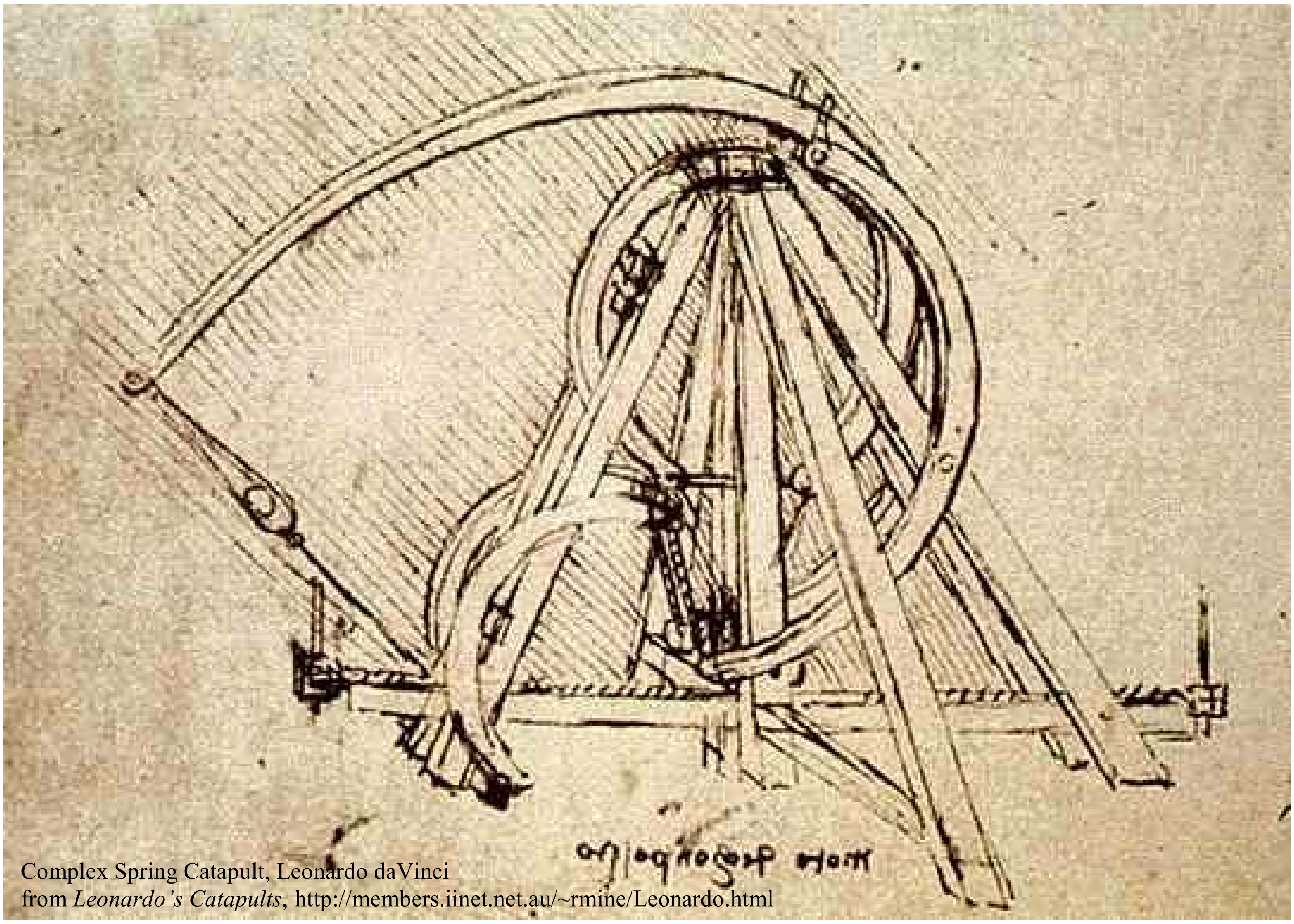
Hands-On in the

Inventor Center

The Catapult Forces Challenge

EDUCATOR'S GUIDE


Complex Spring Catapult, Leonardo daVinci
from *Leonardo's Catapults*, http://members.iinet.net.au/~rmine/Leonardo.html

WHAT'S INSIDE?

- Essential Questions
- Making the Most of Your Visit
- Correlations to Standards
- Facilitation
- Glossary
- Resources
- Activities (Coming Soon)

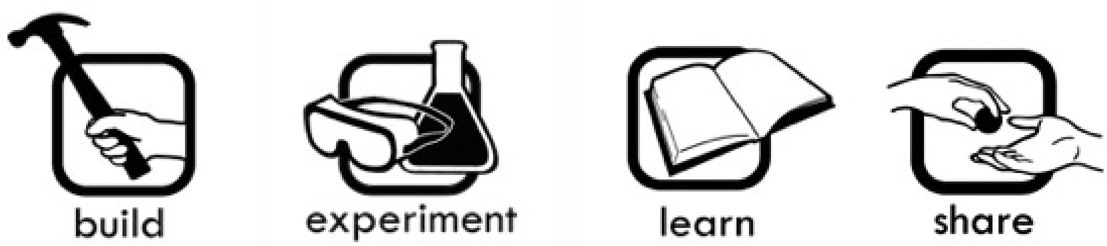
RMSC
Rochester Museum & Science Centre

ESSENTIAL **QUESTIONS**

During your facilitated hands-on experience in the *Inventor Center: Catapult Forces Challenge*, the facilitator will be posing essential questions to your students in two categories: The Inventive Process and the Science of Catapults and Trebuchets. These questions may also be useful for you as a teacher to gain background information as well as for facilitating higher order thinking during class discussions.

The Inventive Process

Inventor Center encourages students to explore the thrilling process of invention. The Inventor Center includes a series of participatory stations: build, experiment, learn and share. Students will define the problem, build a prototype, experiment with the prototype, learn how well the prototype works (solves the problem), and share their ideas or inventions with others.



Who is an inventor?

An inventor is someone who uses technology in a new way to solve a problem. An invention is a unique or novel device, method, or process. Inventions are different than discoveries because a discovery is detecting something that already exists. In the Inventor Center everyone is an inventor.

What is the inventive process?

There are many ways to invent. Most inventive processes consist of four main parts: learning, building, testing (or experimenting), and sharing. These four parts of the inventive process can happen in any order. See the Pre-Visit Activities for a close reading on the inventive process.

What do good experimental practices sound like and look like?

The first and most important thing to remember is to be safe. This means to conduct yourself in a responsible manner at all times while working with tools and equipment. In this challenge it is essential that students wear safety glasses and never launch a catapult or trebuchet anywhere except at the experiment station, which is equipped with a net to intercept stray balls.

It is also good practice to be clutter free. Leaving tables the way you found them and putting back any materials you use helps both avoid accidents and allows others to find materials if they want to use them.

Inventors discuss their ideas in quiet voices. When we speak of *scientific arguments based on evidence* we do not mean the kind of "argument" that involves raised voices or high emotions. Inventors respect each other's view points and explain their reasoning and their evidence calmly.

Last but not least is to record what you do. This is so that you can prove that you are the inventor of your design. Even more importantly, good records allow you and others to repeat what you have done. In ancient times, science was in its infancy and careful record keeping had not yet been established as important. In fact, the plans for many catapults were lost and people needed to start from zero each time. When science began to flourish during the Renaissance, Leonardo daVinci's drawings of inventions such as trebuchets were very detailed artistically but were still often hard to interpret scientifically. It is only in the last several hundred years that repeatability has become established as a fundamental rule of science.

The Catapult Forces Challenge

Students are presented with a problem: we (in our scenario, the English) need to take control of the RMSC castle away from the enemy (the Scots). To break the siege, we need students to work with each other and the laws of physics to design and build a catapult or trebuchet that can consistently launch projectiles into the castle. See the “Facilitation” section for details on how this will be presented to students.

Why were catapults and trebuchets invented?

Inventions usually start with a problem.

Human conflict has existed as far back as can be determined. Just as people invented better technology for constructive purposes such as travel, building shelter, and obtaining food, people also engaged in a continual arms race for better technology to attack others and to defend themselves.

A rock in a hand was replaced by a sling, which was replaced by a bow and arrow, which evolved into a crossbow. Defense technologies kept pace. Shields were supplemented with armor. By the Middle Ages, castles had become so strong that they could withstand long sieges. Sieges were expensive for everyone, including the attackers.

Catapults and trebuchets were invented to fill the need for a *way to transmit a lot of force from a safe distance.* A human arm could not throw a rock with enough force to knock down castle walls. In other words, mechanical advantage was needed.

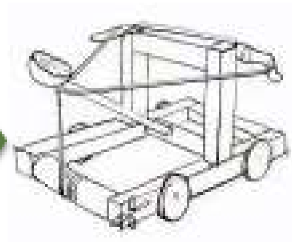
Who invented catapults and trebuchets?

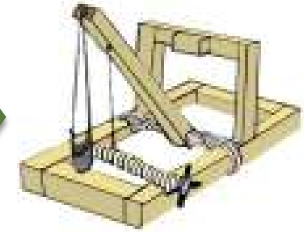
The history of catapults and trebuchets is a fascinating study of human ingenuity and the exchange of cultures that accompanied exploration, trade, and wars over two continents over thousands of years. For a short summary please see the Timeline in the Post-Visit Activities.

Rather than being a single invention, catapults and (later) trebuchets evolved over time by a series of modifications involving trial and error. This trial and error was in fact a form of the build-experiment-learn process. However, the sharing part of the process was often omitted.

The first written evidence of catapults being used in battle dates from about 400BC, in both China and simultaneously in Greece. The Chinese catapult was like a large crossbow, with the addition of a swinging arm. The Greek Dionysius the Elder, of Syracuse, is responsible for the invention of the Greek version. To make the crossbow more powerful it was made larger and set on a base. Two forms of catapults evolved from the Greek catapult: the double-armed catapult, called a ballista, which was used for shooting arrows, and a single-armed catapult designed for hurling stones. With many modifications, catapults remained a key weapon of warfare up through mediaeval times.

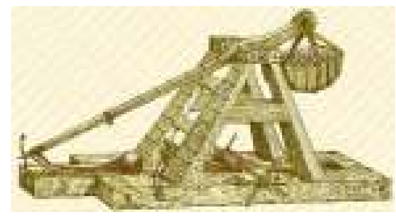
The force and distance with which catapults could launch projectiles was increased when torsion (twisted ropes) replaced tension (pulled ropes) but catapults always, by definition, involved the storage of potential energy as elastic stress. At first catapults were cocked by the use of muscles directly, but later gears were added.





Crossbow (stretch and bend)	Chines Catapult 400 BC (stretch and bend)	Greek Catapult 400 BC (stretch and bend)	Later Torsion Catapult (twist)

The trebuchet was invented in France and was first reported to be used in 1124AD in the siege of Tyre (in present-day Lebanon) during the Crusades. As it was much more powerful than a catapult, a trebuchet became the siege weapon of choice.



Trebuchet, *image from: http://medievallifestyle.com/siege-engines/trebuchet.html*

One of the largest and most famous trebuchets, called the Warwolf, was used by the English in 1304 to break the siege of Sterling Castle, in Scotland. See the Pre-visit Activities for a close reading about this historic event.

By the Renaissance, when the famous Italian painter, sculptor, draftsman, architect, engineer, and scientist. Leonardo daVinci (1452-1519), was designing trebuchets, the use of catapults and trebuchets had largely been replaced by cannons. DaVinci, although against war, designed intricate trebuchets, as well as many other ingenious devices.

Leonardo daVinci, *self-portrait*

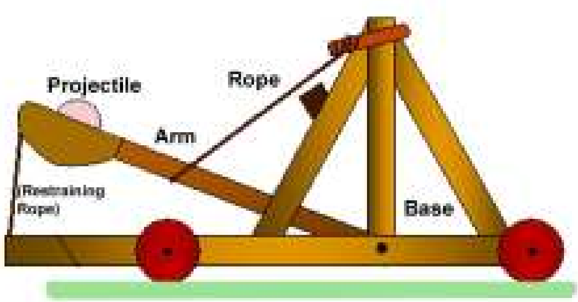
Modern-day enthusiasts, such as those participating in the annual Punkin' Chunkin' Contest (http://punkinchunkin.com/) reconstruct mechanical throwing machines from ancient plans and vary the design to increase efficiency.

What are catapults and trebuchets?

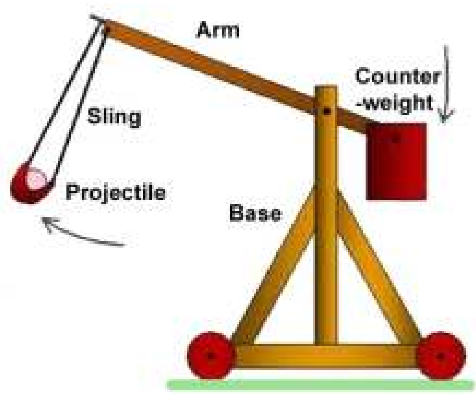
Many sources refer to catapults and trebuchets interchangeably, which can be confusing, but in the context of this Inventor Center Challenge we will use the commonly accepted scientific definitions:

Catapults and trebuchets are large-scale mechanical weapons that are used to throw objects, either defensively or offensively. They differ in their mechanics. Both catapults and trebuchets are made up of 3 essential parts:

1. a stable base
2. an arm
3. a structure that (slowly) stores potential energy until it can be released (quickly) as the kinetic energy of motion of the projectile.



Catapult



Trebuchet

The Base:
For a catapult or trebuchet to work efficiently it is important for the base to be stable so that when the stored potential energy is released, only the arm and the projectile move, not the base.

The Arm:
For a catapult the arm is a long straight part with an area at the free end to hold the object being thrown (projectile). For a trebuchet the arm rotates on a fulcrum so that it acts as a lever. The projectile is placed on one end (often in a sling) and a counterweight on the other.

The Structure for Storing Potential Energy:
The difference between a catapult and a trebuchet is how the potential energy is stored in the 3rd part.

How is Potential Energy stored in a Catapult vs. in a Trebuchet?

For a *catapult*, potential energy is stored as *elastic energy*. This energy results from the force put in as the muscular push or pull needed to stretch, bend, or twist some sort of elastic material that is attached to the throwing arm.

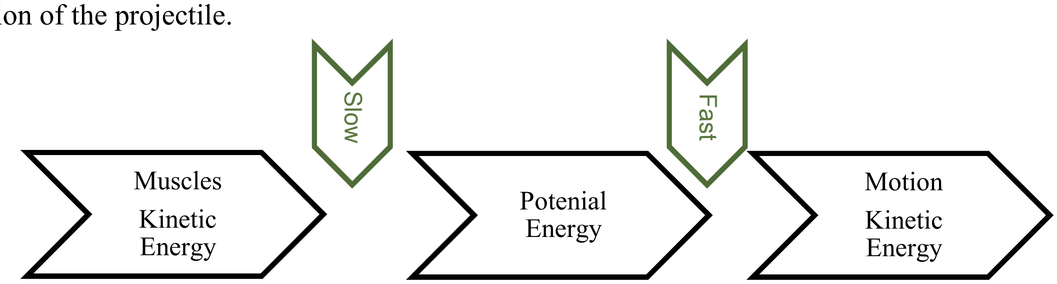
For a *trebuchet*, the potential energy is *gravitational*. This energy results from the force put in as the muscular push or pull needed to lift up the end of the lever with the heavy counter weight.

How is Energy Transformed in a Catapult and Trebuchet?

Energy is the ability to do work or cause a change. There are two types of energy: kinetic and potential. Kinetic energy is moving energy while potential energy is stored energy.

Energy also takes many forms: mechanical, electrical, chemical, magnetic, radiant (light), elastic, gravitational, thermal (heat), and even nuclear. Energy can change into a different form of energy; this is called energy transformation. The Law of Conservation of Energy states that energy cannot be created or destroyed, it can only change forms

During this Inventor Center Challenge we want to use the kinetic energy coming from our muscles to slowly build-up potential energy in the machine, and then release the energy very quickly in the form of the kinetic energy of motion of the projectile.



The chemical energy stored in food is transformed into chemical energy in the attacker's muscles, which is transformed into the kinetic energy to cock the siege machine. The energy in the cocked position has now been transformed into potential energy.

When the trigger is released, this potential energy is transformed suddenly as the kinetic energy of motion of the projectile. When the projectile hits the castle wall, the kinetic energy is used to do the work of crumbling the wall. Eventually all of this energy is dissipated as heat energy.

What forces do catapults and trebuchets use?

Force is a push or a pull. When force is applied over a distance, “work” is done. By “work” we mean the scientific definition of work, which is a form of energy. In the language of mathematics:

work = force x distance
$$w = f \times d$$

Catapults:

Catapults take advantage of *elastic force*, involving stretched, compressed, bent, or twisted material. To prepare a catapult to launch a rock, it takes work to twist a rope (provide torsion), to stretch a rubber band (provide tension), or bend wood. The potential energy is stored as elastic energy of a stretch (tension), bend, or twist (torsion).

The material has to be elastic. Elastic materials are good at storing energy when they are reshaped, and releasing it when they return back to their natural shape. Think of stretching a rubber band. It gets long and skinny. Now let it go. It goes flying! Where did this kinetic energy of motion come from? It came originally from your muscles when you stretched it. Rubber, certain kinds of wood, steel, tendons, horns, and to some extent rope, are examples of elastic materials. Try bending a rock. If we apply enough force the rock will crack, not bend. Rock and glass are examples of non-elastic materials.

Stretch | Bend | Twist

Trebuchets:

Gravitational force is one kind of force that can be exerted even across empty space. Trebuchets take advantage of this kind of force. To prepare a trebuchet to launch a rock, it takes work to raise the arm with the massive counterweight against the acceleration of gravity. The force that we apply depends on the mass of the counterweight.

force = mass x acceleration
$$f = m \times a \qquad (a = 9.8 \text{ meters / second}^2)$$

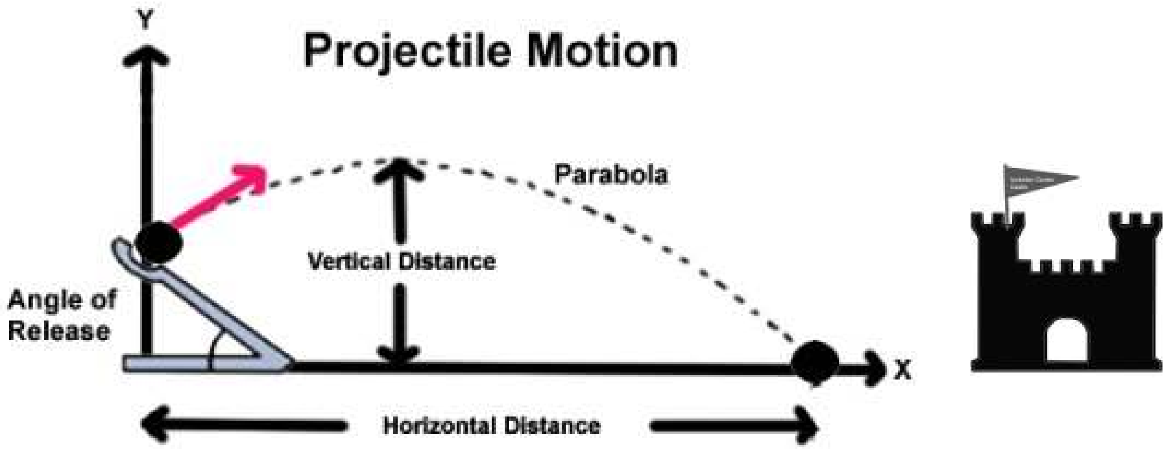
In either case, when the catapult or trebuchet is released, the potential energy is released as kinetic energy in the form of the motion of the rock. In this case the work that is performed is the crumbling of the castle wall. The more massive the rock and the faster it is moving, the more damage, or “work” is done on the wall.

What variables affect the trajectory of a projectile?

When designing a catapult or at trebuchet to throw an object, such as a large rock at a real castle wall or a small ball at our model castle in the Inventor Center, there are a lot of variables to consider.

Please see the Pre-Visit Activities for how to stimulate student thinking about what variables students should consider when building their catapults or trebuchets. See the Post-Visit Activities (for Grades 6-8 only) for a more complete exploration of projectile motion.

Let’s look at a typical trajectory of an object after it is thrown from a catapult or trebuchet with an initial velocity. Let’s suppose that it falls short of the target, the castle, as shown below:



This kind of motion is called projectile motion and follows some simple laws of physics, assuming no force other than gravity is acting on the object. (In other words, we assume that the air and the wind have no effect on the object.) The shape of the path, called a parabola, can be described with an equation. After the initial velocity has been applied, the object continues in motion by its own inertia. (Birds in flight do not follow the laws of projectile motion because birds are continually self-propelling themselves after take-off.)

What could we change about the catapult to make the object travel further? Variables are things that change. In an experiment (or in trying to get a projectile over a castle wall), an *independent variable* is the one which can be varied and controlled by the experimenter (attacker). The *dependent variable*, such as how far the object travels, depends on the independent variables.

In this case, independent variables include the amount of potential energy stored by the machine, the materials, the mass of the projectile, the angle of release, and (for a trebuchet) the relative distances of the counterweight and object from the fulcrum of the lever.

Potential energy

Storing more potential energy in the catapult will increase how far the projectile will travel. The higher the potential energy stored, the higher the kinetic energy of the projectile when released. How could we store more potential energy? There are many ways, such as winding a rubber band more tightly, or (for a trebuchet) increasing the mass of the counterweight.

Materials

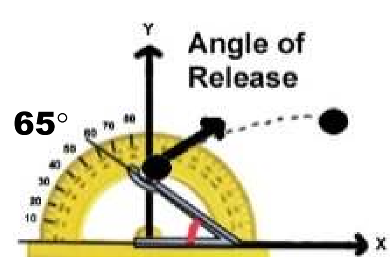
Changing the materials that the catapult is made from will change how fast a projectile will be hurled through the air and therefor how far it will go.

Mass of projectile

The mass of the projectile thrown by a catapult will change how far the projectile will be thrown before it falls to the ground. There is a trade-off between mass (m) and velocity (v) when a projectile is thrown by a catapult or trebuchet with a certain amount of kinetic energy (KE). The higher the mass of the projectile, the lower the velocity will be when it is released.

$$\text{Kinetic energy} = \tfrac{1}{2} \times \text{mass} \times \text{velocity}^2$$
$$KE = \tfrac{1}{2} \times m \times v^2$$

Angle of release



The angle that the projectile is launched at will change the trajectory and thus how far the projectile will travel. The angle of release can be measured by a protractor. An optimum angle is approximately 45 degrees.

Distance from fulcrum

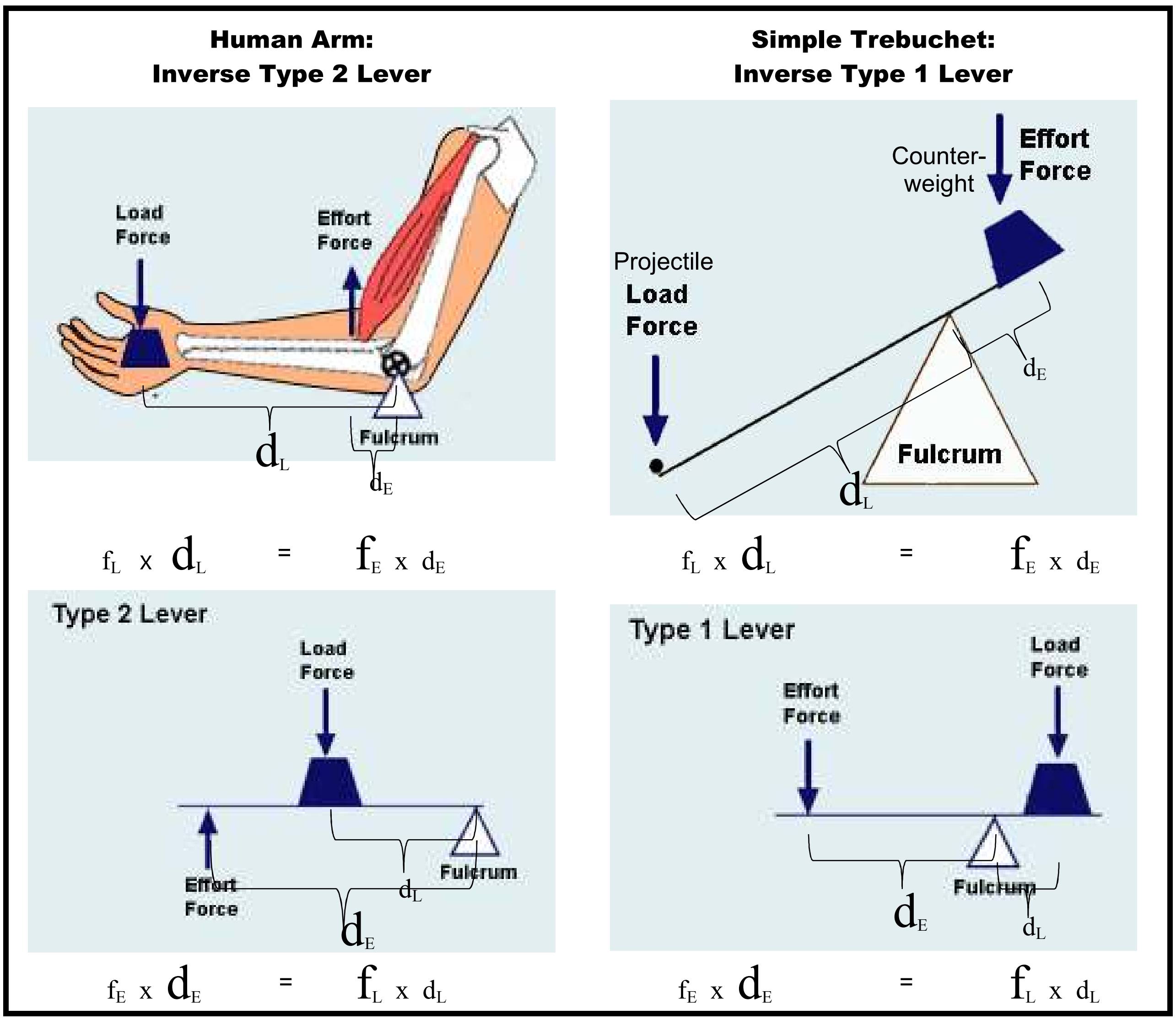
For a trebuchet, the greater the distance of the projectile from the fulcrum,
the higher the mechanical advantage will be, and the larger the distance the projectile will travel.

There are many other variables. Even less quantifiable factors such as skill can be considered variables.

Are trebuchets and catapults simple machines?

Some catapults and trebuchets, the ones that are very simple, are simple machines, devices that require the application of only one kind of force. Others, that contain more than one type of simple machine, are complex machines.

Catapults and trebuchets can be considered mechanical throwing arms. When we look carefully at a human arm we can see that it is an inverse Type 2 Lever, where the load and effort have been reversed. Likewise, an early trebuchet is an inverse Type 1 Lever, with the load and effort reversed.



Work is equal to force times distance. The work put in on the effort side of the arm is always equal to the work done on the load side of the arm.

Effort (E)		Load (L)
work = force x distance		work = force x distance
w_E	=	w_L
f_E x d_E	=	f_L x d_L

Normally, our goal in using a lever is to decrease the amount of force that we need to apply on the effort side (f_E). We do this by increasing the distance that we apply this effort force (d_E) to, so that the product of (f_E x d_E) remains the same.

But in the case of a trebuchet, our goal is to increase the velocity of the object, or load, in other words to increase the distance (d_L) that the load will travel in a certain amount of time. In other words, the load must be placed on the long arm of the lever and the effort (the counterweight) on the short end, making the distance that the effort is applied (d_E) small. Therefore, the effort force (f_E) must be large so that the product (f_E x d_E) remains the same. In other words, an Inverse Type 1 Lever <u>increases</u> the force needed to do the work. But the sore muscles are worth it if the object is thrown faster.

The higher the ratio of the length of the projectile arm to the counterbalance arm, the greater the mechanical advantage and the faster the projectile will be thrown.

Most of the catapults and trebuchets over history were complex machines that became more and more complex over time. For example, wheels and axels were added to trebuchets so that when launched, the trebuchets could travel along a track rather than over-balancing themselves forward. Catapults often contained gears to apply maximum force to the elastic material attached to the arm.

MAKING THE MOST OF YOUR VISIT

Using This Guide

Before you visit, review the Essential Questions to see how the Inventor Center's educational themes connect with your curriculum. Identify what you would like your students to learn from the Inventor Center and how they could continue learning back in the classroom.

This Guide includes Activities for Before Your Visit, During Your Visit, and Back in the Classroom.

Correlation to **Standards**

Science and Engineering:

NY State Science and Technology Standards (MST)

Standard 1: Inquiry Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Standard 4: Science, Physical Setting (PS)

Key Idea 4: Energy exists in many forms, and when these forms change energy is conserved.

Key Idea 5: Energy and matter interact through forces that result in changes in motion.

Standard 5: Technology Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Standard 6: Interconnectedness: Common Themes

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 6: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs

Standard 7: Interdisciplinary Problem Solving

Key Idea 2: Strategies. Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

Next Generation Science Standards

Grade 3 **3-PS2 Motion and Stability: Forces and Interactions**

http://www.nextgenscience.org/3ps2-motion-stability-forces-interactions

Students who demonstrate understanding can:

3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object

3-PS2-2. Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

Grade 4 **4-PS3 Energy**

http://www.nextgenscience.org/4ps3-energy

Students who demonstrate understanding can:

4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide.

4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Grade 5 **5-PS2 Motion and Stability: Forces and Interactions**

http://www.nextgenscience.org/5ps2-motion-stability-forces-interactions

Students who demonstrate understanding can:

5-PS2-1. Support an argument that the gravitational force exerted by Earth on objects is directed down.

Grades 3-5 **3-5-ETS1 Engineering Design**

http://www.nextgenscience.org/3-5ets1-engineering-design

Students who demonstrate understanding can:

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Middle School:

MS-PS2 Motion and Stability: Forces and Interactions

http://www.nextgenscience.org/msps2-motion-stability-forces-interactions

Students who demonstrate understanding can:

MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.*

MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

MS-PS3 Energy

http://www.nextgenscience.org/msps3-energy

Students who demonstrate understanding can:

MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

MS-ETS1 Engineering Design

http://www.nextgenscience.org/msets1-engineering-design

Students who demonstrate understanding can:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Scientific and Engineering Practices

- Asking Questions and Defining Problems
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Developing and Using Models
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Using Mathematics and Computational Thinking
- Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas (DCIs)

- PS2A: Forces and Motion
- PS2B: Types of Interactions
- PS3: Energy
- ETS1: Engineering Design

Crosscutting Concepts

- Patterns
- Cause and effect: Mechanism and explanation
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change

Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects

(R,CRR,7) Reading:

#7 Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words

(IR,PreK-5,7) Reading Standards for Informational Text:

Integration of Knowledge and Ideas

(W,CRR,2) Writing:

#2 Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

(SL,CCR,1,2,3) Speaking and Listening: Comprehension and Collaboration:

#1 Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

#2 Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

#3 Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric

(SL,CCR,4,6) Speaking and Listening: Presentation of Knowledge and Ideas:

#4 Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

#6 Adapt speech to a variety of contexts and communicative tasks, demonstrating command of formal English when indicated or appropriate.

(L,CCR,1) Language Conventions for Standard English

#1 Demonstrate command of the conventions of standard English grammar and usage when writing and speaking

(L,CCR,4) Vocabulary Acquisition and Use

#4 Determine or clarify the meaning of unknown and multiple-meaning words and phrases by using context clues, analyzing meaningful word parts, and consulting general and specialized reference materials, as appropriate.

Common Core State Standards for Mathematics

Standards for Mathematical Practice

#1 Make sense of problems and persevere in solving them.

#2 Reason abstractly and quantitatively.

#3 Construct viable arguments and critique the reasoning of others.

#4 Model with Mathematics.

#5 Use appropriate tools strategically.

Domains:

Grades 4,5:

Measurement and Data, 4.MD, 5.MD

Common Core Frame Work for Social Studies

Correlation with Content Sequence

Grade 3 Communities around the World

Grade 6 The Eastern Hemisphere

Standards:

3) Geography
4) Economics
5) Civics, Citizenship, and Government

Social Studies Practices

1) Gathering, Using, and Interpreting Evidence
2) Chronological Reasoning and Causation
3) Comparison and Contextualization
4) Geographic Reasoning
5) Economics and Economics Systems

Themes with Context

2) Development, Movement, and Interaction of Cultures
- Cultural diffusion and change over time as facilitating different ideas and beliefs.

3) Time, Continuity, and Change
- Reading, reconstructing, and interpreting events
- Analyzing causes and consequences of events and developments

4) Geography, Humans, and the Environment
- Interactions between regions, locations, places, people, and environments
- Spatial patterns of place and location

6) Power, Authority, and Governance
- Conflict, diplomacy, and war

8) Creation, Expansion, and Interaction of Economic Systems
- Scarcity of resources and the challenges of meeting wants and needs

9) Science, Technology, and Innovation
- Scientific and intellectual theories, findings, discoveries, and philosophies
- Applications of science and innovations in transportation, communication, military technology, navigation, agriculture, and industrialization
- Relationship between science, technology, and innovation and social, cultural, and economic change

10) Global Connections and Exchange
- Past, current, and likely future global connections and interactions
- Cultural diffusion; the spread of ideas, beliefs, technology, and goods
- Role of technology

Career Development and Occupational Studies (CDOS)

Standard 1: Career Development

Students will be knowledgeable about the world of work, explore career options, and relate personal skills, aptitudes, and abilities to future career decisions.

Standard 2: Integrated Learning

Students will demonstrate how academic knowledge and skills are applied in the workplace and other settings.

Standard 3a: Universal Foundation Skills

Students will demonstrate mastery of the foundation skills and competencies essential for success in the workplace.

FACILITATION DURING YOUR VISIT

Your class's hands-on experience during your visit to the Inventor Center will be a 50 minute long exploration into the inventive process and the science of mechanical throwing machines, facilitated by a member of the Rochester Museum & Science Center's floor staff. There is a lot for the students to do within this time period so *please arrive promptly*.

What to Expect

Introduction:
The facilitator will first engage students in a short introduction to the hands-on experience, which will include:

- An overview of the build, experiment, learn and share stations, what students will be doing, and the timing.
- A demonstration of several prototype catapults and trebuchets and how to test them.
- A discussion of what kinds of variables students should be considering when they design their catapult or trebuchet.
- The importance of teamwork and safety.

Building Their Prototype:
Students will be divided up into teams of 3-6 students per build table. Each team will build only one catapult or trebuchet. As a team they should decide their design and choose materials from the junk pile. They will need to work very efficiently in order to have their own prototype built quickly.

> *Students should draw their design in their journal.*

Experimenting with and Tweaking Their Prototype:
The team will obtain a ball from the facilitator and test their catapult or trebuchet at one of the castles. Based on their observations they will have a few minutes to make modifications to their design.

> *Students should record observations from their experiment and what modifications they made in their journal.*

Testing Their Final Catapults or Trebuchets (Class Attack of the Castle):
Students then clean up their work stations and come together for a concerted attack of the castle, each team taking a turn. Can your class make the castle surrender?

> *Students should record the results in their journals.*

Wrap-Up:
The facilitator will then lead a short discussion of what was successful, what did not work, and how students would improve their designs if they had more time.

> *Students should record in their journals what they would try next if they had more time.*
>
> *Student journals will be collected and handed to the teacher. We suggest using these for a wrap-up, especially an oral or written argument based on evidence (See Post Activities).*

Notes: You may wish to bring a camera to take pictures of your students' inventions.

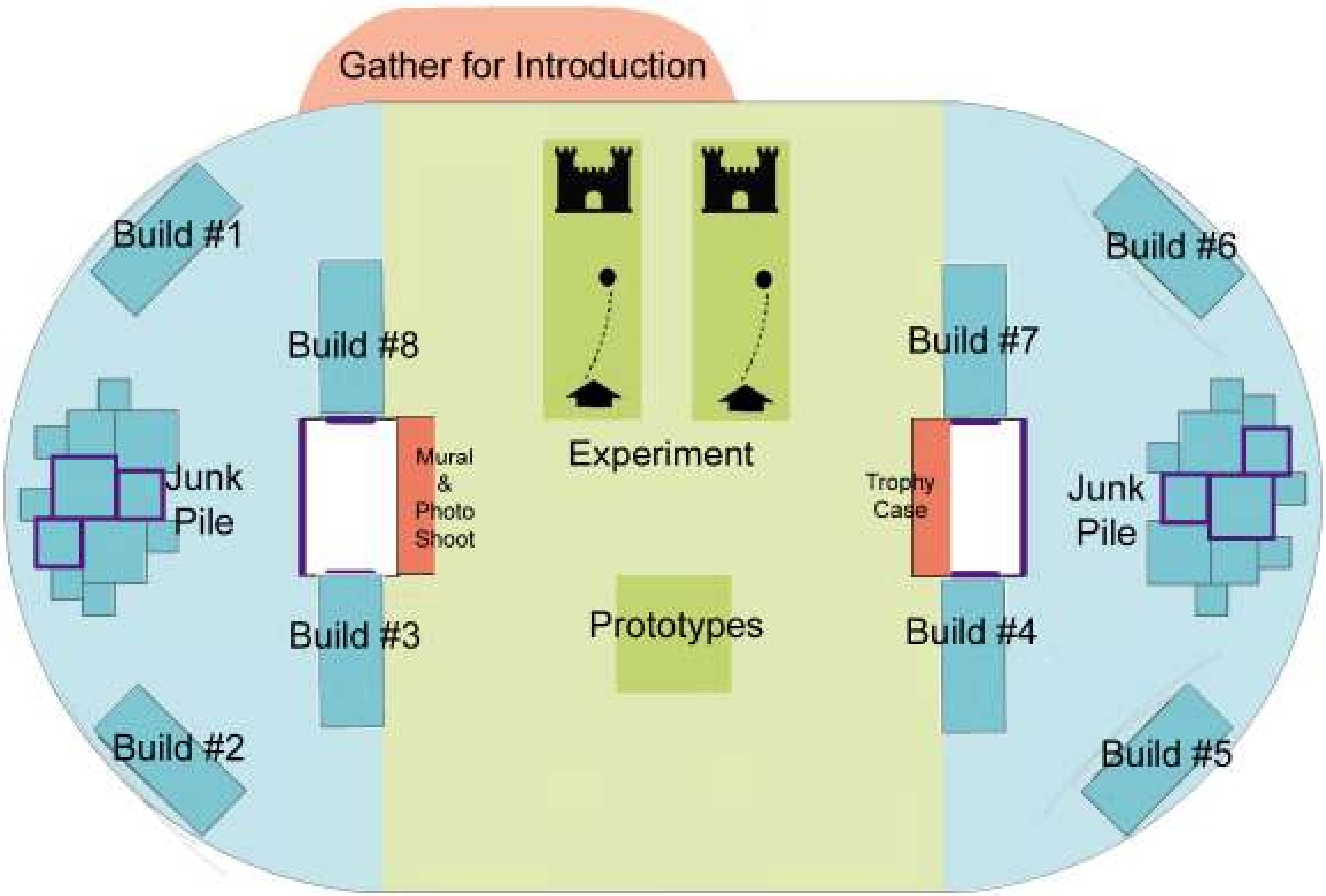
No materials or inventions may leave the Inventor Center. Before leaving, students will be asked to place their designs on the trophy case for other visitors to learn from their inventions.

Floor Plan

There are eight **build tables**; each can sit 3-6 students.

The "**junk piles**" house the building materials.

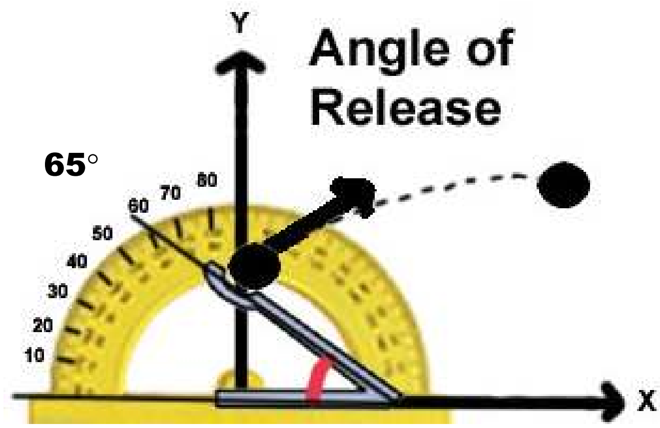
Two **experiment stations** have castles at one end surrounded by nets. Students place their catapults or trebuchets at the other end and launch balls into the castles.



Glossary of Terms

Acceleration:
The rate of change of velocity with respect to time; in other words, the change of velocity. It is measured in meters/second^2 (meters per second squared *or* meters per second per second).
For example, when an object falls, it travels faster and faster as it falls, gaining speed at a rate of 9.8 m/s every second

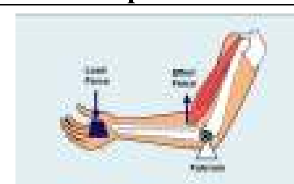
Angle of Release: The amount of turn between two straight lines that have a common end point (the vertex).



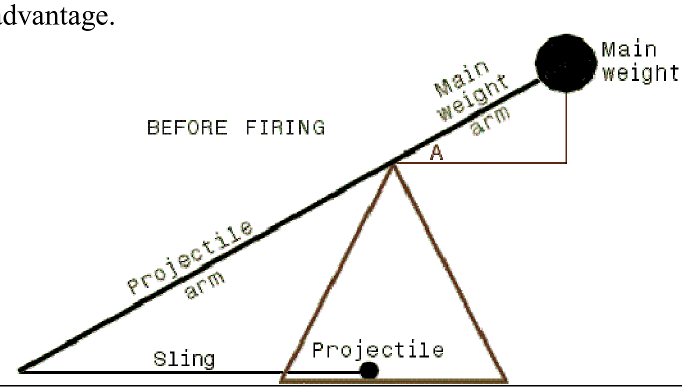
The angle of release can be measured with a **protractor**.

Argument: The process of forming reasons, justifying beliefs, and drawing **conclusions** with the aim of influencing the thoughts and/or actions of others.

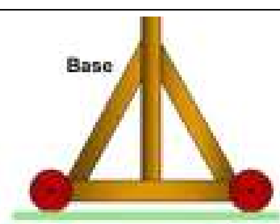
Arm: An upper limb of the human body, or a similar long thin part extending from a central support in a machine. An arm is one of the three basic components of a catapult or trebuchet.



The human arm and an arm in a trebuchet or catapult both act as simple machine levers that can provide a mechanical advantage.



Base: The lowest part of something that supports the rest. A base is one of the three basic components of a catapult or trebuchet.



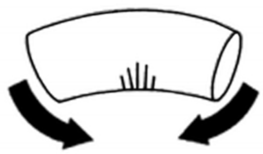
For a catapult or trebuchet to work efficiently it is important for the base to be stable so that when the stored potential energy is released, only the arm and the projectile move, not the base.

Bastion: A tower or turret projecting from a fortification.
The purpose of these small towers which projected out from the castle wall was to cover the blind spots when the castle was under siege.

Battlements: The slot-shaped architecture at the top of a castle wall. Archers inside the castle could stand on a surface at the top of the castle wall and shoot through the gaps and still be somewhat protected.

Bell tower: A tower that supports or shelters a bell. Bell towers were usually located in the village, not the castle, but the Tower of London, a very large and well-fortified castle, had a bell tower.

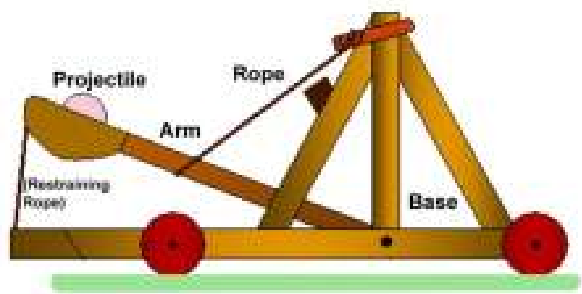
Bend: One of the ways that a force can be applied to elastic material in a catapult in order to store potential energy. In ancient catapults, a bend could be obtained using wood (especially yew) or layers of wood and horn in a bow or arm. In the inventor center you may want to use wood.



Blueprint: A detailed plan or drawing serving as a model for how to build something. The name comes from the fact that in the past these drawings were printed in white on a blue background.

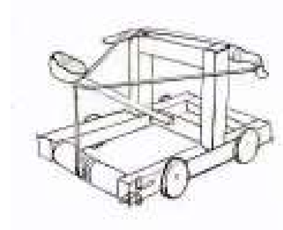
Architects create blueprints that are used to construct a building. Leonardo daVinci's detailed drawings of inventions such as trebuchets could loosely be referred to as blueprints.

Catapult: An ancient weapon, too big to be held by one person that was used for throwing objects such as rocks.



Composed of 1. a base, 2. a throwing arm, and 3. some sort of an elastic spring-type structure that stores potential energy until it is released and converted into the kinetic energy of motion of the projectile.

In a catapult, the potential energy is stored as elastic energy in the form of
1. a stretch (tension)
2 a bend, or
3. a twist (torsion). The material stretched, bent, or twisted must be elastic in nature, such as rope, rubber, wood, or steel.



The earliest catapult, such as the one shown, first appeared in China in 400 BC and were made by adding a pivoting arm to a crossbow.

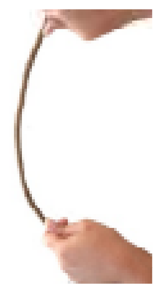
Note: Some sources refer to a trebuchet loosely as a "catapult" but the accurate definitions will be used in the Inventor Center.

Communication: Using words, pictures, charts, graphs, and diagrams to share information.

Conclusion: A decision reached after thinking about facts and details.

<table>
<tr><td>Counterweight: A weight that provides a balance against another weight.


Trebuchets store potential energy in a massive counterweight placed at one end of the arm. A projectile is placed in a sling hanging from the other end of the arm. When the counterweight is allowed to fall, the potential energy is converted to the kinetic energy of motion as the projectile is hurled through the air.</td><td>Courtyard: An open area inside the castle walls, sometimes called a bailey.</td></tr>
<tr><td>Crusades: Military expeditions that the Christian powers of Europe undertook in the 11th through 13th centuries to travel to the Middle East and attempt to take the Holy Land from the Muslims.</td><td>Data: Observations and measurements that are recorded and gathered into graphs, tables or charts.</td></tr>
<tr><td>Drawbridge: A wooden bridge that spanned a moat in front of the main entrance to a castle. If a castle was under attack, the drawbridge could be moved either sideways or raised up so that the attackers could not reach the castle gate.
</td><td>Elastic Materials: A springy material (such as rubber, certain types of wood such as yew, tendon, horn, and steel) that is good at storing and releasing energy.

Catapults use elastic materials for the storage and release of energy. We store the energy slowly and release it quickly to get a lot of speed with the release.

Stretch a rubber band. It gets long and skinny. Now let it go. It goes flying! Where did this kinetic energy of motion come from?
When we apply stretch (provide tension to), bend, compress, or twist (provide torsion to) an elastic material it changes shape. The force from our muscles that we applied as a push or pull to make it change shape is stored as potential energy.
When the stretching, bending, compressing or twisting force is released, the stored potential energy is released as kinetic energy.
This is in contrast to non-elastic, brittle materials such as glass or stone. If we apply enough force to glass it doesn't change shape, it shatters. (Don't try this.) Glass is not elastic.</td></tr>
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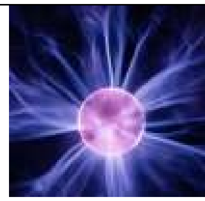
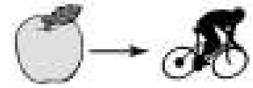
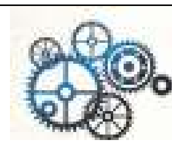
Energy: The ability to do work or cause a change.  Every time that we observe a change (an apple growing, a low note going to a high note) there must have been an input of energy (solar energy in the sun converted to chemical energy in the apple, increased energy and frequency of vibration of a guitar string).	**Energy transformation**: Energy can be changed from one form to another. The chemical energy stored in an apple can be converted into kinetic energy by the bicyclist.  For siege engines, the chemical energy stored in food is stored as chemical energy in the attacker's muscles which is converted to the kinetic to cock the siege machine. For a catapult this is the work of stretching, bending, or twisting an elastic material. For a trebuchet this is the work of raising a heavy counterweight up on the lever. The energy in the cocked position has now been transformed into Potential Energy. When the trigger is released, this potential energy is released as the kinetic energy of motion of the projectile. When the projectile hits the castle wall, the kinetic energy is used to do the work of crumbling the wall. Eventually all of this energy is converted to heat energy.
Engineering: The application of science to the design and creation of large structures (such as roads and bridges) or new products or systems.  The pyramids of Egypt are one of the greatest civil engineering accomplishments of the world. 	**Error**: The most common meaning of error is a mistake. However, in science and engineering it can also mean the difference between a measured observation and the true value. There is always a certain amount of uncertainty, or error, in <u>any</u> measurement – how much depends on the measurement device and how the measurement is done. For example, if you measure the length of a fly's wing while it is in flight with a yard stick you will get a lot of error. You would get less error if you used a very small ruler with lots of lines in it and got the fly to hold still.
Experiment: Using scientific methods to test a hypothesis.	

Force: A push or a pull. A quantitative description of the interaction between two objects.

Force can be measured in newtons (N). One newton of force is equal to 1 kg * m/s^2.

It takes a form of energy called "***work"*** to apply a force over a distance (work = force x distance, w= f x d).

One type of force, called ***contact force***, occurs when objects come in direct contact with each other. For example, when a huge rock hurtled by a siege engine hits a castle wall, it applies a large force to the wall that can do the "work" of breaking down the wall. The more massive the rock and the faster it is moving, the more damage, or "work" is done on the wall.

Catapults take advantage of another kind of force: the stretching, compressing, bending, or twisting of an elastic material. To prepare a catapult to launch a rock, it takes ***work*** to twist a rope (provide ***torsion***), to stretch a rubber band (provide tension), or bend wood.

Gravitational force can be exerted even across empty space. Trebuchets take advantage of this kind of force. To prepare a trebuchet to launch a rock, it takes ***work*** to raise the arm with the massive counterweight against the ***acceleration*** of ***gravity*** (force = mass x acceleration, f = m x a).

In either case, when the catapult or trebuchet is released, the ***potential energy*** is released as ***kinetic energy*** in the form of the motion of the rock. In this case the ***work*** that is performed is the crumbling of the castle wall.

Gravity: the **force** of attraction that moves or tends to move physical bodies together, the force that causes things to fall towards the Earth.

The force that an object on Earth is attracted downward towards the center of the Earth, is called its **weight** and is equal to the mass of the body times the local **acceleration** of gravity, which is about 9.8 m/s^2.
Weight = mass x acceleration of gravity (weight = m x g).

Inertia: the resistance an object has to a change in its state of motion.

Newton's first law of motion states that "An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force." Inertia is the property of matter that makes it act in this way.

Invention: The idea of a new and useful device, material, or process.

Inventor: Someone who uses technology in a new way to solve a problem. For example, Madame C J Walker, 1867 – 1919, invented hair lotion for black women.

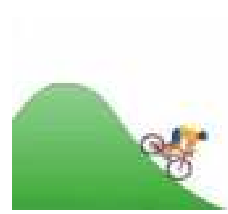
The individual inventors of siege machines have mainly been lost in history. This is because accurate records were often not kept, and also because catapults evolved slowly from cross bows by trial and error over many centuries in many countries.

One inventor of catapults and trebuchets that kept very detailed and beautiful records was Leonardo DaVinci.

Keep: In early castles this was a single square-walled structure where those defending the castle could retreat. When castles became larger and more complex, it was the tallest and strongest part of the castle and the last point of retreat when under attack.

Kinetic energy: Energy due to motion.

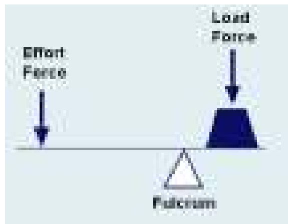
A bicyclist speeding down a hill has high kinetic energy because he is moving quickly.



The Law of Conservation of Energy: Energy can neither be created nor destroyed, only change forms.

Leonardo daVinci: (1452-1519) An Italian Renaissance painter, sculptor, draftsman, architect, engineer, and scientist. DaVinci, although against war, designed intricate trebuchets, as well as many other ingenious devices.

Lever: One of the few types of simple machines. It consists of an arm pivoting on a fulcrum. Effort exerted on one position of the lever is used to lift a load. The amount of effort required is related to the position of the pivot and the relative lengths of the sections of the bar. The fulcrum is the point around which the lever pivots.
A type 1 lever is shown here.



A Trebuchet is an inverse type 1 lever.

Machine: A device that changes the direction or the amount of effort needed to do work.

For example, the human arm is limited in how much force it can provide. It would be hard for one human holding a rock to knock down a castle wall. However, by inventing machines such as a catapult or trebuchet, the force in a human's muscles can be used to slowly do enough work to store enough potential energy in a machine so that when that energy is released all at once, a large amount of kinetic energy is released…large enough to hurl a huge rock very quickly at the castle wall with a lot of force.

Mass: The quantity of matter in something. It is not dependent on the volume that it occupies. Mass is measured in grams (g) or kilograms (kg).

Mass is what causes a body to have weight in a gravitational field (weight = mass x acceleration) but it is different from weight. ***Weight*** is the measure of the force of gravity acting on a body.

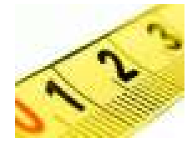
There is a trade-off between mass (m) and velocity (v) when a projectile is thrown by a catapult or trebuchet with a certain amount of kinetic energy. The higher the mass of the projectile, the lower the velocity it will be thrown with because Kinetic energy = ½ x mass x velocity^2
($KE = \frac{1}{2} m v^2$).

Material: The material that the base and other components of a catput or trebuchet are made of is another crucial **variable**. The word material is related to **matter** which is a physical substance, as opposed to energy.

There exists a whole field of study called **material science**, the scientific study of the properties and applications of materials of construction or manufacture. For example, it would make a lot of difference to how practical and how much fun a bicycle is if it is constructed of paper, aluminum, or steel.

In the Inventor Center you will have lots of materials in the Junk Pile to choose from when building your catapult or trebuchet, such as rubber bands, tongue depressors, Choose materials or ways of putting the materials together that make the base rigid and stable. For your catapult choose elastic components.

Measurement: The assignment of numbers to objects or events.



It is a cornerstone of science, technology, engineering, economics, and quantitative research in other social sciences. One reason for this is that the communication of measurements is essential for reproducibility by others, which is essential.

Scientist learn which type of measuring device to use for different measurements. For example, a meter stick could be used to measure how far a projectile traveled in meters (m) or centimeters (cm). A protractor could be used to measure the angle of release of the projectile (measured in degrees) from the siege machine.

Mechanical Advantage: The ratio of the force that performs the useful work of a machine to the force that is applied to the machine. In other words, it is how helpful or "advantageous" it is to use a machine such as a catapult or a trebuchet to launch a rock, rather than just throwing it by hand.

Mechanical Energy: The energy of motion used to perform work.
When a bicyclist pushes on the pedals, the wheel and axel turns, which performs the work of moving the bicycle. This can be a lot of work if it is uphill.

Middle Ages: The period of European history from the fall of the Roman Empire at about 500AD to the dawn of the Renaissance at about 1500AD. This was a period of great turmoil in Europe. To defend themselves, nobles built castles. To attack the castles, other nobles built siege machines such as catapults and trebuchets.

Moat: A body of water that was built around the outer wall of a castle to keep attackers from tunneling under the castle walls. ***Drawbridges*** were constructed so that people living in the castle could cross over the moat. Drawbridges could be raised when the enemy attacked.

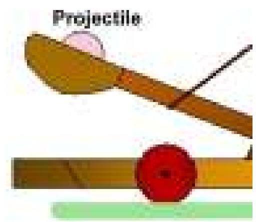
Parabola: The shape of the path through the air that an object follows when the object is thrown forward and up in the air and falls back to the ground.

There is a mathematical equation for this shape that you will learn in High School.

Potential energy: Energy that is stored in an object due to its position or arrangement. It is related to an object's position relative to a force (like gravity).
A bicyclist poised at the top of a hill has low kinetic energy (because he is barely moving) but high potential energy because he will be able (or has the "potential to" move very quickly soon.

Projectile: In a battle field**:** an object (such as rock in the battle field or a small ball in the Inventor Center) that is thrown as a weapon.

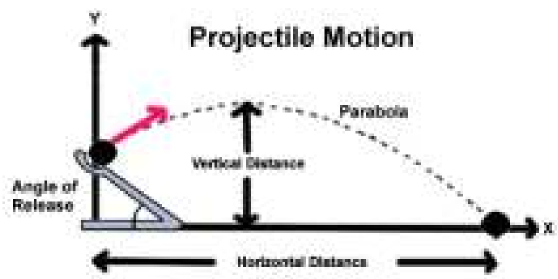
In physics: an object that, once it is propelled with some initial **velocity**, continues in motion by its own **inertia** and is influenced only by the downward force of **gravity**.



Projectile Motion: – The motion of an object (**projectile**) that has been propelled with some initial velocity. This motion follows some simple laws of physics. After the initial **velocity** has been applied, the object continues in motion by its own **inertia** and it is assumed that no force other than **gravity** is acting on the projectile. Birds in flight do not follow the laws of projectile motion because birds are continually self-propelling themselves after take-off.

The shape of the path of the object is called a **parabola** and can be predicted using a mathematical equation. Soccer players can become very good, with practice, at predicting projectile motion so as to know just where to be to head a ball.

The motion of a rock hurled in the air by a catapult or trebuchet follows the rules of projectile motion as long as we ignore the effect of wind or air on the projectile.



Prototype: A first model of something, especially a machine, from which other forms are developed.

This 1915 prototype shape for the coke bottle never went into mass production because its shape would have made it unstable on conveyor belts.

It is often best not to spend too long making a prototype. Make it quickly and test it. Modify it slightly and test it again.

When you visit the Inventor Center you will be making a prototype catapult or trebuchet as quickly as you can so that you have time to make some quick experiments and modify your invention.

The Renaissance: The period of European history from about 1400AD to 1600AD. Renaissance means "rebirth" in French. During this time there was a rebirth of interest in science, art, and literature, especially in Italy.

Siege: A military blockade of a castle or fortified place to make the inhabitants surrender. Sieges were costly to both sides. The people inside the castle might run out of food and water. Soldiers on the outside had to be fed and provided with shelter. To shorten the length of time that sieges lasted, inventors came up with more and more sophisticated siege machines: catapults and trebuchets.

Simple Machine: One of a few devices that only require the application of a single force to work. These include: the lever, the wheel and axle, the pulley, and the inclined plane. (Sometimes people consider the wedge and the screw as other simple machines but these can both be considered special kinds of inclined planes.)

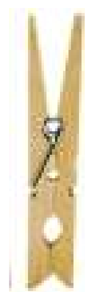
Machines that use two or more simple machines are called Complex Machines. Most of the catapults and trebuchets over history were complex machines. They became more and more complex as they were improved.

Sling: An instrument for throwing stones that usually consists of a short strap with strings that is whirled around to release the projectile. Trebuchets usually used slings to increase the force and velocity that a stone could be hurled at.

Speed: How fast an object is moving, expressed as distance divided by time (for example meters per second, m/s).

Speed is the same as velocity except that velocity includes the direction that an object is traveling whereas speed is irrespective of direction.

Spring: A specific type of elastic body or device consisting of a twisted or coiled piece of metal. When the spring is pressed together (compressed) or pulled apart (stretched), the spring temporarily changes shape and stores potential energy. When the pressing or pulling force is stopped, the spring returns to its original shape, releasing kinetic energy that can be used to do work.

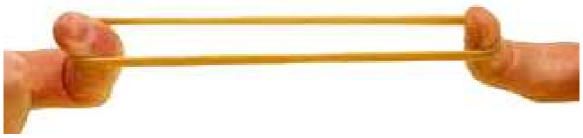


Some kinds of clothespins contain a spring that is holding two levers together at the fulcrum. It takes force to squeeze the two long ends of the lever together because this is changing the shape of the spring. If a clothespin was built into a catapult that potential energy could be released as kinetic energy of motion of a projectile when the pressure is released.

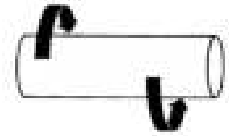
Stirling Castle: Located in Stirling, Scotland, the castle was the scene of one of the most important battles of the Wars of Scottish Independence. In order to break the siege, King Edward I of England had a trebuchet named the Warwolf built.

Tension: The condition or amount that an elastic substance has been stretched, or pulled apart. The stress (potential energy) that results from stretching an elastic body.

One of the ways that a force can be applied to elastic material in a catapult in order to store potential energy. In ancient catapults tension was obtained using tendon, wood (especially yew), or horn. Rope also is somewhat elastic. In the inventor center you may want to use rubber bands or wood.



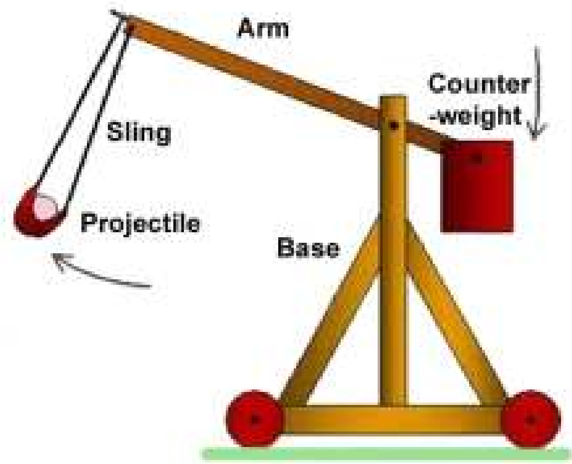
Torsion: The condition or amount that an elastic substance has been twisted. The stress (potential energy) that results from twisting an elastic body.



One of the ways that a force can be applied to elastic material in a catapult in order to store potential energy. In ancient catapults torsion was obtained by twisting rope. In the inventor center you may want to twist a rubber band.

Trebuchet: A medieval weapon used for throwing objects such as huge rocks, usually at a castle under siege.

Like a catapult, a trebuchet is composed of
1. a base,
2. a throwing arm (in this case it must be able to pivot), and
3 a structural way of storing potential energy until it is released and converted into the kinetic energy of motion of the projectile.



Unlike a catapult, gravity is the force used to produce the potential energy of a trebuchet. A trebuchet makes use of mechanical advantage by placing a massive counterweight at the end of the short arm and the projectile (usually in a sling) at the end of the longer arm. The force of muscles is used to raise the counterweight. When the counterweight is allowed to fall, the potential energy stored is released as the kinetic energy of motion of the projectile.

The trebuchet was invented in France and was first reported to be used in 1124AD in the siege of Tyre during the Crusades. As it was much more powerful than a catapult, a trebuchet became the siege weapon of choice until about 1600AD when it was largely replaced by the use of canon and gunpowder.

Note: Some sources refer to a trebuchet loosely as a “catapult” but the accurate definitions will be used in the Inventor Center.

Variable: Something that changes.

In an experiment, an **independent** variable is the one which can be varied and controlled by the experimenter. The **dependent** variable depends on the independent variable.

For example, changing the materials that a catapult is made from will change how fast a projectile will be hurled through the air. The type of material is the **independent variable** and how fast the projectile moves is the **dependent variable**.

As another example, changing the mass of the projectile thrown by a trebuchet will change how far the projectile will be thrown before it falls to the ground. The mass of the projectile is the **independent** variable and how far the projectile travels is the **dependen**t variable.

Velocity: How fast an object is moving, expressed as distance divided by time (for example meters per second, m/s).  Velocity is the same as speed except that velocity includes the direction that an object is traveling whereas speed is irrespective of direction. (Mathematically, velocity is a vector.) The velocity of release of a projectile from a catapult or trebuchet depends on many variables. One variable is the mass of the projectile. According to the equation, Energy = ½ x mass x velocity^2 ($E=1/2\ mv^2$), for a given amount of stored potential energy, the heavier the projectile, the slower its velocity will be.	**Wars of Scottish Independence:** A Series of military campaigns fought, between 1286 and 1329, between the Kingdoms of England and Scotland over whether Scotland should remain an independent nation. One of the most important battles was the siege of Stirling Castle in 1304.
Warwolf (trebuchet): A trebuchet built in 1304 under the orders of Edward I of England in order to break the siege of Stirling Castle during the Wars of Scottish Independence. Some consider the Warwolf the most powerful and famous of the trebuchets in history. 	**Weight:** The force that an object on Earth is attracted downward towards the center of the Earth, equal to the mass of the body times the local **acceleration** of gravity, which is about 9.8 m/s^2. Weight = mass x acceleration of gravity (weight = m x g).
Work: Force multiplied by distance. The amount of energy related to the amount of force applied to an object and how far the object moves as a result of the forces. work = force x distance (w = f x d).	

Resources

On-Line

- National Inventors Hall of Fame, **Grades 3-12**, www.invent.org Web site of the National Inventors Hall of Fame, which the next generation of innovators by connecting them through the story of invention.

  Zoom Inventors and Inventions, **Grades 3-8**, http://www.enchantedlearning.com/inventors/indexe.shtm from Enchanted Learning, search for inventors or inventions by topic or alphabetically,

- Nova Builds a Trebuchet, **Grades 2-12**, **http://www.pbs.org/wgbh/nova/lostempires/trebuchet/builds.html** Follow NOVA's successful attempt to build and shoot a giant trebuchet, the most destructive war machine that ever laid siege to a medieval castle. (Castle Urquhart, located on the shores of Loch Ness in the Scottish Highlands)
- Life in a Castle, NOVA, **Grades 6-12**, **http://www.pbs.org/wgbh/nova/lostempires/trebuchet/castle.html** Professor Richard Holmes, a British military historian and member of the NOVA trebuchet-building team, describes what everyday life was like in a typical English castle of the Middle Ages.
- Leonardo's Catapults, **Grades 6-12**, http://members.iinet.net.au/~rmine/Leonardo.html Drawings and explanations of some of Leonardo daVinci's war machine inventions.
- Medieval Arms Race, NOVA, WXXI, **Grades 3-8**, http://www.pbs.org/wgbh/nova/lostempires/trebuchet/race.html A glimpse into the medieval world of technology. The trebuchet was only the most frightening of the weapons early European warriors employed in siege warfare. They also relied on battering rams, siege towers and tunnels - anything to gain access to a castle. Defenders, meanwhile, had a few tricks of their own.
- Characteristics of a Projectile's Trajectory, De Solution Physics Room, Grades 6-12, https://desolutioncourse.wordpress.com/physics-room/vectors-motion-and-forces-in-two-dimensions/lesson-2-projectile-motion/characteristics-of-a-projectiles-trajectory/, Discuss the horizontal and vertical components of a projectile's motion with specific attention given to the presence or absence of forces, accelerations, and velocity.

Simulations:

- Destroy the Castle, NOVA, **Grades 3-8** http://www.pbs.org/wgbh/nova/lostempires/trebuchet/destroy.html, Build your own virtual trebuchet and fire giant sandstone balls at a castle wall. There are five variables you can adjust in your trebuchet: stone ball weight, sling length, counterweight design, distance from the castle, whether to add wheels. Requires Shockwave.
- Projectile Motion, PBS Learning Media, **Grades 6-12**, http://www.pbslearningmedia.org/resource/hew06.sci.phys.maf.projmotion/projectile-motion/ Explore the properties of projectile motion. You can try to hit a target by varying conditions, such as the direction and location of the launch, the projectile's mass and shape and size, and the presence of air resistance. The parabolic trajectory of each projectile is plotted, along with markers to show changes in position at quarter-second intervals. Data can be easily collected. Includes resources and a Teachers' Guide.

Videos:

- Kinetic and Potential Energy, Wilee Coyote and the Roadrunner, **All ages**, 1:22, http://safeshare.tv/w/wqyxKUFLEK - Fun video that is very helpful in understanding elastic potential energy
- Push and Pull **Grades PreK-1**, 1:18, http://www.youtube.com/watch?v=XZlqas0tixo
- Force Work and Energy Relationship, makemegenius.com, **Grades 2-4**, 5:30, http://www.youtube.com/watch?feature=player_embedded&v=PD7a1EWjsTc Explains the difference between force, work & energy.
- Force and Motion, PBS Learning Media, **Grades 2-6** , 2:50 http://www.pbslearningmedia.org/resource/idptv11.sci.phys.maf.d4kfom/force-and-motion/ Defines gravity, force, friction and inertia through examples from amusement park rides. Examples and explanations of Sir Isaac Newton's 3 Laws of Motion are also included.
- Force and Motion Grinch, (song by Heath), **Grades 4-6**, 4:21 https://www.youtube.com/watch?v=WcoYeNbyqvw Concepts of forces and energy are reinforced in an amusing way.
- Misconceptions about Falling Objects, **Grades 4-12**, 3:21http://www.youtube.com/watch?feature=player_embedded&v=_mCC-68LyZM An interviewer drops a basketball and correct common misconceptions about falling objects.
- What forces are acting on you? Veritasium, **Grades 6-8**, 2:14 http://www.youtube.com/watch?feature=player_embedded&v=aJc4DEkSq4I Simple and effective overview of forces.
- Energy Transfer in a Trebuchet, NOVA, **Grades 6-12**, 4:18, http://www.pbslearningmedia.org/resource/hew06.sci.phys.maf.trebuchet/energy-transfer-in-a-trebuchet/, *Engineers*, and trade experts work with historians to recreate a medieval throwing machine called a trebuchet to throw an old piano. As part of their design process, the engineers

use models to help evaluate how well their designs will work.

- Lord of the Rings- Minas Tirith: **Grades 6-12**, Use discretion with young viewers. 4:08 but can stop at 2:10 https://www.youtube.com/watch?v=18vPx6A7cnY Dramatic video of catapults at work.
- Trebuchets and Catapults, Ancient Discoveries: Mega Machines, **Grades 6-12**, 4:19, http://www.teachertube.com/video/trebuchets-amp-catapults-238758 History of catapults and reconstruction of a giant trebuchet, including operation and a measurement of the projectiles motion.

Local Invention Conventions

- Finger Lakes Invention Convention, **Grades 1-8**, http://flicsterny.com/ Information about how you can get involved with an educational program for public and private school students from grades 1-8. The goal is to stimulate the development of students' creativity and imaginations, thereby building a new generation of American inventors.

Books

Inventions and Inventors

- *1,000 Inventions and Discoveries* DK Publishing, 2002
- M. Hare, *Rochester-made: From egg trays to marshmallows,* Democrat & Chronicle, Feb. 27, 2005
- D. Macauley and N. Ardley *The Way Things Work,* Dorling Kindersley, 2004
- D. Stewart *Brain Power: What's the Big Idea? 2,400,000 Years of Inventions*, grades 6 to 8, 2005, Barron's, Beginning with the period 2,400,000 to 8000 BC, when the "Big Idea" was the cooperative hunt and stone tools, and when animal-fat lamps, cave painting, and fish traps were cutting-edge technology, this book explores humankind's groundbreaking inventions, discoveries, and ideas through the ages. Each era gets a two-page spread with lavish, colorful, and comic illustrations.
- S. Tomecek and D. Stuckenschneider, *What A Great Idea! Inventions That Changed the World,* Scholastic Reference, 2003
- C. Vorderman, *How It Works: How Things Work,* Readers Digest, 1995

Castles

- S Beasty*, Stephen Biesty's Cross-sections Castle,* An intimate guide to the inside of a castle and the lives of its residents..
- C. Gravett, *Castle*, DK Eyewitness Books, An in-depth, comprehensive look at castles with a unique integration of words and pictures.
- D. Macauley, *Castle*, Best Children's Books of 2014, Factual and artistic details shine in light of newly researched information. With characteristic zest and wit, David Macaulay retraces the planning and construction of Lord Kevin's fictional castle.

Catapults and Trebuchets

- J. Austin, *Mini Weapons of Mass Destruction: Build Implements of Spitball Warfare*, Chicago Review Press, 2009, All ages, Easy to follow instructions for catapults that can be built easily with everyday materials.
- J. Austin, *Mini Weapons of Mass Destruction 3: Build Siege Weapons of the Dark Ages*, Chicago Review Press,2013, all ages, Easy to follow instructions for catapults and trebuchets that can be built easily with everyday materials

Simple Machines

- Mason, et al. *Simple Machines,* Kid Can Press, 2000
- S. Nankivell-Aston , et.al., *Science Experiments With Simple Machines*, Franklin Watts, 2000