Berkeley Engineers and Mentors

Catapulting into BEAM!

Target Grade: Elementary/Middle School
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Brief Overview

In this lesson, mentees will be introduced to BEAM and the physics behind catapults! In the first module, mentors and mentees will be playing a name game together (either from the selection provided or something else that works for your site). Introduce yourselves and get to know your students! Module 2 will be a brief introduction to 1D and 2D motion using a tennis ball demo. Finally, mentors should be spending the majority of time focusing on the last module, building and testing the catapults!

Teaching Goals

- Learning names!
- Vectors versus scalar quantities [specific terms are for advanced sites]
- Three quantities of translational motion and what they measure:
    - **Displacement** - vector that describes the change in position of an object from its original position.
    - **Velocity** - the vector quantity for how quickly the object is moving
    - **Acceleration** - a vector quantity for how quickly the object is speeding up or slowing down
- **Projectile Motion** is the motion of an object thrown or projected into the air, which moves along a curved path due only to the force of gravity and the initial force applied
    - An object launched at a **45 degree angle** has the greatest range
- **The Engineering Design Process** is a series of steps that engineers follow in order to come up with a solution to a problem
- The strength of **triangles**

Careers and Applications

One dimensional and two dimensional motion are omnipresent in the real world! For instance, every time you see a car driving down the freeway or stopping at a stop sign you are witnessing changes in displacement, velocity, and acceleration. As a result, for many career paths the physics behind translational motion is an integral part of their daily lives. Many researchers working in aerospace as well as civil engineers who work work road design all have to understand these concepts in order to do their jobs effectively.

Agenda

- Introduction
- Module 1: Welcome to BEAM! (10-15 min)
- Module 2A: Intro to 1D motion (5-10 min)
- Module 2B: Intro to 2D motion (5-10 min)
- Module 3: Marshmallow Catapults (20-30 min)
- Conclusion

Introduction

Welcome students to BEAM! Do they know what BEAM stands for? Ask them! Introduce who we are and what we do. Immediately proceed to module 1, as there's a lot to cover in today's lesson.

Module 1: Welcome to BEAM!

Introduction

Begin the semester by playing an ice breaker or two to get to know your students by name!

Teaching Goals

1. Learn everyone's names and introduce BEAM!

Background for Mentors

Learning names is especially important for developing good relationships with the mentees because they are a lot more receptive when you call them by their name (as opposed to pointing to them or using some other generic identifier). In a few years, students may not necessarily remember the specific concepts they've learned, but they will definitely remember how they felt during their one-on-one interactions with you! Playing name games will both break the ice and allow everyone to get to know each other in a fun way. Every site leader probably has a slightly different method of introducing BEAM and getting to know the students so this module is pretty flexible in terms of activity choice!

Materials

- 2 tennis balls *per site*

Procedure

1. Introduce yourselves and what BEAM is! Your site leader will most likely decide how to do this but some introductory questions you can ask your students include:
    a. What is BEAM? What do the letters in BEAM stand for?

    b. What is engineering? What do engineers do?
    c. You can also briefly explain each of your major/intended majors and a cool application of something you've learned (ex: I'm a biology major and a cool application could include understanding your ancestry by sequencing your genes through companies like 23andMe!)
2. Play a name game to familiarize yourselves with your students! Here are a couple suggestions, but feel free to try other name games.

https://docs.google.com/document/d/1gYIX4zVA8WUJNawhMP8MAW5kSIBvDOW-RKT9NDNiypg/edit?usp=sharing

Additional Notes for Mentors

For larger sites, be sure to stay within the time allotted for this module because there is a lot to do today! If necessary, consider splitting off into smaller groups and having a mentor lead the game for each of these groups.

Also it's a great idea to create a written list of names to review at the end of site with the mentors so everyone remembers as many as they can.

Module 2A: Intro to 1D Motion

Introduction

In this module, mentors will introduce mentees to a couple important concepts in translational motion using a tennis ball demo. Mentors will be tossing the ball in the air to explain the relationship between distance, velocity, and acceleration in an example of simple 1D motion. This demo will provide students with some of the background that they will need to understand 2D motion and projectiles.

Teaching Goals

1. Vectors versus scalar quantities [specific terms are for advanced sites]
    a. **Vectors** - a value that contains both a quantitative magnitude and direction
    b. **Scalar** - a value that contains only the quantitative magnitude
2. Displacement versus distance
    a. **Displacement** - vector that describes the change in position of an object from its original position.
    b. **Distance** - the scalar change in the position of an object [for advanced sites]
3. Velocity versus speed
    a. **Velocity** - the vector quantity for how quickly the object is moving
    b. **Speed** - the scalar quantity for how quickly the object is moving [for advanced sites]
4. **Acceleration** - a vector quantity for how quickly the object is speeding up or slowing down

Background for Mentors

With any sort of motion, we are concerned with several quantitative values, mainly how far has the object traveled, how fast was it traveling, and how quickly did it speed up or slow down. In physics, measurements can be given as **vectors** or **scalars**. A scalar is simply the numerical value of a measurement while vectors include both this value and a direction. *For our advanced sites, you can try to introduce the terminology behind these concepts. But for younger students, it is still important to emphasize the concept of directions of motion as opposed to the terms since they'll need to understand the different directions when it comes to 2D motion.*

Distance is a scalar quantity that describes how much ground an object has covered during its entire time in motion. Distance is a **scalar** which means it does not consider the direction of motion.

Displacement is a vector quantity that describes change in the position of the object based on its start and end points by also taking into account the direction of motion. For this lesson we will primarily be concerned with the vector quantities.

To make a distinction between displacement and distance, consider the following scenario:

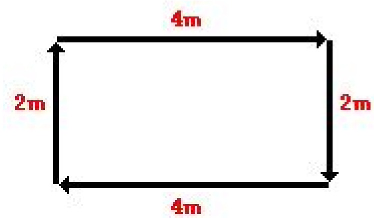

Figure 1: Displacement and Distance

Suppose a mentee walks from the top left corner 4m to the right and then follows the arrows back to his original position, what is the distance traveled? The displacement?

Distance is 12 meters or just the sum of the sides. Displacement is actually 0 since the student ended up exactly where he started! *However, displacement isn't always different from the distance, sometimes the value is the same!*

Another value we should be taking into account when measuring motion is the speed and velocity of the moving object. **Speed** is a scalar while **velocity** is a vector. But both describe in essence how fast the object is moving. Can you think of a scenario when the average speed might be + but the average velocity is 0?

Speed = distance/time   Velocity = displacement/time

Finally, we should think about how quickly the object's velocity is changing. Is it slowing down or speeding up? In other words, is it decelerating or accelerating? **Acceleration** is also a vector quantity!

Acceleration = velocity/time

With 1D motion, all of these quantities are considered along only *one axis.* For instance, a person pacing left to right would be traveling along only one axis (the x-axis). His or her displacement, velocity, and acceleration will all be along one line. Another example is one you will be demonstrating to the mentees, tossing a ball in the air! The ball will be tossed only on one axis, as well, but this time along the y-axis.

Materials

- 1 tennis ball *per* site

Procedure

1) Part one: Free Fall
    a) Take the tennis ball and hold it around 5 feet from the ground.
        i) How far approximately the ball is from the ground? (**Ans**: 5 ft)
        ii) What is the velocity of the ball? (**Ans**: 0 ft/sec)
    b) Now, drop the tennis ball.
        i) How far is the ball from the ground now? (**Ans**: 0 ft)
        ii) What direction did the tennis ball travel to the ground? (**Ans**: downward)
        iii) Was the ball speeding up, slowing down, or traveling at the same speed? (**Ans**: speeding up)
        iv) What direction is the acceleration? (**Ans**: downward)
        v) When was the ball travelling the fastest? (**Ans**: right before the ball hit the ground)
2) Part two: Ball Toss [advanced sites]
    a) Take the tennis ball and hold it around 5 feet from the ground.
        i) How far approximately the ball is from the ground? (**Ans**: 5 ft)
        ii) What is the velocity of the ball? (**Ans**: 0 ft/sec)
    b) Toss the ball upward (try to toss it straight upward).
        i) What direction is the initial velocity of the ball? (**Ans**: upward)
        ii) Is the ball speeding up or slowing down or traveling at the same speed? (**Ans**: slowing down)
        iii) What direction is the acceleration? (**Ans**: downward)
        iv) What is the speed of the ball when it reaches the top of its motion? (**Ans**: 0 ft/sec)
        v) When was the ball traveling the fastest on the way up? (**Ans**: right after it was tossed)
    c) As the ball falls down from the max height...
        i) What is the direction of the velocity after the ball comes down from the height of the arc? (**Ans**: downward)
        ii) Is the ball speeding up or slowing down or traveling at the same speed as it descends? (**Ans**: speeding up)
        iii) What is the direction of the acceleration? (**Ans**: downward)
        iv) When is the ball traveling the fastest? (**Ans**: right after it is tossed)
3) Explain to mentees that this demonstration illustrates 1D motion along the vertical/y axis. The quantities of displacement, velocity, and acceleration also apply along the horizontal/x axis.

Additional Notes for Mentors

This module is pretty simple! **The questions listed are only potential prompts for mentors.** They can be extended or omitted.

Module 2B: Intro to 2D Motion

Introduction

In this module, mentees will build off of what they learned about 1D motion and explore the concept behind projectile/2D motion before they build their marshmallow catapults!

Teaching Goals

1. **Projectile motion/2D motion** incorporates vertical and horizontal directionality.
    a. **Projectile motion** is the motion of an object thrown or projected into the air, which moves along a curved path due only to the force of gravity (for the purposes of this lesson, we will neglect air resistance)
    b. An object launched at a **45 degree angle** has the greatest range because it maximizes the *hang time* and *horizontal velocity*.
        i. An object launched at a 60 degree angle has *the greatest hang time* compared to launching at 30 and 45 degrees, but does not exhibit enough *horizontal velocity* to go as far as a 45 degree launch would
        ii. An object launched at a 30 degree angle has *plenty of horizontal velocity*, but it has a *short hang time,* and as a result the projectile doesn't travel for as long, so it hits the ground earlier than a 45 degree launch would

Background for Mentors

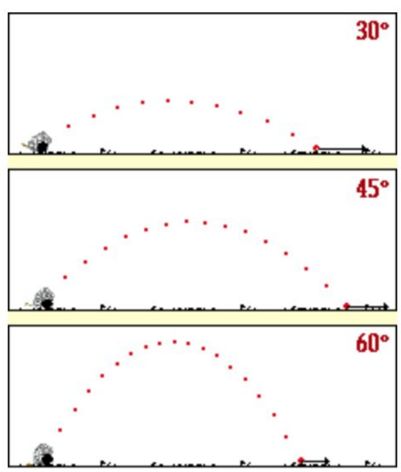

Figure 2: The 45 degree angle has the greatest range

The range of a projectile is determined by two parameters

1) The **initial value of the horizontal velocity** (the velocity of the object along the horizontal axis when time t=0)
2) The **hang time** of the projectile (the number of seconds that the object remains in the

air. Hang time correlates with an object's maximum height, the higher the maximum height of an object, the longer the hang time.)

As can be seen from the figure above, the object launched at 60 degrees has the greatest hang time (it has the highest maximum height), yet it has very limited horizontal velocity. The projectile launched at 30 degrees has the greatest horizontal velocity, yet it has the smallest hang time. The projectile launched at 45 degrees does not have either the greatest hang time, nor the greatest horizontal velocity. However, the object is able to achieve the greatest range because it maximizes both the horizontal velocity and hang time by perfectly splitting the upward and forward forces.

Materials

- 1 tennis ball per site

Procedure

1. Take the tennis ball and hold it around 4-5 feet from the ground.
    a. How far approximately the ball is from the ground? (**Ans**: 4-5 ft)
    b. What is the velocity of the ball? (**Ans**: 0 ft/sec)
2. Now, have a mentor toss the ball in an arch to another mentor/well-behaving mentee
    a. Discuss the following questions with your mentees
        i. How is this toss different from the ball toss from module 1? **(Ans:** the ball is moving in the horizontal (x) and vertical (y) direction, as opposed to just in the y direction aka up and down)
        ii. What is the ball's velocity when it reaches the peak of the arch? **(Ans:** 0ft/sec)
    b. Without a partner, find a position in the classroom where you can comfortably toss the ball a short distance (consider having a partner collect the ball after it lands and toss it back to you)
        i. Throw the ball at a shallow angle (approx 30 degrees)
        ii. Throw the ball at a 45 degree angle
        iii. Throw ball at steep angle (approx 75 degrees)
        iv. Discuss what happened
            1. Which toss had the greatest hang time? **(Ans:** the 75 degree toss)
            2. Which toss had the greatest horizontal velocity? **(Ans:** the 30 degree toss)
            3. Which toss allowed the ball to go the farthest? (aka which toss has the best range) Why? **(Ans:** The 45 degree angle toss because it maximizes the hang time and initial horizontal velocity.)

Additional Notes for Mentors

This module, along with the previous module, are meant to be brief demos to 1D and 2D motion. Don't take up too much time on these, and allow mentees to spend most of their time building their catapults!

Module 3: Marshmallow Catapults

Introduction

In this module, mentees will use popsicle sticks, plastic spoons, tape, and rubber bands to make small catapults that will launch marshmallows into the air. Catapults will be judged by their range (how far the marshmallows are launched) and by their accuracy. During the building process, mentees will learn about the engineering design process and the importance of prototyping. Furthermore, they will use what they learned about projectile motion in module 2B to understand how to maximize the range of their catapult.

Teaching Goals

1. **Projectile Motion-2D motion**
2. **Engineering Design Process!**
    a. A series of steps that engineers follow in order to come up with a solution to a problem
3. An object launched at a **45 degree angle** has the greatest range
4. **Strength of Triangles**
    a. Any force that is applied to one vertex of a triangle is evenly distributed throughout the shape

Background for Mentors

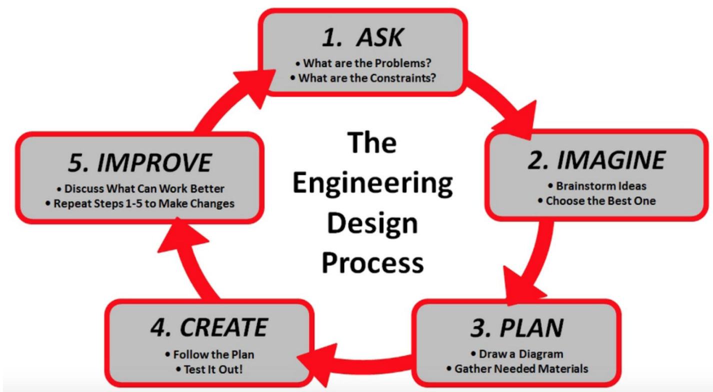

Figure 3: The Engineering Design Process

The Engineering Design Process is a series of steps that engineers follow in order to come up with a solution to a problem. The process involves planning, designing, and ultimately revising the plan in order to improve the original design.

The strength of triangles. Have you ever noticed how prevalent triangles are in structures, such as bridges? Take a closer look at San Francisco's Golden Gate Bridge, and you'll notice that it's foundations heavily rely on the shape.

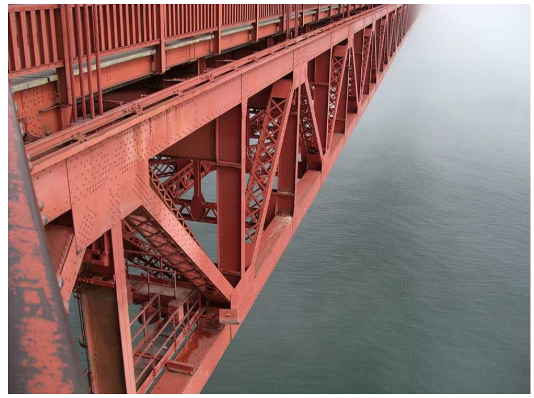

Figure 4: Triangles on the Golden Gate Bridge

Why use triangles? Turns out that **triangles are stronger and more rigid than other shapes**. Any force that is applied to one vertex of a triangle is evenly distributed throughout the shape. In contrast, the same force applied to the corner of a square would cause it to collapse. This is why triangles are the shape of choice when constructing bridges and other buildings. Therefore, using triangles as the sides of a catapult will make it stronger and more stable than using squares.

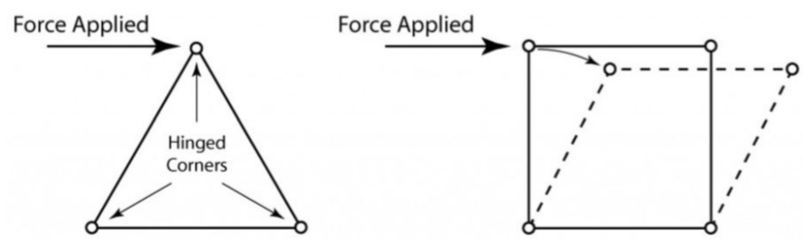

Figure 5: The strength of triangles

Materials

- 2 rolls of tape per site
- 1 bag of marshmallows per site
- 10 popsicle sticks per student
- 1 spoon per student
- 3 rubber bands per student
- 1 binder clip per student
- 3 pairs of scissors per site

Procedure

Note: The following catapults are guidelines for mentors to get some ideas on how a catapult could be constructed. After introducing the Engineering Design Process and explaining the strength of triangles, *let your students build their own catapult*. Allow them to learn through trial and error.

Example catapults for mentors:

https://docs.google.com/document/d/19aMSeG-_dgTmxMTWu30cWmi6T_kQ-pLD42-JzF6sJpE/edit

1. Optional (and if time allows): Consider allowing students to plan their design on paper, or talk through their design, for a couple minutes before building.
2. After building, it's time to put what mentees have learned in earlier modules to the test! Choose between the following two challenges, try both (if you have time), or come up with your own!
    a. Target practice
        i. Try to get students to accurately hit an inanimate object (like a backpack)
    b. Test the range
        i. Whose catapult can launch their marshmallow the farthest?
            1. What's the best launch angle to maximize range? Why? (see Module 2B)

Additional Notes for Mentors

When working on their catapults, allow the mentees to follow the engineering design process. When creating their original design, or improving it, it's always good to remind them about what we learned earlier in the lesson, but *don't tell them exactly what to do*. Allow them to be creative and brainstorm catapult ideas and revisions for themselves.

Additional Notes for *Mentor Development*

Written by Nikki DeNamur and Tiffany Tran

What should you do if a student is struggling with a concept? There are a few ways to go about this:

1) **Connect the concept** to a topic that the mentee is familiar with. For example, you could relate the strength of triangles back to the bridges example given in Background for Mentors.
2) Make it **interactive**! For example, if a student doesn't understand the strength of triangles, actually build a triangle and a square using materials provided for the lesson and push both shapes at the corner. In this way, the mentee can see the different impacts of force on each shape. Using something they can interact with can help make the concept more applicable and understandable.
3) Though the module is focused on the Engineering Design Process, if a student is really struggling and doesn't know where to begin on their catapult consider starting out with a **guided build**. Ask the mentee *why* it would be beneficial to include a feature (such as a triangle) in the catapult as you build with them. Allow them to finish the catapult on their own as they gain confidence.
4) In contrast, use the **Engineering Design Process** to your advantage! If a student tries a design and it doesn't work out, ask the student "why do you think this didn't work?" Allow them time to think, re-work, and test their new design. This gives the mentee an opportunity to learn from their mistakes.
5) **Start with the basics.** When in doubt, go back to the basics. Students can easily get

lost in jargon (ie. projectile motion, scalar, velocity), and it can help to reinforce the basic concepts or limit jargon and explain the concept directly. You may have experienced this in your own classes when a professor assumes that you know a certain concept, skips over it, and immediately jumps into advanced topics. This is overwhelming to us, and to your mentees.

6) Don't forget to **encourage and support** your struggling mentee. Keep in mind that *not understanding a concept doesn't reflect a student's lack of intelligence, but can oftentimes be based in a lack of confidence*. It always helps to simplify the concepts and teach in the form of questions. Build their confidence by asking simple questions, and be sure to praise their hard work and thought process.

Conclusion

Conclude the lesson by reinforcing the topics learned today. Do mentees know the difference between 1D and 2D motion? Why does an object launched at a 45 degree angle have the greatest range? What is the engineering design process? Also, thank them for coming to the first BEAM lesson of the semester! We hope they are excited to come back next week :)

References

- Maximum Range, The Physics Classroom. https://www.physicsclassroom.com/mmedia/vectors/mr.cfm
- Marshmallow Catapults, Matthew Sit, BEAM Fall 2017.

Summary Materials Table

Material	Amount per Group	Expected $$	Vendor (or online link)
Tennis balls	2 per site	N/A	Nico!!!
Tape	2 rolls per site	N/A	Inventory
Marshmallows	1 bag per site	$42.58	Safeway
Popsicle sticks	10 per student	N/A	Inventory
Spoons	1 per student	N/A	Inventory
Rubber bands	At least 3 per student	N/A	Inventory
Binder clips	1 per student	N/A	Inventory
Scissors	3 per site	N/A	Inventory