Waterwheel Power Testing
1.7.15

Introduction	Students will investigate how the speed and height of falling water (potential energy) affects the mechanical energy produced by a waterwheel.
Target Grade	Grades 5-8
Time	60-90 minutes
Lesson Preparation	You will need the following materials for **EACH** wheel you plan to make: • 2 Styrofoam or plastic plates, about 8-inch diameter with holes in center large enough to allow axle to turn. We have found it works well to drill through a small stack of plates. • 2 small plastic cups with holes in center large enough to allow axle to turn • 8 1-ounce plastic portion or tartar sauce cups • 1 new pencil or ¼-inch diameter wooden dowel or pencil (about 12-inches long). This will be the wheel's **AXLE**. • About 4 yards of string • A S-shaped paper clip  • A larger plastic cup (3-ounce) with an un-bent paper clip handle for a bucket (this will be for holding weights) Punch/drill holes in center of plates and small cups, holes should be large enough to allow plate to rotate on axle. Have on hand: • Masking tape • Permanent marking pens • Extra Paper clips • Extra String • Extra plastic cups • A large supply of pennies or other weights. • Duct tape We recommend using a deep sink, over which to conduct the experiments, however, a regular sink with a gallon jug of water to serve as a waterfall will work.
Prior Knowledge Required	Students should have a basic understanding about waterwheels and pulleys. For this activity, the water will flow into plastic cups and the wheel will turn. A string attached to a cup "pulley" will wrap around the pulley as the wheel turns raising a bucket.
Background Information	The use of waterfalls and waterwheels for power goes back hundreds of years. Here in Lowell, however, waterwheel technology reached its highest level of efficiency. During the nineteenth century, ambitious investors sponsored

	scientific research and development of waterwheels with the aim of maximizing mill profits. The result was waterwheels that could power more machines than ever before. In this activity, students will build their own water wheels. They will test them and observe how they turn; learn how they interact with waterfalls; and devise a way to make them do a task such as lifting a heavy load and test variable for flow rate and height of water.
Vocabulary	Flow Rate: The amount of fluid that flows in a given time. For water wheels, this is generally the speed of the water. Hypothesis: A tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation. Axle: A bar or shaft on or with which a wheel or pair of wheels revolves. Baseline: Information used as a starting point by which to compare other information. Mechanical Energy: The energy that is possessed by an object due to its motion or due to its position. Mechanical energy can be either kinetic energy (energy of motion) or potential energy (stored energy of position). Objects have mechanical energy if they are in motion.
Anticipated Student Preconceptions/ Misconceptions	The energy of water is constant, does not differ for different circumstances. The speed of the moving wheel is the same as the energy produced by the wheel.
Frameworks	Common Core Curriculum Frameworks: CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. Massachusetts Science Frameworks Grade 7 MS-PS3 Energy MS-PS3-1. Construct and interpret data and graphs to describe the relationships among kinetic energy, mass, and speed of an object. MS-PS3-7(MA). Describe the relationship between kinetic and potential energy and describe conversions from one form to another.

Guiding Question	How does flow rate and height impact a waterwheel's efficiency?
Objectives	Students will be able to: • Explain how a waterwheel captures the kinetic energy from a waterfall and produces mechanical energy. • Compare how waterwheels behave with different heights and flow rates of

<table>
<tr><td></td><td>water.
List the factors that determine how much mechanical energy can be harnessed from a given waterfall.</td></tr>
<tr><td>Activity</td><td>Small groups (3-4) students will each make and test a waterwheel.

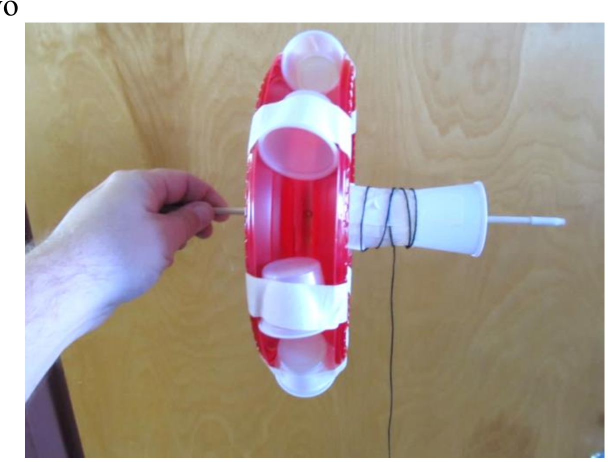
Making a Waterwheel:

Place plates bottom to bottom, attaching them with rolled-up masking tape loops and taping them around the inner edge.
Space eight portion cups evenly around the plates in the small space between the plates' outer rims. Tape them securely in place, making sure they are all catching water in the same direction. These are the "buckets".
Push the axle through the center of the plates.
Connect two small plastic cups end to end, with holes in center, place on dowel and attach to one side of water wheel. Tape string to center of the two cups to make a pulley. Tape a long piece of string onto the axle and wind it up onto the axle.
On the free end of the string, tie the S-shaped paper clip.




To Operate the Wheel:

To support wheel hold in two hands.
Aim the water source, faucet, so that it pours onto the wheel. The wheel should be set so that the water pours into the cups. As the wheel turns, the pulley should turn also. If using water from a gallon jug, try to keep the pouring speed constant.

</td></tr>
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Experimenting with the Wheel:

1. Put a mark on one of the cups that is easily visible as the wheel turns. Now run the "waterfall" on the wheel for 10 seconds and count how many turns it makes. How many times does it turn?

2. Predict what would happen if you changed the amount of water flowing into the wheel. The amount of water flowing into the wheel is called the flow rate.

3. Test your prediction. Reduce the flow rate of the water (e.g., slow it down to a thin stream). Again, count the turns in 10 seconds. How many turns? Was your prediction correct?

4. Increase the flow rate and see how that affects the number of turns the wheel makes in 10 seconds.

5. Summarize what you think might be the relationship between the flow rate of the waterfall and the amount of power delivered to the wheel:

6. Predict what would happen if you changed the height of the waterfall. Test your prediction. Return the flow to its original rate, but raise the height through which it is falling. Pick a distance for the whole class to use and use a ruler or yardstick to measure the height. This is easiest with a "jug" waterfall. Now count your turns for 10 seconds. How many turns?

7. Summarize what you think might be the relationship between the height of the waterfall and the amount of power delivered to the wheel:

8. Now put these results all together to form a hypothesis, a statement that you believe answers the following question:

9. What factors affect how much power a waterfall can deliver to a water wheel?

10. You have hypothesized that the power might depend upon two factors: the height of the waterfall and the flow rate of the waterfall. Let's see how this hypothesis can be tested when you put your wheel to work. Suppose your mill owner asks you to design a way for the water wheel to lift a bucket of pennies. How will you begin?

	11. First, let's find out how powerful your wheel actually is. Run your wheel several times, adding more pennies to the load each run, but keeping your flow rate and height the SAME for each run. How many pennies can you have in your bucket before your wheel cannot lift the bucket? This number of pennies is your Baseline Penny Number", and it represents how much work your wheel can do under "standard" conditions, when the water is at its normal height and flow rate. 12. Now make your flow rate LESS. How many pennies can the wheel lift? 13. Explain why the number of pennies has changed from the "Baseline Penny Number": 14. Try the experiment again, only this time, return to your ORIGINAL flow rate but raise the height of the fall. How many pennies can the wheel lift? 15. Explain why the number of pennies has changed from the "Baseline Penny Number".
Assessment	Class Discussion: Look back at your hypothesis about the way the flow rate and the height of the fall affect the amount of power in the fall. Do the results of your penny-lifting experiments support your predictions? Explain. Additional questions for discussion: • If you are planning on building a water-powered mill, you will look for a certain type of waterfall to use. What other characteristics might you look for in a waterfall? • As the seasons change, what factors could make your water-powered mill difficult to operate?
Differentiation Suggestions	You may want to assemble waterwheels in advance for students that may not be able to handle the assembly directions. Place axle on a box or other sturdy source if students cannot hold the pulley while turning.
Adapting the Activity for Other Grades	Younger students may only do waterwheel tests and not try with weights in the bucket. Do the entire experiment as a class, with one waterwheel. Older students can try different angles for the “buckets” of the waterwheel for maximizing the wheel.

	Additional questions for discussion: • If you are planning on building a water-powered mill, you will look for a certain type of waterfall to use. What other characteristics might you look for in a waterfall? • As the seasons change, what factors could make your water-powered mill difficult to operate?
Bibliography	Macaulay, David. *Mill*. Boston: Houghton Mifflin, 1983. Welch, Catherine A. *Forces and Motion: A Question and Answer Book*. Mankato, Minn.: Capstone, 2006.

CATEGORY	4	3	2	1
Participation	Used time well in lab and focused attention on the experiment.	Used time pretty well. Stayed focused on the experiment most of the time.	Did the lab but did not appear very interested. Focus was lost on several occasions.	Participation was minimal OR student was hostile about participating.
Evidence	Uses data powerfully as evidence to support statements.	Uses data to support statements.	Refers to data in the body of the report as support.	Does not use data to support arguments
Conclusion	Conclusion includes whether the findings supported the hypothesis, possible sources of error, and what was learned from the experiment.	Conclusion includes whether the findings supported the hypothesis and what was learned from the experiment.	Conclusion includes what was learned from the experiment.	No conclusion was included in the report OR shows little effort and reflection.

Waterwheels Worksheet

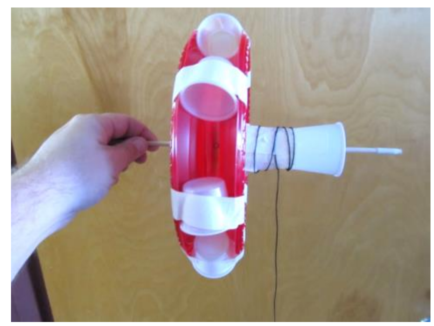
Making a Waterwheel:

1. Place plates bottom to bottom, attaching them with rolled-up masking tape loops and taping them around the inner edge.

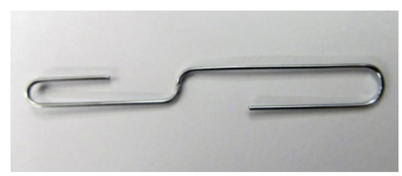
2. Space eight portion cups evenly around the plates in the small space between the plates' outer rims. Tape them securely in place, making sure they are all catching water in the same direction. These are the "buckets".

3. Push the axle through the center of the plates.

4. Connect two small plastic cups end to end, with holes in center, place on dowel and attach to one side of water wheel. Tape string to center of the two cups to make a pulley. Tape a long piece of string onto the axle and wind it up onto the axle.



5. On the free end of the string, tie the S-shaped paper clip.



To Operate the Wheel:

- To support wheel hold in two hands.

- Aim the water source, a faucet, so that it pours onto the wheel. The wheel should be set so that the water pours into the cups. As the wheel turns, the pulley should turn also. If using water from a gallon jug, try to keep the pouring speed constant.

Experimenting with the Wheel:

1. Put a mark on one of the cups that is easily visible as the wheel turns. Now run the "waterfall" on the wheel for 10 seconds and count how many turns it makes.

   How many times does it turn? ____

2. Make a hypothesis about what would happen if you changed the amount of water flowing into the wheel. The amount of water flowing into the wheel is called the *flow rate*.

   Hypothesis: ____

   ____

3. Test your hypothesis. Reduce the flow rate of the water (e.g., slow it down to a thin stream). Count the turns in 10 seconds.

   How many times does it turn? ____

   How was this like or different then your hypothesis? ______________________

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4. Increase the flow rate.

   How many turns do you get 10 seconds? ________________________________

5. What you think is the relationship between the flow rate of the waterfall and the amount of power/energy delivered to the wheel?

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6. Make a hypothesis about what would happen if you changed the height of the waterfall.

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   Test your hypothesis. What happened? ____________________________________

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7. Test the speed on the wheel at different heights (but keep the flow rate constant) Return the flow to its original rate (from step 1), but raise the height through which it is falling. Pick a height for the whole class to use and use a ruler or yardstick to measure the height. This is easiest with a "jug" waterfall. Now count your turns for 10 seconds. How many turns?

8. What do you think is the relationship between the height of the waterfall and the amount of power delivered to the wheel?

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9. Now put these results all together to form a hypothesis, a statement that you believe answers the following question:

   What factors affect how much power a waterfall can deliver to a water wheel?

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10. Let's test this hypothesis by putting your wheel to work. Suppose your mill owner asks you to design a way for the water wheel to lift a bucket of pennies.

11. Let's find out how powerful your wheel actually is. Run your wheel several times, adding more pennies to the load each trial, but keeping your flow rate and height the SAME for each trial.

    How many pennies can you have in your bucket before your wheel cannot lift the bucket?

    ____

    This number of pennies is your "Baseline Penny Number." It represents how much work your wheel can do under standard conditions, when the water is at its normal height and flow rate.

12. Now make your flow rate LESS.
    How many pennies can the wheel lift? ______________________________

13. Explain why the number of pennies has changed from the "Baseline Penny Number":

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14. Try the experiment again, only this time, return to your ORIGINAL flow rate but raise the height of the fall.
How many pennies can the wheel lift? ________________________________

15. Explain why the number of pennies has changed from the "Baseline Penny Number":

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