HIGH SCHOOL LESSON GUIDE

THE PHYSICS OF BECOMING AN ARCHERY SUPERHERO

GRADE LEVELS - High School 9 – 12

CONTENT AREA – Physical Science

UNIT THEME – Physics of Archery

TOPICS – Potential Energy Conversions

TIME REQUIRED:

6 Minutes video

20 minutes class discussion

2 hours research

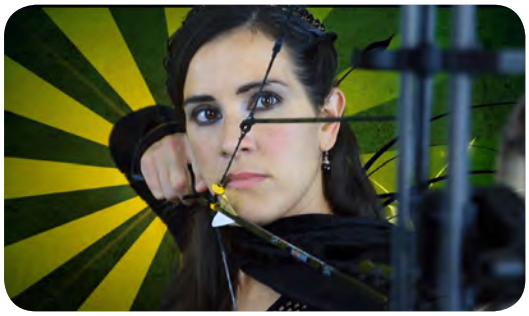
LEARNING OBJECTIVES:

1. **ENDURING UNDERSTANDING:** It is important for students to understand the physics involved in the conversion of a bow's stored potential energy into the kinetic energy of an arrow.

2. **CONTENT OBJECTIVES:** Students will develop an understanding of key vocabulary words related to the physics of archery.

3. **LEARNER OBJECTIVES:** Students will describe how different types of bows can convert stored potential energy into varying degrees of kinetic energy into a launched arrow. They will also compare and contrast the physics of how the various bow designs exhibit different force/draw curves.

4. **PROCESS OBJECTIVES:** Students will work in groups to process new information and use research and evidence to come to conclusions.



LESSON GUIDE TO COMPANION THE VIDEO

MATERIALS NEEDED (each group, each student):

1. **Video** – Online at http://www.untamedscience.com/become-archer-superhero/
2. **Notebooks** for students to write down questions, take notes during the video and during their research
3. **Graph paper** for groups to use during their research
4. **Calculator** for research calculations
5. **Access and permission** to conduct research at an archery shop or club with;

- Longbow, recurve, and compound bows
- Arrows (matched to the bows)
- Bow scale
- Arrow grain scale
- Chronograph
- Safe shooting area and backstop

TEACHER BACKGROUND

Special Note to Teachers and Students: To perform this activity to its fullest, you can locate an archery retailer near you at http://www.archery360.com/archery-stores/?address=&radius=100. If doing research at an archery shop or club is impractical, you can replace or supplement this exercise with Internet access for online research.

The homemade longbows of pioneers in American archery eventually gave way to the laminated recurve bow, with limbs that both unfolded and bent back during the draw. This increased the conversion of stored energy when the bow was shot. The conversion of a bow's stored energy really changed with the invention and refinement of the compound bow in the late 1960's and early 1970's.

Today's Bows

Today we have three types of commercially produced bows commonly used in archery and bowhunting that blend both the past and the present.

1. **The longbow i**s made of laminated wood and fiberglass with varying limb shapes from straight to slight deflexed and reflexed.

2. **The recurve bow** is made from laminated wood and fiberglass with pronounced "recurved" limbs.

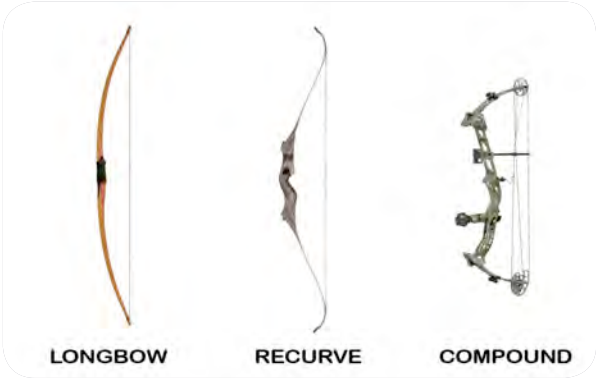
3. **The compound bow** is made from a variety of substances that employs the mechanics of cams and cables to alter the energy conversion of the short limb's stored energy. This creates "let-off" that allows the archer to hold and aim the bow at full draw with much less weight than the bow's peak draw weight.

TEACHER BACKGROUND *(continued)*

Archery Note: All three types of bows have also been adapted into crossbows with shorter horizontal versions equipped with a gun style stock and trigger mechanism.

Which bow is best?

Today's super heroes in the movies equip themselves for their super adventures using one of these three styles of bows. So how does Hollywood or the superhero choose which bow is right for their super adventure? Each bow has its own combination of advantages and limitations.



That's a function of their design and the physics of how they shoot an arrow, as they relate to our human anatomy. And understanding all that is the key to understanding why a superhero, or you for that matter, would select a certain type of bow to use in different types of archery.

The differences in how these three types of bows store and release energy in shooting an arrow present an interesting series of questions for us to explore and answer in our quest to understand "which bow is best" – especially in becoming an archery superhero.

The physics of archery

A bow is essentially a two-armed spring that stores mechanical "potential energy" when the string is drawn and pulls back the limbs. Here's how the different parts work.

When you draw back the bowstring, you use your muscles to exert a force on the string that bends the limbs backward. The amount of force that your fingers exert on the string when you've pulled it all the way back is called the "draw weight." The elastic or spring energy is now "potential energy" that can be converted into launching an arrow when you release the string. See? This isn't so hard. Oh, but wait…what about the physics?

Ah, here it comes. Hooke's Law states that the draw weight is proportional to the draw length. The greater amount that you deform the limbs by pulling them back further in your draw length, the more you increase the force that in turn increases the stored potential energy. Of course there's a limit to all that in both what your body is capable of drawing a bow and the bow's ability to withstand a limited draw length before it breaks. Fortunately, Mother Nature has taken care of that for most of us by limiting our physical "draw length" to around 28 to 30 inches.

Energy Conversion

Holding our bow at full draw, we now have stored a certain number of pounds of "elastic potential energy". The key word here is "potential". Because if we release the string without an arrow nocked on it, the energy isn't converted into much of anything, other than being reabsorbed into the limbs and bow, which in turn is called "dry firing" that can easily damage or break your bow. With an arrow nocked on the string, much of the stored energy is transferred to launching the arrow, though some of the energy remains in the bow.

So rule number one in your research; don't dry fire a bow. Nock an arrow first. Then you'll be ready to convert much of that stored potential energy into the kinetic energy of launching your arrow.

SPECIAL CONSIDERATIONS:

Because the research in this activity involves actual shooting of bows and arrows while recording data, the activity is richest when completed in groups with results shared and discussed with the whole class.

VOCABULARY:

1. **Longbow:** A traditional style bow with straight limbs that bend in a single uniform arch.
2. **Recurve bow:** A traditional style bow with limbs that "recurve" forward near the limb tips.
3. **Compound bow:** A modern bow that uses cables, cams and pulley system to alter the force-draw curve and shooting performance of the bows relatively short limbs.
4. **Potential energy:** The energy stored in the bow's limbs and string from the archers' muscles drawing the bow.
5. **Kinetic energy:** the energy of a moving object relative to its mass and speed (as in an arrow)
6. **Chronograph:** an electronic device that measures the speed of a moving object (as in an arrow in feet-per-second)

PROCEDURE – HOW TO WORK THROUGH YOUR SUPERHERO CHALLENGE:

1. **Before watching the video,** ask students what forces they think a bow uses to launch an arrow. Discuss as a class what bow characteristics might be important to a theoretical archery superhero. If students need more guidance, ask them to describe the process of shooting a bow and arrow. Lead the class into a discussion about how different bow designs might convert different amounts of stored potential energy into arrow velocity and kinetic energy.

2. **Tell students to write down questions** they have while watching the video. Some important questions to consider and discuss include:

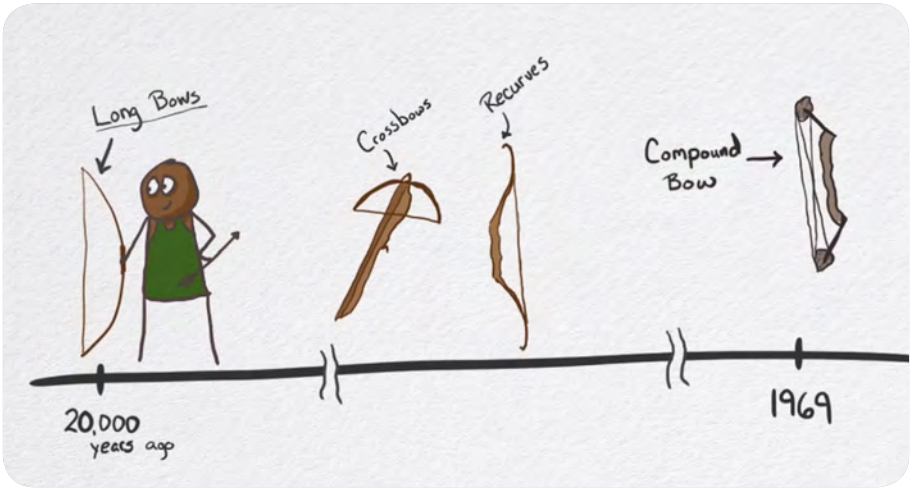
- What are the differences between the three types of bows?
- What role does an archer introduce into the physics of archery?
- What is potential energy and how does it relate to kinetic energy?

3. **After viewing the video**, ask students to share any questions they wrote down and discuss the questions together as a class. If students missed some important questions, be sure to discuss the concepts with the class.

4. **Divide the class in "research groups"** of 6 to 8 students. Distribute any students with archery experience evenly between the groups.

5. **Have groups locate and get permission** from a local archery shop or archery clubs to help with their research. (Depending on the research groups, access to the three types of bows at an archery shop or club with a bow scale, and a chronograph for measuring arrow velocity (speed), they may have to adapt their gathering of data to research on the Internet.) However, even shooting one of the three types of bows and recording the data will take the group through the physics exercise and calculations of determining the percent of efficiency of the bow's conversion of potential energy into the arrow's kinetic energy.

Note: *You can locate an archery retailer near you at http://www.archery360.com/archery-stores/?address=&radius=100. If doing research at an archery shop or club is impractical, replace or supplement this exercise with Internet access for online research.*



PROCEDURE CONTINUED:

The following steps can be used on one bow, or on all three types of bows. If you don't have access to all three types, fill in the blanks with research from the Internet.

1. **Okay, safety first.** Work with the supervision and safety advice of qualified persons in archery shop or club before attempting this research. Shooting arrows from bows can be dangerous. Just ask the ghosts from the Battle of Agincourt. Review safety rules before beginning your research.

2. **Next, determine the force-draw curve** and peak draw weight of each bow. Using a bow scale, record the pounds of draw force at one-inch intervals from the bow's "brace height" to 28 inches. Then plot your recorded pounds per inch on graph paper with an X and Y-axis. Plot the inches on the X-axis and the pounds on the Y-axis. Draw a line connecting all the points plotted and you will have a visual of "the force-draw curve" of your particular bow. Examples of force-draw curves are available online.

3. **The bow's potential energy (PE)** is not the peak draw weight, but rather the "integration" of the entire force-draw curve. This represents the total potential energy of the bow and is related to the total area under the plotted force-draw curve.

4. **If you've had access to and plotted the force-draw curves** for more than one bow, discuss with your research partners how and why the force-draw curves of the different bows might result in difference energy conversions. Consider point #3 above and that launching an arrow is related to the reverse energy dissipation of a force-draw curve.

5. **Now get an arrow that is "spined" correctly** for the bow's draw weight. Your archery expert can help with this part. Also select an arrow that weighs about 9 grains of arrow weight for each pound of bow draw weight. For example, for a 60-pound draw weight bow, you should select an arrow (with target point combination) that weights a total of 540 grains. Using this formula of grains of arrow weight per pound of draw weight more accurately levels the playing field in determining various energy conversion factors for the different bows.

6. **Let's get ready to shoot that thing**. Using a marker, mark the arrow 28 inches from the bottom of the nock groove. This will help you to consistently draw the arrow back to 28 inches and minimize variables. Yes, this seems a bit persnickety for simple bow and arrow fun, but come on, try to keep your scientist hat on while doing this experiment. Superheroes need to know these details if they're going to battle forces of evil or bring down flying dragons.

7. **The chronograph**. Most archery shops, clubs, and some archery enthusiasts have a chronograph for recording arrow velocity. If you're not experienced at shooting the bow, then by all means, get some expert shooting advice from the archery shop pro or an experienced archer. Shoot the arrow three times through the chronograph. Record the arrow velocity in feet-per-second (fps) and calculate the average. Again, if you don't have access of bows or a chronograph, you can research and find this information on the Internet.

8. **Calculate the bow's "kinetic energy conversion factor"** using the following formula. This is a two-step process. You'll first calculate the bow's conversion of stored energy into arrow kinetic energy. Then you'll calculate what percentage of the different styles of bows' stored potential energy was converted into actual kinetic energy.

PROCEDURE CONTINUED - CALCULATIONS:

STEP 1 - Now let's calculate the foot-pounds of kinetic energy that is delivered into the arrow.

Here's the formula: KE= wv2/450,240

- **w is the weight** of the arrow in grains (use a grain scale)
- **v is the velocity** of the arrow in feet-per-second ("fps" taken from the average of your 3 chronograph speeds).
- **The number 450,240 is the denominator** that converts everything from fps and grains into "foot-pounds" (ft-lbs.) of kinetic energy.

For example; if you were testing 45-pound draw weight compound bow, you would use an arrow that weighs 400 grains. (45 pounds times 9 grains per pound = 400 grains). Now let's say that the average of three shots through the chronograph was 250 feet-per-second (fps).

KE= wv2/450,240

KE = $[(400)(250^2)]/450,240$

KE = 25,000,000/450,240

KE = 55.53 ft-lbs

STEP 2 - Now for the cool part. Let's estimate the bow's "relative efficiency" using this simplified formula;

The bow's peak draw weight/Kinetic Energy

45/ 55.53 = .81

In other words, that bow was about 81% efficient. (Note that professional archery engineers use much more sophisticated formulas that include the bow's total PE to calculate a bow's true efficiency).

9. **So what does that "relative efficiency" percent suggest?** Somehow, the bow converted 45 pounds of stored potential energy into 55.53 pounds of kinetic energy. You'll see how that compares after you've completed the same testing on the longbow and the recurve (all three types of bows).

10. **Groups should discuss their research** procedure and results with the entire class, comparing differences. Be sure to also discuss the concept of a bow's PE as it relates to the total area under the force-draw curve. Also compare and contrast the location of the different bows' "peak draw weight" in the different force draw curves.

ASSESSMENT:

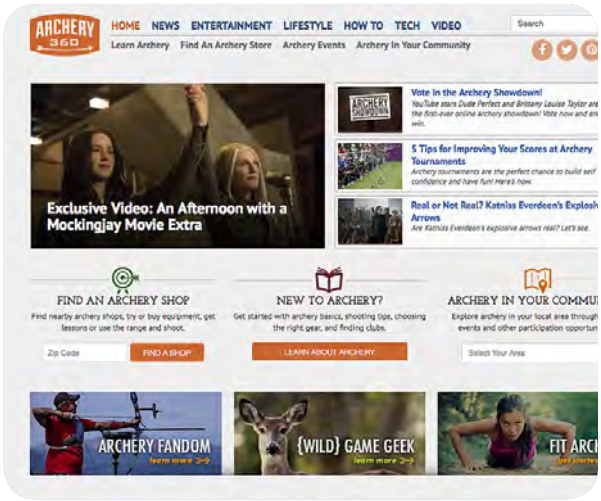
Students will be informally assessed on their understanding of archery energy conversions through their small and whole group discussions during the lesson. Students will also be formally assessed on their ability to explain their understanding of the concepts explored during their research and energy calculations.

EXTENDED LEARNING:

1. **Have students research the modern archery uses** of various types of bows and compare and contrast the advantages of each (competitive target archery, bowhunting, bowfishing)

2. **Divide the class into three groups** and assign each group a different type of bow. Have them take part in a classroom debate on the advantages of their bow type in three "Superhero Scenarios" take from movies that feature archer heroes (Avatar, Hunger Games, Avengers)

3. **Based on their archery shop or club research**, have students design a "Superhero Archery Challenge" that would demonstrate the differences in the three types of bows.



REFERENCES:

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- Bow Efficiency
- http://www.huntersfriend.com/carbon_arrows/hunting_arrows_selection_guide_chapter_5.htm
- http://archeryreport.com/2012/01/kinetic-energy-momentum-arrows-simplified-approach/
- http://archeryreport.com/2009/12/arrow-kinetic-energy-quick-reference-chart/
- http://archeryreport.com/2011/02/bow-efficiency-care/

EDUCATIONAL STANDARDS:

Teachers: Please evaluate this guide for the Educational Standards in your state. We encourage you to please e-mail those standards to us so we can add them to this web page.