STEM on Site Summer Program

The Tortoise and the Hare

Image taken from (https://gretchenrubin.com/2013/04/are-you-a-tortoise-or-a-hare-about-work)

Recommended for Grade Levels: 6 - 8

Content Notice

This activity has been put together as a free, open source resource from the Milwaukee School of Engineering STEM team for self-guided, at home learning.

Unless otherwise noted, in person or live instruction is not provided and questions should be directed to stem@msoe.edu.

Safety Notice

Parents or guardians should review activity materials before students begin the activity. Some activities from MSOE may require cutting, hot gluing, electricity, manipulating sharp objects, and other tasks that may warrant adult supervision. MSOE is not liable or responsible for any injury, property damage, or other incidents that arise from completing these activities at home. If you have questions or concerns about any activities, please contact stem@msoe.edu

Notes

Welcome to the Tortoise and the Hare kit! Below you will find learning outcomes (goals), background knowledge, and questions to ask yourself to help guide you through your problem-solving journey.

If you ordered a kit from MSOE. the box that your kit came in will become your ramp for this activity. Please do not cut up the box that this kit came in until you are ready to create your ramp. If you did not order a kit from MSOE, any cardboard box you have on hand should work for this activity.

All the answers to the questions asked in the background knowledge section are at the end of this packet. Parents, please remove the answer key from the kit before proceeding. If your student is stuck on a question, please refer to the answer key to help guide them.

Goals

- Understand the forces that help speed up or slow down an object rolling down a ramp.
- Be able to calculate average velocity.
- Be able to measure the impact a design change has on the variable we are measuring.
- Be able to manipulate kinetic energy though principles of friction and weight distribution.

Materials Required

	NAME
	Cardboard (*)
	Plastic wrap (*)
	Aluminum foil
	Popsicle sticks (x20)
	Felt
	Foam (plates/cups)
	Construction paper
	Bubble wrap
	Plastic bottles (x2) (*)
	PomPoms or Cotton Balls
	Newspaper (*)

REQUIRED TOOLS

	Writing tool for designing and drawing (*)	
	Craft glue (*)	
	Scissors (*)	
	Tape (*)	
	Marker / Sharpie (*)	
	Stop watch or phone with stop watch app (*)	

OPTIONAL TOOLS

	Digital Scale (*)

(*) This item is not included in the kit of parts if you ordered a kit from MSOE

Introduction

The tortoise and the hare have a big race coming up, and they need your help! They must race down a ramp, but the hare wants to go faster, while the tortoise wants to go slower. In this kit you will explore ways to make the hare run faster and make the tortoise walk slower.

In this activity, you will use two identical water bottles (one filled and one empty) to simulate the tortoise and the hare. During the first part of the activity, you will explore ways that you can change the outside of the bottle to make the bottles travel faster or slower down the ramp. During the second part, you will explore how you can add something to the inside of the bottle to change the speed. In the end, you will put together what you have learned to create the fastest and slowest bottle that you can!

Rules for the activity:

1. The racer (the bottle) cannot be cut. You may glue or tape items to the outside if you desire.
2. External forces may not be applied to the racer when it is traveling down the ramp. E.g. you cannot blow on the tortoise to make them go slower.
3. If the racer stands still for more than 3 seconds they are disqualified from the race. They must be constantly moving.
4. You may change the materials that the ramp is made from for durability purposes only! Meaning, you cannot change it to a frictionless surface. Change the racer not the course.

Background Knowledge

<u>Forces and Free Body Diagram</u>

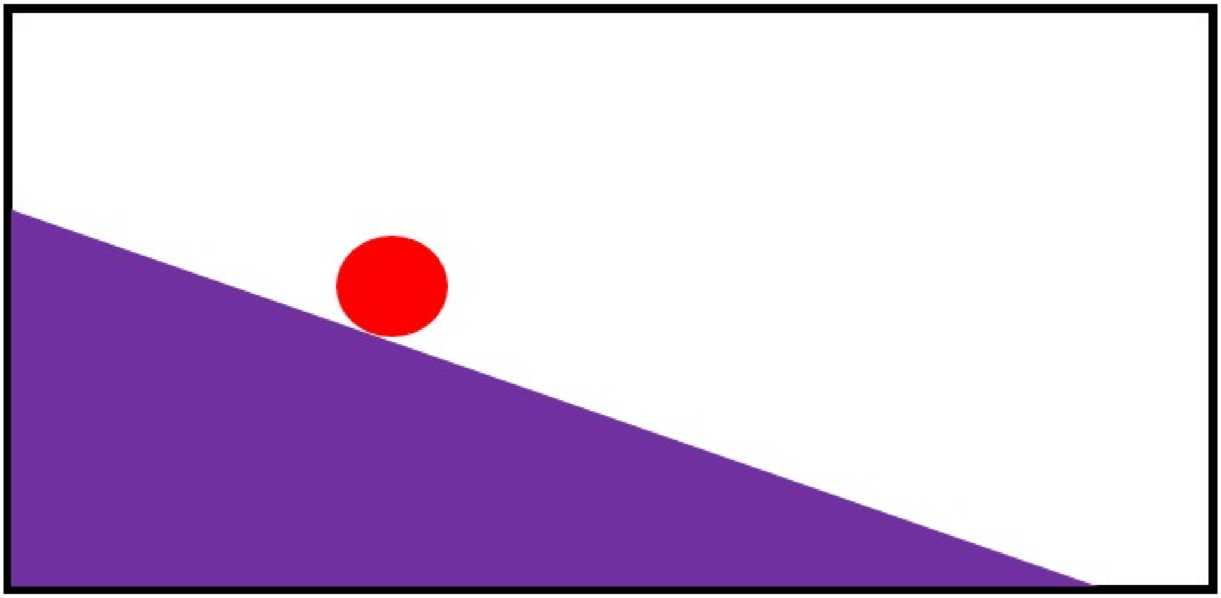
There are several forces that push or pull an object as it is traveling down a ramp. Engineers use what is called a free body diagram (abbreviated as FBD) to draw the forces on the object they are interested in. In our scenario, we will look at a single bottle that is traveling down the ramp.

Every bottle will have a weight to it. If we add more items to the inside or outside of our bottle, the heavier it will be. The weight of the bottle is what causes the bottle to move faster down the ramp. You'll see why when we draw our free body diagram.

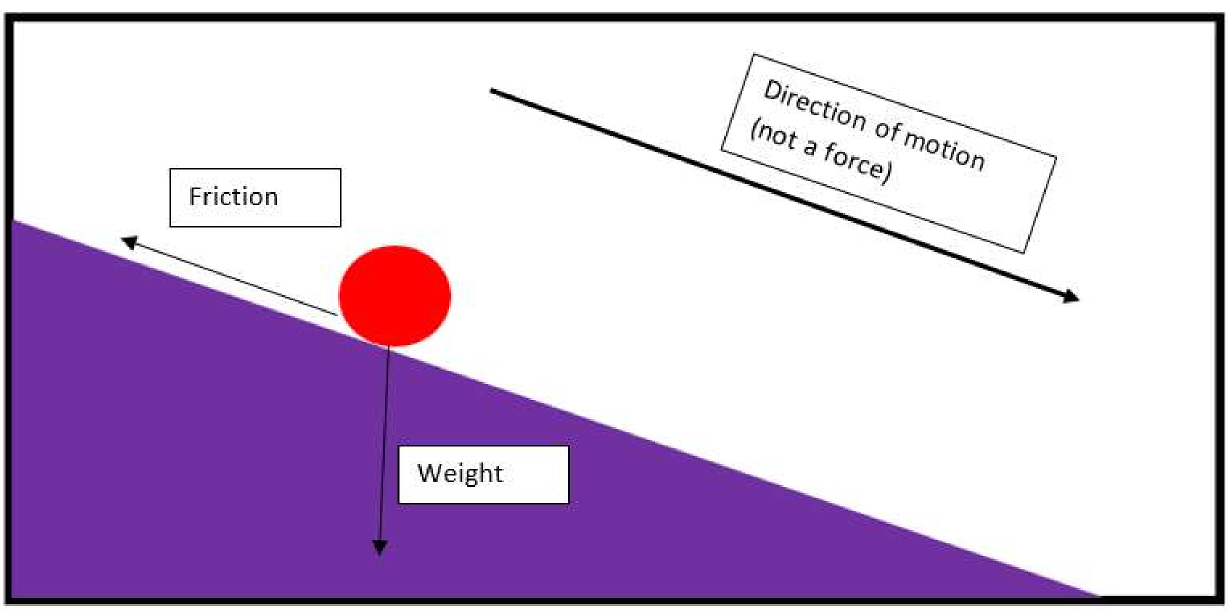
Similarly, every bottle will have friction acting on it and friction will cause the bottle to slow down. Friction can be changed by one of two ways. The first way is by changing the materials that are in contact with each other. For example, think about pushing a box on the sidewalk vs pushing the same box on carpet. Pushing the box on the concrete sidewalk is going to be harder than on the carpet, because the concrete has more friction than carpet. The second way to change the amount of friction to the bottle is by changing the weight of the bottle. For example, let's say that you have two boxes, one that is empty and one that is filled with heavy cinderblocks, and both boxes are on carpet. It will be much easier to push the empty box since it has less friction. Below are two videos that you can watch to better describe friction. For video one, click here, for video two, click here.

Now that we have talked about the two main forces acting on our bottles, lets start drawing our free body diagram. Free body diagrams are not meant to be works of art, so they are going to look like very simple drawings, however, these are highly valued by engineers.

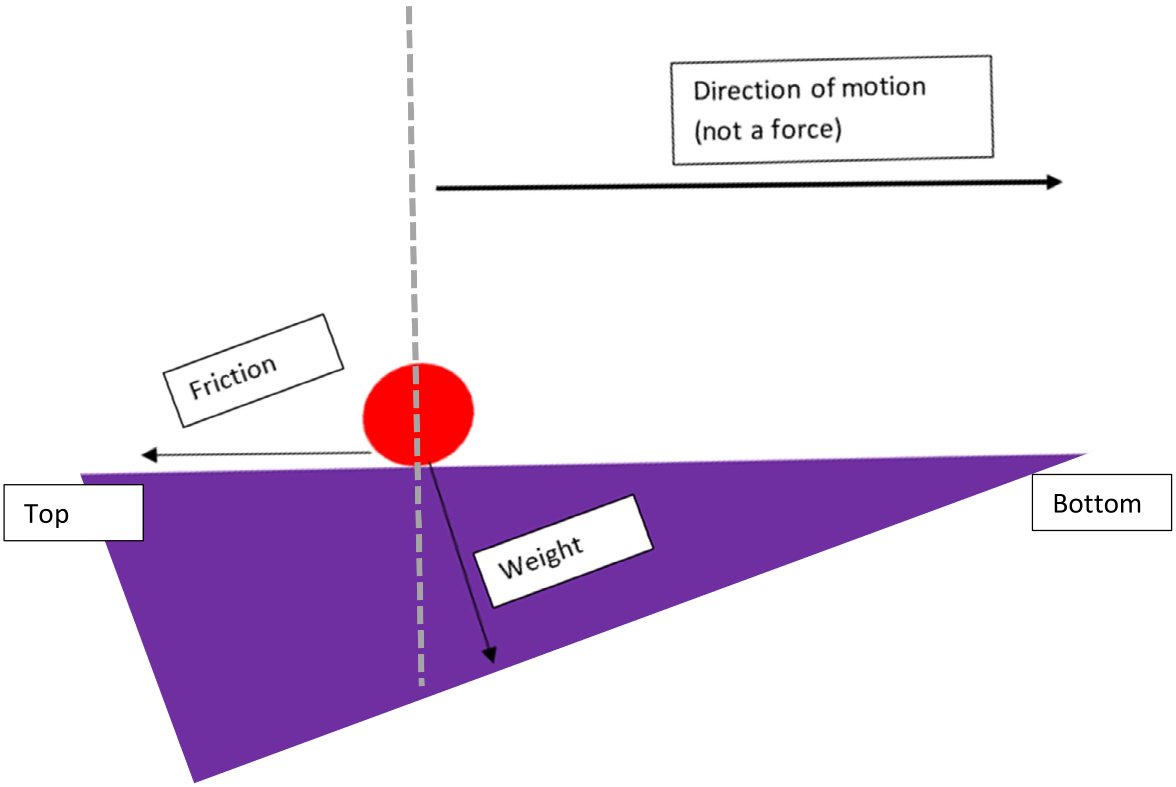
To start, let's draw a side view of the ramp with the bottle in the center of the ramp. The ramp is in purple while the bottle is in red.



Now that we have our basic drawing, we can add our force arrows. All forces have magnitude and direction. Meaning, each arrow will be a different size depending on how strong the force is (magnitude) and each arrow will be pointing in a different direction, depending on how the force acts on the bottle. Since we don't know the magnitude of each force we will choose a random size for each arrow. Weight will ALWAYS be pointing straight down, while friction will ALWAYS point in the opposite direction of motion. Since our bottle is traveling down the ramp, our friction arrow will be pointing up the ramp.



Now that we have drawn our free body diagram, we can rotate it to help us see which side of the ramp (top or bottom) each arrow is pointing to. After we rotate our picture, we can draw a vertical line to help use see which side each arrow is pointing to.



From our finished free body diagram, we can see that force due to weight is pointing in the *general* direction of the bottom of the ramp, while the friction is *directly* pointing to the top of the ramp. Since our weight arrow isn't pointing directly at the bottom of the ramp, that means that we need to change the weight of our bottle, by a considerable amount, if we want to see big changes in the speed of our bottle.

Practice what you learned:

On a piece of paper, draw a free body diagram of you on a sled going down a steep hill. HINT: since snow/ice is so slippery (has very low friction), most engineers wouldn't add friction to their free body diagram, so feel free to do the same.

How does the free body diagram that you drew compare to the one shown above?

If you were to go sledding on a grassy hill, would you go faster or slower than someone of the same weight going down a snowy hill?

Challenge question: if you were to race someone 3 times your weight, what could you do to make yourself go faster without adding weight to your sled? HINT: this concept is not talked about in this kit but will be in July's aerodynamics kit.

Average Velocity

Simply put, velocity is how fast an object is moving. Velocity is measured in units of distance per unit of time. For example, miles per hour (MPH) and meters per second (M/S). By calculating the average velocity, we can quantify (or measure) the effect that our design had on our bottle.

We can calculate the average velocity of an object by taking how far the object moved and dividing it by how long it took of the object to travel that distance. We can also describe this relationship by using the equation below:

$$V = \frac{D}{T}$$

In the equation above, V is the velocity, D is the distance that our object traveled, and T is the time it took the object to travel the full distance.

Example

Let's say our ramp is 4 feet (or 48 inches) long. The tortoise took 48 seconds to get down the ramp while the hare took 2 seconds to get down the ramp. What was the average velocity of the tortoise and the hare?

First, we will calculate the average velocity for the tortoise using the equation above:

$$Velocity = \frac{Distance}{Time}$$

We know that our ramp is 48 inches long, so that will be the distance that each of our racers will travel. We also know that the tortoise took 48 seconds to get down the ramp, so that will be our time for calculating average velocity for the tortoise. Now that we know our variables, let's plug in them into our equation.

$$V = \frac{(48\, inches)}{(48\, Seconds)}$$

When we divide 48 inches by 48 seconds, we get our average velocity for the tortoise:

$$V = 1\,\frac{inch}{second}$$

Now let's calculate the average velocity for the hare. The length of the ramp will not change, the only thing that we will have to change is the time which will be changed from 48 seconds to 2 seconds.

$$V = \frac{(48\, inches)}{(2\, Seconds)}$$

When we divide 48 inches by 2 seconds, we get our average velocity for the hare:

$$V = 24\frac{inch}{second}$$

What does this mean? For every inch that the tortoise moved, a second has gone by. Similarly, the hare was able to travel 24 inches (or half the length of the ramp) for every second that has gone by. Since the hare was able to cover more distance in the same amount of time, we can conclude that the hare is moving much faster than the tortoise, 24 times faster to be exact.

Practice what you learned:

Taking the example that we did above, we decided to improve our design by trying to make the hare go faster and the tortoise move slower. After testing our design, we see that the hare made it down the ramp in 1 second and the and the tortoise went down the ramp in 24 seconds. Calculate the average velocity for both of our racers. NOTE: the ramp is the same length as the example above.

How do the velocities that you just calculated compare to the velocities in the example?

Were our design changes successful? Remember the hare wants to move faster (higher velocity) and the tortoise wants to move slower (lower velocity).

Using your answer from above, what should your next steps be in the design process? Feel free to use the engineering design process handout as a reference.

<u>Viscosity</u>

This part of the background knowledge is for the second part of the activity, where you will change the contents of the bottle to change its speed. Feel free to come back to this section when you feel that you have explored all there is in the first part of the activity.

Viscosity can simply be defined as how thick a liquid is. In a liquid, all the molecules are constantly moving around and sliding past each other. Like everything that moves, each molecule is experiencing friction from the other molecules. The more friction there is, the thicker the liquid is going to be because the molecules are not able to move around as freely.

Test it out!

How can you compare liquids to see which one is more viscous than the other? Simple! All you need is a marble and a clear glass or cup. Fill the cup halfway with the liquid you want to test, drop the marble in, and time how long it takes the marble to reach the bottom of the cup. The longer it takes the more viscous the liquid! Repeat these simple steps with multiple liquids, being sure that you fill each cup to the same spot. NOTE: be sure to ask permission from an adult before you test the liquid! When you test a liquid, you don’t want to pour it back in its original container.

How can we use viscosity to help us slow down the bottle?

Without the help of the internet, what is the most viscous liquid that you can think of? Would you be able to use it in your design?

Directions For Exploration

General Set up

1. For setting up the ramp go to the “Ramp Set-Up Guide” document.
2. Find book, movie cases, video game cases, or anything else that you can stack 3 inches high.
3. Set the ramp on the stack that you made. You may need to make more than one stack to ensure that the ramp is stable.
4. Draw a straight line at the top of the ramp. This will be your starting line, your finish line will be ground.
5. Take a tape measure or ruler and measure the distance from the starting line to the finish line. This will be your distance in all of your calculations.

Part 1 – The outside

1. Locate your two bottles and fill one of them with water while keeping the other empty. When starting the activity, the filled bottle will be your tortoise and the empty will be your hare. When you get further into the activity you are welcome to drain or add water/ other materials
2. On a sheet of paper, make a list of ideas of how you can increase or even decrease friction. Feel free to search online for ideas. HINT: the longer the list you make the more you can experiment!
3. When you have a long list of ideas, test them out! Build your bottle according to your ideas and calculate the average velocity for multiple trials. Feel free to use the table below to help keep track of your designs. If you have more than 10 designs, re-draw this table on the provided graph paper and add the needed number of rows.
4. When you have built and tested all of your ideas, make a note of which one is the best

Part 2 – The Inside

1. Locate your two bottles and make sure that both of them are empty.
2. On a sheet of paper, make a list of viscous liquids. Feel free to search online for ideas. HINT: the longer the list you make the more you can experiment! Also, try to make a list of liquids that you have around the house!
3. When you have a long list of ideas, test them out! Fill one of your bottle according to your ideas and calculate the average velocity for multiple trials. Feel free to use the table below to help keep track of your designs. If you have more than 10 designs, re-draw this table on the provided graph paper and add the needed number of rows.
4. When you have built and tested all of your ideas, make a note of which one is the best

Part 3 – The Big Race

1. Review your calculated average velocity tables. What designs produced the best results?
2. Combine the designs from part 1 and part 2 to create the ultimate racer!
3. When you feel that you have made the best possible racers, share your ideas with everyone! Take a video and post it on our Facebook page. Parental assistance required.

Questions To Ask Yourself:

Tape is a great way to slow down your racer, but over time it becomes less sticky. Is there a more long-term solution?

When filling your bottle with various liquids, is there a difference in how the bottle behaves when the bottle is filled to the top vs filled halfway vs barely any liquid in there?

Is there a way to change the inside and the outside of the bottle such that the bottle doesn’t rotate down the ramp, it slides down the ramp?

Part 1 – The Outside

Bottle Design Name	Average Velocity (Trial 1)	Average Velocity (Trial 2)	Average Velocity (Trial 3)	Average of the three trails***

*** To find the average of the three trials, add up the velocities from each trial and divide by the number of trials. If you did three trails, you would divide by 3***

Part 2 – The Inside

Bottle Design Name	Average Velocity (Trial 1)	Average Velocity (Trial 2)	Average Velocity (Trial 3)	Average of the three trails***

*** To find the average of the three trials, add up the velocities from each trial and divide by the number of trials. If you did three trails, you would divide by 3***

Part 3 – The Big Race

Bottle Design Name	Average Velocity (Trial 1)	Average Velocity (Trial 2)	Average Velocity (Trial 3)	Average of the three trails***

*** To find the average of the three trials, add up the velocities from each trial and divide by the number of trials. If you did three trails, you would divide by 3***

Ramp Set Up Guide

Materials Needed:

- A cardboard box (if you ordered a kit from MSOE, use the box your materials came in)
- A Marker
- A pair of Scissors or box cutter
- Popsicle sticks (optional, but strongly encouraged)
- Tape (optional, but strongly encouraged)
- Parental supervision (optional, but strongly encouraged)

Note: If you have scrap materials at home, like wood or foam insulation, feel free to use that as a sturdier ramp. We recommend trying the cardboard box version first to practice.

Steps for set up:

1. Remove contents of the box. Notice that your box may have a side larger than the other.

2. With the box sitting upright and the largest side facing you, put a star of the front and back.

3. Cut along the vertical edges so the box lays flat but is still connected by the bottom.

4. Locate the starred sides and remove the **unstarred** sides.

5. (optional step) Tape popsicle sticks to the folds of the box to make the ramp sturdier. In the picture blow I used old pens and mechanical pencils, you may also use more books or movie cases for more support

6. When you are done, the ramp should be stiff enough to hold its own weight and the weight of a bottle. Please note, depending on your designs you may need to reinforce the ramp, if you choose to weigh down the ramp.

Answer Key

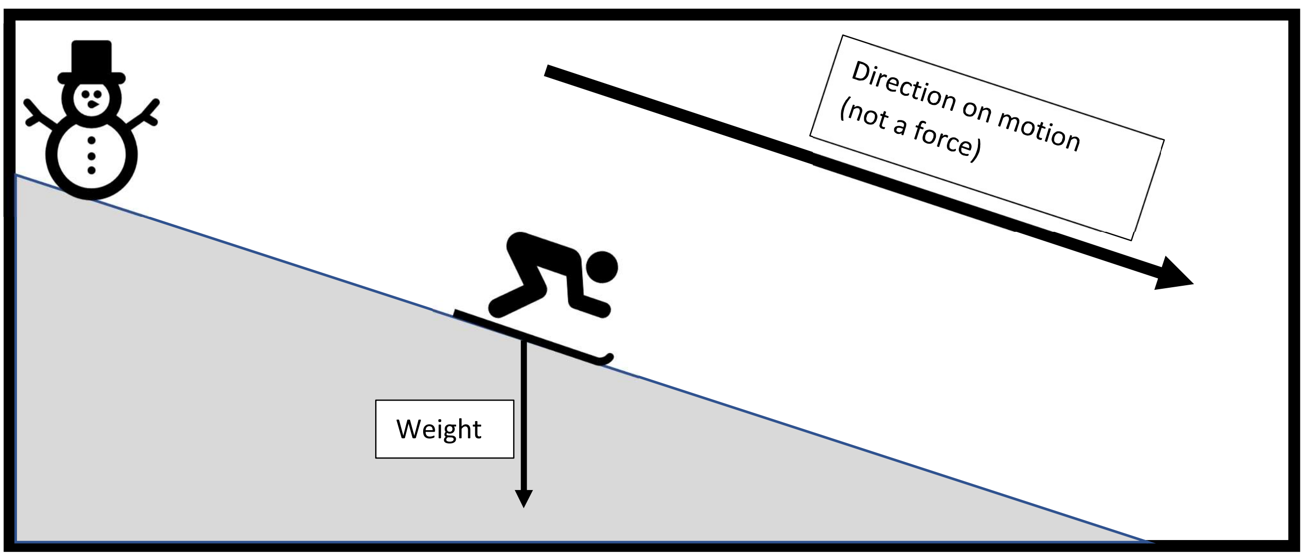
All the answers to the questions asked in the background knowledge section are in this document. **Parents, please remove this answer key from the packet of instructions before your student begins.**

If your student is stuck on a question, please refer to this document to guide them to the answer. Note, not all of the answers will be exactly the same. For questions that have more than one response, there will be the word "sample" in front our response.

Forces and Free Body Diagram

On a piece of paper, draw a free body diagram of you on a sled going down a steep hill. HINT: since snow/ice is so slippery (has very low friction), most engineers wouldn't add friction to their free body diagram, so feel free to do the same.

SAMPLE:



How does the free body diagram that you drew compare to the one shown above?

It does not have the force due to friction. Since ice/snow has a low coefficient of friction, it is often considered a frictionless surface in most cases.

If you were to go sledding on a grassy hill, would you go faster or slower than someone of the same weight going down a snowy hill?

You would travel much slower on a grassy hill compared to a snowy hill. A snowy hill would be considered frictionless while the grassy hill would have a considerably high amount of friction.

Challenge question: If you were to race someone 3 times your weight, what could you do to make yourself go faster without adding weight to your sled? HINT: this concept is not talked about in this kit but will be in July's aerodynamics kit.

You can lay flat on your sled reducing your overall surface area. By reducing your surface area, you reduce the amount of wind resistance that is slowing you down.

Average Velocity

Taking the example that we did above, we decided to improve our design by trying to make the hare go faster and the tortoise move slower. After testing our design, we see that the hare made it down the ramp in 1 second and the and the tortoise went down the ramp in 24 seconds. Calculate the average velocity for both of our racers. NOTE: the ramp is the same length as the example above.

Velocity for the tortoise:

$$V_{Tortoise} = \frac{D}{T}$$

$$V_{Tortoise} = \frac{(48\ inches)}{(24\ Seconds)}$$

$$\boldsymbol{V_{Tortoise} = 2\frac{inches}{second}}$$

Velocity for the hare:

$$V_{Hare} = \frac{D}{T}$$

$$V_{Hare} = \frac{(48\ inches)}{(1\ Second)}$$

$$\boldsymbol{V_{Hare} = 48\frac{inch}{second}}$$

How do the velocities that you just calculated compare to the velocities in the example?

In the original example the tortoise moves at velocity of 1 in/sec and in this example, they moved at 2 in/sec. In this problem, the tortoise moved faster than he originally did.

In the original example the hare moves at velocity of 24 in/sec and in this example, they moved at 48 in/sec. In this problem, the hare moved faster than he originally did.

Were our design changes successful? Remember the hare wants to move faster (higher velocity) and the tortoise wants to move slower (lower velocity).

The design changes that we made for the hare were successful. The changes allowed the hare to double his speed.

The design changes that we made for the were unsuccessful. The changes that we made allowed the tortoise to travel at double his original speed.

Using your answer from above, what should your next steps be in the design process? Feel free to use the engineering design process handout as a reference.

*For both the tortoise and the hare we need to ask ourselves, is there a way I can improve this? For the hare, we achieved our goal by making them faster, however, is our design the **best** design that is possible? For the tortoise, the original design was better, but again, was the original design the **best** design possible?*

Viscosity

How can we use viscosity to help us slow down the bottle?

If applied correctly, a viscous liquid will slow the rotation of or bottle. By slowing the rotation, our bottle will travel down the ramp at a slower rate or velocity.

Without the help of the internet, what is the most viscous liquid that you can think of? Would you be able to use it in your design?

Sample:

Below is a table of possible ideas. "would I be able to use it?" refers to if it is present in a typical household.

Liquid Type/ Name	Would I be able to use it?	Notes
Vegetable Oil	Yes	Slightly more viscous than water
Tar	No	Extremely viscous when warm, considered a solid when cooled
Corn Syrup	Yes	Very viscous
Honey	Yes	Very viscous
Vinegar	Yes	Same viscosity as vinegar