Rockets

Overview

This activity is both a STEM Engineering challenge and a way to gain a basic understanding of the engineering process involved in the National Aeronautics and Space Administration's (NASA's) space program. In this activity, students follow instructions to build a simple rocket fueled by an effervescent tablet and water. This rocket design works, but not well. Students redesign it to go higher, carry a payload, and be less expensive. They do this by adjusting tube size, amount of water, amount of fuel, and balancing this with costs. They are then challenged to build a 'commercial' rocket that reaches a certain height, carrying a payload, at a low enough cost to make a profit. Throughout this guide, all information in italics is a "teacher tip."

North Carolina Essential Science Standards

6.E.1.3 Summarize space exploration and the understandings gained from them.

Background

Rockets move by powerfully expelling material in one direction, causing the rocket to move in the opposite direction. The rocket moves because the force that ejects the material from the rocket also acts upon the rocket. It is as if you are on roller skates at a standstill and throw a ball. The force of your hand on the ball pushes you and makes you move. These are examples of Newton's 3rd Law ("for every action there is an equal and opposite reaction").

In the model rocket in this activity, an effervescent tablet mixes with water in a tube to produce carbon dioxide (CO_2) gas, which builds pressure (force) that pushes against the stopper. Eventually, the stopper and the water in the tube are forced out. The force that pushes out the stopper and water also acts on the rocket tube. The stopper and water shoot down, and the rocket tube shoots up.

Factors that influence how high our models fly include the mass of the rocket and payload, the mass of water and stopper ejected, the pressure buildup inside the tube, and the time it takes for the water and stopper to release. Aerodynamics of the rocket tube, such as streamlining and fins for stability, also influence the flight. In the first part of this exercise, students get a feel for these factors by trial and error. They will learn about the underlying physics in a later course.

Students discover that adjusting the amount of water is critical. Not enough, and not much CO_2 is generated. Too much water, and too much energy goes into heating it instead of pushing out the stopper. Either way, the rocket doesn't go very far. The rocket flies high when just the right amount of water makes plenty of gas, and energy isn't wasted in heating too much water.

Another factor is the volume of air in the tube. Too little air causes pressure to build and release so rapidly that the pressure is gone before the water is out of the tube. With too much air in the tube, not enough pressure can build up. The right amount of air keeps the pressure high enough and keeps pushing long enough to get all of the water out quickly.

When NASA or a private company builds a rocket, engineers and scientists work within the laws of physics and within a budget. Likewise, in the second part of this activity, students try to keep costs low. Their rockets must carry a payload and reach a height of 3 meters, and they track the expenses of fuel, the rocket itself, and the number of launch attempts (more attempts = greater cost). Income is generated by the rocket's payload (more weight carried = more money earned). Like real engineers, students balance a lighter, less lucrative payload that is more likely to succeed versus heavier payloads that may take more trials and still not reach the destination.

Materials

Materials for the whole class

- 3 launch platforms (to prevent rockets from hitting anyone)
- A flat outdoor surface, >10 meters from any obstruction
- Assorted plastic tubes—2 diameters (1" and 1 1/4") and 2 lengths (5", 7")
- Assorted plastic caps matched to tubes
- Assorted rubber stoppers matched to tubes
- Pieces of vinyl tubing (for payload)
- Effervescent tablets
- Water
- 2 scales for weighing materials, fuel, payloads, etc.
- 1 tape measure
- BLM 11 Rocket Challenge to project

Materials for small groups

- 1 graduated cylinder (25 ml)

Materials for individual students

- * 1 pair of safety glasses
- * science notebook.

* supplied by the teacher

Preparation

1. Find an open area outdoors, flat and clear of obstructions for 10 meters on every side, for launch sites. Athletic fields or empty parking lots work well. Observers should stand 3-4 meters from the launch.
2. Set up several launching platforms far enough apart so that students won't be in each others' way and safety won't be compromised.
3. For Part 2, mark a line 3 meters from the ground on a wall or post that students can refer to for meeting the height challenge. A standard basketball hoop works (only about 3 inches higher than 3 meters).

Procedure for Part 1

In teaching this activity, keep specific instructions to a minimum. Simply demonstrate a launch slowly enough for observant students to get a feel for the process, then let them discover details on their own. For example, let them find out that they need to seat the stopper firmly. If a student has difficulty, give only small hints. Let students do all manipulations themselves without the teacher touching their rockets. Emphasize that when they design for their challenge, they will need thorough notebook records of their trials that include all variables.

1. Explain safety procedures:
    - Students must wear safety glasses.
    - Rockets must have their protective caps in place.
    - Launches may only be made one at a time from the designated launching platforms.
    - Observers must stand 3-4 meters from the launching platforms.
2. Demonstrate a rocket launch.
    - Put a protective cap over the closed end of a tube (plastic cap shown below)
    - Add 5 ml of water to the tube.
    - Hold the tube at an angle as shown in the left side of Figure 1 and insert half an effervescent tablet just inside the mouth so that it doesn't touch the water.

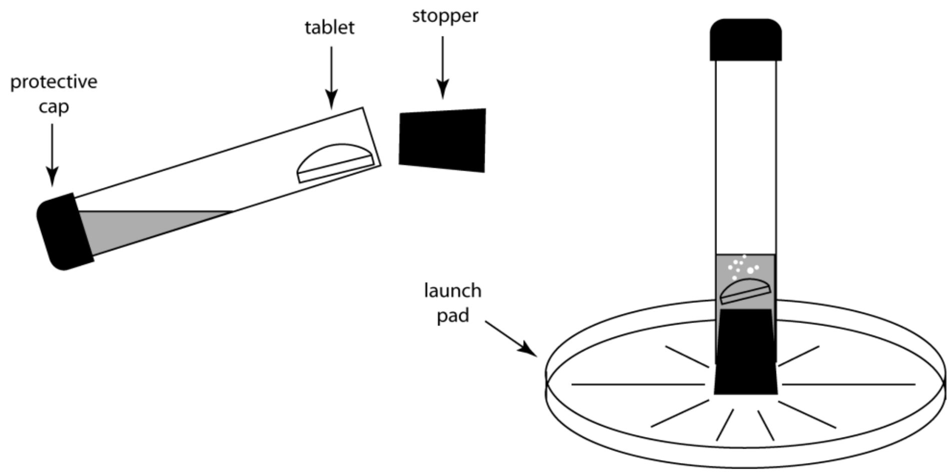

Figure 1.

    - Insert the stopper tightly without pushing the tablet into the water.
    - Turn the whole assembly stopper-side down and quickly stand it up on the launch pad as in the right side of Figure 1.
    - Stand back and watch the rocket take off.
3. Tell students that this class period, they are getting ready for a challenge they will get *next* class period. Project the student sheet at the end of this activity to show what that challenge will be: to design a rocket to carry a payload up 3 meters. This will be a commercial venture to make a profit. Materials, fuel, and launch

fees have specific costs, and rockets earn money from their payloads – the more weight they carry, the more they earn, if they reach 3 meters.

4. Make materials available to student groups. Consider limiting the number of tablets at first (half a tablet is more than enough for a trial), but tubes, caps and stoppers can be set out for groups to choose from.
5. Show the different tubes and ask what variables they might experiment with to prepare for the challenge. Write a class list of variables and project this for all to see. Include, at a minimum, different diameters and lengths of tubes, different amounts of water, and different amounts of effervescent tablets.
6. Allow the rest of this class period to test-launch rockets. After students complete a few test launches, make the 'standard payload' pieces of vinyl tubing available. Students learn important lessons from adjusting designs to carry extra weight.
7. Allow time at the end of class for cleanup and to present the challenge for the next class period. Give out copies of the challenge (handout at the end of this lesson) so that students can think about it overnight.

Procedure for Part 2

1. Start with a short discussion of what worked and what caused problems with the rockets.
2. Present the challenge: "Design a rocket that will carry a payload to a minimum of 3 meters. Since this is a commercial enterprise, you will want to make a profit. You will have to pay for materials, fuel, and launch fees. You will earn money from your clients for your payload if you are successful."

   Here is a list of materials costs:

Expenses	
Rocket body (one-time fee unless changes are made for later launches; includes fins, nosecone, etc.)	$ 3,500,000.00
Protective cap (one-time fee unless changes are made for later launches)	$ 50,000.00
Stopper (one-time fee unless changes are made for later launches)	$ 100,000.00
Water (per milliliter)	$ 1,000.00
Effervescent tablets (per gram)	$ 20,000.00
Launch fee (per launch)	$ 250,000.00

   And here's how much your customers are willing to pay for your services:

Income	
Service charge (one-time fee for first launch only)	$ 3,000,000.00
Payload (per gram)	$ 400,000.00

The price structure has been set so that most students will make a small profit if they take a conservative approach—modest use of fuel, modest payload, etc. Here is a sample profit/loss statement for one launch:

Item	Unit Price	# of Units for 1 Launch	Cost
Expenses			
Rocket body (one-time fee)	$ 3,500,000.00	1	$ 3,500,000.00
Protective cap (one-time fee)	$ 50,000.00	1	$ 50,000.00
Stopper (one-time fee)	$ 100,000.00	1	$ 100,000.00
Water (per milliliter)	$ 1,000.00	5	$ 5,000.00
Effervescent tablets (per gram)	$ 20,000.00	1.5	$ 30,000.00
Launch fee (per launch)	$ 250,000.00	1	$ 250,000.00
Total cost			**$ 3,935,000.00**
Income			
Service charge (one-time fee)	$ 3,000,000.00	1	$ 3,000,000.00
Payload (per gram)	$ 400,000.00	3.5	$ 1,400,000.00
Total income			**$ 4,400,000.00**
Profit (or loss)			**$ 465,000.00**

If students are not successful on their first attempt, they can still make a small profit after a second identical launch. In this case, they only have to pay for the additional fuel and a second launch fee. All other costs and incomes are the same.

Item	Unit Price	# of Units for 2 Identical Launches	Cost
Expenses			
Rocket body (one-time fee)	$ 3,500,000.00	1	$ 3,500,000.00
Protective cap (one-time fee)	$ 50,000.00	1	$ 50,000.00
Stopper (one-time fee)	$ 100,000.00	1	$ 100,000.00
Water (per milliliter)	$ 1,000.00	10	$ 10,000.00
Effervescent tablets (per gram)	$ 20,000.00	3	$ 60,000.00
Launch fee (per launch)	$ 250,000.00	2	$ 500,000.00
Total cost			**$ 4,220,000.00**
Income			
Service charge (one-time fee)	$ 3,000,000.00	1	$ 3,000,000.00
Payload (per gram)	$ 400,000.00	3.5	$ 1,400,000.00
Total income			**$ 4,400,000.00**
Profit (or loss)			**$ 180,000.00**

Students can make more profit if they are willing to risk taking on a larger payload. This might take more launch attempts (greater expense), but eventually reap larger profits.

Before launch, students should design and present a profit/loss statement like the ones above. They will need to weigh their tablets and payloads and measure the amount of water they will use with a graduated cylinder. The balance sheets could be kept in their science notebooks along with any records of observations they make during the trials.

Reflection/Discussion

- What are the main factors that seemed to influence how high your rocket flew?
- What construction 'flaws' caused problems? *[Examples might include: The stopper was too loose. The stopper was not put in straight and the rocket fell over. Too much water. Not enough fuel. The position of the payload on the rocket body (better at the bottom, unstable at the top).]*

Assessment

After the challenge attempts are completed, students should turn in a final report that includes a sketch of their rocket, their profit/loss statement(s), the amount of profit (or loss), and an explanation of their success or failure.

BLM 11

Rocket Challenge

Design a rocket that will carry a payload to a minimum of 3 meters. Since this is a commercial enterprise, you will want to make a profit. You will have to pay for materials, fuel, and launch fees. You will earn money from your clients for your payload if you are successful.

Here is a list of materials costs:

Expenses	
Rocket body (one-time fee unless changes are made for later launches; includes fins, nosecone, etc.)	$ 3,500,000.00
Protective cap (one-time fee unless changes are made for later launches)	$ 50,000.00
Stopper (one-time fee unless changes are made for later launches)	$ 100,000.00
Water (per milliliter)	$ 1,000.00
Effervescent tablets (per gram)	$ 20,000.00
Launch fee (per launch)	$ 250,000.00

And here's how much your customers are willing to pay for your services:

Income	
Service charge (one-time fee for first launch only)	$ 3,000,000.00
Payload (per gram)	$ 400,000.00