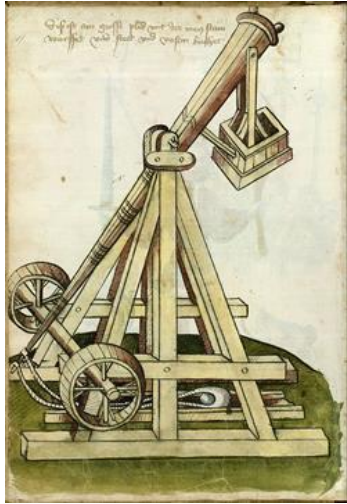




Name: _____

Date: _____

Student Exploration: Trebuchet



Vocabulary: air resistance, counterweight, counterweight trebuchet, efficiency, gravitational potential energy, kinetic energy, launch angle, payload, projectile, siege engine, torque

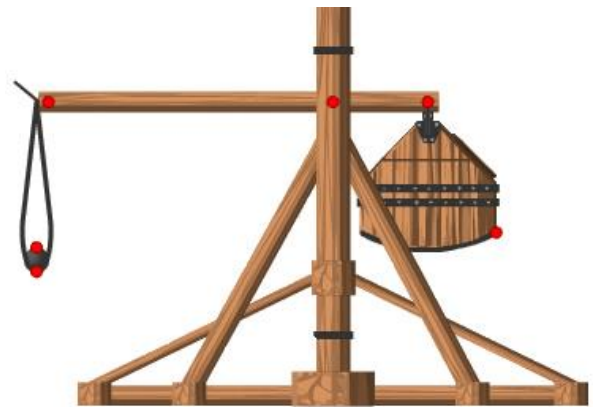
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. During the Middle Ages, armies often attacked castles using large **siege engines** such as the **counterweight trebuchet** at left. What challenges might you face if you attacked a castle?

2. What are some ways to defend a castle against attack? _____

Gizmo Warm-up

A counterweight trebuchet acts like a giant seesaw. Hanging from the “short arm” of the beam is a heavy **counterweight**. From the “long arm,” a sling holds the **payload**, usually a rock. In the *Trebuchet* Gizmo, you can design your own trebuchet to attack a city or castle.



1. From the **Tools** menu, drag the **Help** icon over each red dot on the trebuchet to see the name of the part. Use letters to label each part on the diagram to the right.

A) Counterweight, B) payload, C) fulcrum, D) short arm, E) long arm, F) sling, G) prong

2. Click **Launch test**. Describe the motion of a trebuchet. _____



Activity A: Trebuchet design	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> Click Reset. On the DESIGN tab, check that the Counterweight is 4500 kg, Payload is 160 kg, Fulcrum is 9.0 m, Short arm is 3.0 m, Long arm is 9.0 m, Sling is 5.0 m, and Prong angle is 40°. 	
---	--	---

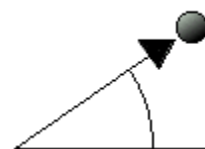
Introduction: Once the payload is in the air, it is called a **projectile**. In this activity, you will see how each dimension of the trebuchet affects the angle and speed of the projectile.

Question: How can you adjust the angle and speed of a projectile thrown by a trebuchet?

1. Test: Click **Launch test**. Look at the results displayed at lower right.

A. What is the initial angle of the launch? _____

The **launch angle** is measured from the horizon, as shown:



B. Which trebuchet dimensions do you think will have the biggest effect on the launch angle? _____

2. Experiment: While keeping all of the other settings the same, experiment with different sling lengths. You can change the sling length by dragging the bottom of the sling, or by entering the desired length in the **Sling length** text box. For each sling length, click **Launch test** and record the launch angle and initial speed of the projectile. Click **Reset** between each test.

Sling length	5.0 m	6.0 m	7.0 m	8.0 m	9.0 m
Launch angle					
Initial speed					

3. Analyze: How does increasing the sling length affect the launch angle and initial speed of the projectile? _____

4. Experiment: You can change the angle of the prong by dragging its tip inside the circle or by entering the desired angle in the **Prong angle** text box. Check that the **Counterweight** is 4500 kg, **Payload** is 160 kg, **Fulcrum** is 9.0 m, **Short arm** is 3.0 m, **Long arm** is 9.0 m, and **Sling length** is 9.0 m. For each prong angle, record the launch angle and initial speed.

Prong angle	0°	20°	40°	60°	80°
Launch angle					
Initial speed					

(Activity A continued on next page)



Activity A (continued from previous page)

5. Analyze: How does increasing the prong angle affect the launch angle and initial speed of the projectile? _____

6. Compare: Moving the counterweight farther from the fulcrum will increase the **torque**, or rotational force, on the beam of the trebuchet. However, it will also mean that the counterweight has to move farther to move the long arm the same distance.

Set up the trebuchet using the measurements given with each table below. For each trebuchet, explore different **Short arm** lengths and record the initial speed of the projectile.

Trebuchet 1

Counterweight = 4,000 kg, **Payload** = 200 kg, **Fulcrum** = 9.0 m, **Long arm** = 9.0 m, **Sling** = 9.0 m, and **Prong angle** = 40°.

Short arm length	1.0 m	2.0 m	3.0 m	4.0 m	5.0 m	6.0 m
Initial speed						

Trebuchet 2

Counterweight = 6,000 kg, **Payload** = 40 kg, **Fulcrum** = 9.0 m, **Long arm** = 9.0 m, **Sling** = 9.0 m, and **Prong angle** = 40°.

Short arm length	1.0 m	2.0 m	3.0 m	4.0 m	5.0 m	6.0 m
Initial speed						

7. Analyze: Compare Trebuchet 1 (T1) and Trebuchet 2 (T2).

A. How do the trebuchets differ? _____


B. For Trebuchet 1, which short arm length produced the greatest initial speed? _____

C. For Trebuchet 2, which short arm length produced the greatest initial speed? _____

D. In general, what short arm length maximizes the initial speed when the payload is very heavy compared to the counterweight? _____

E. How does the optimum short arm length change when the payload is very light compared to the counterweight? _____



Activity B: Attack!	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> • Select the LAUNCH tab. • Check that the Siege of Acre is selected. 	
--	--	---

Introduction: The Siege of Acre occurred during the Third Crusade. Acre, a port city north of Jerusalem, was attacked by the combined armies of King Philip II of France and King Richard I of England. The crusaders used trebuchets to breach the city walls, eventually leading to the city's surrender in July, 1191.

Goal: Design trebuchets to breach the walls of Acre and Castle Stirling.

1. Observe: To breach the walls of Acre, your projectile has to hit the walls with enough force.

A. What is the distance from the trebuchet to the city walls? _____

B. The projectile's **kinetic energy** (KE) depends on its mass and speed, given by

$KE = \frac{1}{2} m \cdot v^2$. How much kinetic energy is required to break through? _____

C. On the DESIGN tab, set **Counterweight** to 4500 kg, **Payload** to 160 kg, **Fulcrum** to 9.0 m, **Short arm** to 3.0 m, **Long arm** to 9.0 m, **Sling** to 5.0 m, and **Prong** to 40°.

On the LAUNCH tab, click **Play** (▶). How far did the projectile go, and what was its impact KE ? _____

2. Design: Click **Reset** (↺). Use what you have learned, as well as trial and error, to create a trebuchet that can fling a projectile and break the city walls. Use the DESIGN tab to build your trebuchet, and then test your design with the LAUNCH tab.

When you have created a successful trebuchet, click **Screen shot** on the **Tools** menu to take a snapshot. Right-click the image, choose **Copy**, and then paste the image into a blank document to turn in with this worksheet. Record the dimensions of your trebuchet below.

Counterweight: _____ Fulcrum height: _____ Long arm length: _____

Payload: _____ Short arm length: _____ Sling length: _____ Prong angle: _____

3. Challenge: Suppose King Philip could only build a 3,500-kg counterweight. Can you create a trebuchet with a 3,500 counterweight that can still break the walls of Acre? If so, take a screenshot and record the dimensions below.

Counterweight: _____ Fulcrum height: _____ Long arm length: _____

Payload: _____ Short arm length: _____ Sling length: _____ Prong angle: _____

(Activity B continued on next page)



Activity B (continued from previous page)

4. Observe: Click **Reset**. On the LAUNCH tab, select **Stirling Castle**. In 1304, King Edward I of England ordered the construction of the world's largest trebuchet, dubbed the Warwolf, to attack Stirling Castle in Scotland. Although the Scots tried to surrender before the trebuchet was finished, Edward refused to accept their surrender until after the power of the mighty Warwolf had been demonstrated, and part of the castle was demolished anyway.

A. What is the distance from the trebuchet to the castle walls? _____

B. How much kinetic energy is required to break through? _____

5. Design: Create a trebuchet that can fling a projectile and break the walls of Stirling Castle. When you have created a successful trebuchet, take a screenshot of the destroyed castle and add it to your document. Record the dimensions of your trebuchet below.

Counterweight: _____ Fulcrum height: _____ Long arm length: _____

Payload: _____ Short arm length: _____ Sling length: _____ Prong angle: _____

6. Challenge: The Warwolf hurled rocks as heavy as 160 kg at the castle walls. See if you can create a trebuchet that can hit Stirling Castle with a 160-kg projectile. If you succeed, paste a screenshot into your document and record the dimensions below.

Counterweight: _____ Fulcrum height: _____ Long arm length: _____

Payload: _____ Short arm length: _____ Sling length: _____ Prong angle: _____

7. Explore: Today, hobbyists build trebuchets for fun and competition. At the annual "Punkin Chunkin" contest, modern trebuchets have hurled pumpkins over 800 meters!

On the LAUNCH tab, select **Distance contest**. Turn on **Show grid**. Try to build a trebuchet to hurl the payload as far as possible. Take a screenshot of your longest launch and record the trebuchet dimensions. If possible, compare your results to those of your classmates.

Counterweight: _____ Fulcrum height: _____ Long arm length: _____

Payload: _____ Short arm length: _____ Sling length: _____ Prong angle: _____

8. Summarize: What are the characteristics of trebuchets that can hurl objects the farthest?



<p>Extension:</p> <p>Trebuchet analysis</p>	<p><u>Get the Gizmo ready:</u></p> <ul style="list-style-type: none"> On the DESIGN tab, set the Counterweight to 4500 kg, Payload to 160 kg, Fulcrum to 9.0 m, Short arm to 3.0 m, Long arm to 9.0 m, Sling to 5.0 m, and Prong angle to 40°. 	<p>Design Parameters</p> <p>Counterweight: 4500</p> <p>Payload: 160</p> <p>Fulcrum height: 9.0</p> <p>Short arm length: 3.0</p>
---	--	--

Introduction: Before the trebuchet launches a projectile, the long arm must be pulled down, which raises the counterweight. This stores **gravitational potential energy** in the counterweight. When the trebuchet is fired, this potential energy is converted to kinetic energy as the counterweight moves down and the long arm, sling, and projectile start to rotate.

Question: How is energy converted from one form to another in a trebuchet?

- Estimate:** An object's gravitational potential energy (*GPE*), measured in joules (J), is given by the formula $GPE = mgh$, where *m* is mass, *g* is gravitational acceleration (9.8 m/s^2 at Earth's surface), and *h* is height. To convert to kilojoules (kJ), divide the result by 1,000.

 - Click **Launch test**. Because the counterweight is nearly directly above the fulcrum, its starting height is estimated by adding the short arm length to the fulcrum height.
What is the approximate initial height of the counterweight? _____
 - In kJ, what is the approximate initial potential energy of the counterweight? _____
 - When the projectile is launched, the counterweight is almost directly below the fulcrum. What is the approximate final height of the counterweight? _____
 - In kJ, what is the approximate final potential energy of the counterweight? _____
 - What is the change in potential energy for the counterweight? _____
- Estimate:** Some of the potential energy of the counterweight is converted to gravitational potential energy and kinetic energy (*KE*) of the projectile. The formula for kinetic energy is $KE = \frac{1}{2} m \cdot v^2$, where *v* is speed. Remember to divide by 1,000 to convert to kilojoules.

 - When it is released, the projectile is nearly directly above the fulcrum. Its height is equal to the height of the fulcrum plus the length of the long arm and the sling length.
What is the approximate height of the projectile when it is released? _____
 - What is the estimated gravitational potential energy of the projectile, in kJ? _____
 - Look at the initial speed. What is the kinetic energy of the projectile, in kJ? _____
 - What is the estimated total energy (*GPE* + *KE*) of the projectile, in kJ? _____

(Extension continued on next page)



Extension (continued from previous page)

3. **Compare:** Compare the change in gravitational potential energy in the counterweight to the total energy of the projectile when it is launched.
- A. What percentage of the energy change of the counterweight was converted into projectile energy? _____ This value is the **efficiency** of the trebuchet.
- B. Where do you think the rest of the counterweight potential energy was expressed? (Hint: Do any other parts of the trebuchet have kinetic energy?) _____

4. **Evaluate:** Select the LAUNCH tab and the **Siege of Acre**. In the second menu, select **Atmosphere: None**. This removes the effects of **air resistance** on the projectile. Click **Play**.
- A. What was the total energy of the projectile the moment it was fired? _____
- B. What was the impact speed of the projectile? _____
- C. What was the impact kinetic energy of the projectile? _____
- D. How does the impact *KE* compare to the initial energy of the projectile? _____

- E. Click **Reset**, and select **Atmosphere: Air**. Click **Play**. How much energy did the projectile lose due to air resistance? _____
5. **Apply:** On the DESIGN tab, set the **Counterweight** to 5,000 kg, **Payload** to 80 kg, **Fulcrum** to 9.0 m, **Short arm** to 3.0 m, **Long arm** to 9.0 m, **Sling** to 9.0 m, and **Prong angle** to 30°. On the LAUNCH tab, select **Stirling Castle** and **Atmosphere: None**. Click **Play**.
- A. Based on the initial speed, what was the projectile's initial kinetic energy? _____
- B. The height of the projectile at launch was approximately 25 m. What was the initial gravitational potential energy of the projectile at launch? _____
- C. Given the impact height, what was the potential energy at impact? _____
- D. What was the kinetic energy at impact? _____
- E. How does the total energy at impact compare to the total energy at launch? _____

