



Physics: Momentum and Impulse Car Safety Engineering (the Egg Drop)

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-PS2-3 Motion and Stability: Forces and Interactions		
<p>Students who demonstrate understanding can:</p> <p>HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]</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</p> <p>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"> Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. 	<p>PS2.A: Forces and Motion</p> <ul style="list-style-type: none"> If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. <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>ETS1.C: Optimizing the Design Solution</p> <ul style="list-style-type: none"> Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. <i>(secondary)</i> 	<p>Cause and Effect</p> <ul style="list-style-type: none"> Systems can be designed to cause a desired effect.
<p><i>Connections to other DCIs in this grade-level: N/A</i></p>		
<p><i>Articulation of DCIs across grade-bands:</i></p> <p>MS.PS2.A ; MS.PS3.C</p>		
<p><i>Common Core State Standards Connections:</i></p> <p>ELA/Literacy -</p> <p>WHST.11-12.7 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. (HS-PS2-3)</p>		



Physics – Momentum and Impulse – Car Safety Engineering (egg drop)

	Intro to Momentum	Conservation of Momentum	Impulse
Student Experience	<p>Students brainstorm the meaning of momentum.</p> <p>Students use different balls to investigate what the factors are in momentum.</p>	<p>Students qualitatively experiment with elastic collisions to construct the conservation of momentum.</p> <p>Teacher leads a demonstration of elastic and inelastic collisions with a Newton’s Pendulum.</p>	<p>Students design and carry out an investigation to identify the differences between when a ball is dropped on a book versus a ball dropped on a foam pad. Then, students identify the factors involved in the difference.</p> <p>Students participate in a water balloon toss. They write about how the toss relates to the impulse equation.</p>
T4T Material	Golf balls. Also needed, ping pong balls and marbles.	1 Clear tube, tube cut in half or some other channel, 1 Golf ball, 1 ping pong ball, 1 marble per group. A Newton’s Pendulum for a demo.	One golf ball, a book and a foam pad per group. Additionally, one water balloon per pair.
Big Idea	Momentum = mass x velocity	Momentum is conserved. Elastic and Inelastic collisions have similar but different equations.	$Ft = \Delta mv$ A cushioned landing takes more time.
Connection to Culminating Activity	Definition and equation of momentum	Momentum can be changed.	This is the central concept for the Culminating Activity.
CA Standards	PH2. d; IE1. j	PH2. g; IE1. j	PH2. f; IE1. j
Next Generation Science Standards	HS-PS2-2 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.	HS-PS2-2, 3 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.	HS-PS2-1 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.
Time	One 55 min period	Two 55 min periods	One 55 min period



Culminating Activity – Car Safety Engineering

	Force to Break Egg Test	Materials Test	The Drop and Write up
Student Experience	Students are introduced to the Culminating Activity (if not done at the beginning of unit)	Students design and carry out a test to determine which material will best help their egg survive.	Students design and build a device (vehicle) that minimizes the force on an egg, after the device is dropped from a height to collide with the ground.
T4T Material	Students design and carry out a test to determine the force required to break an egg. One egg per pair, in a baggie. Mass, spring scales or house scales, meter sticks, stop watches. *Water balloons can be used as an alternative.	The Cart	One egg per pair. The Cart. *Water balloons can be used as an alternative.
Big Idea	How much force can an egg withstand?	Designing a controlled experiment. Thinking about how the testing of materials helps students understand the Impulse Equation better.	$Ft = \Delta mv$
CA Standards	-----	-----	PH2. f
Next Generation Science Standards	HS-PS2-1, 3 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions.	HS-PS2-1, 3 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions. Engaging in Argument from Evidence	HS-PS2-1, 2, 3 Asking questions and defining problems. Analyzing and interpreting data. Constructing explanations and designing solutions. Engaging in Argument from Evidence
Time	One 55 min period	One 55 min period	Two 55 min periods

Total Time: about eight 55-min periods.

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.



Lesson Plans for Momentum and Impulse

Prior Knowledge: Students are proficient with the concepts and equations of basic kinematics and Newton's Laws, to the level of the California Physics Content Standards. If mechanical energy covered beforehand, this unit can be extended to accommodate energy analysis with respect to elastic versus inelastic collisions.

1. Intro to Momentum

Objective:

Students explore and construct meaning of momentum.

Engage

1. Teacher asks students, "What does it mean for a sports team to have momentum?" "What is momentum?"
 - a. Students will respond with something like "They can not be stopped."
 - b. Teacher says, "So, if a team has no momentum, then...?" Students will probably respond, "...They are easy to stop." Or, "They are already stopped."
 - c. Teacher concretizes momentum as "how hard it is to stop something," making it clear this is just a temporary working definition.

Explore and Explain

2. With a ping pong ball, golf ball and marble, students are to figure out the factors involved in momentum.

Elaborate

3. Students hypothesize what the equation for momentum is, briefly test it, then report out.

Evaluate

4. Students do a problem set on momentum with conceptual and computational problems.
- 5.

2. Conservation of Momentum

Objective: Students are to construct the idea of the conservation of momentum, and its equations, with respect to elastic and inelastic collisions.

Engage and Explore

1. On horizontal track, students send a ball to collide with a stationary ball and make observations. They should have a golf ball, a ping pong ball, and a marble. Groups can share so that the same type of ball can be collided for comparison. The teacher wants to try to limit collisions to 1 dimension.
 - a. For example, the teacher could say, "Set the ping pong ball at rest in the middle of the track. Send the golf ball toward the ping pong ball and observe the collision. What happens if the balls are reversed? What happens if you use two golf balls? Try different combinations, make



diagrams of your observations, and try to find an equation.” The teacher can prompt students with the following...

Collisions Observation Guide

- Predict what will happen
- Observe the collisions.
- Draw a diagram of what you see.
- Explain what happened.
- Find the equation.

	Before		After
Diagram		=	?
Equation	?	=	?

Explain

2. Lead students on a discussion of their observations and equations. Use questioning techniques to guide students to the concept and equation of the conservation of momentum and its elastic collision form.
3. Students should do some conceptual and computational questions on elastic collisions.

Elaborate

4. Teacher demonstrates the Newton’s Pendulum. Show one ball hitting the 4 balls at rest. Show two balls hitting the 3 balls at rest. If time allows, have students continue to 3 and 4 balls hitting the others.
 - a. Have students explain what is happening and why. “Does this agree with the Law of the Conservation of Momentum?” “Predict what will happen when 4 balls collide with the 1 ball at rest”
 - b. Isolate 2 balls and put a lump of clay on one ball. Ask, “What do you think will happen if I put a piece of clay in front of the ball at rest and let the other one go?” Have students make observations and connect those observations to the Law of Conservation of Momentum.
 - c. Explicitly go over elastic and inelastic collisions. The PhET Collision Lab is another good resource for additional student exploration and elaboration, or for additional demonstrations (<http://phet.colorado.edu/en/simulation/collision-lab>).

Evaluate

5. Students should do problems on elastic and inelastic collisions, separately at first, then mixed collisions (where they have to decide if the collision is elastic or inelastic) later. *Students need to know Conservation*



of Kinetic Energy in order to solve elastic collisions. If you don't/haven't taught this, be careful regarding your problem sets!

3. Impulse

Objective: Students design and carry out an investigation to identify the factors involved in the impulse equation, $Ft = \Delta mv$.

Engage and Explore

1. Teacher says, "If I were to drop this golf ball on a book and then on a foam pad, what would be the same, and what would be different between the two phenomena?" Hold a golf ball above a book and then hold the golf ball above a foam pad.
2. Students write down their prediction and then try it out.

Explain

3. Ask students to answer these prompts...
 - a. What are the factors involved in these phenomena?
 - b. Which of these factors stay the same, and which change?
4. Through discussion, guide students to construct the impulse equation.

Elaborate

5. Take the students outside for a water balloon toss. Give students one water balloon per pair. Before you go outside, tell students to think about this prompt and they will answer it after the toss...
 - a. Explain the water balloon toss in terms of impulse. Use the words "force", "time", "change of...", "mass", and "velocity" to accurately describe what happens during a water balloon toss. What must be done so that that the water balloon does not break? In those terms, what happens when the water balloon breaks?

Evaluate

6. Students should do a problem set using the concept and equation for impulse.



4. Culminating Activity – Vehicle Safety Engineering (the egg drop)

Engage

1. Introduce the Culminating Activity (if not done at the beginning of the unit). Inform students that they are going to play the role of Vehicle Safety Engineers. In order to design and build cars to help people safely survive auto accidents, the students are to design and build a device that will keep an egg from breaking after being dropped from a tall height. (A water balloon can be used as an alternative.)

Explore and Explain

1. Force to Break an Egg
 - a. Ask students, “How much force can an egg withstand? Devise a test and carry it out.” Students carry out the test and determine the force required to break an egg. (A water balloon can be used as an alternative.)

Elaborate

2. Materials Test
 - a. Students design and carry out a controlled test to determine which material will best help their egg survive.
 - i. Teacher says to students, “Based on the impulse equation, in order for an egg to survive an impact, should the collision take a longer time or a shorter time?” It may help to explicitly rewrite $Ft = \Delta mv$ into $F = \Delta mv/t$ (but with the t written underneath). Then substitute a small and a large number for t and have the students see what happens to the force. Or, this could be worked into the problem sets.
 - ii. “Based on the answer to the question above, design a controlled test to determine which material would best increase or decrease time during a collision.” Students are to base their test on materials in the T4T cart.
 - iii. Students carry out the test.
 - iv. Students explain, “Which material is best? Use evidence from your test to support your answer?”

Evaluate

3. The Egg Drop
 - a. Main Question – Use the impulse equation to determine how much time is needed to safely bring an egg to rest from a tall drop.
4. Students gather their materials and construct their containers.
5. Teacher instructs students to think about what data will need to be collected
 - a. Important data
 - i. Mass of egg
 - ii. Force to break egg (already determined)
 - iii. Time of fall (alternatively, height of fall)



6. Teacher facilitates the egg drop from a tall height.

7. Lab Write-up

b. Students write a formal lab write up

i. To be determined/reported ($Ft = \Delta mv$)...

1. Force to break an egg
2. Mass of egg
3. Final velocity of egg
4. Velocity of egg just before impact
5. Time it should take for an egg to safely come to rest (assuming no bounces)

ii. To be discussed...

1. A rationale for the materials they used (drawn from the Materials Test)
2. Did your egg survive? In terms of the impulse equation, explain why/how your egg either survived or was cracked.
3. Does the mass of a device matter? Why or why not.
4. Would it be better to use a hard/solid exterior or a soft/malleable exterior for a device? Why? Give reasons.

Teacher's Guide for calculations in the Lab Write-up

We are looking for the time the egg needs to survive the crash from the impulse equation $Ft = \Delta mv$

Because the mass does not change we can rearrange... $Ft = m\Delta v$.

$t = ?$ (we are looking for the time)

F = force to break an egg (measured from the force to break an egg test)

m = mass of egg

$\Delta v = v_f - v_i$

$v_f = 0$ (assuming no bounces)

v_i = the velocity at the beginning of the crash (the velocity at the end of the fall)

We will find this by analyzing the fall of the egg.

Analyzing the fall to determine the final velocity (the initial velocity of the crash)... $a = (v_f - v_i)/t$

$a = 9.8\text{m/s}^2$ (we are assuming free-fall)

$v_f = ?$ (We are looking for this. It will be the initial velocity of the crash)

$v_i = 0$

t = time for egg to fall to ground, measured by stopwatch

*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.

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.