Blast Off with BEAM!

Target Grade: Elementary/Middle
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Semester: Spring 2020

Brief Overview

In this lesson, students will learn about core physics topics such as forces and Newton's Third Law, and they will have the opportunity to launch their own paper and bottle rockets! Mentees will also be introduced to the engineering design process, a teaching goal that will be reinforced again and again throughout the course of the semester.

Main Teaching Goals

- **Force:** Any interaction that will change an object's motion, if unopposed. Force can also be described intuitively as a push or a pull. It has both magnitude and direction.
- **Newton's Third Law:** For every force, there is an equal and opposite force (basically a force of equal magnitude in the opposite direction).
    - **Thrust:** The "equal and opposite force". Also known as the force which moves an aircraft/rocket through the air.
- **Engineering Design Process:** The process of trial and error and repeatedly testing and improving upon models.

Mentor Development Goals

- Learn as many of your mentees' **names** as possible.
- Establish **classroom rules/expectations**.

Careers and Applications

This lesson inherently relates to the aerospace field, as students will witness the thought process behind designing air vehicles. Fundamentally, being able to visualize the forces acting on an object or process is important in physics.

Agenda

- Module 0: Welcome to BEAM! (10 min)
- Module 1A: Balloon Launcher (5 min)
- Module 1B: Paper Rockets (20 min)

- Module 2: Bottle Rockets (20 min)
- Conclusion (5 min)

Module 0: 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/ping pong 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. Check out the Additional Notes For Mentor Development section for a super helpful classroom rules activity to start off the semester!
3. Play a name game to familiarize yourselves with your students! **Here** are a couple suggestions, but feel free to try other name games.

Additional Notes for Mentors

- For larger sites consider splitting off into smaller groups and having a mentor lead the game for each of these groups.
- Create a written list of names to review at the end of site with the mentors so everyone remembers as many as they can.

Additional Notes for Mentor Development

Rules in the Classroom: *Written by Tiffany Tran*

Rules are important to ensure appropriate behavior and mutual respect up front and to create an environment appropriate and optimal for learning. ***Proactive disciplinary strategies that avoid behavioral problems*** *are always better than reactive strategies that try to reduce behavioral problems after they are already present.*

It is important to ***collaborate with the mentees to establish rules and expectations*** *for the semester, so that they feel heard and respected*. The mentees will often already know the rules and expectations from their own school, and many of these will carry over to BEAM. Some that may be especially helpful for BEAM are:

- No running in the classroom.
- Be respectful of materials, share with your peers, and try to reduce waste.
- Raise your hand before speaking.
- Respect each other's personal space.

These rules and expectations are important to continue to enforce throughout the semester through **positive feedback**. In this context, positive feedback is when a student is given praise and encouragement to things that the student did well or when they followed rules and expectations. Negative feedback is when an instructor reacts to a misbehavior by reprimanding or somehow redirecting that misbehavior. It has been found that for students receiving more positive feedback, there was a significant increase in prosocial behaviors such as helping and sharing. For students that received more negative feedback, there was a significant increase in problems with emotion regulation, concentration problems, and disruptive behavior. Thus, establishing and continuing to reinforce classroom rules and expectations will be helpful in creating a smooth classroom environment throughout the semester.

Module 1A: Balloon Launcher

Introduction

In this short demo, students will be introduced to forces and how they act on different objects in the real world. Specifically, students will be using a balloon and a string to learn about the forces involved in rocket propulsion.

Teaching Goals

1. **Force:** any interaction that will change an object's motion, if unopposed.
2. **Newton's Third Law:** For every force (that object A applies on object B), there is an equal force in the opposite direction (from object B on object A).
    a. **Thrust:** The "equal and opposite force". Also known as the force associated with the ejection of mass at a velocity.

Background for Mentors

A **force** is defined as any interaction that will change an object's motion, if unopposed. Forces are vectors, having both magnitude (the numerical value) and direction (which way the force is acting), so it's useful to draw forces on diagrams as arrows to make it easy to visualize them. These diagrams are called free body diagrams. (There's no need to define free body diagrams for mentees, or even discuss them, but we are introducing them here for mentors to get a visual on the concept of forces.) An object accelerates when the forces acting on it do not sum up to zero. In other words, the forces are not equal. Thus, for a rocket to blast off, for example, a force must be applied in order to launch it into space.

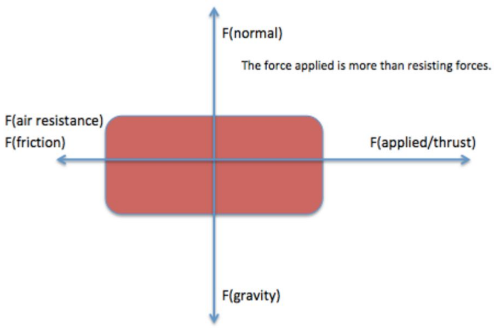

Figure 1: Example of a Free Body Diagram (object will accelerate, as forces aren't equal), *Bryan's Blog*

Newton's Third Law states that if an object A exerts a force on object B, then object B must exert a force of equal magnitude and opposite direction back on object A. Consider a balloon. When a balloon is filled with air and tied, in what directions is the balloon experiencing force? [Figure 2] **(ask the students about this at site!)** In this situation, the balloon experiences forces in all directions from the air inside the balloon bouncing against the skin. For advanced sites, you can also explain that the balloon doesn't continually expand or move because air pressure also acts on the balloon skin from the outside due to the weight of the atmosphere.

How about when the balloon is untied, in which directions would forces act? In the diagram below [Figure 2], when the balloon is untied, the air will flow out of the opening exerting a force toward the right on the air in the atmosphere. Newton's Third Law suggests that there will be an "equal and opposite force" to the left from the air in the atmosphere pushing back on the balloon. This force is called the **thrust.** Thrust pushes the balloon toward the left, causing the balloon to speed toward the left.

A rocket works in a similar manner, relying on Newton's Third Law and forces!

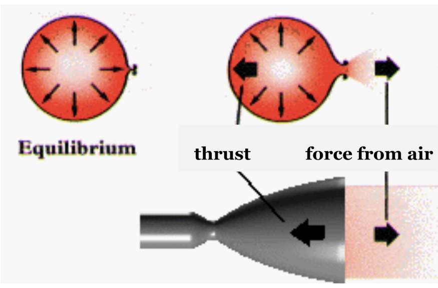

Figure 2: Forces on a balloon and rocket, *NASA*

Materials

1) 1 balloon per site

2) 1 three foot long piece of string/thread per site
3) 1 four inch piece of straw per site
4) 1 tape roll per site

Procedure (video)

1) Collect all materials and introduce forces, thrust, and Newton's third law
2) Have a mentor inflate the balloon and hold the end so no air escapes
3) Then tape the balloon to the straw such that the end of the balloon and one end of the straw point in the same direction
4) Pass the string through the straw such that the end of the balloon is closer to the end of the string
5) Have two mentors hold the string taut and then the third mentor can release the balloon's end
6) Watch as the model rocket flies along the string toward the other end and ask the kids how they think this model might work!

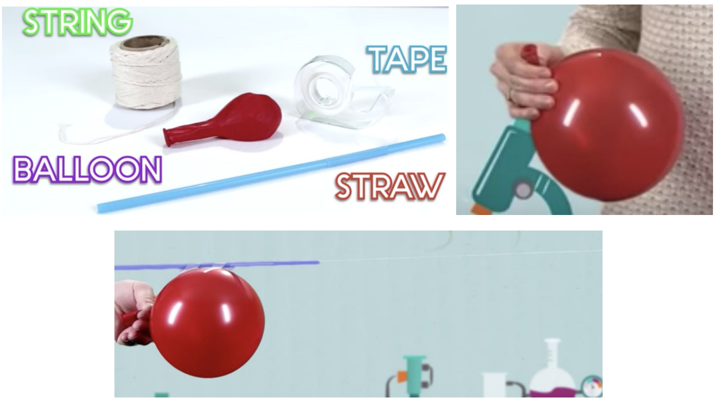

Figure 3: Procedure Step 1, 2, 3, 4 *SciShow Kids*

Additional Notes for Mentors

- Are your students still having trouble understanding forces, Newton's third law, and thrust? Try asking the following question to improve your site's understanding of the teaching goals: if a person shot water out of a fire hose to the right, would the person feel a force to the right or left? The answer is to the left. This is because of Newton's third law and thrust. When water is shot out of the hose, there is a force to the right. There is an equal and opposite force to the left which the person experiences. This equal and opposite force is the thrust.

Figure 4: Hose Example, *123rf*

- If your mentees ask what Newton's first and second laws are, they are as follows:

a. 1) An object at rest stays at rest and an object in motion stays in motion with the same speed and same direction unless acted upon by an unbalanced force
b. 2) The force exerted on an object is equal to the object's mass times its acceleration (F=ma)

- **Important Note**: If you're feeling pressed for time *skip* this module and introduce the concepts during module 1B. We want mentees to spend most of their time building and reconstructing their paper rockets (and of course, make sure you have time for bottle rockets!)

Module 1B: Paper Rockets

Introduction

In this module, students reinforce their knowledge of forces and Newton's Third Law and how they relate to propulsion by designing paper rockets. They will practice the engineering design process as they design the optimal paper rocket that will fly the farthest!

Teaching Goals

1. **Force:** Any interaction that will change an object's motion, if unopposed.
2. **Newton's Third Law:** For every force, there is an equal and opposite force
   a. **Thrust:** The "equal and opposite force". Also known as the force associated with the ejection of mass at a velocity.
3. **Engineering Design Process:** The process of trial and error and repeatedly testing and improving upon models.

Background for Mentors

Students just learned about forces, thrust, and Newton's third law in module 1a. Recap the definition of forces, and reemphasize the meaning of Newton's Third Law and how it applies to rockets in motion. In order for a rocket to blast off, a force must be applied to launch it into space. The gases ejected from a rocket push it upward (this force is also known as **thrust**). This force must also have an equal and opposite force, and in the case of rockets, the engine pushes the gases down.

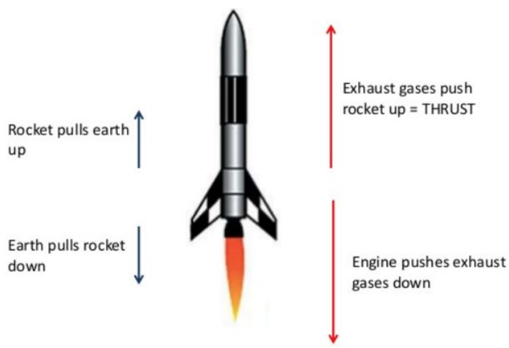

Figure 5: Forces acting on a rocket, *Cambridge Online Learning*

Thrust is the force that the balloon experienced as it raced across the string in module 1a and it is also the force that makes our rocket travel upward. Specifically, it is the force associated with an ejection of mass at a velocity. We can define thrust using the following equation.

$$F = \frac{dm}{dt}v$$

Thus, if you shoot the mass out faster (at a greater velocity), it will have more thrust. Thrust is why actual rockets work! A common misconception is that the flame propels the rocket. In reality, the *rapidly expanding gas* shot out at the bottom of the rocket is what propels the rocket up (see figure 5).

So how does this apply to our paper rockets? In our straw rocket, squeezing the bottle pushes air into the rocket, creating a space of **higher pressure** within the rocket. **Air likes to travel from higher pressure to lower pressure**, so the rocket will then push the air back out. This ejection of a mass (in this case, air) at a velocity causes a resultant force called **thrust**, pushing the rocket forward! With greater thrust, the rocket travels farther. So how do we increase thrust within our rocket rocket design? Squeezing the bottle harder should be the most obvious answer. The harder we squeeze the bottle, the greater the force of the air exerted by the rocket. If there appears to be time, let students squeeze the bottle at different magnitudes of force.

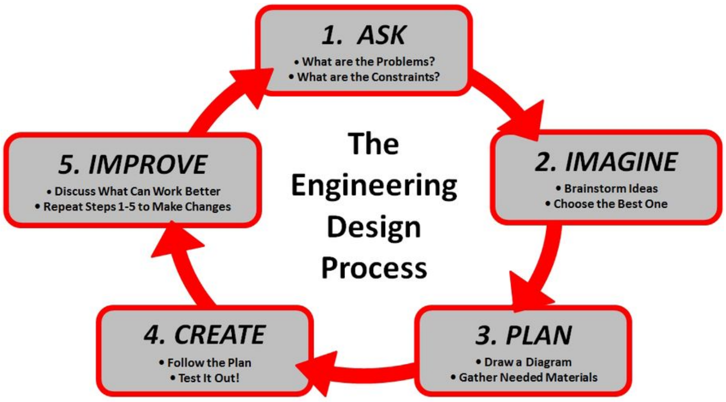

Figure 6: Engineering Design Process, *Mr. Fleming Science*.

Engineers constantly practice the engineering design process when they design new inventions. The **engineering design process** involves prototyping and trial and error. Discuss the importance of the engineering design process (specifically trial and error and prototyping) with students. If students are still confused, you can split up the process into 5 main steps: Ask, Imagine, Plan, Create, Improve. This can be visualized in Figure 8. It is fine if they do not immediately grasp this concept, as they will practice it throughout the entire semester!

Materials

- At least 1 Squeezable Bottle Base *per site*
- 2 pieces of construction paper *per student*
- 5-8 pairs of scissors *per site*
- 3-4 rolls of tape *per site*

Students may keep their paper rockets!

Procedure

1. Talk about what engineering is.

2. Build the fuselage (the tube making up the body of the rockets) of the paper rockets by wrapping paper around the launch tube.
3. Make a nose cone with the same or **bigger** diameter as the fuselage.
    a. As pointed as possible to reduce air drag, but not too long to destabilize the rocket
        i. **Note:** air drag will be discussed further in the last module (for advanced sites), but consider giving a brief introduction to it here
    b. Let the students build whatever they want, but when discussing the results bring up the fact that a pointier nose cone is more aerodynamic. Make sure the nose cone is really securely taped to the top of the fuselage so that air doesn't leak out when you launch the rockets.
4. To launch the rocket, place the rocket on the stomp rocket base. Stomp the base and the rocket will fly!
5. Encourage students to try out different designs and practice the engineering design process! For example, will adding fins help the rocket fly? If so, which style of fins work best? Other possible modifications include diameter of nose cones, "pointiness" of nose cones, diameter of rocket, length of rocket, and more!

Figure 7: Sample Paper Rockets, courtesy of Sophie and Nikki

Additional Notes for Mentors

- For advanced sites, you can give incentives for using less materials. Engineers aim to make practical designs that use the least amount of resources.
- It's important to take this activity as an opportunity to **draw a connection** between aerospace engineering and paper rockets. Emphasize to your mentees that they are utilizing the engineering design process exactly like an aerospace engineer would do to build a real-life rocket!

Module 2: Bottle Rockets

Introduction

In this classic BEAM activity, students will apply what they learned about forces, thrust, and Newton's third law as they launch bottle rockets.

Teaching Goals

1. **Force:** any interaction that will change an object's motion, if unopposed.
2. **Newton's Third Law:** For every force, there is an equal and opposite force.
    a. **Thrust:** The "equal and opposite force". Also known as the force associated

with the ejection of mass at a velocity.

3. Other Forces (for advanced sites)
    a. **Gravitational Force:** Also known as weight; the force that attracts any objects with mass.
    b. **Air Drag:** Also known as air resistance and similar to the force of friction; opposes the object's motion in air.

Background for Mentors

All fundamental concepts that applied to paper rockets apply here. When we pump air into the rocket filled with water, we build up pressure within the bottle. When the rocket is released, water flies out and is pushed downward. Refer students back to **Newton's Third Law**. As the water is pushed downward, the rocket is pushed upward and becomes lighter. An important distinction between paper rockets and bottle rockets is that in the case of bottle rockets, the pressurized air within the rocket *continues* to push the water out creating a thrust while the rocket is *in the air*. In contrast, for the paper rockets, the only thrust provided is through introducing pressurized air from the initial stomp of the base on the ground. In this way, bottle rockets have the potential to fly higher and for longer since thrust is continuous (until the water within the rocket runs out.)

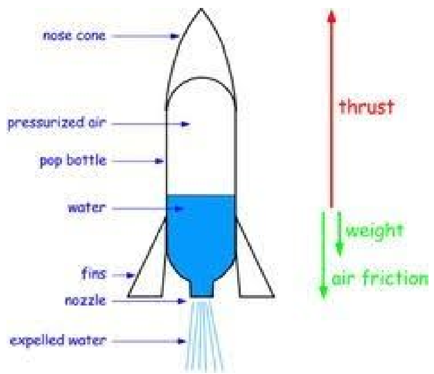

Figure 8: Rocket Force Diagram, *Ohio University.*

Students should hopefully understand the three forces involved in propulsion: thrust, air drag, and gravity. By indicating the magnitude of the forces with the arrows' lengths, it should be easier to introduce the concept of force balances and how they apply to the rocket. In order for the rocket to launch, thrust has to be larger than air drag and the gravitational force.

For more advanced sites, you may go into more detail about the other kinds of forces, specifically:

1. **Gravitational Force:** Also known as weight; the force that attracts any objects with mass.
2. **Air Drag:** Also known as air resistance and similar to the force of friction; opposes the object's motion in air.

So how do we affect these other forces with our rocket design? For the gravitational force, students should hopefully figure out that making the rocket lighter will reduce the pull of gravity. Air drag might be harder for students to understand at first, but if students visualize the rocket having to actually push the air particles away, they might have a better conceptualization of how the shape of the cone affects air drag (the sharper the cone, the lesser the drag).

Materials

These materials are all reusable from site to site.

- 2 Empty Soda Bottles (2-liter size) *per site*
- Bottle Rocket Stand *per site*
- Bike Pump *per site*

Procedure

1. Fill the bottle around halfway full with water.
2. Check that the collar of the base is below the zip tie heads.
3. Invert the base, place the bottle on the tube, and slide the bottle up the tube.
4. Position the zip tie heads so that they wrap all the way around the bottle.
5. Slide the collar over the zip tie heads and the bottle neck. Check that it's secure by pulling down on the bottle.
6. Invert the base so it is upright, and place on the ground. Check that there is no leakage.
7. Have one person ready to pull the string attached to the collar and one person ready to pump. Either/both can be students depending on mentors' choice.
8. Start pumping rapidly.
    a. Attempt to reach past 30-50 psi.
    b. Water will begin leaking rapidly.
    c. Tell students the faster and harder they pump, the higher the rocket will go!
    d. Before launching the rocket, have one mentor place his/her foot on the base to hold it pointing straight up. This is to prevent the rocket from launching sideways and hitting someone.
9. Once enough pressure has built up inside the bottle (at least a third of the water should remain), release the bottle by pulling on the string.
10. See the **link** for helpful pictures and tips

Figure 9: BEAM Bottle Rocket in Action - Cal Day, *Ed Oswald.*

Additional Notes for Mentors

- The bottles will come empty and should be filled up during site. To save time, when you are doing Module 1, have one or two designated mentors fill up the site tub and bottles with water.
- Because the rockets are known to launch ridiculously high, this activity must be done **outside**. Make sure students stand far away from the rocket launch! Set rules prior to launching the rockets and make known that students should stand behind a chosen line on the ground. It is important to keep the students as calm as possible to prevent any possible injury.

Conclusion

As we will see throughout this semester, forces are everywhere! To wrap up the lesson, ask some concluding questions: What is engineering? Who are engineers? What is the engineering design process? What are some important forces in rockets? What is thrust and Newton's Third Law?

References (link)

Summary Materials Table

Material	**Amount per Group**
Tennis/Ping pong balls	2 per site
Balloon	1 per site
3 foot long string/thread	1 per site
4 inch straw	1 per site
Stomp Base	1 per site
Construction Paper	1 piece per student
Index Card/Small piece of cardstock	1 per student
Scissors	5-8 pairs per site
Tape	3-4 rolls per site
2L Soda Bottle	2 per site
Bottle Rocket Base	1 per site
Bike Pump	1 per site