Science Unit: ***The Force, Energy Transfer and Machines***

Lesson #3: ***Spring Catapult – Testing: "Force equals Mass x Acceleration"***

Lesson Summary

Students build simple machines (catapults made of popsicle sticks and elastic bands) to observe and test *Newton's Second Law of Motion*. They measure the distance their catapults are able to "throw" two different sizes of marshmallows. Students will observe that (because of the 2nd law) the smaller marshmallows have a greater accerlation and therefore travel a futher distance.

School Year:	2016/2017
Developed for:	Cunningham Elementary School, Vancouver School District
Developed by:	Dominic Tollit (scientist); Marielle Weisinger and Atsuko Fairweather (teachers)
Grade level:	Presented to grades 4-5, suitable for grades 4-7 with modifications
Duration of lesson:	1 hour and 20 minutes
Notes:	This lesson links with two more lesson on force and energy transfer

Objectives

a) Learn about kinetic energy transfer to mechanical energy (work) through building a simple machine and testing one of Newton's three Laws on Motion: Newton's 2nd Law of Motion, which is most easily explained as Force = Mass x Acceleration.

b) Build a popsicle stick-elastic band catapult to learn about energy transfer and force. Test the distance the catapult can shoot 2 different sizes of marshmallow. Discuss results in the light of Newton's 2nd Law. A catapult that provides equal force to an object will accelerate objects with small mass quicker than those with a large mass and thus throw the smaller mass objects further.

Background information

Sir Isaac Newton (1642 -1726) was an English mathematician, astronomer, and physicist ("natural philosopher") who is thought of as one of the most influential scientists of all time and a key figure in the scientific revolution. His book "Principles of Natural Philosophy", published in 1687, laid the foundations of classical mechanics. Newton's Principia formulated the laws of motion and universal gravitation that dominated scientists' view of the physical universe for the next three centuries. Newton also built the first practical reflecting telescope.

His three laws of motion can be summarised as follows:

First law: An object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.

Second law: The sum of the forces **F** on an object is equal to the mass **m** of that object multiplied by the acceleration **a** of the object: **F = ma.**

Third law: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

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Vocabulary

Force: There are forces all around us. A force is a push or a pull. It is something that acts on an object. The wind makes a force when it blows, gravity is a force that pulls everything down to the center of the earth (because the earth is both large and spins). Animals and machines make force. Force is measured in Newtons. A catapult uses force to shoot rocks at a city wall during a siege. So to move something or do work you exert a force. The bigger the object the more force needed to move it. This is known as Newton's Second Law of Motion, summarized as Force equals Mass x Acceleration (i.e., F = ma).

Mass: Mass is the amount of matter in an object. Mass is measured in kilograms and the mass of an object will not change if the object is moved to another planet. In contrast, weight refers to the force exerted on an object by gravity and will change if moved to another planet. Weight is therefore actually measured in Newtons!

Velocity: Equivalent of speed or rate of change in position as a function of time e.g., metres per second. A car moving from stationary (zero velocity) to 60 km/h is accelerating or changing speed.

Acceleration: Rate at which the velocity of a body changes with time e.g., metres per second per second. A car travelling steadily at 60 km/h on a highway is not accelerating (it is at a constant velocity).

Machine: Mechanical devices that allow us to make our energy transfer more efficient. Work is performed by applying a force over a distance. Simple machines create a greater output force than the input force (called mechanical advantage). There are six simple machines: the lever, wheel and axle, inclined plane, wedge, screw and pulley. All six have been used for thousands of years. These machines can be used together to create even greater mechanical advantage, as in the case of a bicycle.

Materials

- 6 small popsicle per catapult
- 2 large popsicle sticks per catapult (note these need notching before class)
- Bag of small elastic bands (3 needed per catapult)
- 1 bag of small marshmallows
- 1 bag of large marshmallows
- 6 - 5 m tape measures, 12 - 1cm high blocks of wood or book

<u>In the Classroom</u>

Introductory Discussion

1. Short description of 'hook' to capture student's attention.
   - There are forces all around us. A force is a push or a pull. It is something that acts on an object. The wind makes a force when it blows, gravity is a force that pulls everything down to the center of the earth (because the earth is both large and spins). The greater the mass of the object the greater the force of gravity. Animals and machines make force. Frogs jumping, jet engines forcing a plane into the sky, a catapult uses force to shoot rocks at a city wall during a siege.
   - So to move something or do work you exert a force. The bigger the object the more force needed to move it. This is known as Newton' Second Law of Motion. We all know it's easier to move a football with our feet than a brick wall – this is one of the laws of science and helped humanity start to better understand the universe!

- Today - we're going to learn about force (and test this 2nd 'Law of Motion') and as we observed in the previous two lesson - see how energy changes from one form to another within a simple machine. We are going to make and then fire our own self-built catapults. We will apply a force and shoot objects (hold up the bags of marshmallows – and explain they will be safe to use). The force in this case will come from 'a machine' - made out of popsicle sticks (show one already made) – and using stored potential energy from a tightened elastic band.
- Discuss briefly the use of a catapult in past times such as the Romans (or in medieval times) who built large catapults to smash city walls or fish opposing armies – capable of shooting large rocks 100s of metres.

2. Short description of other items to discuss or review.

   Remind students that our populations have used complex machines (cars, planes, trains, looms, mighty machines) to accelerate the use of the planet's resources in the last century and so urgent need for conservation is required. Get the students to brainstorm solutions – re-introduce the four 'Rs' Reduce, Recycle, Reuse and Renewable energy.

3. Briefly describe science experiment/activity.

   Every student will build a popsicle stick-elastic band catapult to learn about energy transfer and force. They will test the distance the catapult can shoot 2 different sizes of marshmallow and then discuss results in the light of Newton's 2nd Law. A catapult that provides equal force to an object will accelerate objects with small mass quicker than those with a large mass and thus throw the smaller mass objects further. It is suggested the teachers builds a catapult in front of the class to show them how it is done and how easy it is.

4. Briefly describe the processes of science that the students will focus on (prediction/hypothesis, observations, recording results, conclusions.)

   This lesson includes making predictions, planning and conducting an experiment and observing and making measurements, collecting data and making conclusions.

5. Briefly describe safety guidelines.

   - Remind students that the catapult can be dangerous if hard objects are fired and that the object can shoot straight up from the catapult. Encourage nothing but marshmallows should be used.

Science Activity/Experiment

<u>Experiment Title</u>: Catapults – Testing "Force equals mass times acceleration"

<u>Purpose of Experiment</u>: Students will learn how if energy input from a catapult remains the same then an object with low mass will be fired quicker and so further than an object with high mass.

<u>Methods:</u>

1. Before the class, using a hacksaw, cut a small notch on either side of each large popsicle stick about 2 cm in form one end.

2. Explain to the class that we already know we cannot create new energy and show the catapult gives the same amount of energy (and force) to the marshmallow each time it is fired, because there is a limit to how much we can stretch the elastic band (show the catapult working by shooting a small marshmallow).

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We also know more force is required to move (accelerate) a large object than a small object (as predicted by Newton's second law of motion – which is Force = Mass x Acceleration).

3. Ask the students: "What can we then predict if we fire two sizes of marshmallow (each with a different mass – one small and one large marshmallow) using the same force or amount of energy?"
   - Take answers from students.
   - Encourage final answer of "The catapult will shoot the small marshmallow faster and so further (and/or higher)" (or "The catapult will shoot the large marshmallow slower and so not so far (and/or higher)".

4. Agree upon a final experimental prediction of hypothesis: The energy from the catapult will shoot the small marshmallow faster and so further than the large marshmallow.

5. Discuss with the class how this might be done. How do we set up an experiment to test this? Encourage firing (in exactly same way) some small marshmallows and some large marshmallows and comparing the distance they are fired. Provide an example of what's required during a test fire, display the worksheet and how to fill it out.

6. Have the students come up and collect 6 small popsicle sticks, 2 large notched popsicle sticks, 5 elastic bands, 2 small, 1 large marshmallow and a worksheet.

7. Have them each build a catapult. The following website shows how to build the catapult (see https://www.youtube.com/watch?v=XchdUB-ZnKc for details).

   It can be built as follows:

   - Stack the six small popsicles neatly together, and wrap an elastic band around each end of the stack 5 times (tightly).

   - The two large popsicle sticks are placed (with the pre-cut notches lined up on both sticks evenly) one on top of the small popsicle stack and one between the last small popsicle stick and the 2nd last popsicle stick. It is actually easier to place this second large stick prior to wrapping the elastic bands in the step before rather than try to insert it.

   - Make three wraps around **both** the large popsicle sticks wherever the pre-cut notches are lined up. Slide the stack of small sticks towards the rubber band until the catapult feels solid and strong when the non-notched ends of the large popsicle sticks are compressed together and then released.

8. Once everyone has built their catapults, pair up students, remind them to write their name and the date on worksheets and then provide a tape measure for each 2 student pairs to measure their marshmallow launches.

9. Set the tape measures out on the floor around the room. Pairs of students can work side by side by each tape measure. The small marshmallow will shoot at least 4-5m. Rest the back of the catapult (the end of the large popsicle sticks without the elastic) on the wooden blocks or a book to prevent the marshmallows going to high. Explain that you want them to test one of the pair's catapult – using it to fire the small then large marshmallow three times (i.e., repeats). One student fires from a set line and the other student measures the distance in cm from the catapult to the place the marshmallow lands on each launch. Students swop between different marshmallow sizes so each does both activities.

10. Record the results in worksheet and calculate average distance (distance = value a + value b + value c / 3) for small and large marshmallow using a calculator.

11. Explain students have to determine which size of marshmallow is fired the greatest distance and then to make a conclusion based on our understanding of force and its relationship to mass and acceleration (i.e., is our prediction based on Newton's Law of Motion correct?).

12. Make sure measuring in cm and placing the catapult from the same place (start of the tape measure). Help as necessary. Check that the measurements have been added up and divided by three to get an average for each marshmallow size.

Closure Discussion:

- Ask which pairs had a greater average distance for the small marshmallow (all should). Congratulate the class on proving a universal law of motion.

- Discuss the logic of why this always happens - bringing in F = m x a.

- If need be, use whiteboard to provide an example. Let's say our catapult provides a constant force of 10 Newtons and our small marshmallow weighs 1 g and the large marshmallow is 5g – so using Force=mass x acceleration. The small 1g marshmallow shot with 10 Newton's of force = 1 grams multiplied by a (acceleration), therefore a=10. The large 5g marshmallow shot with same Newton's of force = 5 grams multiplied by a (acceleration), therefore a=2. The acceleration of the small marshmallow will be 10 and the large one only 2. Greater acceleration (rate of velocity change) means it will travel further.

- Review class knowledge of force, energy transfer in catapults. Discuss forces involved in shooting a rocket into space noting less force is needed to propel a rocket in deep space than when outside the gravitational pull of the earth! What would happen if we had fired an even bigger marshmallow? How did the Romans fire huge rocks (with larger machines that create more force). Ensure students understand difference between acceleration (rate of speed) and velocity (speed).

Extension of Lesson Plan

1. Review other Laws of Motion
2. Discuss other simple machines (see description of the six main types below)

The Six Types of Simple Machines

1. **Lever**

A lever is a simple machine that consists of a rigid object (often a bar of some kind) and a fulcrum (or pivot). Applying a force to one end of the rigid object causes it to pivot about the fulcrum, causing a magnification of the force at another point along the rigid object. There are three classes of levers, depending on where the input force, output force, and fulcrum are in relation to each other. Baseball bats, seesaws, wheelbarrows, crowbars and catapults are types of levers.

2. **Wheel & Axle**

A wheel is a circular device that is attached to a rigid bar in its center. A force applied to the wheel causes the axle to rotate, which can be used to magnify the force (by, for example, having a rope wind around the axle). Alternately, a force applied to provide rotation on the axle translates into rotation of the wheel. It can be viewed as a type of lever that rotates around a center fulcrum. Ferris wheels, tires, and rolling pins are examples of wheels & axles.

3. **Inclined Plane**

An inclined plane is a plane surface set at an angle to another surface. This results in doing the same amount of work by applying the force over a longer distance. The most basic inclined plane is a ramp; it requires less force to move up a ramp to a higher elevation than to climb to that height vertically. The wedge is often considered a specific type of inclined plane.

4. **Wedge**

A wedge is a double-inclined plane (both sides are inclined) that moves to exert a force along the lengths of the sides. The force is perpendicular to the inclined surfaces, so it pushes two objects (or portions of a single object) apart. Axes, knives, and chisels are all wedges. The common "door wedge" uses the force on the surfaces to provide friction, rather than separate things, but it's still fundamentally a wedge.

5. **Screw**

A screw is a shaft that has an inclined groove along its surface. By rotating the screw (applying a torque), the force is applied perpendicular to the groove, thus translating a rotational force into a linear one. It is frequently used to fasten objects together (as the hardware screw & bolt does), although Babylonians developed a "screw" that could elevate water from a low-lying body to a higher one (which later came to be known as Archimedes' screw).

6. **Pulley**

A pulley is a wheel with a groove along its edge, where a rope or cable can be placed. It uses the principle of applying force over a longer distance, and also the tension in the rope or cable, to reduce the magnitude of the necessary force. Complex systems of pulleys can be used to greatly reduce the force that must be applied initially to move an object.

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Catapult Data Sheet:
Testing Newton's 2nd Law of Motion

(fill in grey area using tape measure)

Name(s):

Date:

Hypothesis: Newton's 2nd Law of Motion (Force = m x a) means the energy from a single catapult will shoot the small marshmallow faster and so further than the large marshmallow.

Marshmallow size	**Catapult launch number**	**Distance from catapult to where marshmallow landed (measured in cm)**
Small	1:	1:
Small	2:	2:
Small	3:	3:
Small marshmallow summary	All three launches	**Average distance:**
Large	1:	1:
Large	2:	2:
Large	3:	3:
Large marshmallow summary	All three launches	**Average distance:**

Conclusion:

1. **Which size** of marshmallow (large or small) is on average **fired further** distance?

2. Does this prove our prediction based on the Newton's second Law of Motion?

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Background Information for the Teacher:

How Newton's Second Law of Motion Describes the Phenomenon Observed in this Experiment

1. This experiment demonstrates a fact about our universe: F=ma. In this case, this means that a smaller marshmallow will be "thrown" a greater distance by a catapult than a larger marshmallow (when the catapult uses the same amount of force to launch both marshmallows).

2. Physics uses math to describe the universe, which is *very* cool!

3. Newton's 2nd Law states that:

   Force (F) = mass (m) x acceleration (a)
   F = m x a

4. Let's say we know that our catapult provides a constant force of 10 Newtons.
   (That means **F** = 10 Newtons)

5. Now, let's say that the masses of our marshmallows are known:
   Mass of small marshmallow = 1 gram
   Mass of large marshmallow = 5 grams

6. To calculate the acceleration for each marshmallow, we can **rearrange** the equation above. First, divide both sides of the equation by mass (m). Then, cancel the m/m (because it equals 1).

Step 1: The original equation	F = m x a
Step 2: Divide both sides by m	F/m = (m x a)/m
Step 3: Cancel the m/m	$F/m = (\cancel{m} \times a)/\cancel{m}$
Step 4: "Solve for a"	F/m = a

7. Calculate the *acceleration* for the **small marshmallow** (1 gram):

   F / m = a 10 / 1 = **10**

8. Calculate the *acceleration* for the **large marshmallow** (5 grams)

   F / m = a 10 / 5 = **2**

9. Finally, compare the two marshmallow accelerations. (The greater the acceleration, the farther the marshmallow will travel.)

10. The **smaller marshmallow** has a **greater acceleration**, so it will travel farther. And it does!

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