Fling It!!

Content: *Science:* A1-6, B4, B5, E1-5, G1, G3
Math: 1A-C, 2A-C 3A, 3C, 3D, 4A, 4B, 5A-D, 6A-C, 7B, 8A, 8B, 8D, 9C, 10A-C
Technology: 2B-F, 2H-J, 3A-B, 4A-B, 6A-C, 7A-D, 8A-D, 9A-D, 10A-D, 11A-F, 12A-E, 13A, 16A, 16B, 16E,19B, 19E, 20B, 20D
ABET: A, B, C, D, E, F, G, J, K

Time: 10-15 class hours

TEACHER PREPARATION

This case study will take ten to fifteen classroom days to complete. It is recommended that the instructor obtain the necessary calculations to complete this prototype and be proficient in their use. The objectives for this case study are:

1. To design a working model of a trebuchet and demonstrate the power of a Class 1 lever.
2. To determine the effectiveness of each trebuchet based on how far it will throw a water balloon.

Instructors should introduce students to these machines through lecture and viewing of videos on Medieval Siege Machines. The suggestion is that you obtain the NOVA video "Secrets of Lost Empires: Medieval Siege". There is a companion website to the video that has a lot of information that will help you and your students in the classroom. The website is listed in the resource section below. Instructors should review simple machines, specifically the three classes of levers with the class. Teams of three should be randomly selected using a deck of cards that they draw numbers from. Each team will be responsible for documenting the process they went through. This can be through daily lab reports or a team journal. Detailed drawings and descriptions should be included. It is also suggested that the instructor be familiar with calculations that are associated with the case study and be proficient in their use.

There are also books and software programs that allow students to plug numbers in and do calculations in order to plan for the length o the throw.

In celebration of Saint Barbara Day, patron saint of artillery, the Marines of the 11th Marine Regiment decided to take part in a rather strange, yet challenging competition, at Camp Pendleton. Marines from 3/11's survey section put the finishing touches on the bowling ball throwing catapult. With the throwing arm in its fully erect position, the trebuchet is 21 ft. tall.

Photo by: Sgt. Ken Griffin

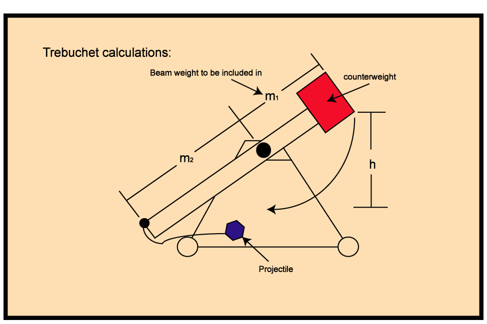
CASE STUDY

The history of catapults goes back to medieval times. The Romans however, were the first group to make catapult design an "art of war". Catapults could be made to sling projectiles over 100 meters but they could only be used a small number of times before the components (mostly oak wood) began to fatigue. A trebuchet is similar to a first order lever, with the counter weight providing the effort and the projectile supplying the load. All this is on a fulcrum.

Your three person team has been charged to design and build a mighty siege machine – called a trebuchet – that will fling a water balloon across a far distance. You have been provided with some materials to build your trebuchet: You must use 2 x 4's, selected plywood scrap, wood screws, 1" black pipe for the axle, flat steel where needed, and twine. Your missile will be a water balloon. You will need to construct the following parts of a working trebuchet:

- Two triangular pieces for the sides of the frame; these will need to be supported or braced to stay upright. Parameters for base and height of fulcrum point will be:
- 2' wide by 4' long, fulcrum point shall be no higher that 3'.
- A long, throwing arm pierced by the axle; the short end of the throwing arm should have a small, heavy counterweight that will allow the throwing arm to swing freely without touching the sides of the frame or ground.
- A sling that will hold the water balloon during the upswing and release it at the top of the arc.

You team is responsible to research safety when using trebuchets as well. Make notes of any issues that are read about and be sure to include a section on safety in your final presentation. Each member of the teams should do individual research on catapults, trebuchets and the systems associated with these machines.



$m1$ = the mass of the counterweight and beam (in Kg)

$m2$ = the mass of the projectile and beam (in Kg)

h= the distance that the counterweight falls (in meters)

1. Compute theoretical velocity of projectile:

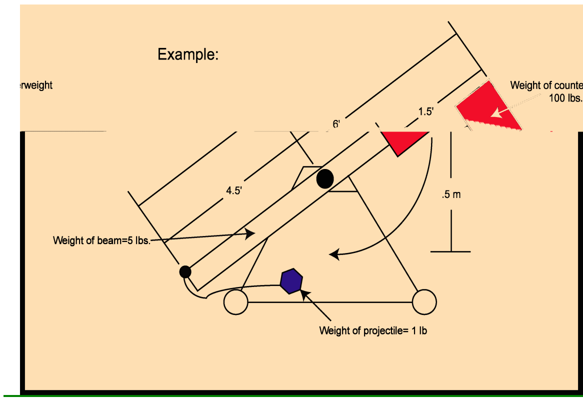
$$V_{Theo} = \sqrt{\frac{2(m)(g)(h)}{(m)^2}} \qquad g = 9.087 m/s^2$$

2. Computer theoretical range of projectile:

$$R_{Theo} = \frac{(V_{Theo})^2}{g} \times \text{Sin } 2(\theta)$$

θ= the angle of elevation at which the projectile leaves the trebuchet

Here is one trebuchet and its calculations:



1. Compute theoretical velocity:

$$V_{Theo} = \sqrt{\frac{2(.567Kg + 45.359Kg)(9.087m/s^2)(.5m)}{(1.701Kg + .454Kg)}}$$

$$= \sqrt{\frac{450.396\,\frac{Kgm^2}{s^2}}{2.155\,Kg^2}} = \sqrt{209.001\ m/s} = 14.457m/s$$

2. Computer theoretical range:

$$R_{Theo} = \frac{(14.457\ m/s)^2}{9.087m/s^2} \text{ x Sin } 2(45^{\circ}) = \boxed{\text{21.311m or about 70 feet}}$$

ASSESSMENT

Fling it!! Rubric

Category	Exemplary 30-24	Accomplished 18	Developing 12	Beginning 6	Score
Gantt chart	The timeline is complete with formatting tasks, dates and persons assigned to tasks	The timeline is complete with formatting, tasks, and dates	The timeline is complete with tasks, dates	The timeline is incomplete, but an effort was made	
Calculations	The calculations are complete with detail and relevant formulas and labels	The calculations are complete using relevant formulas and labels	The calculations are complete using relevant formulas	The calculations are incomplete, but use relevant formulas	
CAD Drawings	The drawings are complete with detail and relevant materials and labels	The drawings are complete using relevant materials and labels	The drawing includes relevant information but is missing dimensions	The drawings are incomplete, but an attempt was made	
Cost analysis	The cost analysis is complete and formatted with pricing, sources and total costs per item	The cost analysis is complete with pricing, sources and total costs per item used	The cost analysis is complete with pricing and total costs per item used	The cost analysis is incomplete but has some pricing available	
Electronic presentation	Presents easy-to-follow information that is logical and adequately detailed. All graphics and supplemental information included	Most of the information is included. All graphics and supplemental information is included	Most of the information is included. No graphics or supplemental information included	Most of the information is missing, disordered or is confusing	
Prototype	The Prototype and sketches are complete with detail and relevant materials and labels	The Prototype and sketches are complete using relevant materials and labels	The Prototype and sketches are complete using relevant materials	The Prototype and sketches are incomplete, but use relevant materials	
Design Proposal/ Research report	Information is well organized with ideas and details added to give meaning.	Information is well organized and an attempt is made to add meaning.	Student is demonstrating a basic understanding of content and information.	Limited effort is made to understand content at a very simplistic level.	

RESOURCES

http://www.pbs.org/wgbh/nova/lostempires/trebuchet/ the companion web site to the NOVA program "Medieval Siege." In the film, which is a part of the NOVA series Secrets of Lost Empires, a team of timber framers and other specialists design, build, and fire a pair of trebuchets, a devastating engine of war popular in the Middle Ages.

http://www.trebuchet.com/sim/ The ATreb Simulator Program. You can add the effects of air drag, friction, do stress analysis on your arm, sling, pin, axle... and work out all the finer details of your trebuchet design before you even buy a single piece of lumber. It also includes a metric conversion calculator, release pin optimizer, and you can save hundreds of design parameters and simply load them from disk to work on different projects at the click of a button.

Special thanks to Mr. Vern Jordan and Mr. Johnson in Fort Atkinson, Wisconsin for the initial design and testing of this case study.