Unit Title: Paper Roller Coasters	**Grade Level:** 9-12
Date Developed/Last Revised: September 2012/April 10, 2013	**Time Frame:** 9 60-minute periods
Unit Author(s): Andrew Suenobu	**Primary Content Area:** Physical Science

UNIT DESCRIPTION: Students will learn about energy and energy transformation through inquiry investigations. This unit will culminate with an engineering project that will challenge students to use their knowledge gained from the science inquiry to complete the task: You are a roller coaster manufacturer competing for a bid to build a roller coaster for an amusement park. Your task is to design and build a paper model of the most fun and exciting roller coaster you can using the templates provided (www.paperrollercoasters.com). You also need to be able to explain the physics behind it.

Big Ideas (Student Insights that Will Be Developed Over the Course of the Unit):

- Energy is required to produce force which can be used to do work.
- Energy can change from one form to another, but it is neither created nor destroyed.

Essential Questions (Questions that Will Prompt Students to Connect to the Big Ideas):

- How can energy change from one form to another?
- What is the relationship between PE & KE?
- How is energy used to cause motion, generate force, and do work?
- How can the energy of an object be calculated?

	BENCHMARKS/STANDARDS/LEARNING GOALS
Science	**HCPS III Science Benchmarks** • SC.PS.6.2: Explain how the law of conservation of energy is applied to various systems • SC.PS.7.1: Apply the laws of motion to determine the effects of forces on the linear motion of objects • SC.PS.7.2: Use vectors to explain force and motion
Technology	• HCPS III CTE Standard 1: TECHNOLOGICAL DESIGN: Design, modify, and apply technology to effectively and efficiently solve problems
Engineering	• HCPS III CTE Standard 1: TECHNOLOGICAL DESIGN: Design, modify, and apply technology to effectively and efficiently solve problems

Mathematics	**Supporting Common Core Math Standards** • CCSS.Math.Content.HSA-SSE.A.1. Interpret expressions that represent a quantity in terms of its context. • CCSS.Math.Content.HSA-CED.A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. • CCSS.Math.Content.HSN-VM.A.1. Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes.
English Language Arts and Literacy	• CCSS.ELA-Literacy.WHST.9-10.W.1. Write arguments focused on *discipline-specific content*. • CCSS.ELA-Literacy.WHST.9-10.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. • CCSS.ELA-Literacy.SL.9-10.1 Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively. • CCSS.ELA-Literacy.L.9-10.6 Acquire and use accurately general academic and domain-specific words and phrases, sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when considering a word or phrase important to comprehension or expression. **Supporting Common Core ELA Standards** • CCSS.ELA-Literacy.WHST.9-10.7 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. • CCSS.ELA-Literacy.RST.9-10.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.
STEM Competencies	• 2.2: Collaborates with, helps and encourages others in group situations. • 2.6: Reasonably implements a solution. • 3.3: Generates new and creative ideas and approaches to developing solutions. • 3.4: Evaluates the effectiveness (and ethical considerations) to a solution and makes adjustments as needed. • 4.1: Recognizes and understands what quality performances and products are.

LESSON SEQUENCE

	Lesson Title/Description	Learning Goals (What Students Will Know and Be Able to Do)		Assessments	Time Frame
1	Energy Transformations	**Know:** • Energy is the ability to do work • PE=mgh • KE= ½ mv^2 • Energy can change from PE to KE • When an object is lifted above its resting point it gains gravitational energy due to its position (height). • When a raised object is released, it is pulled downward by the force of gravity. As it falls and loses height it loses potential energy but gains kinetic energy as its velocity increases. Its kinetic energy just before it hits the bottom should be equal to the potential energy it started with. • Moving objects lose energy due to friction, air resistance, and rotational motion.	**Do:** • Calculate gravitational potential energy by measuring mass and height: PE=mgh • Calculate velocity by measuring distance and time: v=d/t • Calculate kinetic energy based on velocity. KE= ½ mv^2 • Explain how the law of conservation of energy is applied to their roller coaster: How does the PE at the start relate to the KE at the end? Why are they not the same? • Describe ways that energy is transformed from one form to another in their roller coaster (e.g., PE to KE)	**Formative** • Conversations: o Ask students to explain what they are doing periodically o Ask students to explain how physics concepts relate to different parts of their roller coaster periodically • Observations: o Students building roller coaster and talking within their groups • Products: o Bell work o PE & KE worksheet **Summative** • Energy Quiz	2 60-minute periods
2	Paper Roller Coasters	**Know:** • Energy is the ability to do work • PE=mgh • KE= ½ mv^2 • Energy can change from PE	**Do:** • Calculate gravitational potential energy by measuring mass and height: PE=mgh • Calculate velocity by	**Formative** • Conversations: o Ask students to explain what they are doing periodically o Ask students to explain	7 60-minute periods

		to KE • When an object is lifted above its resting point it gains gravitational potential energy due to its position (height). • When a raised object is released, it is pulled downward by the force of gravity. As it falls and loses height it loses potential energy but gains kinetic energy as its velocity increases. Its kinetic energy just before it hits the bottom should be equal to the potential energy it started with. • Moving objects lose energy due to friction, air resistance, and rotational motion.	measuring distance and time: v=d/t • Calculate kinetic energy based on velocity. KE= ½ mv^2 • Explain how the law of conservation of energy is applied to their roller coaster: How does the PE at the start relate to the KE at the end? Why are they not the same? • Describe ways that energy is transformed from one form to another in their roller coaster (e.g., PE to KE) • Explain how each of Newton's Laws of Motion applies to their roller coaster • Use vectors to show the relative speed, direction, and acceleration of the marble as it travels down their roller coaster	how physics concepts relate to different parts of their roller coaster periodically • Observations: o Students building roller coaster and talking within their groups • Products: o Small-scale ramp with basic calculations o Rough drafts of calculations and explanations o Rough draft of roller coaster plan **Summative** • Energy Quiz • Products: o **Roller Coaster** o **Engineering journal** w/ diagrams, calculations, and answers to questions relating to roller coaster o **Data sheet** (see attached) o **Presentation**: Demonstration of roller coaster, explaining energy changes along the way	

Unit Title: Paper Roller Coaster Lesson Title: Energy Transformations Date Developed/Last Revised: 4/10/13 Unit Author(s): Andrew Suenobu	Lesson #: 1 Grade Level: 9-12 Primary Content Area: Physical Science Time Frame: 2 60-minute periods

PLANNING (Steps 1, 2, & 3)

1. Standards/Benchmarks and Process Skills Assessed in this Lesson:

- HCPS III SC.PS.6.2: Explain how the law of conservation of energy is applied to various systems
- HCPS III SC.PS.7.1: Apply the laws of motion to determine the effects of forces on the linear motion of objects
- CCSS.ELA-Literacy.WHST.9-10.W.1. Write arguments focused on *discipline-specific content*.
- CCSS.ELA-Literacy.L.9-10.6 Acquire and use accurately general academic and domain-specific words and phrases, sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when considering a word or phrase important to comprehension or expression.

2A. Criteria- What Students Should Know and Be Able to Do:

Students should know:

- Energy is the ability to do work
- PE=mgh
- KE= ½ mv^2
- Energy can change from PE to KE
- When an object is lifted above its resting point it gains gravitational energy due to its position (height)
- When a raised object is released, it is pulled downward by the force of gravity. As it falls and loses height it loses potential energy but gains kinetic energy as its velocity increases. Its kinetic energy just before it hits the bottom should be equal to the potential energy it started with
- Moving objects lose energy due to friction, air resistance, and rotational motion

Students should be able to:

- Calculate gravitational potential energy by measuring mass and height: PE=mgh
- Calculate velocity by measuring distance and time: v=d/t
- Calculate kinetic energy based on velocity. KE= ½ mv^2
- Explain how the law of conservation of energy is applied to their roller coaster: How does the PE at the start relate to the KE at the end? Why are they not the same?
- Describe ways that energy is transformed from one form to another in their roller coaster (e.g., PE to KE)

2B. Assessment Tools/Evidence:

Formative:

- Conversations:
  - Ask students to explain what they are doing periodically.
  - Ask students to explain how physics concepts relate to different parts of their roller

coaster periodically.
- Observations:
  - Students building roller coaster and talking within their groups.
- Products:
  - Bell work
  - PE & KE worksheet

Summative: (please attach copies of rubrics and/or other assessment tools)
- Energy Quiz

3. Learning Experiences (Lesson Plan)

Materials:
- Meter sticks (8)
- Timers (8)
- Clay
- Plastic wrap
- Ball bearing
- Ink
- Pipette
- Tennis ball
- Scissors
- Ramp
- Sand
- Container

Handouts/Other Resources: (please attach copies)
- Falling Things Lab
- PE & KE Worksheet
- Energy Quiz

Procedure:

ENGAGE
- Bell work: What happens to the speed of objects as they fall? What evidence do you have that supports this?
- Class discussion: Students share answers and respond to each other. Don't actually give the answer yet.

EXPLORE
- Falling things mini-lab
  - Students will go through the Falling Things Lab (see attached)
  - Class discussion: Now how would you answer the bell work question? Students should be able to conclude that objects accelerate as they fall. They should now have more evidence to back up their claims.

EXPLAIN

- Lecture: Energy transformations – Slideshow lecture on Energy transformations with focus on PE & KE with sample exercises. Go over exercises as a class.

ENGAGE

- Dropping bowling ball demo – Teacher drops a bowling ball onto a soda can. As you do the demo, explain that, as you lift the bowling ball, you are giving it PE and PE=mgh. Ask students what will happen to the PE if you drop it. Students should be able to tell you that PE is transformed into KE. Ask how much KE it should have before it hits. They should be able to tell you that it's the same as the PE at the top. Drop the ball onto the can. It should crush if you hit it squarely. Tell the students that the KE was used to do work on the can. Ask how much work. If students cannot answer, tell them it is the same as the initial PE and the final KE. Remind students that work, like E, is measured in Joules.

EXTEND

- PE & KE worksheet (See attached) – Students work on exercises on their own to calculate PE, KE, and velocity.

Homework Activity (Optional):

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TEACHING & ASSESSMENT (Steps 4, 5, 6, &7)
Completed by teacher after instruction has taken place

4. Teaching and Collecting of Evidence of Student Learning:
Teacher Notes:

5. Analysis of Student Products/Performances - Formative:
Teacher Notes:

6. Evaluation of Student Products/Performances – Summative (Not necessary for every lesson):
Teacher Notes:

7. Teacher Reflection: Replanning, Reteaching, Next Steps:
Teacher Notes:

Falling Things Lab

Stations will be set up around the room. Students will have 2 minutes at each station, during which time they will be dropping objects from higher and higher heights and observing what happens. They will record their observations for each station and then try to make a generalization about what happens to the speed of objects as they fall based on their observations.

Instructions for each station are shown below. These can be printed out and taped at each station. A meter stick and timer should be provided at each station.

Clay Ball

Drop the clay ball onto the floor from various heights. Before each drop, roll the ball back into a round shape.

Plastic Wrap & Ball Bearing

Stretch plastic wrap over the plastic cup, holding it on with the rubber band. Drop the ball bearing onto the plastic wrap from gradually increasing heights.

Ink Drops

Use the dropper to squeeze drops of ink onto the paper from various heights, beginning at about 1 cm.

Ball Bounce
Drop the tennis ball from various heights.

Scissors & Play-Doh
Hold the scissors point-down directly over the Play-Doh. Release the scissors. Smooth the Play-Doh out before each drop. Drop the scissors from various heights.

Ball Bearing on a Ramp
Roll the Ball Bearing off the ramp and onto the floor, using the block of wood to raise the plastic track to various heights.

Ball Sounds
Drop the balls from various heights and listen to the sound they make when they hit the ground.

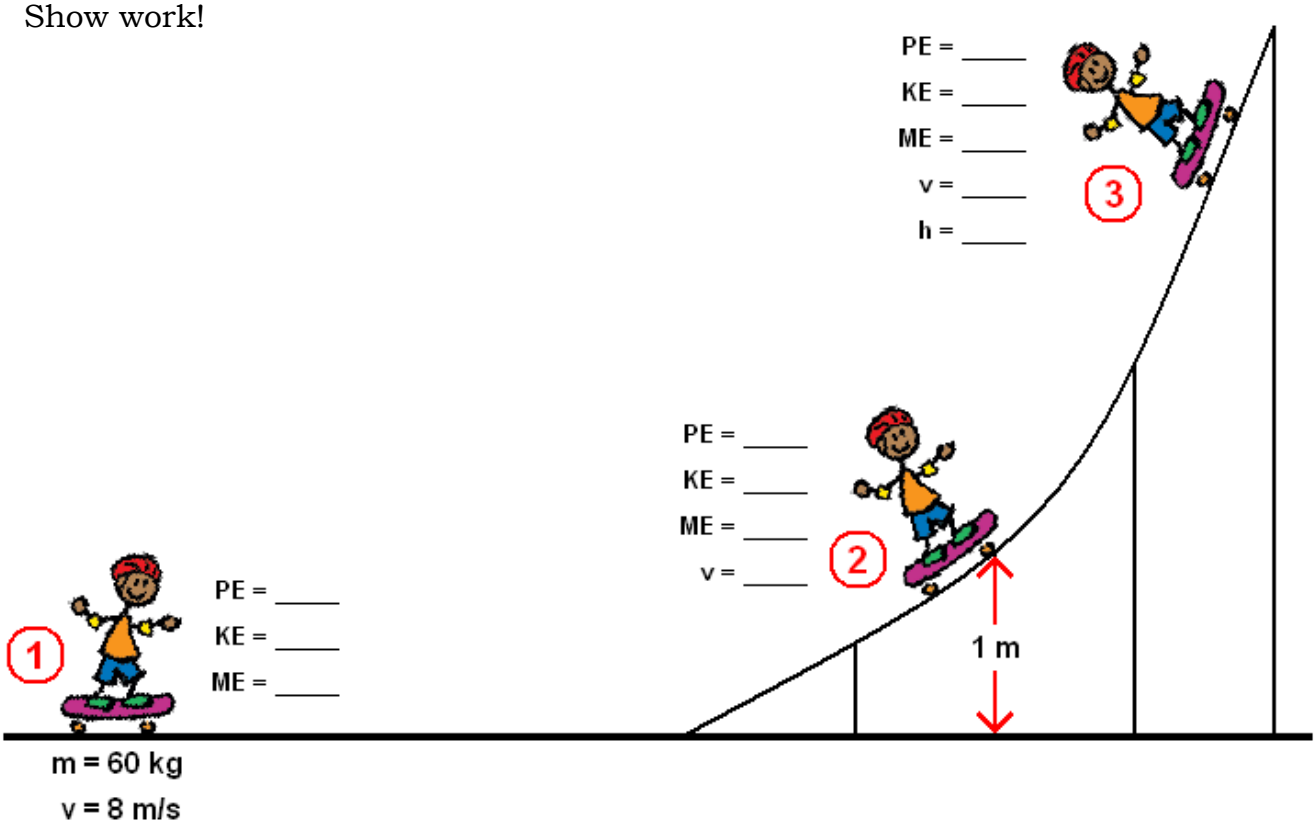
Ball Bearing & Sand
Drop the ball bearing into the container of sand from various heights.

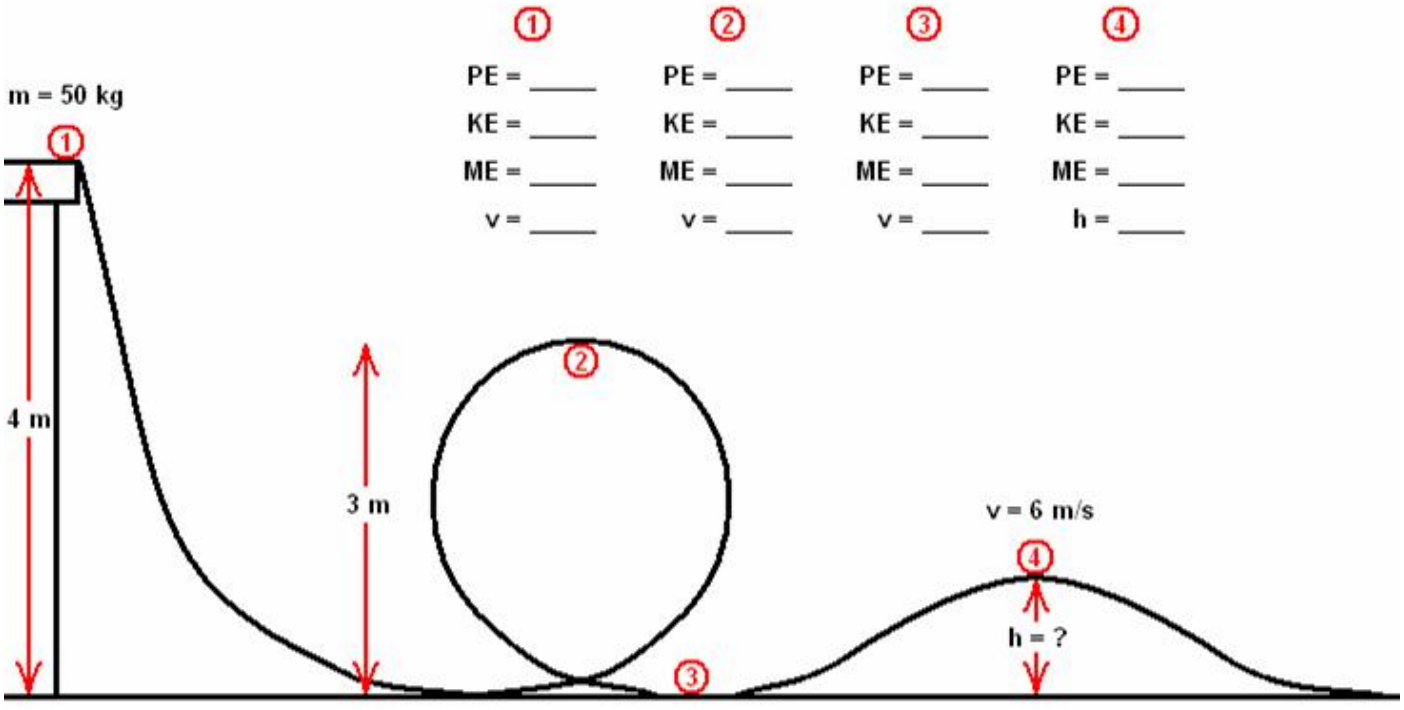
Name_____ Date_____ Period_____

Potential Energy & Kinetic Energy Worksheet

Diagrams from http://www.mrfizix.com/home/energy.htm

Show work!





Exercises

1) If you do work on an object, does its energy change?
2) How can you increase the gravitational potential energy of an object?
3) What happens to your potential energy as you go up in an airplane? Compared to what?
4) If an object weighs 500 N and you lift it 2 m,
   a) how much work have you done on it?
   b) how much potential energy does it have relative to its starting point?
5) If an object has 100 J of PE, how much work can it do (with that PE)? Ignore friction.
6) How much energy does a 2 kg ball sitting on a 1m high table have?
7) If a 1,000 N rock falls 10 m, how much work will it do when it hits?
8) How can you increase the kinetic energy of an object?
9) If a car is traveling at a steady speed, but you double its mass, what happens to its kinetic energy?
10) If you double a car's speed, what happens to its kinetic energy?
11) When you throw a ball up in the air, when is its kinetic energy greatest? When is its potential energy greatest? Explain.
12) Draw a picture of a 20 N rock falling from a 100 m high cliff. Give its PE and KE when it is 100 m high, 75 m, 50 m, 25 m, and 0 m. Ignore air resistance.
13) Galileo (supposedly) dropped two balls from the leaning tower of Pisa. If the bigger ball had twice the mass of the smaller one, what was its KE compared to the smaller one just before they hit?
14) By what factor does the KE of a plane change if it doubles its speed?
15) Two identical rocks are dropped from different heights. The higher one starts out four times as high as the lower one. How much faster is the higher one going just before they hit? Ignore air resistance.

Unit Title: Paper Roller Coaster Lesson Title: Paper Roller Coaster Date Developed/Last Revised: 4/10/13 Unit Author(s): Andrew Suenobu	Lesson #: 2 Grade Level: 9-12 Primary Content Area: Physical Science Time Frame: 7 60-minute periods

PLANNING (Steps 1, 2, & 3)

1. Standards/Benchmarks and Process Skills Assessed in this Lesson:

- HCPS III SC.PS.7.1: Apply the laws of motion to determine the effects of forces on the linear motion of objects
- HCPS III SC.PS.7.2: Use vectors to explain force and motion
- HCPS III CTE Standard 1: TECHNOLOGICAL DESIGN: Design, modify, and apply technology to effectively and efficiently solve problems
- CCSS.ELA-Literacy.WHST.9-10.2 Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.
- CCSS.ELA-Literacy.SL.9-10.1 Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

2A. Criteria- What Students Should Know and Be Able to Do:

Students should know:

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Students should be able to:

- Calculate gravitational potential energy by measuring mass and height: PE=mgh
- Calculate velocity by measuring distance and time: v=d/t
- Calculate kinetic energy based on velocity. KE= ½ mv^2
- Explain how the law of conservation of energy is applied to their roller coaster: How does the PE at the start relate to the KE at the end? Why are they not the same?
- Describe ways that energy is transformed from one form to another in their roller coaster (e.g., PE to KE)

2B. Assessment Tools/Evidence:

Formative:

- Conversations:
  - Ask students to explain what they are doing periodically.
  - Ask students to explain how physics concepts relate to different parts of their roller coaster periodically.
- Observations:
  - Students building roller coaster and talking within their groups.
- Products:
  - Small-scale ramp with basic calculations
  - Rough drafts of calculations and explanations
  - Rough draft of roller coaster plan

Summative: (please attach copies of rubrics and/or other assessment tools)

- Energy Quiz
- Products:
  - **Roller coaster**
  - **Engineering journal** w/ diagrams, calculations, and answers to questions relating to roller coaster
  - **Data sheet** (see attached)
  - **Presentation**: Demonstration of roller coaster, explaining energy changes along the way

3. Learning Experiences (Lesson Plan)

Materials:

- Paper Roller Coaster Templates from http://www.paperrollercoasters.com/products.htm
- Scotch tape or masking tape
- Scissors
- Marbles

Handouts/Other Resources: (please attach copies)

- PE & KE Lab
- Paper Roller Coaster Handout
- Paper Roller Coaster Data Sheet
- Paper Roller Coaster Engineering Journal
- Paper Roller Coaster Evaluations
- Project Planning Form

Procedure:

ENGAGE (Prior to Day 1 in timeline shown below)

- Show video on roller coasters. (see samples at http://videos.howstuffworks.com/science/roller-coaster-videos-playlist.htm)
- Show sample paper roller coaster. (teacher or student-created)
- Show videos of sample paper roller coasters. (samples available at paperrollercoaster.com or on youtube.com)

EXPLAIN (Prior to Day 1 in timeline shown below)

- Review PE & KE, velocity, acceleration, and vectors. (Newton's Laws optional)
- Go over project requirements & criteria. (See attached)
- Explain how to use the paper templates to build their roller coasters. Templates available for sale ($20) at http://www.paperrollercoasters.com/products.htm

EXPLORE (Day 1 in timeline shown below)

- Practice. PE & KE Lab. Build a simple ramp using paper roller coaster templates. Calculate PE at the top and the KE and velocity at the bottom. See lesson plan at http://www.paperrollercoasters.com/fillable_Paper_Roller_Coaster_lesson_advanced.pdf

EXTEND (Days 2-5 in timeline shown below)

- Students build their own roller coasters in groups.
  - Ask: Students ask questions to clarify their understanding of the project requirements.
  - Imagine: Students brainstorm ideas for making their roller coasters. Students brainstorm individually at first and then get together and share their ideas in their group.
  - Plan: Students draw out and submit a plan for their roller coasters.
  - Create: Students build their roller coaster according to their plans.
  - Experiment/Improve: Students will record what they tried, why they tried it, what the results were, and what they ended up doing to improve the roller coaster.

EVALUATE (Days 6-7 in timeline shown below)

- Data sheet. (see attached)
  Data sheet will include a diagram of their roller coaster, a table with data and calculations, and an explanation of why their roller coaster is fun using the concepts of speed, velocity, acceleration, and potential & kinetic energy. (Newton's Laws optional)
- Roller coaster. Use criteria. (handout attached)
- Presentation: Students will present their roller coasters explaining what they included on it and why they built it the way they did, and why their roller coaster is the best. Students must use the concepts of speed, velocity, acceleration, and potential & kinetic energy (Newton's Laws optional) in their explanation. (See criteria on attached handout)

Paper Roller Coaster Timeline

Day 1: PE & KE Lab

- Do this lab after going over PE/KE calculations to give practice with calculations and also to give students practice making a paper roller coaster part (straight ramp) and introduce them to using the templates. Do this at the beginning of the unit so that as you're going over the science content, students can be working on the roller coaster on their own.
- Stress that they should make the edges of their folds as smooth and straight as possible to reduce friction. They can do this by using a ruler and tracing over the fold lines with a ballpoint pen to create a crease. Then they can fold the paper over the ruler to keep the line straight.

Day 2: Template Practice

- Do this the day after the PE & KE lab so that following the template is still fresh. Do this at the beginning of the unit so that as you're going over the science content, students can be working on the roller coaster on their own.
- Prep: Make as many copies of the templates that you think you will need. Suggestion: Make the supports on white paper and then make each of the track templates on a different color so they are easy to identify and you can clearly see the track on the finished coaster.
- Show the students how to cut and fold the templates.
  - Cut on solid lines.
  - Fold on dotted lines. Draw over w/ pen and use ruler to make folding easier and keep the folds straight.
  - Shadowed areas: Cut if there is a solid line. If no solid line, the shadow areas are where you overlap part of it.
- Go over how to make a hill (no template piece). Basically make straight track and make cuts in rails (kind of like the loop). Then fold out instead of in as much as you want and tape the rail.
- Pass out one of each template to each group of students.
- Give students the rest of the period to practice. They should cut out, fold, and tape each one of their templates.
- Whatever they don't finish in class, they should divide up and finish for homework so they have all of the pieces for the next class.

Day 3: Planning & Design (start)

- Students should have all pieces cut, folded, and taped for homework.
- Pass out Roller Coaster handout and Engineering Journals and go over the assignment. Let students ask questions and fill in the "Ask" portion of their Engineering Journals.
- Give each group of students one set of instructions and a base.
- Give students time (5 min.) to examine each roller coaster piece they made to see how they fit together and how big they are in relation to the base.
- Students brainstorm ideas individually on scratch paper, pick the best one, and sketch it in their Engineering Journals (Individual Plan). The individual plan can be a simple line drawing, but ride elements should be labeled.
- Groups then get together and discuss the individual plans. They can either choose one to refine or they can take ideas from different individual plans to make a group plan. They should then sketch the final group plan in their Journals. This plan should be more detailed. Each ride element and template piece should be shown and labeled.
- Groups use their plans to make a list of how many of each template they need. Once groups have their "shopping list," they can give it to the teacher and the teacher will give them the templates. I set a limit of 30 pages for the whole project. They should plan to use half that for their initial plan and leave some extra in case they need to make revisions.
- Students can cut, fold, and tape as many pieces as they can in class. Whatever they don't finish, they can divide up and finish at home.
- Students turn in Engineering Journals at the end of the period with Ask, Imagine, and Plan

sections filled in.

Day 4: Planning & Design (continued)

- Students start wherever they ended up from Day 3.
- Pass back Engineering Journals. Tell the students to keep this and fill it in as they go.
- Students start building.
- Students cut, fold, and tape as many pieces as they can in class. Whatever they don't finish, they can divide up and finish at home.

Finish up Energy Unit. Give quiz.

Day 5: Finish Building/ Finishing Touches/Revising Roller Coaster

- Review criteria. Remind students that they need a ride element of their own design as well as a hill.
- Students finish building.

Day 6: Data Sheet/Prepare for Presentations

- Go over what needs to be done on data sheet.
- Students do all tests and measurements to fill in Data Sheet. They need to make a 1-m straight track to attach to the end of their coasters in order to calculate the final velocity.
- Students do calculations and turn in data sheet.
- Students prepare for presentations. Go over criteria.
- Students turn in completed Engineering Journals.

Day 7: Presentations

- Give students time to prepare for presentations (5-10 min.)
- Presentations
  Use criteria on handout to grade.
- Audience fills in the evaluation form during presentations and turn in.

Homework Activity (Optional):

TEACHING & ASSESSMENT (Steps 4, 5, 6, &7)
Completed by teacher after instruction has taken place

4. Teaching and Collecting of Evidence of Student Learning:
Teacher Notes:

5. Analysis of Student Products/Performances - Formative:
Teacher Notes:

6. Evaluation of Student Products/Performances – Summative (Not necessary for every lesson):
Teacher Notes:

7. Teacher Reflection: Replanning, Reteaching, Next Steps:
Teacher Notes:

Name_____ Group____ Date_____ Period___

PE & KE Lab

Background

The Law of Conservation of Energy states that energy can be neither created nor destroyed. However, energy can change from one form to another. In the case of a marble on a paper roller coaster, a marble starts at the top of the roller coaster with a relatively large amount of potential energy (PE) and no kinetic energy (KE). As the marble starts rolling down the roller coaster, the amount of PE stored in the marble decreases while its KE increases. PE is also converted into heat energy due to friction.

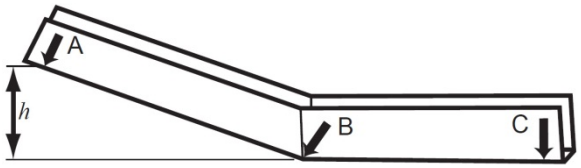
Research Question

What is the change in PE of a marble travelling down a track compared to the KE that was gained during the same time?

Materials

- Paper roller coaster
- Stopwatch
- Marble
- Meter stick
- Calculator
- 2 Wood blocks

Procedure



1. Use the templates to make a paper ramp as shown:
2. Place three marks on the ramp. Label the beginning of the hill "A", the end of the hill "B", and the end of the level section "C". You will be measuring the distance between each of these points so make sure that those distances will be easy to measure. Point A should be in from the edge so that the front of the marble can be lined up with it without the marble falling off.
3. Prop up section AB using one wooden block. It should not be too steep.

Gravitational Potential Energy

4. Find the mass of the marble in grams. Convert to kilograms.
5. What is the gravitational acceleration (g)?
6. What is the starting height (point A) of the marble in meters?
7. Use these answers to fill in the table below. Then calculate the GPE of the marble at its starting point. **GPE=mgh**

Mass (kg)	g (m/s^2)	Height (m)	GPE = mgh (J)

Kinetic Energy

8. Measure the distance between point B and C in meters. Record this in the table below.
9. Release the marble from point A and let it roll down the ramp. Time how long it takes to get from point B to point C. Record the time in the following table. Do this 5 times and calculate the average time. Record this in the table below.

Time 1	Time 2	Time 3	Time 4	Time 5	Ave. Time (s)

10. Calculate the velocity using the formula, **v=d/t**. Record your answer in the table below.

Distance BC (m)	Time (s)	Velocity (m/s)

11. Calculate the linear Kinetic Energy of the marble when it reached the bottom of the ramp using the formula: $\mathbf{KE_l = \frac{1}{2}mv^2}$. Record your answer in the table below.
12. The marble will also have kinetic energy due to its rotational motion. Calculate its rotational Kinetic Energy using the formula: $\mathbf{KE_r = {}^1/_5 mv^2}$. Record your answer in the table below.
13. Add the KE_l and KE_r to get the total KE. Record your answer in the table below.

$KE_l = \frac{1}{2}mv^2$ (J)	$KE_r = {}^1/_5 mv^2$ (J)	$KE_{total} = KE_l + KE_r$ (J)

Conclusion

1. What was the Potential Energy of the marble before it started rolling down the ramp?

2. What was the total Kinetic Energy of the marble after it rolled down the ramp?

3. How did the marble's PE at the top of the ramp compare to its KE at the bottom of the ramp? Were they similar or very different?

4. Should they have been the same? Why or why not?

Paper Roller Coasters

Purpose: To investigate the relationship between potential and kinetic energy.

Background: Roller coasters operate on the principles of potential and kinetic energy. The car is raised to a certain height, giving it gravitational potential energy. Then it is released, and the potential energy is converted into kinetic energy—the energy of motion. You will build your own roller coaster to investigate the relationship between potential and kinetic energy.

Task:

1. You are a roller coaster manufacturer competing for a bid to build a roller coaster for an amusement park. Your task is to design and build a paper model of the most fun and exciting roller coaster you can using the templates provided (www.paperrollercoasters.com). You also need to be able to explain the physics behind it.

2. The entire roller coaster must fit on the base provided (18″x 24″). The coaster must include at least one curve, loop, and hill. It must also include one other element of your own design; this may be made by modifying the supplied templates or you may make it out of a material of your choice (not pre-made). The end point should be at ground level and free from obstruction.

3. You will be expected to keep an engineering journal of your design and build process as well as a data sheet that summarizes the physics behind your roller coaster.

4. You will then present your roller coaster to the amusement park manager (teacher) and a panel of roller coaster enthusiasts (fellow students) and explain the design and build of the roller coaster and why it is the most fun and exciting based on the physics involved.

Names_____ **Date**_____ **Pd**____

Criteria

Roller Coaster	**Score**	**Poss.**
Roller coaster is made entirely of paper and tape (ex. for your ride element). Roller coaster is fixed securely to a base 18″x 24″. End point is free from obstruction.		4
Sign identifying the roller coaster is prominently displayed. Sign shows the name of the roller coaster, the names of the designers/builders, and their class period. Sign is neat & attractive.		4
Roller coaster includes at least one curve, loop, and hill. Each element adds to the fun & excitement of the roller coaster.		8
Roller coaster includes one ride element of your own design. This element adds to the fun, excitement, and interest of the roller coaster.		3
Marble successfully completes the track 3/3 times. Marble maintains contact with the track throughout each run.		6
Quality & Craftsmanship: Roller coaster is free-standing. Roller coaster can withstand repeated use and movement. Paper is neatly cut and taped together. Decoration is added to create a theme or enhance the design.		7
Roller coaster is original, interesting, and fun.		3
Total		**35**

Presentation	**Score**	**Poss.**
Information: • Describe 4 elements you built into your roller coaster. • Explain why you built those elements. • Explanations include the concepts of speed, velocity, acceleration, force, PE, KE, work, and/or Newton's Laws of Motion.		5
Sales Pitch: • Explains why your roller coaster is the best. (1) • Explanations supported by physics concepts. (2) • Physics concepts related to fun, excitement, and safety. (2)		5
Presentation Delivery • Preparedness: All group members know what to do & say, are able to explain w/o reading & talk to the audience, pronounce words correctly, & are able to answer questions. (5) • Poise: Group members stand up straight & face the audience. (2) • Speaking Voice: Loud & clear. Not too fast or slow. (3)		5
Total		**15**

Project Planning Form

Group Members

1)	2)
3)	4)

Each group may have between 1-4 members. Please select your group members carefully because your grade will be based off of the work your group does together.

Group Responsibilities

Products we need to create	What we need to do to create the products	Date products should be done

Member Responsibilities

Name	Responsibilities	Due Date	% Contribution
1)			
2)			
3)			
4)			

% Contribution is the amount of work you will put into the project. Total for group should add up to 100%.

Member Contract

By signing below, you agree that you will complete all the responsibilities assigned to you by the given deadline in order for you to receive the grade corresponding to your % contribution. If you do not complete your assigned responsibilities, a percentage of your grade will be given to the group member that completes it for you and you will lose that percentage of your grade. If you do not understand this agreement it is your responsibility to ask for more information. By signing you acknowledge understanding and agree to the above.

Print Name	Signature	Date

FYI

To determine project grade, we will use the following equation:

Individual Grade = % Contribution x Group Grade x # of People in Group

Using this equation, it is possible for a student to receive more than a 100% on the project if he/she does more than his/her share of the work. However, the maximum score allowed will be capped at 105%.

Paper Roller Coasters

Engineering Journal

Name:

Group:

Period:

Due date:

Problem: You are a roller coaster manufacturer competing for a bid to build a roller coaster for an amusement park. Your task is to design and build the most fun and exciting roller coaster you can, given the space allowed, and be able to explain the physics behind it. You will then present your roller coaster design and justify why yours is the best.

Criteria:

- Roller coaster is made entirely of paper and tape (except for one element of your design).
- Roller coaster is fixed securely to a base 18″x 24″.
- End point is free from obstruction.
- Sign identifying the roller coaster is prominently displayed.
- Roller coaster includes at least one curve, loop, and hill.
- Roller coaster includes one element of your own design that adds to the fun and excitement of the roller coaster.
- A marble must successfully complete the track 3/3 times.
- Marble maintains contact with the track throughout each run.
- Must be sturdy and neatly put together.

Ask - questions to clarify your task:

Questions	Answers

Improve – Final Plan: Draw a plan for your new roller coaster (Detailed drawing showing each piece you will use. Label parts.)

Improve – How could you change your design to:

- Be more fun and exciting
- Have the marble complete the entire track
- Stay in contact with the track throughout the entire course
- Other:_____

Changes I will make (at least 3):

What I changed	Why I changed it	Result of change

Imagine – Brainstorm ideas for your roller coaster design:

Consider the following:

- Height of starting point
- Where you will position the curve, loop, and hill
- What element of your own you could include to make it more fun

Individual Plans (Rough Draft, label parts):

Plan – Draw a **detailed** diagram of how you will build your roller coaster. **Show each piece (ride element)** and **label each part**. Show where **your ride element** will be and how you will make it.

Roller Coaster Design
(Detailed drawing showing each piece you will use. Label parts.)

Estimate how many of each template you will need:

- Columns(2) _____
- Beams (2)_____
- Diagonal Supports (2 each) _____
- Shelf (10) _____
- Brackets (enough) _____
- Straight Track (4) _____
- Sharp Turn (2) _____
- Wide Turn (2)_____
- Loop (4) _____

Create – Make your roller coaster following your plan.

Experiment – After you build your roller coaster, test it out. Check for:

- Is it fun and exciting?
- Does the marble complete the entire track?
- Does the marble stay in contact with the track the whole time?

Reflection – What worked and what didn't work?

Roller Coaster

Data Sheet

Name_____ Date_____ Period_____

Diagram

- Draw a diagram of your roller coaster.
- Label the top **A** and the bottom **E**.
  Find another point on the track where the marble is speeding up. Label it **B**.
  Find another point on the track where the marble is not speeding up or slowing down. Label it **C**.
  Find another point on the track where the marble is slowing down. Label it **D**.
- At each point on the diagram, draw in and label vectors for velocity (v →) and acceleration (a →). Make sure the arrows are pointing in the right direction and their lengths are proportional to their relative magnitudes.

Data Table

Use points A, B, C, D, & E to fill in the following table.

Point	**Location**	**Height (m)**	**PE (J)** PE=mgh	**Ideal KE (J)** KE=ME-PE	**Ideal ME (J)** $ME=PE_A$	**Ideal v (m/s)** $v=\sqrt{\frac{2KE}{m}}$
A	Top					
B						
C						
D						
E	Bottom	0				

Questions

1. At what point do you have the greatest PE? _____ At what point do you have the greatest KE? _____
2. At what point do you have the lowest PE? _____ At what point do you have the lowest KE? _____
3. Attach a 1-m length of straight track to the end of your roller coaster. Time how long it takes for the marble to travel the 1 m after traveling down the roller coaster. Do this 5 times, and take the average. Use the average time and 1-m distance to calculate the final velocity of the marble at the bottom of the coaster.

Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average t (s)

Equation	Plug in #s	v (m/s)
$V = d/t$		

4. Does the ideal velocity at the bottom of the track (see table) match the actual velocity that you calculated above? Why or why not?

5. Why is your roller coaster the best? State as many reasons as you can, and back each one up with data or observations from your roller coaster. Your answer should include the concepts of potential energy, kinetic energy, velocity, and acceleration. Answer this on a separate sheet of paper and attach it.

Name_____ Date_____ Period___

Paper Roller Coasters Evaluations

Group	What you liked & why	What you didn't like & why	How interesting, fun, & exciting (1–5)

Name_____ Date_____ Period_____

Energy Quiz

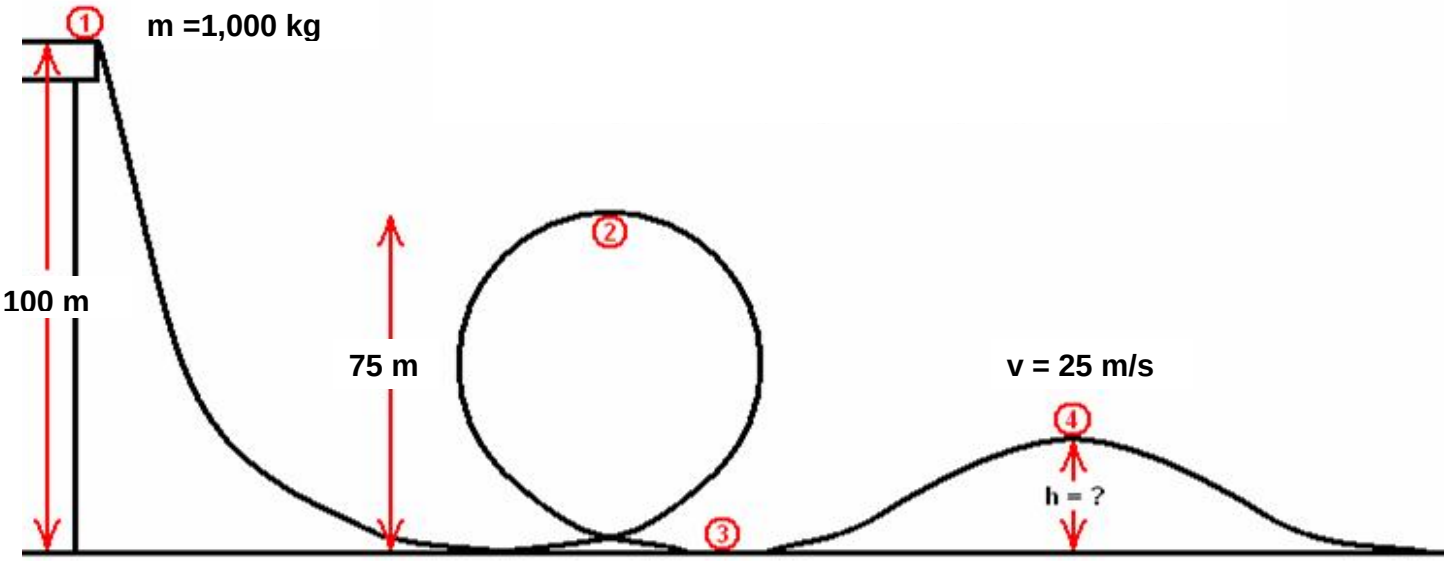
1. Do a SEXI on the difference between Potential Energy and Kinetic Energy

State (definitions)	
Elaborate (explain the difference)	
e**X**emplify (example of the difference)	
Illustrate (picture showing the difference)	

2. Fill in the blanks in the paragraph below using **PE** (potential energy) and **KE** (kinetic energy) to describe the energy transformations that occur as an object is dropped.

When an object is lifted above its resting point it gains gravitational a)_____ energy due to its position (height). When a raised object is released, it is pulled downward by the force of gravity. As it falls and loses height it loses b) b)_____ but gains c) _____ as its velocity increases. Its d)_____ just before it hits the bottom should be equal to the e)_____ it started with.

W=Fd ***F=ma*** ***PE=mgh*** ***KE= ½ mv²*** ***ME=PE+KE***



http://www.mrfizix.com/home/energy.htm

Show all work!

3. Find the following variables for the roller coaster at position 2 in the diagram. Show calculations if necessary or write in the reason for your answer.

Variables known	Variable to find	Equation	Plug in numbers	Solve
	PE=?			
	KE=?			
	ME=?			
	v=?			

4. Find the following variables for the roller coaster at position 4 in the diagram. Show calculations if necessary.

Variables known	Variable to find	Equation	Plug in numbers	Solve
	PE=?			
	KE=?			
	ME=?			
	v=?			