Berkeley Engineers and Mentors

Drop It Like It's Hot

Target Grade: Elementary/Middle School
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Brief Overview

In this lesson, mentees will explore the physics of forces such as gravity and air resistance, as well as study the importance of the idea of impact through an engineering design process classic: the egg drop! The lesson begins with a brief introduction to forces and impact using paper, chips, and a plastic bag. They will then explore the effect of impact in their daily lives by studying the design of cars. Finally, mentees will get to put their new knowledge to the test by designing a device that will protect an egg from breaking when it is dropped from high up.

Teaching Goals

- **Forces and Gravity:** A **force** is a push or pull that changes an object's speed or direction. One such example is the **gravitational force.**
    - **Newton's Second Law:** Forces cause a change in acceleration proportional to the object's mass (formula for advanced sites)
- **Air Resistance:** A force on an object that opposes its motion due to frictional interactions with the air.
    - The magnitude of the force increases with speed and surface area.
- **Impact:** A change in momentum with respect to time
    - Simply put, how much your speed changes in a given time is proportional to the force that you'll feel
- **Models (**for advanced sites)**:** Something that is designed to behave similar to the way the real thing will behave without being the real object or situation.
- As engineers, we want our designs to be **cost effective,** meaning they are the least expensive they can be without losing functionality.
- **Engineering Design Process:** Come up with an idea, build it, test it, revise it, repeat!

MD Teaching Goals

- Being sensitive to the needs of different students is crucial to having a healthy mentor-mentee relationship. In this lesson, be mindful of this concept when going over the car crash modeling module, and think about how to teach this lesson to students who may have had bad experiences with car accidents.

- Different students prefer different styles of learning, out of the general visual, oral, and kinesthetic. Try and incorporate one of each of these into your teaching, and gauge how students respond.

Careers and Applications

The principles of forces and impact are central to many fields of science and engineering. Forces are the reason that things in our world move and change direction. Biologists use the concept of force as it applies to pressure because fluid wouldn't flow through us, and medicine could not be administered intravenously, if not for a difference in pressure. Chemists and physicists use the idea of forces to come up with our current understanding of the atom, the quantum mechanic model. Forces are also the basis for nearly the entirety of the field of physics. Impact also plays a significant role in physics because it is a measure of change in an object's momentum, and as momentum is always conserved in a system, understanding impact can be a helpful tool in calculating and understanding a system. Engineers also use the idea of impact when trying to design safety features in things like cars, something we will explore in the lesson today!

Agenda

- Introduction (2 minutes)
- Module 1a: Floating Paper (5 minutes)
- Module 1b: Crackin' Up (5-10 minutes)
- Module 2: Physics Is Impactful (5-10 minutes)
- Module 3: Eggceptional Egg-gineers (30-40 minutes)
- Conclusion (2 minutes)

Introduction

Since Module 1 of the lesson will be a more interactive introduction to the concepts needed for the later module, the introduction should be kept short. One way to pique interest is to ask if the mentees have ever seen a parachute. How is it that they fall slowly? Why do they fall at all? The mentees will likely know, or have heard of, gravity, and may volunteer this as an answer. However, this doesn't explain why a parachute makes something fall slower- this is due to air resistance, segwaying into the first module.

Module 1a: Floating Paper

Introduction

In this module, mentees will be introduced to the concept of a force, and will be working with two everyday examples: gravity and air resistance.

Teaching Goals

1. A **force** is a push or a pull on an object that causes its speed and/or direction to change
    1. **Gravity** is an example of a force that acts downwards on Earth
2. Acceleration: the change in speed or direction a force creates on an object
    1. On Earth, we all experience the same acceleration due to gravity; therefore, all things theoretically fall at the same rate. (for advanced sites)
3. **Air Resistance** is a type of force caused by friction with the air. It acts opposite the direction of motion of an object, and increases with speed and surface area.

Background for Mentors

In this module, mentees will be introduced to the concept of a **force**. A force is defined as any push or pull on a mass that causes a change in speed and/or direction. Newton's Second Law defines the relationship between force, mass and acceleration (the change in speed and direction or an object) as **Force=mass*acceleration**(formula for advanced sites). One example of a force that we interact with in our daily lives is **gravity**, a force that pulls us towards the center of the Earth. Because we are all on the same planet, we all experience the same acceleration due to gravity. However, we all have different masses, so according to Newton's Second Law, we all experience different magnitudes of gravitational force! This is why bigger people who have more mass also weigh more. However, for this module, it is important to note that the acceleration due to gravity on any two objects is always the same. This means that if two objects start from rest and are dropped from the same height, they would hit the ground at the same time regardless of their mass. Don't believe me? Watch this video for more info!

There are a few things that our above conclusion neglects. Our theory assumes that gravity is the only force acting on our falling objects, so they both experience the same acceleration. In reality, this is not the case. On Earth, we have a thick atmosphere that causes a force known as **air resistance.** Air resistance is a frictional force that acts opposite the direction of motion of an object. Air resistance occurs due to the interaction of the atmospheric molecules with the falling object. One way to visualize air resistance is to think about a small motor boat. The engine on the back of the boat is strong and supplies a lot of force to push the boat forwards. However, the boat still has to do work to push the water out of its way as it goes forwards, meaning it moves more slowly than we would predict if we considered only the engine's power output. Air resistance works much the same way; even though gravity is very strong, the objects that it acts on still have to push the air out of their way as they fall down, so they move slower than we would predict. Air resistance also increases in magnitude as the speed of the object increases and the object's surface area increases. For example, an object moving downwards due to the gravitational force would experience an upwards force due to air resistance as well. As the object speeds up in its descent, it experiences a greater force upwards, as if our boat were now trying to move through molasses as opposed to water. Eventually, the air resistance force will equal the gravitational force. This speed is called the **terminal velocity,** and is explained in terms of forces in the diagram above. Since we are only dropping our objects a few feet, they will not reach terminal velocity, but if you're interested in the concept, read more about it here.

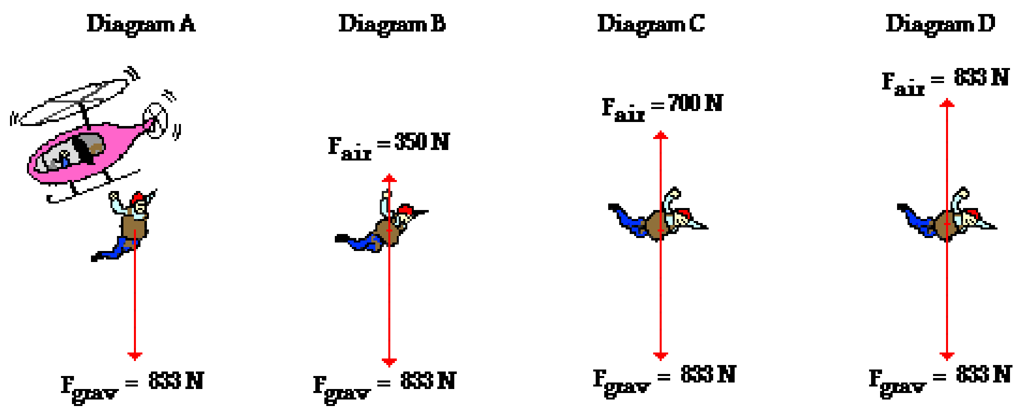

Figure 1: Air Resistance Magnitude

While we are not dropping our objects from high enough for terminal velocity to come into play, the increase in air resistance due to surface area will play a big role in this module. Because the full piece of paper has more surface area relative to its mass, it will experience a greater force and upwards acceleration due to air resistance than the crumpled piece of paper because it has more area for the air to act on.

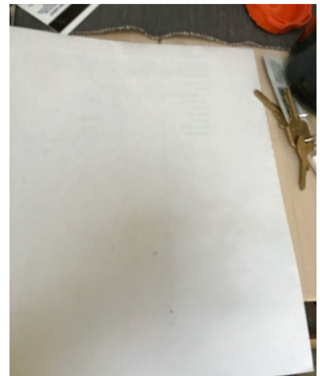

Figure 2: Open Sheet of Paper

Materials

- 2 pieces of identical paper per site
- 1 ball or hacky sack per site (for advanced sites only)

Procedure

1. This is a short, demo-based module designed to introduce the concept of air resistance.
2. Begin by showing the mentees the two sheets of paper so they know that they are exactly the same (not that it makes a difference because gravity is the same for both). Then, crumple one of the sheets up into a ball.
3. Hold both pieces of paper at the same height. Ask the mentees to predict which will fall faster and **why**.
4. Drop the papers. The ball should fall faster than the full sheet. Why is this? The <u>sheet of paper has a larger surface area</u>, so it experiences a larger air resistance force, slowing down its descent.
5. Ask whether the heavy ball or crumpled paper will fall faster and why.
6. Drop both objects from the same height. They hit the ground at the same time! Why is that?

Figure 3: Crumpled Paper

<u>Module 1b: Crackin' Up</u>

Introduction

In this module, the mentees will explore impact, which relates the force an object feels to its speed and the time of collision. They will see that a greater force means that things are more likely to break.

Teaching Goals

1. **Momentum:** A quantitative measure of an object's motion with respect to its mass
2. **Impact:** A change in momentum with respect to time
    1. Simply put, how much your speed changes in a given time is proportional to the force that you'll feel
3. When a brittle object, like a chip or an egg, <u>experiences a greater force</u>, it is more likely to break.

Background for Mentors

Now that we've covered forces, we're interested in how these could apply to breaking, or better yet not breaking, an egg. To understand this, we need to understand the concepts of **momentum** and **impact**. **Momentum** is essentially the amount of motion that an object has. It is proportional to both its mass and its velocity. The

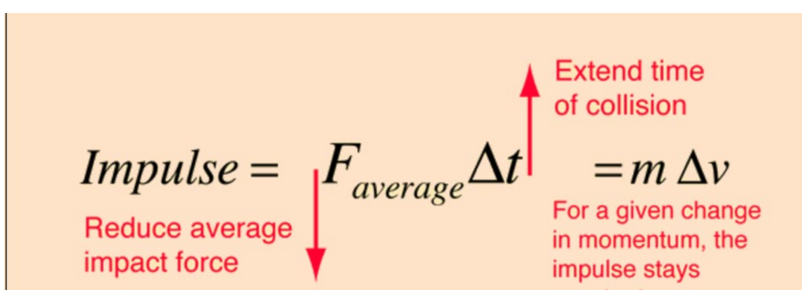

Figure 4: Impulse Equation

equation for calculating momentum is: **Momentum=mass*velocity.** This shows us that an object moving fast has more motion, as we'd expect, but also that a bigger object moving at the same speed as a smaller object has more momentum, a result we may not have predicted. **Impact** is the change in momentum, typically upon collision with another object. Impact as defined as **Force*time=Impact=Momentum=mass*velocity** . So, we know an object whose speed changes more upon collision, who has a greater mass, or whose time of collision is smaller will experience a greater force. An object that experiences a greater force is more likely to suffer damage (like an egg breaking!). In this module, we will explore one way to change the force an object experiences using the principle of impact: testing a large and small change in object velocity while keeping mass and time constant.

Materials

- 1 Ziploc bag per mentee
- 3-4 chips, such as Tostitos, per mentee

Procedure

1. Mentors should put 3-4 chips into each mentee's Ziploc bag, then lightly tie the bag shut.
2. First, mentees should hold the chip bag at about waist height, then **drop** the chips.
3. Open the bag and note how many survived. Most of the chips should be intact.
4. Then, have the mentees retie their bags. The mentees should then **throw** the chips to the ground.
5. Open the bag and note how many chips survived this time. Fewer chips should survive. Why is this? They were moving faster at the beginning, then experienced the same gravitational force and same change in velocity during the fall as the chips we dropped. Therefore, the change in speed when they hit the ground was bigger and happened in about the same time, so the force they experienced was bigger, causing the chips to break!

Additional Notes for Mentors

Make sure that mentees do not throw the chips during the first round because if they all break, they won't be able to do the second part, and the teaching goals of the module will be lost on them.

If you're running short on time, this module can be done as a short demo like 1a.

Module 2: Physics Is Impactful

Introduction

Now that we know how impact works theoretically, we will study one of many real-life applications of impact: designing a car.

Teaching Goals

1. **Impact**: A change in momentum with respect to time
    1. Simply put, how much your speed changes in a given time is proportional to the force that you'll feel.
2. **Shock Absorption:** Objects that are able to decrease the energy of a shock wave caused by impact, reducing the force and damage on an object.

. Examples: cotton balls in the egg drop, bubble wrap or packing peanuts in boxes

3. **Models (**for advanced sites): Something that is designed to behave similar to the way the real thing will behave without being the real object or situation. Engineers use modeling to estimate true behavior!
4. Using seatbelts and airbags in cars helps to keep us safe during collisions by using the principles of physics and impact.

Background for Mentors

Much of the background information needed for this module overlaps with Module 1b. This module focuses on one of many real-life applications of impact: cars. We will test two different cars. One car will have no long, crushable nose and will just have one piece of cardboard in front of our toothpick passengers, while the other will have a few pieces of paper in between the impact zone and our passengers. This crushable front end, which all cars today are manufactured with, serves to keep passengers safe in two different ways. One is by reducing the force passengers experience. Because the front end crushes, the time of collision with the wall will be greater, but the change in velocity and mass will be constant. Therefore, the passengers will experience a lesser force and will be less likely to be injured. Watch this video for more information on recent safety features in today's cars!

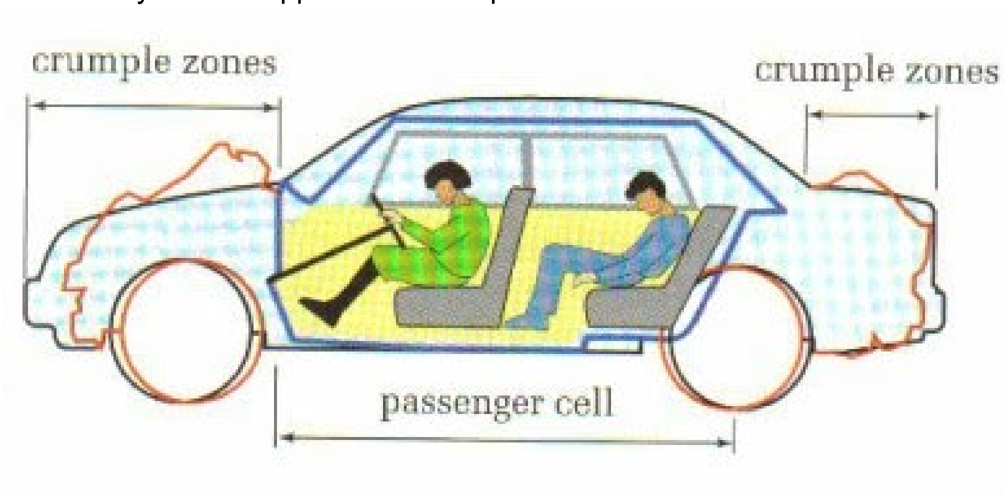

Figure 5: Car Design

The front of cars, as well as airbags in cars, also serve to keep us safe by acting as **shock absorbers.** Shock absorbers are things that serve to lower the energy of the shock wave released during the collision so that we experience a lesser force from it. Again, since the force we experience is decreased, we are less likely to be injured.

Materials
- 1 car w/o a crushable front end per site
- 1 car w/ a crushable front end per site
- 8 toothpicks per site

Procedure
1. Mentors should have built the cars so that each car has 2-4 toothpick people taped in it, but one car has a crushable front end, like a car we drive, and one only has a cardboard front.

a. Instructions for building the cars can be found here and completed in Decal.

2. Hold up both cars for the students to see. Ask them which one is more likely to break fewer toothpicks in a collision and why.
3. Test the car without the impact zone first by running it into a table or wall. Most of the toothpicks should break or be


Figure 6: Safe Car

ejected from the vehicle. What does this tell us about the force they experienced? What about their impact?
4. With approximately the same force, test the second car by running it into a table or wall. Fewer toothpicks should break. Why? What does this tell us about the force they experienced? Which part of the impact equation changed?

Additional Notes for Mentors

This module may be a little bit off-putting for some mentees. Make sure to explain that the better car is how cars are built today and using things like seatbelts and airbags can make us even safer too! Check out the MD teaching goals for strategies on handling this!

Module 3: Eggceptional Egg-gineers

Introduction

Finally, the mentees will be designing devices to protect an egg from breaking when dropped from high up. For an added challenge, mentees will only be given 10 chips to “buy” materials for their devices!

Teaching Goals

1. **Models (**for advanced sites): Something that is designed to behave similar to the way the real thing will behave without being the real object or situation. Engineers use modeling to estimate true behavior!
2. As engineers, we want our designs to be **cost effective**, meaning they are the least expensive they can be without losing functionality.
3. **Engineering Design Process:** Come up with an idea, build it, test it, revise it, repeat!

Background for Mentors

In this module, mentees will get the chance to apply what they’ve learned about forces, impact, and shock to build their own protective devices for an egg. The goal is for the device to protect an egg from breaking when dropped from high up (i.e. at the top of a staircase). Two concepts mentors should stress during the building process are the **engineering design process** and **being cost effective**. There will be a lot of time left for this module, so it is important to encourage mentees to test their designs and make revisions multiple times based on the results of those trials before allowing them to test on the real egg. This will encourage creative problem solving, working together as a group, and will yield better outcomes when testing on the real eggs.

The other twist in this module compared to a traditional egg drop is the use of legos as a currency to buy materials for the designs. As engineers, it is important that the technology made is **cost effective,** meaning it maximizes effectiveness per dollar spent. Mentees will get to practice being conservative with their resources and analyzing which items they believe will get them the most bang for their buck. Furthermore, it will encourage them to come up with ideas and prototype before they jump right into building, just like real engineers do! Make sure to stress the parallels between their building challenge and a challenge a real engineer would have; building a technology to serve a purpose at an affordable rate by trial and error.

Materials

Object Name	Price	# per mentee
Legos	This is the currency	10 per 4 mentees
Construction Paper	1 Lego per 2 pieces	1 per mentee
Popsicle Sticks	1 Lego per 2	2 per mentee
Balloons	3 Legos	1 balloon per 4 mentees
Plastic Cups	2 Legos	~10 per site
Paracord	2 Legos per foot	4 feet per site
Yarn	1 lego per foot	5 feet per site
Cotton Balls	1 Lego per 10 balls	10 per 4 mentees
Pipe cleaners	1 Lego per 2	1 per mentee
Toothpicks	1 Lego per 3	10 per 4 mentees
Tape	Free	2-3 rolls per site
Scissors	Free	2-3 pairs per site
Plastic Easter Eggs	Free	1 per 4 mentees
Eggs	Free	1 per group (4-5 mentees)

Procedure

1. This module gives the mentees a lot of free reign on how they want to approach the challenge. Make sure to explain that each group will only be given 10 tokens to buy their materials. Exchanges/refunds are allowed, but exchanges can only be made of something for equal value (ie exchanging two pipe cleaners for 10 cotton balls, but not for a balloon).
2. Mentors should split up and work with one group, and should “sell” them their materials to speed up the distribution.
3. Let the mentees prototype and build a design, then test it on the plastic egg. Based on that egg’s result, they can decide how to improve their design. The engineering design process is key here!
4. Only allow mentees to test on a real egg once they’ve tested on the plastic one and made revisions that have also been tested.

Additional Notes for Mentors

Each site will only be given a few real eggs, so it is in everyone’s best interest to prevent them from breaking. One way to reduce the likelihood of a broken egg is to make sure that mentees are prototyping and testing with the plastic egg many times first!

Conclusion

Wrap up the lesson with a recap of what did and didn't work in the egg drop designs. Try to have the mentees explain why their successful designs were successful based on the principles of force and impact, and why their less successful designs didn't use the concepts discussed in the rest of the lesson as well.

References

- Newton's Second Law, NASA. https://www.grc.nasa.gov/WWW/k-12/airplane/newton2.html
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- Impulse equation picture, Hyperphysics. http://hyperphysics.phy-astr.gsu.edu/hbase/impulse.html
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Summary Materials Table

Material	**Amount per Group**	**Expected $$**	**Vendor (or online link)**
Printer Paper	2 per site	Free	Inventory or printers around campus
Ball/hacky sack	1 per site	Free?	Hopefully people will have some. Doesn't have to be anything super specific
Compostable bags (can be reused each day)	1 per mentee	$11.95 (or free if we can steal enough from TJs)	Amazon
Tostitos Chips	4 per mentee	$14	Amazon
Approx. 2 sq. ft of cardboard	1 per site	$28 (if we can't reuse cardboard from elsewhere)	Amazon
Beads	40 per site	Free	Inventory

Printer or construction Paper	2 pieces per site	Free	Inventory or printers around campus
Toothpicks	10 per 4 mentees, plus 8	$3	Amazon
Construction Paper	1 piece per mentee	Free	Inventory
Popsicle Sticks	2 per mentee	Free	Inventory
Balloons	1 per 3-4 mentees	$20	Amazon
Plastic Cups	1 per 2 mentees	Free	Inventory
Pipe Cleaners	1 per mentee	Free	Inventory
Tape	2-3 rolls per site	Free	Inventory
Scissors	2-3 pairs per site	Free	Inventory
Cotton Balls	10 per 4 mentees	$28	Amazon