NATURE
Sunday Academy 2012-2013

Projectiles: Earth to Earth;
The Dynamics of Catapults & Trebuchets

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Description:

In this Sunday Academy session, students will learn the ways the historic European weapons catapults and trebuchets worked and they will also discover design choices that influence those devices performance. After review of the applications and basic differences between the two devices, the activities in the lesson will include design and construction of a catapult or trebuchet structure, considerations influencing optimization of its performance and then pay competition utilizing that performance. Academic principles of dynamics, stored energy, energy conversion, and projectile motion will be discussed.

Objectives:

Objectives of this session include learning

1. the concept of stored energy and the conversion to kinetic energy,
2. the fundamentals of the relationship between force and acceleration,
3. the descriptive qualities of ballistic trajectories
4. the connection between the topic and real-life engineering designs.

Standards covered:

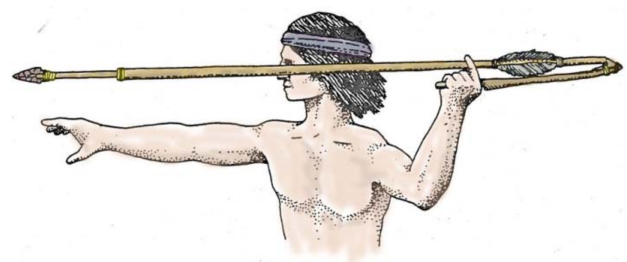
9-10.2.2.Use appropriate safety equipment and precautions during investigations
9-10.2.3. Identify questions and concepts that guide scientific investigations
9-10.2.7.Maintain clear and accurate records of scientific investigations
9-10.2.8.Analyze data found in tables, charts, and graphs to formulate conclusions
11-12.3.8.Identify the principles and relationships influencing forces and motion

Session Organization:

11:00-11:30	Introduction and Cultural relevance
11:30-12:00	PowerPoint presentation
12:00-12:30	Lunch
12:30-3:30	Hands-on activities and classroom discussion

Cultural Connection:

Native Americans had a need for impacting things at large distances. This could be game hiding in the bush or horses to be herded or enemies hiding behind barricades. In each of these cases Native Americans had to carry the tool of influence (be it rock or arrow or ax) to the point of application. Sometimes requirement for the projectile was speed, other times force or other times stealth. In all these cases the same equations of motion apply. One possible area of connection is to discuss the use of Atlatl by the Aztecs to defend against the conquistadors. (The mechanics of the second arm to increase the velocity of the projectile is comparable to the differences between a catapult and a trebuchet.)



Vocabulary:

(Adapted from Engineering Mechanics: Statics & Dynamics, 11th Ed. R. C. Hibbeler**)**

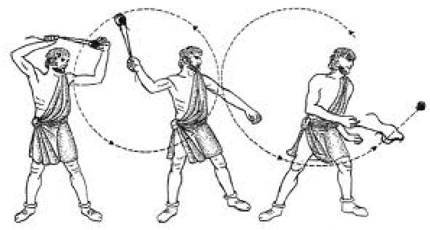
1. matter – atomic particles, individually or in collections, that have mass
2. mass – m, a property of matter that indicates the amount present (in a body or object)
3. force – f or **F**, "Push" or "Pull" exerted on a body by something else, another body or a field (**F** is related to direction)
4. weight – w or **W**, the "Pull" force exerted by the earth on a body, **W** = m***g** (**W** is related to direction)
5. displacement – the change in position, s or **r**, of an object, Δs (pronounced "Delta s") or Δ**r** (**r** is related to a direction)
6. velocity – v or **V**, the change of position per change in time, Δs/Δt (**V** related to direction)
7. speed – v_{sp}, the magnitude of velocity (not related to direction, but able to be + or -)
8. acceleration – a or **a**, the change of velocity per change in time, Δv/Δt (**a** related to direction)
9. trajectory – the path that an object follows as it travels in reaction to applied forces
10. ballistic – a trajectory done without control of the forces applied to the object (a ball, without spin, after release)
11. target – the "intended" end point of a trajectory

Equipment and Supplies Needed:

1. Internet access
2. Materials Fabrication package to include, per team:
   16D Common Nail, 3ea 1 oz. bank sinker weights, 3/16" (4.76mm) x 12" (305mm) dowel, household twine, 12 – 15 mm diam. ball of Play-Doh, medium paper clip (see Material Purchase List)
3. Roll(s) of duct tape (of your favorite color)
4. General items for session: Weight Scale (0 to 50 g), rulers, (meter sticks & tape measure (25 ft.), scissors, lab stands, pencils or popsicle sticks taped together or similar devices to act as stands for the catapult (Note: the nail must be at least 6 1/2 inches off the work surface.)

Background Information:

The topics being discussed today referred to devices used in ancient times (approximately 1100 BC) in most parts of the world, although not in North America. These ancient tools of war were useful against stronghold cities, that is to say cities that have been fortified and are meant to be permanent constructions. The ancients recognized that more than simple hand power was needed to be able to overcome these fortifications and thus these "siege engines" were developed. An example here would be to consider the damage that could be inflicted by either throwing a rock by hand or using a sling to throw the same rock. Another illustration could be throwing an arrow versus using a bow or atlatl to throw the arrow. The PowerPoint associated with this lesson will go into more detail about the background. Today we will do a comparison between a traction trebuchet and a gravitationally driven catapult. We will take this approach so that the comparisons will be based on the exact same type of energy source in both devices.



References:

http://en.wikipedia.org/wiki/Catapult

http://en.wikipedia.org/wiki/Trebuchet

http://en.wikipedia.org/wiki/Atlatl

http://en.wikipedia.org/wiki/Sling_%28weapon%29

Activity 1: Research on the Design of Trebuchet/Catapults

Procedure:

1. Divide the class into teams (About three or four people per team). One half of the teams will construct trebuchets and the other teams will construct catapults.
2. Each team will get online and search for sites describing the construction of their throwing machine either catapults or trebuchet. The students should view the four websites given in the references above.
3. Each team will record items of importance for their device design, and then decide, as a group, which to include in their idealized design of their machine.
4. Each team will then submit a design plan for approval before materials are dispersed. This plan will include a sketch as well as construction steps. The key element to the plan will also be a description of how the machine will be modified to improve performance for the competition below.
5. Answer the questions below before constructing your design plan.

Questions:

1. What part of the throwing machine is used to store energy? How does the energy get stored?

2. How long can the energy be stored? What can be changed to increase the amount of stored energy?

3. How does the machine change the stored energy to the motion of the projectile? What can be changed to enhance this conversion?

4. How does the design of the machine get to be strong enough to do that transfer? Where in particular does that transfer/conversion occur?

Design Plan: (use the space below to sketch and described your throwing machine design.

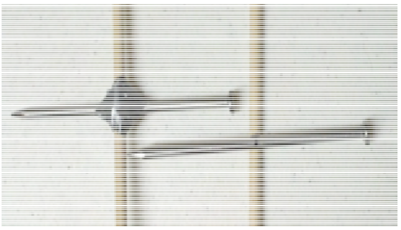
Design Approval:________________________ Date: ________

Activity 2 ; Fabrication and Certification of the Team's Throwing Machine

Fabrication Procedure:

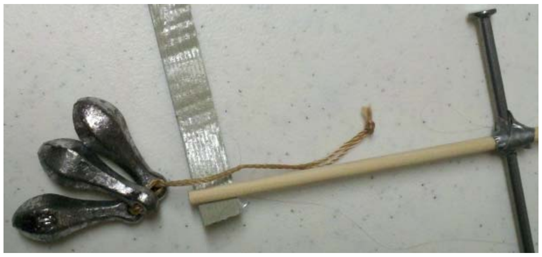
1. After obtaining approval for your throwing machine design, collect the bag of fabrication materials and perform an inventory. If there are missing pieces report this to your instructor.

2. The fabrication materials will be used for the throwing arm. This will ensure that the arm design between those making catapults and those making trebuchet's are similar so that performance capabilities can be directly compared. Your design opportunities will focus on tweaks to the throwing arm and design of the support structure for that arm. The structure should have the characteristics of allowing the throwing arm to rotate freely about the nail, staying in a flat rotational plane. You can consider whether the structure can move or not and other things are design considerations for your team to work out. The directions for the lower half of either the catapult arm or trebuchet arm are identical (the end with the weights).

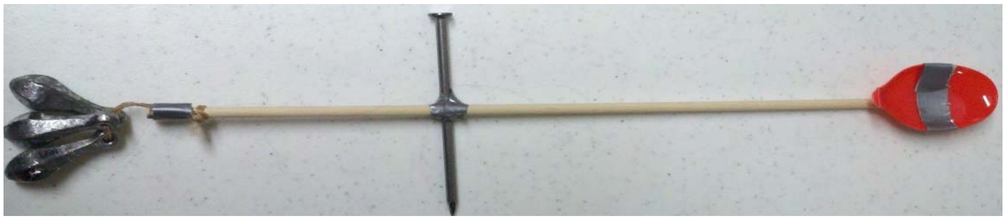


3. Take a 3/16 dowel and put a mark on the dowel 10 cm from one end. In another mark in the middle of the 16d nail. Put the two marks over each other and tape the nail and dowel together, see figure.

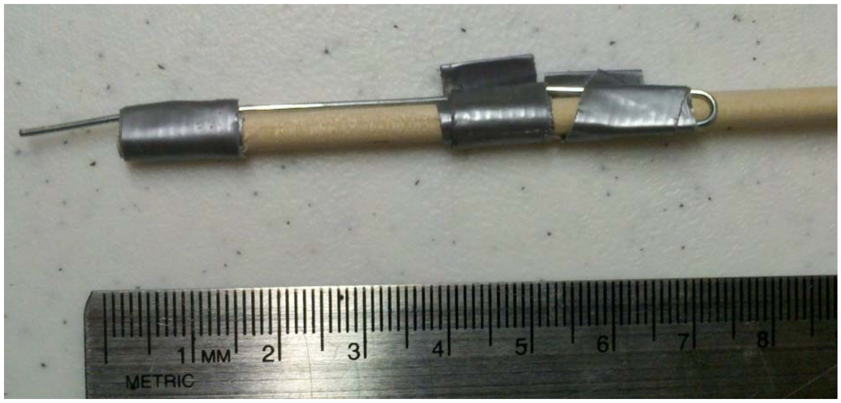
4. Take a length of the twine, 18 to 20 cm long and make a loop. Take three of the 1 ounce sinkers and tie them together with this loop. Take the tied sinkers and tape the loop holding them to the end of the throwing arm being sure to allow them to swing freely but not slip, see figure below.



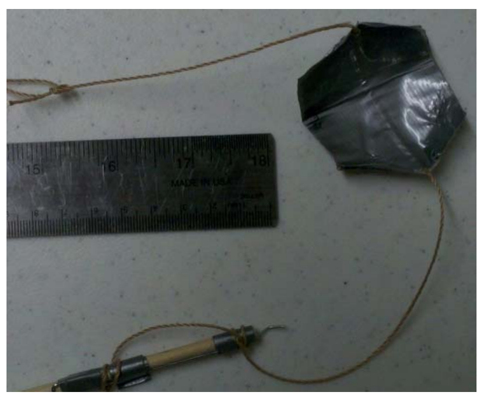
5. FOR THE CATAPULT: Take a plastic spoon and break the handle off. Tape the spoon to the other end of the throwing arm. The resulting throwing arm can be seen in the picture below.



6. FOR THE TREBUCHET: After adding the weights , as shown above, take a paperclip and straighten it except for the smallest final turn. Tape that to the open and of the throwing arm, having approximately 1 cm extending from the end of the arm, see figure below.



7. Take approximately 60 to 80 cm of twine and tie it to that same end of arm (a hitch may work the best here). Put a large loop in the opposite end of the twine and hook the loop over the end of the paperclip. In the middle of that length of twine fabricate a cup with two pieces of duct tape to hold the projectile, see figure below. Hint: Folding darts in the back piece of duct will help form the cup.



8. The final trebuchet throwing arm should look something like the arm pictured below.

9. Fabricate a number of projectiles by making Play-Doh into balls with diameters of approximately .5 cm, 1 cm, 1.5 cm and 2 cm. (The 1 cm diameter ball is ~ 4 g)

10. Fabricate the support structure for your throwing device, either the catapult or trebuchet, according to your plans or site instructor's directions. Remember, based upon the space between the weights and the dowel, the nail needs to be more than 17 mm above the work surface.

11. Before going to the performance certification stage, have your instructor certified the throwing arm and support structure.

Performance Certification Procedure:

12. Place the fabrication certified throwing machine on the performance certification range. When cleared by the range safety officer, perform three throws using the 1 cm diameter Play-Doh ball before making any modifications to the device. Use average distances in Data Table 1. Take some time to standardize the release method for the device to insure repetitive operation. Even if it is as simple as just a finger, be sure to do it about the same each time.

13. Make modifications as needed to control differences in throwing distance or right/left throwing offsets. Use three throws each to evaluate each modification.

14. When three throws do not very in distance or an offset by more than 5% of the total throw length (for example a 10 foot throw would have forward distance plus/-6 inches and would be consistently to one side or the other no more than 6 inches, see diagram below).

15. Answer the questions below.

Activity two questions:

1. What can you modify your throwing machine to have the projectile to go farther?

2. What can you modify in your throwing machine to have the projectile travel straighter?

3. Was this modification easy to control or difficult (that is to the small modification make a small change to the throne)?

4. For trebuchet makers, view the following website, http://www.pbs.org/wgbh/nova/lostempires/trebuchet/destroy.html. What items can be ingested to improve performance of your device.

Data Collection, Analysis and Reporting:

Data Table 1

Throw Number	Distance forward	Left or right of center	Amount left or right	Corrective actions before next throw

Activity 3: Maximium Throwing Weight

Procedure:

1. Use the performance certified throwing machine to test its reaction to a variety of projectile weights. Take the projectiles prepared use them in the exercise below.
2. Accomplish three throws with each of the projectiles and average the performance for each throw and report in data table two.
3. Plot the distance thrown for each of the weights (include the standard weight from activity number two.
4. Answer the questions below.

Questions:

1. Describe what happens to the distance the projectile is thrown as its weight changes?
2. Describe what happens to the flight trajectory of the projectile as its weight increases?
3. Are there any design changes that can be applied to compensate for the projectile weight change? And if they exist, what are they?

Data Table 2

Throw Number	Weight of projectile	Distance forward	Distance left or right	Corrective actions before next throw

Activity 4:Throwing C Throwing Competition (if there is time)

Procedure:

1. For this activity, pair each of the catapult teams with a trebuchet team.

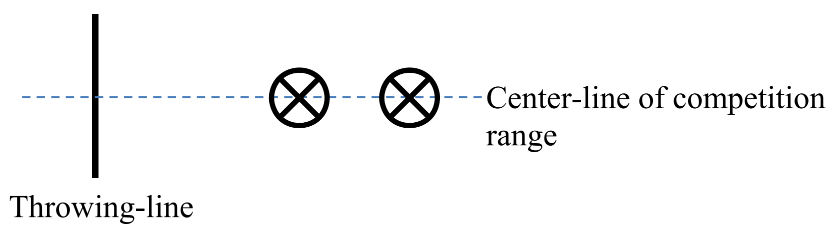
2. Set two targets on the floor directly in front of a 'throw line' (use a small paper plate or a circle of tape on floor, etc., something 10 to 15 cm in diameter). Place one at the average throw distance for the all the catapults in the session and the other at the average throw distance for all the trebuchets in the session. Mark the center of each target. (Several of these "ranges" can be set-up, but they will all be the same) See figure below.

3. Each team in the pairing will use their device to complete six throws of a 1 cm and a 2cm diameter projectile at either of their targets. (That is to say that 6 throws will be made by the catapult team and 6 by the trebuchet team, three for each diameter)

4. Mark the location of first impact on the floor for each projectile (wash-off marker might be good for linoleum, while tape might be best for carpet). After all throws are made, measure and record the distance, in centimeters, from each impact to the closest target center. Use Data Table 3, below to record and process the data leading to a team score.

5. SCORING: Mean Circular error will be used. The square root of the distance from the closest target is computed. Then that number is inverted (1/ √ distance) and then multiplied by 16. For example, if a throw lands 16 cm from the target center, the square root of that is 4, the invert of that is ¼ or 0.25. That number, 0.25, times 16 results in a score for that throw of 4. If all 12 throws landed that far away, the mean score for the pairing would be 4. Hitting every target dead center would result in a 'perfect' score of 16.

6. Best pairing score wins a prize. (To be determined by local instructor)



Data Table 3: Throwing effectiveness

CATAPULTS					
Throw Number	Weight of projectile	Distance to target center, cm	Square root of Distance error	Throw score (16 * 1/ Distance$^{0.5}$)	Running total
1					
2					
3					
4					
5					
6					
				TOTAL FOR CATAPULTS>>	
TREBUCHETS					
Throw Number	Weight of projectile	Distance to target center, cm	Square root of Distance error	Throw score (16 * 1/ Distance$^{0.5}$)	Running total
1					
2					
3					
4					
5					
6					
				TOTAL FOR TREBUCHETS>>	
				Mean Score (total of scores/12)	