ECOS
Ecologists Educators and Schools: Partners in GK-12 Education

ECOS Inquiry Template

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2. NAME OF INQUIRY: Water Bottle Rockets: an Exploration of Newtonian Physics

3. GOALS AND OBJECTIVES:
   a. Inquiry Questions:
      1. What water to air ratio is needed to achieve maximum height?
      2. How do Newton's laws of motion explain and influence a rocket's flight?
      3. What forces keep a rocket from reaching maximum height?
      4. How are rockets designed to overcome these limitations?
   b. Ecological Themes:
      1. How do laws of physics apply to the field of ecology?
      2. Are there fundamental laws of ecology?
      3. Why or why not?
   c. General Goals:
      1. Introduce Newtonian physics.
      2. Discuss how Newtonian physics influences rocket flight.
      3. Discuss how rockets are engineered to overcome forces acting upon them.
   d. Specific Objectives:
      - Academic: Students are encouraged to develop their own experiments in order to determine the correct water to air ratio that will enable their rocket to achieve maximum height.
      - Procedural/technical: Students learn how to collect data and form experiments (hypotheses) based on observations.
      - Social: Students work in teams to set up and test their hypotheses.
      - Communication: Students present their data in graph or descriptive form.
   e. Grade Level: 5th-12th
   f. Duration/Time Required:
      - **Prep time:** 4-5 hours to collect the necessary materials and build the rocket launcher.
      - **Implementing Exercise During Class**: 20-30 minutes lecture in class. 1 hour for students to determine water-to-air ratio. 1 hour to design and build best rocket possible. 1 hour to test designs.
      - **Assessment:** 30 minutes for students to present data.
4. ECOLOGICAL AND SCIENCE CONTEXT:
   a. Background (for Teachers):

Isaac Newton was born on December 25, 1642 in Woolsthorpe, near Grantham in Lincolnshire, England. He was born the same year Galileo died. Newton is clearly the most influential scientist who ever lived. His accomplishments in mathematics, optics, and physics laid the foundations for modern science and revolutionized the world. As a mathematician, Newton invented integral calculus. He defined the laws of motion and universal gravitation which he used to precisely predict the motions of stars and the orbits of planets around the sun. Using his discoveries in optics Newton constructed the first reflecting telescope. Newton died in London on March 20, 1727 and was buried in Westminster

Abbey, the first scientist to be accorded this honor. A review of an encyclopedia of science will reveal at least two to three times more references to Newton than any other individual scientist.

Newton's Laws of Motion - Important factors for rocket science
Newton's First Law

- An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

The principle behind this law is quite simple: if an object is moving along a path at a certain speed it will continue along this path until another force acts upon it. Example: a car traveling along the highway is acted upon by two forces - friction (air and pavement) and gravity. The car's engine generates a force which overcomes these limitations. In the case of our investigation the rocket is at rest when it is on the launch pad, and when the trigger is pulled the rocket is propelled skyward. However, several forces are acting upon it, including gravity and friction.

Newton's Second Law

- Force = mass x acceleration

This law explains how an object will change velocity if it is acted on by a force. Velocity is directly proportional to the force applied. If twice as much force is applied to an object is will travel twice as far. Also velocity is inversely proportional to mass. This means that the more an object weighs the more force is necessary to accelerate the object. Using our water rocket as an example the force needed to move the rocket off the launch pad is generated by pumping air into the rocket. The more air packed into the rocket the higher it will fly. Remember that the heavier an object is the more force required to generate velocity. The more water that is added to the rocket the heavier it is, and the more force that is needed to propel it forward.

Newton's Third Law

- For every action (force) there is an equal and opposite reaction (force).

This statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The magnitude of the force acting on the first object equals the magnitude of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. When our rocket leaves the launch pad all of the air (force) that was pushed into the rocket hurls out of the nozzle - this force propels our rocket upward.

Designing the rocket

Determining the best water to air ratio needed to achieve maximum flight height for our rocket resembles the classic give and take situation. The less water placed into the rocket the lighter the rocket and the more air that can be applied (i.e. force). However, the water hurtling out of the nozzle provides the pulse that accelerates the rocket upward. If more water is applied to the rocket it is heavier, and contains less air…yet there will be more force generated when the rocket is launched. Will this force be enough to propel the rocket to greater heights?? Based on the data that we collected (see graph) some water is necessary in order to achieve maximum height (approximately 100 ml in a 20 oz pop bottle).

Measuring Altitude
The easiest method for determining the rocket's altitude is to use the AltiTrak (see picture) range finder, manufactured by Estes Rockets. This is a fairly inexpensive ($10-$15) method for determining the rocket's altitude. This device can be found in most hobby shops or online at www.estesrockets.com.

Physics and Ecology??
What is the connection between physics and ecology, beyond the obvious fact that both disciplines seek to explain and describe natural phenomena? Physics is based on natural laws and principles including Einstein's Theory of General Relativity, law of conservation of energy and momentum, law of gravitation, laws of thermodynamics, and Newton's laws of motion (see http://www.glenbrook.k12.il.us/gbssci/phys/Class/BBoard.html or http://www.physicsclassroom.com/). These physical laws are theories which have been widely published and tested, and are considered by the scientific community to be generally valid. These laws are empirical, meaning that they are based on observed behavior.

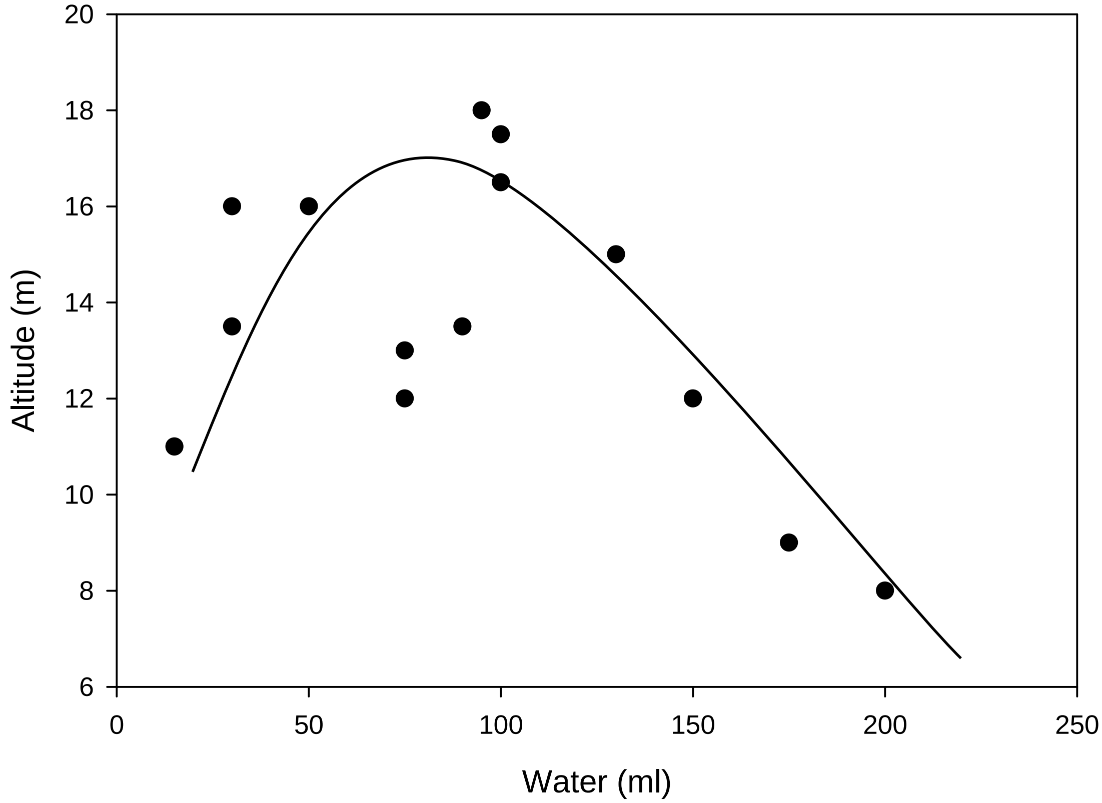
Recently scientists have begun to debate whether there are similar laws in biology and ecology (Colyvan and Ginzburg, 2003). This debate is central in ecology, because if such fundamental ecological rules exist it means that they can be used to express important relationships that are applicable to a wide set of real-world situations. A number of laws have been proposed within the field of population ecology, a branch of ecological science that studies populations of animals and plants. These include Malthusian Law, Allee's Law, Lotka-Volterra's Law, and others (see http://www.ecology.info/laws-population-ecology.htm).

The current inquiry does not explore these proposed laws of population ecology, but rather explores the characteristics of natural laws through an experiment based on Newton's three laws of motion. After completing the water rocket experiment, teachers may discuss with their students whether the same kinds of natural laws or governing principles that describe the behavior of water rockets can also be used to describe the behavior of living organisms. Why or why not?

b. Background (to present to Students):
Pre-investigation discussion
The instructor can introduce the ideas behind Newtonian physics. The easiest way to approach this is by explaining each law and providing a real-world example (see http://physics.webplasma.com/physics01.html). The instructor then asks his/her students to provide their own examples. After all three laws have been thoroughly explored the teacher can then apply these ideas to the water rocket inquiry. For the design section of the inquiry we found it helpful to discuss the components of a rocket and the purposes they serve. This was quite useful when the students began designing their own rockets.

Post-experiment discussion

After the investigation(s) have been completed the instructor can ask the students to explain how Newton’s laws of motion influence the flight of the rocket. The students should see that the air pumped into the rocket acted as the force propelling in upward. They should also understand that the rockets filled with larger amounts of water do not fly as high as those containing less water, due to Newton’s second and third laws.



5. MOTIVATION AND INCENTIVE FOR LEARNING: This is a fun hands-on activity that will enable the students to make observations and apply the scientific process. The students are allowed to develop hypotheses and test their ideas. They are then able to reshape their hypotheses based on the data they gather.

6. VOCABULARY:

- Gravity: 1) a force that pushes objects towards the earth. 2) a force that operates between all objects in the universe. It is **mutually attractive** which means that both objects attract each other 3) the force that holds us on Earth and keeps the Earth and the planets orbiting the Sun. Everything on Earth is pulled down to the Earth's surface by gravity, and this pull gives objects their weight.

- Friction: 1) a force that resists the motion of an object. Friction results from the close interaction between two surfaces that are sliding across each other. 2) In physics, friction is the resistive force that occurs when two surfaces travel along each other when forced together. It causes physical deformation and heat buildup.

- Force: 1) In physics, a force acting on a body is that which causes the body to accelerate; that is, to change its velocity. 2) The amount of energy that can change the state of rest or motion in matter.

- Acceleration: The rate of change in velocity with respect to time. A moving body can accelerate by changing speed or by changing direction.

- Altitude: the height of an object from a known point or sea level

- Altimeter: An instrument that indicates the altitude of an object above a fixed level.

- Nozzle: An exhaust duct for an engine. The air that has passed through the engine passes through the exhaust duct and produces the thrust or forward motion of the engine.

7. SAFETY INFORMATION:

1. Water Bottle (rocket) is placed under extreme pressure before launching; the bottle should not contain any cracks or abrasions that could cause the bottle to rupture.
2. Safety glasses should be worn by the launch crew as the rocket is under pressure and could rupture.
3. The nozzle of the rocket is made of cast aluminum; this makes the rocket bottom heavy. Since there is no recovery system on the rocket it will plummet back to earth much like a “lawn dart”. Everyone observing the launch should pay close attention to the position of the rocket in flight.
4. Hot gluing fins onto the rocket works well; however. the bottle needs to be filled with cold water in order to prevent the glue from melting the plastic.

8. MATERIALS LIST (including any handouts or transparency masters):

Materials needed to construct rocket launcher and base

Description	**Quantity**	**Cost**
7’ PVC pipe 1” diameter		**$3.00 ($0.50/foot)**
1” slip to fit PVC tees	**3**	**$1.50**
Brass ¼”female air coupler	**1**	**6.99**
Brass nipple 3”	**1**	**$1.50**
Plastic tubing 3’		**$1.20**
Schrader air valve	**1**	**$3.00**
Radiator clamps	**3**	**$3.00**
Tent stakes	**4**	**$4.00**
¼” flex tubing 2’		**$1.50**
¼” PVC slip to fit elbow	**1**	**$0.50**
Total		**$26.19**

Prices for materials listed were collected from Ace Hardware. Where necessary pictures of materials have been provided.

Materials needed to construct nozzle

Description	**Quantity**	**Cost**

¼” male plug	**1**	**$1.20**
Flat washer	**1**	**$0.08**
¼” coarse nut	**1**	**$0.75**

Prices for materials listed were collected from Ace Hardware. Where necessary pictures of materials have been provided.

Materials needed for inquiry

1. 20 oz pop bottles
2. Measuring tape
3. Bicycle pump with gauge
4. Altimeter
5. Hot glue gun and glue
6. Safety goggles
7. Graduated cylinder

9. METHODS/PROCEDURE FOR STUDENTS:

a. Pre-investigation work: The purpose of this inquiry is to introduce students to the basic concepts of Newtonian physics. The students are able to observe how mass, friction and gravity influence a rocket’s flight. Students should have a working knowledge of these concepts before beginning the experiment. The instructor can lead discussions related to Newtonian physics, effects of rocket design on flight success, and hypothesis testing.

b. Investigation work: Students can work in small groups of 2-3 individuals - larger groups tend to isolate some members from the design process. For the first part of the investigation students are given an ordinary plastic 20 oz pop bottle which serves as their “test rocket.” The goal of this part of the inquiry is to determine the correct water to air ratio needed to achieve maximum flight height of the rocket. Students are asked to form a hypothesis based on this idea (i.e. Hypothesis 1: the rocket will require 200 ml of water to achieve maximum height). Students fill their test rockets with the specified amount of water. Students then launch their rockets and record the maximum flight height achieved. Students next refine their original hypothesis by adding water to or removing water from the rocket body, and repeating the flight. During the second part of the investigation students design their own rockets by adding nose cones and fins in order to reduce air friction and increase stabilization. After designing the “perfect” rocket students then fill their rockets with a volume of water that will provide enough boost to achieve maximum height (determined from the first part of the investigation).

10. ASSESSMENT:

During the first part of the investigation students are asked to form a hypothesis aimed at determining the best water to air ratio required to propel their rocket to maximum altitude. After each test launch the students refine their original hypothesis based on their observational data. After several launches the students are asked to justify each hypothesis. Hopefully the students will begin to see that both air and water are needed to propel the rocket, but that the proportion of each influences the maximum flight altitude of their rockets. Furthermore, we found it useful to list all of the data collected by the teams, and ask each team to graph the data via scatter plot. This method of analysis greatly enhances the students’ ability to determine the correct water to air ratio.

The second part of the investigation requires the students to design a rocket that will reach greatest altitude based on principles of aerodynamics. Before their maiden launch each team should explain why they selected that particular design.

11. EXTENSION IDEAS:

There are several potential investigations that could easily spin off from this general idea:

- Is there a liquid that is lighter then water that could be used to propel the rocket?
- Will a 2-liter bottle fly higher then ½ liter bottle?
- What adaptations in the natural world mimic these Newtonian principles (ex. Dehiscent seed dispersal in poppies).
- Students can design a recovery system such as a parachute.

12. SCALABILITY

The sky is the limit with this inquiry (no pun intended!).

- Advanced students can use trigonometry to determine the height of the rocket.
- Linear regression analysis can be used to construct a model to predict rocket flight based on theorized water to air ratios.

13. REFERENCES:

1. Colyvan M, Ginzburg LR (2003) Laws of nature and laws of ecology Oikos 101: 649-653
2. Newton's Laws of Motion
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3. Water bottle rocket information
    - dogrocket.home.mindspring.com/WaterRockets/
    - www.emints.org/ethemes/resources/S00001346.shtml
    - home.nc.rr.com/enloephysics/enloephysics/Rocket/Page_1x.html
    - millard.esu3.org/.../ How%20to/howrocketsfly.htm

14. LIST OF EXPERTS AND CONSULTANTS

1. Engineer
2. Physicist
3. Mathematician/Statistician

15. EVALUATION/REFLECTION BY FELLOWS AND TEACHERS OF HOW IT WENT:

This investigation went very well. The students were very proficient at figuring out the correct water to air ratio. Graphing the results seemed to further solidify the students understanding of Newton's first and second law. During our discussion time the students were ably to effectively discuss how each of Newton's laws applied to the flight of their rocket. Furthermore, the design phase of the investigation brought out quite the creative nature of our students.

16. Pictures

Source: dogrocket.home.mindspring.com/.../ coupling.html

Source: www.class4a.com/teaching

Source: thehowzone.com/how/Water_Rockets/6

Water Bottle Rocket Experiment (1 and 2

Objective Experiment 1

1. Introduction to Newtonian Physics.
2. Gain an understanding of rocket flight.
3. Develop you own experiment.

Materials

1. Soda bottle
2. Pencil
3. Imagination

Treatments

1. You decide how much water your rocket needs in order to achieve max flight.

Methods

1. Label your bottle with your team name.
2. As a team decide how much water you needed to achieve max height. This is your original hypothesis! Your bottle holds 600 ml of water.
3. Fill your bottle with water.
4. Launch bottle.
5. Record Height.
6. Rethink original hypothesis??
7. Perform a second test launch??

Amount of Water Added (ml)	Height achieved (m)

Hints

1. When determining how much water to add remember water adds mass to the rocket.
2. Good scientist is observant; watch the launches of the other teams.
3. The distance we are giving you is in meters, if you what to know the distance in feet you need to multiply that number by 3.33

Objective Experiment 2

1. Design a rocket that will achieve maximum height with the water air ratio determined from experiment 1.

Materials

1. Soda bottle
2. Imagination
3. Team work

Treatments

1. You decide how to build a rocket that will fly really high.

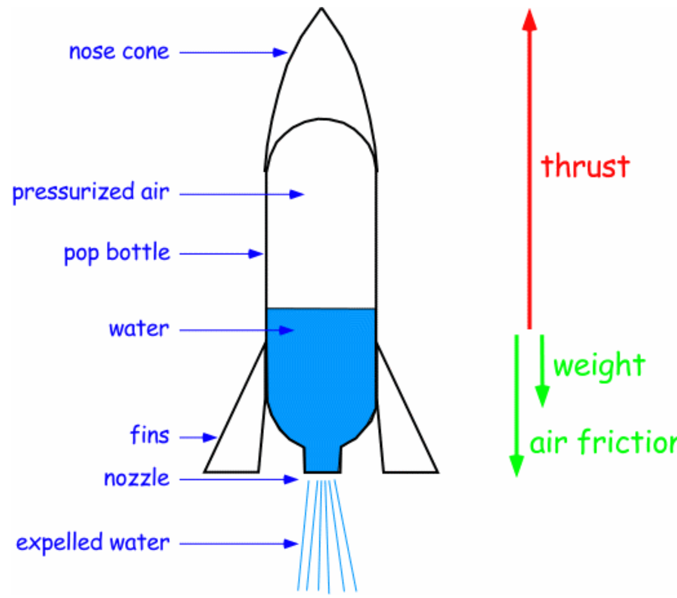

Diagram of what a rocket needs in order to fly.

Methods

1. Decide as a how to build your rocket as a team.
2. Build rocket and be able to justify your design decisions.
3. Decide how much water you are going to use.
4. Launch rocket record data.

Results

1. How much water did you use in your rocket ________.
2. How high did you rocket travel

Hints

1. If you are going to glue fins on your rocket with hot glue make sure to fill the bottle with cold water.
2. Rockets that fly high are light.