1.73
0.5	1.6
0.59	1.59
0.59	1.54
0.59	1.6
0.68	1.4
0.68	1.34

0.68	1.41