



Physics: Conservation of Energy

The Ultimate Chain Reaction Recycling Machine

The following learning activities were backwards planned to facilitate the development of students' knowledge and skills for mastery of this NGSS Performance Expectation. Not all of the dimensions and CCSS are covered in the following activities and teachers are encouraged to address them where possible.

HS-PS3-3 Energy		
<p>Students who demonstrate understanding can:</p> <p>HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]</p>		
<p>The performance expectation above was developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i>:</p>		
<p>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. 	<p>PS3.A: Definitions of Energy</p> <ul style="list-style-type: none"> At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. <p>PS3.D: Energy in Chemical Processes</p> <ul style="list-style-type: none"> Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. <p>ETS1.A: Defining and Delimiting an Engineering Problem</p> <ul style="list-style-type: none"> Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (<i>secondary</i>) 	<p>Energy and Matter</p> <ul style="list-style-type: none"> Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. <p>-----</p> <p>Connections to Engineering, Technology and Applications of Science</p> <p>Influence of Science, Engineering and Technology on Society and the Natural World</p> <ul style="list-style-type: none"> Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
<p><i>Connections to other DCIs in this grade-band:</i> HS.ESS3.A</p>		
<p><i>Articulation of DCIs across grade-bands:</i> MS.PS3.A ; MS.PS3.B ; MS.ESS2.A</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><i>ELA/Literacy -</i> WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (<i>HS-PS3-3</i>)</p> <p><i>Mathematics -</i> MP.2 Reason abstractly and quantitatively. (<i>HS-PS3-3</i>) MP.4 Model with mathematics. (<i>HS-PS3-3</i>)</p> <p>HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (<i>HS-PS3-3</i>) HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (<i>HS-PS3-3</i>) HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (<i>HS-PS3-3</i>)</p>		



	Work Stations	Pinning It!	Ramp Race
Student Experience	Students rotate around the stations writing observations and explanations of how each station relates to work and what they think the components of work are.	Students try to drive a push-pin into a wooden block by dropping a ping-pong ball and a golf ball on the pin. Students identify the factors that go into potential energy.	Students construct two ramps; both start from the same height and end rolling flat on the ground or table. Students “race” marbles down the ramps and figure out how to determine the velocity of the marbles at the bottoms of ramps. Students compare final velocities and try to interpret why they are relatively the same.
T4T Material	Teacher’s choice: block of wood, string, cart, ramp, weight, pulley, heavy object	For each group: 1 golf ball, 1 ping-pong ball, 1 push pin, 1 wooden block.	For each group: 4 blinds, two 4-inch tubes, two 10-inch tubes.
Big Idea	If work is to be done, a force is needed. If an object is forced to move, it takes more work to move it further. $W = F\Delta x$	$PE = mgh$ $\Delta PE = W$ It takes work to lift an object. Once it is lifted it has potential energy. That potential energy can be used to do work.	Marbles may take different amounts of time to reach the bottom but their final velocities are relatively the same. Conservation of Energy $\Delta PE = \Delta KE$
Connection to Culminating Activity	Work is a central concept for the culminating activity.	By placing objects in strategic positions, they can store potential energy for later use.	Mechanical energy is conserved
CA Standards	IE1. d	PH2. b and c; IE1. d, j	PH2. c; IE1. b, c, j
Next Gen Sci Standards	HS-PS3-1 Asking questions and defining problems. Constructing explanations and designing solutions.	HS-PS3-2 Asking questions and defining problems. Constructing explanations and designing solutions.	HS-PS3-2 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.
Time	One 55 min period	One 55 min period	Two 55 min periods

Physics – Conservation of Energy – The Chain Reaction Recycling Machine

These lessons are not intended to be a complete unit, but, rather a learning activity guide for concept attainment. Teachers should supplement these lessons with appropriate reading material and problem sets.



	Energy of Motion	Simple Machines and Other Concepts	The Chain Reaction Recycling Machine
Student Experience	<p>Students use one of the ramps from Ramp Race to investigate the connection between height of the ramp and velocity of the ball at the bottom of the ramp.</p> <p>Students collect data and investigate the relationship between PE and KE for the ball on the ramp and model the equation for the KE.</p> <p>$KE = \frac{1}{2} mv^2$</p>	<p>Students rotate through stations and play/look at simple machines and other concepts.</p> <p>They describe what they do.</p> <p>They try to imagine how each could help to connect their ramp to someone else's ramp.</p> <p>They draw a sketch of how they plan to connect their ramp to someone else's ramp.</p>	<p>Students connect all other ramps to make a whole-class chain reaction machine. The last ramp places a plastic bottle in the plastic recycling bin and a wad of paper in the paper recycling bin.</p> <p>Students determine potential energy, kinetic energy, work done by friction on their ramp, work done to start the next ramp.</p>
T4T Material	One ramp from "Ramp Race" and height adjusters (books, other tubes, etc.)	Simple Machines Stations	The Cart
Big Idea	$KE = \frac{1}{2} mv^2$	Simple machines get work done. They can be used to make connections in the chain reaction (Rube Goldberg) machine.	<p>Energy can transfer from one form to another.</p> <p>Work done by friction can be calculated by using the ideas of conservation of energy.</p>
Connection to Culminating Activity	Mechanical energy is conserved. KE can be determined by measuring mass and velocity.	Simple machines are inspirations for connecting the ramps.	-----
CA Standards	PH2. a	none	PH2. a, b, c
Next Gen Sci Standards	<p>HS-PS3-1 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.</p>	<p>Asking questions and defining problems. Constructing explanations and designing solutions.</p>	<p>HS-PS3-3 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.</p>
Time	One 55 min period	One 55 min period	1 week



Lesson Plans for Conservation of Energy Module

Prior Knowledge: Basic kinematics ($v = \Delta x/t$), how to measure distance and time.

1. Work Stations

Objective

Students will derive the essential components of work.

Engage and Explore

1. Are asked to write the answers to these questions...
 - a. What do you think physical work is?
 - b. What factors do you think go in to making more or less physical work?
 - c. If you could guess at what a work equation would equal, what would it be? $W =$
2. Students rotate around 4 pre-arranged stations (There could be more or fewer. There could be two sets of stations to lower the number of students at each station, so that the students on the right side of the class rotate through the four stations on the right and vice-versa for the left.)

Explain

3. At each station, the students answer these questions...
 - a. How is this a demonstration of work being done?
 - b. What could be changed so that more work is done?

Elaborate

4. Teacher debriefs with students and guides them to the answer that work increases with greater force and work is also increased with greater distance. $W = F\Delta x$

Evaluate

5. Teacher should give a problem set on $W = F\Delta x$

*Student Handout is meant to support this process and guide students through the Explore and Explain phases. Teacher is responsible for the scaffolding of content within the Elaborate Phase and the building of prior knowledge leading into the Engage and Explore piece of the Conservation of Energy.

2. Pinning It! (Nailing It! for those with bowling balls)

Objective:

Students will derive the essential components of work and potential energy.

Engage

1. Have students write down what they think the definition of energy is.



2. Announce that today we will drive a push pin into a block of wood by dropping a ping-pong ball and a golf ball on it. Have students write a prediction about what will happen.

Explore and Explain

3. Have students try driving the push pin in with the balls. Have them explain...
 - a. How the activity shows connection to work.
 - b. What is needed to get more work done?

Elaborate

4. Teacher helps guide students to an understanding that work was done by dropping the ball on the push pin. The ball had energy (the ability to do work), potential energy, and it started to move and gain kinetic energy as it fell. The kinetic energy of the ball went into doing work on the push pin. $PE = mgh$ and $\Delta PE = W$
5. Have students draw a diagram of the activity and illustrate the energy transfers and work being done.

Evaluate

6. Teacher should give a problem set on $PE = mgh$ and $\Delta PE = W$

3. Ramp Race

Objective:

Students will be able to construct 2 ramps to explore the Conservation of Energy.

Engage & Explore

1. Students are informed that they will make a Chain Reaction machine as a culminating activity. But not yet, at this point in time, they are going to build ramps.
2. Students watch the OK GO Music video “This Too Shall Pass”, and/or Honda’s “Cog” commercial
 - a. Inspiration and engagement into the idea behind the chain reaction machine (evaluation piece).
 - b. Can be found for free via YouTube
3. Students use the scientific process to respond to a question
 - a. Students make a prediction (hypothesis) in response
 - i. “Which ramp would come in first place?”
 - ii. “Which ramp produces the greater final velocity? Why?”
 - b. Students construct 2 ramps at the same height
 - i. Different paths must be assembled.
 - ii. Remember to stifle creativity at this point (keep designs simple).
 - c. Students test their hypothesis using their ramps.
 - i. Students create data tables to organize data to support their hypothesis.
 - ii. Students will then perform their experiment and collect data
 - iii. To get final velocity, students will generally need to measure the velocity from ramp end to a point 1-2 meters away, unless some kind of velocity



meter is available. Stopwatches are the most “hands on” measuring method, but imprecise. Photogate devices or video analysis can be more accurate, however, they can consume more time to calculate the data.

- d. Students analyze their data
 - i. Students will draw conclusions from their findings to determine evidence for or against their hypothesis.
 - ii. Was your hypothesis correct? What is your evidence?

Explain

4. The Big Picture

- a. Teacher can facilitate a discussion based on students’ data.
 - i. “Which ramp produces the greater final velocity?”
 - ii. Teacher may have to discuss, error, significant figures, and rounding
 1. “Is 3.9 roughly the same as 4.0 or 3.93?”
 2. “Why do the ramps have approximately the same velocities?”
 - iii. Teacher and class conclusion
 1. Conservation of Energy
 2. Since both ramps began at the same height, their velocities are the same
 3. Link to Potential and Kinetic Energy.
 - a. More accurately, for a rolling solid sphere...

Translational kinetic energy due to velocity = $\frac{1}{2}mv^2$

Rotational kinetic energy $E_r = \frac{1}{2}I\omega^2$

But, for a solid sphere, $I = \frac{2}{5}mR^2$ and $\omega = v / R$

Substituting,

$$E_r = \frac{1}{2} * \frac{2}{5}mR^2 * \left(\frac{v}{R}\right)^2 = \frac{1}{5}mv^2$$

The rotational energy of a solid sphere without slipping is $\frac{2}{5}$ of the kinetic energy.

So, in terms of percentage, for a rolling solid sphere like a marble or a bowling ball:

KE(total) = 71.4% in translational KE and 28.6% in rotational KE

For a hollow sphere like a ping-pong or tennis ball, it becomes 60% KEt and 40% KEr
 - b. This needs to be addressed at the discretion of the instructor. Or, students could use carts or Hot Wheels.

Evaluate

5. Students are evaluated based on their ability to follow scientific practices.
 - a. Hypothesis development
 - b. Ability to test hypothesis
 - c. Collect and analyze data
 - d. Draw conclusions

*Student Handout is meant to support this process and guide students through the exploration phase. Teacher is responsible for the scaffolding of content within the Explain Phase and the building of prior knowledge leading into the Engage and Explore piece of the Conservation of Energy.



4. Energy of Motion

Objective

Students will take data and model $KE = \frac{1}{2} mv^2$

Engage

1. Teacher asks students, “What if we lowered the height of your ramp from yesterday. What effect would that have?”

Explore

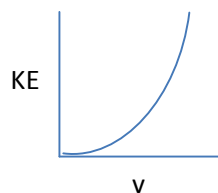
2. Have students take data, at least 5 data points, for different heights of the ramp and the corresponding velocities at the bottom of the ramp.

Explain

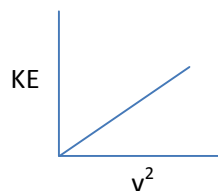
3. Have students graph the data in a way that makes sense to them and have them explain what knowledge they can get from the data.

Elaborate

4. Guide students to connect the ideas that we have learned so far; $PE = mgh$ and $\Delta PE = KE$. So instead of graphing height vs velocity, let’s graph KE vs v.



5. After getting graphs that look like the one above, ask students, “How does v change with KE? Exponential? OK, let’s square v and graph it again.”



6. Students should get a graph that looks like the one above. To students, “So this is a line! And lines have linear equations! Can we find the slope and figure out what that is?” It should come out to be about $\frac{1}{2}$ mass of the ball.
 - a. “So what is the linear equation?”
$$y = m x + b$$
$$KE = (\frac{1}{2} m) v^2 + 0$$
 - b. Therefore, we have modeled that $KE = \frac{1}{2} m v^2$. Reminder: some energy “lost” to rotation.

Evaluate



7. Teacher should give a problem set on $KE = \frac{1}{2} m v^2$

5. Simple Machine Stations

Objective

Students familiarize themselves with simple machines and other concepts in order to prepare for the Chain-Reaction recycling project.

Engage

1. Inform students that the point of the Simple Machines Stations is to spark ideas and inspire creative connections for the chain reaction machine. They are going to take the ramps that they made and connect them into a whole-class chain reaction machine.

Explore & Explain

1. Students rotate around stations and explore each concept
 - a. Students identify the labeled station
 - b. From their experience with the station or prior knowledge describe the concept
 - i. What does it do?
 - ii. How does it work.
 - c. Students brainstorm ways in which this machine may assist with their recycling project.
2. Teacher facilitates student learning
 - a. Monitors station timing
 - i. Based on classroom dynamics – you know your students.
 - b. Circles around classroom
 - i. Asks guiding and supporting questions – deepen student understanding
 - ii. Provides examples of the use of the machine in real-world scenarios
 1. Making real-world connections
 2. Students can provide real-world connections
 - iii. Answers student questions

Elaborate

3. Students “apply” simple machine
 - a. Students sketch a possible transition to another ramp
 - i. Students make connections from lab to project outcome
 - ii. Students participate in engineering practices

*Students should be given the simple machines table hand-out to support this process.



3. Culminating Activity: Chain-Reaction Recycling Machine

Objective

Students connect ramps to create one continual recycling machine that sorts paper and plastic by knocking them into the correct container.

Engage & Elaborate

1. Replay the OK GO – This Too Shall Pass video, and/or Honda’s “Cog” commercial.
 - a. Re-engage students in the Chain Reaction Machine Process
 - b. Provide ideas for students.
2. Students construct recycling machine
 - a. Teacher may have to set supporting guidelines for classroom management
 - i. Delegate roles, provide guidelines on which group communicates to who. The order of which group follows which needs to be clearly defined, so groups can decide how to transition between their elements
 - ii. Support students at tool station – safety
 - b. Students take part in Engineering practices
 - i. Communicate amongst peers and plan
 - ii. Construct and problem solve
 - iii. Design, Expand and Elaborate on ideas
3. Students Explain Conservation of Energy concepts
 - a. Articulate in writing
 - i. Work, Gravitational Potential Energy, Kinetic Energy
 - ii. Possibly Elastic Potential Energy etc.
 - b. Students effectively use academic language and concepts.
 - c. Students sketch their connection
 - i. Label points
 - ii. Identify energy at that point
4. Students develop a procedure to collect and analyze data
 - a. Identify energy at each point
 - b. Calculate the respective energy using the correct formula
 - c. Explain their data collection process
 - d. Articulate areas of trouble to demonstrate deep understanding of content and its application.
5. Students should record in a daily log
 - a. Serves as reflection and collection of the evolution of their thinking process
 - b. Students ought to think deeper about content and its application to engineering and real-world phenomenon.
 - c. Teacher should scaffold the logs to make them appropriate to their class and can be used as a method of assessment (pre and post)
6. Teacher facilitates
 - a. Probes students for conceptual understanding
 - b. Models for students when necessary
 - c. Evaluates and Suggests
 - d. Provides constructive feedback



Evaluate

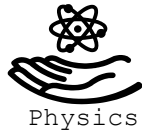
7. Teacher evaluates student progress in each of the following areas (rubric created by instructor)
 - a. Construction of transition
 - b. Explanation and application of content
 - i. Calculations and conceptual understanding
 - c. Application of the scientific method in respect to the collecting and analyzing of data

*During all activities teacher serves as a facilitator of student learning (i.e. student centered instruction). Most tasks should be completed by students after simple directions, or facilitated questions to enhance student learning.

**Use of student handouts serves as guidelines for students.

Accommodations

All individual accommodations for students should be met with respect to your particular students and classroom dynamics and will vary from class to class and group to group. Facilitator should always differentiate instruction by providing the necessary blend of guidance and exploration for each student group and their specific needs.



Work Stations

1. What do you think physical work is?
2. What factors do you think go in to making more or less physical work?
3. If you could guess at what a work equation would equal, what would it be?

$W =$

Station 1 – Pull the block with the string.

4. How is this a demonstration of work being done?
5. What could be changed so that more work is done?

Station 2 – Cart pulled up a ramp.

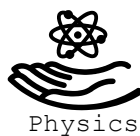
6. How is this a demonstration of work being done?
7. What could be changed so that more work is done?

Station 3 – Weight lifted by string

8. How is this a demonstration of work being done?
9. What are two things that could be changed so that more work is done?

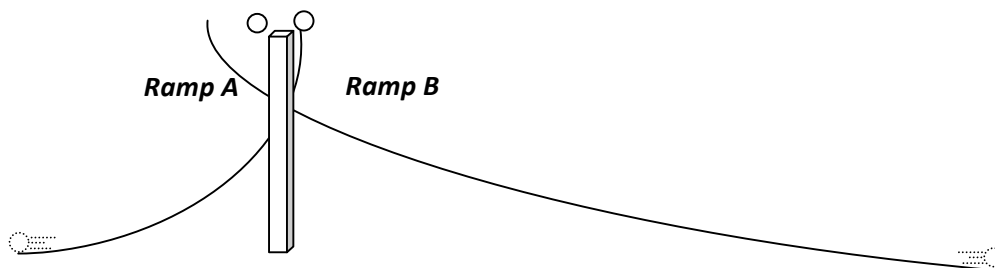
Station 4 – Pushing a heavy object.

10. How is this a demonstration of work being done?
11. What could be changed so that more work is done?



Ramp Race!

We are going to roll marbles of equal mass and size down different ramps of the same height...



Predict ...

If we had a race between the two ramps, which ramp would come in first place, A or B? Why?

Test...

Try it for real! Construct two ramps that start at the same height and end flat, at the same height. Which track won? ____ Was this consistent with your prediction? Please modify your explanation above, if it needs modifying.

Extend...

Predict...

At the end of the tracks, the marbles have final velocities. Which ramp will produce the largest final velocity? Why?

Design...

How can you determine the actual final velocities? Write down how you could do that. What data would you collect and how would you collect it?

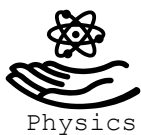
Test...

Collect data and find the results.

	<i>Data</i>				<i>Results</i>
					Final Velocity
Ramp A					
Ramp B					

Connect...

How does this connect to what we have learned about Potential and Kinetic Energy?

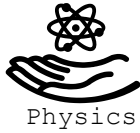


Simple Machines Stations

and Other Concepts

Station	Simple Machine or Concept	Description (What does it do?)	How can it be used to connect the ramps to make a seamless chain reaction machine?
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

11. On the back of this paper, sketch your transition from your ramp to another ramp.



The Chain Reaction Recycling Machine

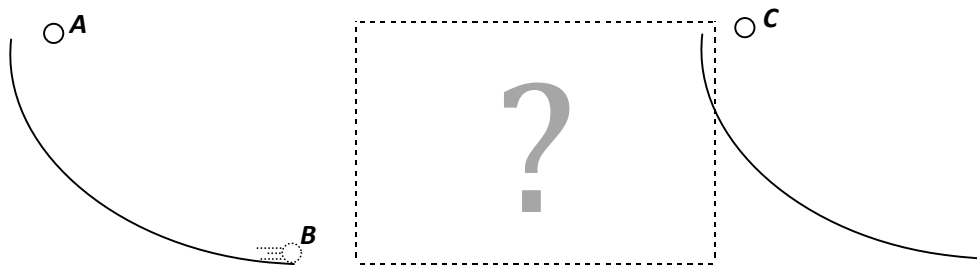
Making Connections

We are going to connect all of our ramps to make a whole-class recycling machine. A ball will be dropped into the first ramp, which will cause a chain reaction that continues through all of the ramps and ends with the recycling of a plastic bottle and a wad of paper.

What are you to do?

- **Construct**

The “last group” will recycle the bottle and paper. All of the other groups will connect their ramps in a non-direct and clever way, so that the motion never stops.



- **Make a poster to present your findings. On your poster...**

Introduce

Write a few sentences that explain what work is, what energy is and what the basics types of energy are.

Log

Keep a log, with dates, on the engineering processes leading up to the creative connection. Any addition or modification to the connection should be listed with the science and the engineering rationale behind it. Include accurate measurements and ratios if applicable. Below is an example of how to start...

Date	Action Taken	The science and the engineering behind it	The outcome of the Action



Sketch

Draw a sketch of your creative connection and label **A**, **B** and **C**, similar to above.

Analyze

Collect data and record data in order to determine the following...

1. What type(s) of energy are at **A**? How much energy is at **A**?
2. What type(s) of energy are at **B**? How much energy is at **B**?
3. Work done by friction from **A** to **B**.
4. Work done from **B** to **C**.

Explain

Explain how you measured and calculated to get the values above.

What was difficult to measure and why?