Newton's Third Law: Actions and Reactions

Duration:
1-2 class periods

Essential Question:

How do the actions and the reactions in a moving system relate to forces and acceleration?

Objectives: Students will...

- see and experiment with a system that moves due to equal and opposite actions and reactions.
- see that a force is necessary to start something moving when it is at rest, or to change its speed or direction.

Science Concept:

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction.

About this Poster

The Swift Gamma-Ray Burst Explorer is a NASA mission which is observing the highest energy explosions in the Universe: gamma-ray bursts (GRBs). Launched in November, 2004, Swift is detecting and observing hundreds of these explosions, vastly increasing scientists' knowledge of these enigmatic events. Education and public outreach (E/PO) is also one of the goals of the mission. The NASA E/PO Group at Sonoma State University develops classroom activities inspired by the science and technology of the Swift mission, which are aligned with the national standards. The front of the poster illustrates Newton's Third Law, and descriptions of the drawings can be found on the next page. This poster and activity are part of a set of four educational wall sheets which are aimed at grades 6-9, and which can be displayed as a set or separately in the classroom.

The activity p. 4 provides an engaging experiment which illustrates Newton's Third Law. The activity is complete and ready to use in your classroom; the only extra materials you need are listed on p. 3. The activity is designed and laid out so that you can easily make copies of the student worksheet and the other handouts.

The NASA E/PO Group at Sonoma State University:

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The Swift Education and Public Outreach website:
http://swift.sonoma.edu.

This poster and other Swift educational materials can be found at:
http://swift.sonoma.edu/education/

National Science Education Standards and Mathematics Standards for the set of four Newton's Law wallsheets can be found at:
http://swift.sonoma.edu/education/newton/standards.html

Description of the Front of the Poster:

Rocket: A rocket works by propelling mass out the back end at high velocity. The action of the mass of the burning fuel accelerating out the back end applies an opposite reaction force to the rocket, moving it forward. The rocket is not simply pushing against the ground; this works even in the vacuum of space.

Trucker and ramp: When the man pushes the heavy box up the ramp, he applies a force to the box, and the box reacts by pushing back. If the man pushes hard enough, he can overcome gravity and friction, accelerating the box up the ramp.

Shopper: The woman pushing a shopping cart feels an opposite force applied by the cart on her.

Baseball player: When the baseball player hits the ball with her bat, the ball reacts by pushing back on her. The player feels this as a jerk backwards when the bat contacts the ball.

Fish: Fish propel themselves forward by pushing water back, behind them. The water reacts by pushing the fish in the opposite direction, forward.

Hand pulling rope attached to weight: When the hand pulls the rope attached to the weight, it applies a force to the weight, and the weight reacts by applying a force in the opposite direction. The hand feels a resistance.

Bridge: Suspension bridges are all about actions and reactions. The main cables push the support poles down, and the poles react by pushing back with an equal but opposite force. Cables hanging down from the main cables pull up the main cables down, which react by pulling back on the vertical cables. The roadway hangs from the vertical cables, pulling them down, and the vertical cables react by holding the roadway up.

Soccer player: When the boy runs up to the ball and kicks it, he applies a force to the ball, moving it forward. The ball reacts by pushing back against the boy, which he feels as pressure on his foot when he kicks the ball.

Hammer and nail: The hammer hitting the nail applies a large force to it. The nail reacts by pushing back against the hammer. The carpenter feels this as a jolt backwards against his hand.

Background Information for Teachers:

Newton's First Law of Motion explains the Law of Inertia, which predicts the behavior of objects when all forces acting on them are balanced. Newton's Second Law of Motion describes quantitatively how unbalanced forces affect motion, and addresses the nature of forces experienced by two interacting objects.

Our daily experiences might lead us to think that forces are always applied by one object on another; for example, a horse pulls a buggy, a person pushes a grocery cart, or a magnet attracts a nail. It took Sir Isaac Newton to realize that things are not so simple, not so one-sided. True, if a hammer strikes a nail, the hammer exerts a force on the nail (thereby driving it into a board). Yet, the nail must also exert a force on the hammer since the hammer's state of motion is changed and, according to the First Law, this requires a net (outside) force. This is the essence of Newton's Third Law: ***For every action there is an equal and opposite reaction***. However, it is important to understand that the action and the reaction are acting on different objects.

Try this: Press the side of your hand against the edge of a table. Notice how your hand becomes distorted. Clearly, a force is being exerted on it. You can see the edge of the desk pressing into your hand and feel the desk exerting a force on your hand. Now press harder. The harder you press, the harder the desk pushes back on your hand. Remember this important point: You can only feel the forces being exerted on you, not the forces you exert on something else. So, it is the force the desk is exerting on you that you see and feel in your hand.

Pre-Activity Reading:
Newton's Third Law and the Swift Satellite

In our previous Newton's Law posters, we examined what happened when Swift was launched in the rocket, and we studied the forces acting on it as it went into orbit. However, recall that when Swift is inside the rocket, the rocket is burning fuel. The burnt fuel is expelled out of the base of the rocket in a stream of exhaust. As the exhaust exits the rocket, it acts on the rocket to propel the rocket upwards through the atmosphere. In other words, there is an upwards force on the rocket from the exhaust stream. There is an equal and oppositely directed force on the exhaust stream from the rocket – the rocket pushes the exhaust stream down with the same force as the exhaust stream pushes the rocket up.

Swift's scientific goal is to detect gamma-ray bursts – brief explosions of high-energy radiation that occur at random locations in the sky at unpredictable times. In order to do this, it has one detector, the Burst Alert Telescope (or BAT) that views about 1/10 of the sky at all times. When the BAT detects a gamma-ray burst, Swift turns and points to the burst very quickly so that two other on-board telescopes - the Ultraviolet-Optical Telescope (UVOT) and the X-ray Telescope (XRT) - can also study the burst. If Swift can turn very quickly and the burst is long enough, all three telescopes can study the burst simultaneously, providing information about the burst at many different wavelengths of light. It is therefore important for Swift to be able to rotate very quickly to point at a burst, and then stop rotating rapidly as well. This is called "slewing." In order to start and stop slewing, Swift uses a set of small wheels (called reaction wheels or flywheels) inside the satellite. Spinning up (or down) the wheels is accomplished by energizing (or de-energizing) a motor that turns the wheel.

To begin slewing, the satellite spins up one of the wheels causing the wheel to rotate in one direction; the reaction force causes the satellite to rotate in the other direction. Once Swift is pointing in the right direction, it spins down the wheel, causing its rotation to slow. This brings the satellite to a stop. By spinning three pairs of wheels in different directions, the satellite can quickly turn and point in any direction. For more information on how Swift slews, see *http://heasarc.nasa.gov/docs/swift/swiftfaq.html#slew*

Newton's Third Law of Motion applies to both of the above scenarios. Both the rocket accelerating away from Earth and Swift quickly slewing in orbit are good examples of equal and opposite actions and reactions. In the classroom activity, students will build a simple balloon rocket that behaves similarly to the rocket carrying Swift into orbit. They will then analyze the rocket's motion to learn about actions, reactions and forces.

Pre-Activity Discussion:

It may be helpful to point to the poster while asking your students if they can explain the action and reaction forces present in the following items pictured on the front of the poster:

a) The dolphins swimming in the water

b) The rocket flying up through the air

c) The woman pushing the shopping cart

d) The hammer hitting the nail

Materials:
- balloons (one for each team)
- plastic straws (one for each team)
- tape (cellophane or masking)
- fishing line, 10 meters in length
- a stopwatch
- a measuring tape

Optional: Students can read the information in the above link that describes how momentum wheels work. Many satellites use momentum wheels to change direction. Why is Swift able to do this more "swiftly" than other satellites?

Answers to Pre-Activity Discussion:

a) The dolphins swimming in the water
As the dolphins swim through the water, they act on the water, pushing it aside and backwards. The water exerts an equal and opposite reaction on the dolphins, propelling them forward.

b) The rocket flying up through the air
As the rocket flies up through space, exhaust exits from the back of the rocket. The exhaust acts on the rocket pushing it upwards. The rocket has an equal and opposite action on the exhaust, expelling it downwards.

c) The woman pushing the shopping cart
The woman acts on the shopping cart, propelling it forward. The shopping cart acts on the woman's hands, pushing back on her hands with a reaction that she can feel. However, while she feels a force pushing her backwards the woman does not actually move backwards, since she can overcome that force with her feet and legs.

d) The hammer hitting the nail
The hammer acts on the nail, driving it into the wood. The nail acts on the hammer, pushing back on the head of the hammer with a reaction that can be felt by the hand holding the hammer. However, typically the hammer is much more massive and is not pushed back very far by the nail. The reaction force is also felt by the hand holding the hammer. As the nail is driven into the wood, the nail acts on the wood, but the reaction force of the wood on the nail is unbalanced, allowing the nail to accelerate into the wood.

Optional: Most satellites have only 4 momentum wheels, and Swift has 6.

Procedure for In-Class Activity : A Day at the Races

Students should be divided into groups of five: a timekeeper, one to hold the fishing line taut, one to blow up the balloon and hold it shut with his or her fingers, one to tape the balloon onto the straw, and one to yell stop when the rocket reaches the finish line. Several trials will be required, and the results will be averaged.

You may wish to use the "explain" questions on the student handout as the basis for class discussion, rather than have the individuals or teams write answers on the worksheet. Optional discussion questions are included in both the classroom activity and post-activity discussion for more advanced students.

Answers to In-Class Activity Questions:

1) The tension of the balloon material, as well as the air outside of the balloon, push on the air inside the balloon, causing it to come out of the balloon. The air coming out of the balloon creates an equal and opposite reaction on the straw rocket sending it forward.

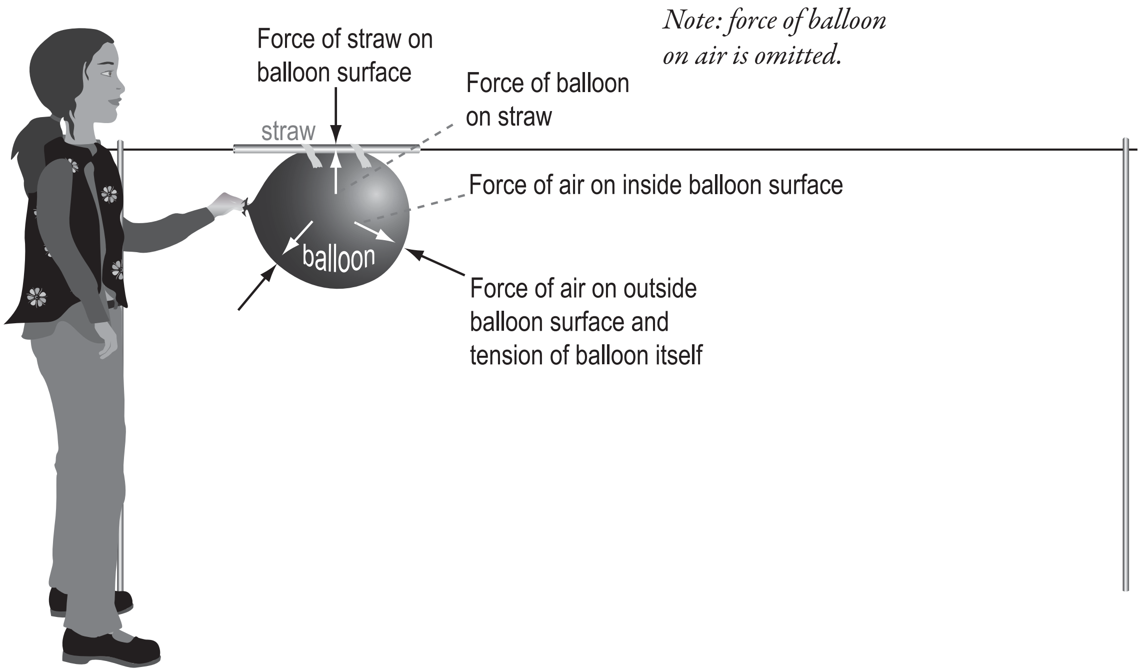
2) The balloon and outside air exert a force on the air inside the balloon, forcing it to exit out the back. The exiting air exerts an opposite force on the balloon rocket, accelerating it forward.

A common misconception is that the forward movement is due to the air inside the balloon rushing out the rear of the balloon and pushing on the outside air. However, this experiment would work even in the vacuum of space! It is the action of the air moving backward that causes the reaction of the balloon moving forward. This is why rockets work even outside the Earth's atmosphere.

3) *Optional for advanced students* - see the following example:

Picture of the balloon forces before release.

List of forces showing action and reaction



Picture of the balloon forces after release.

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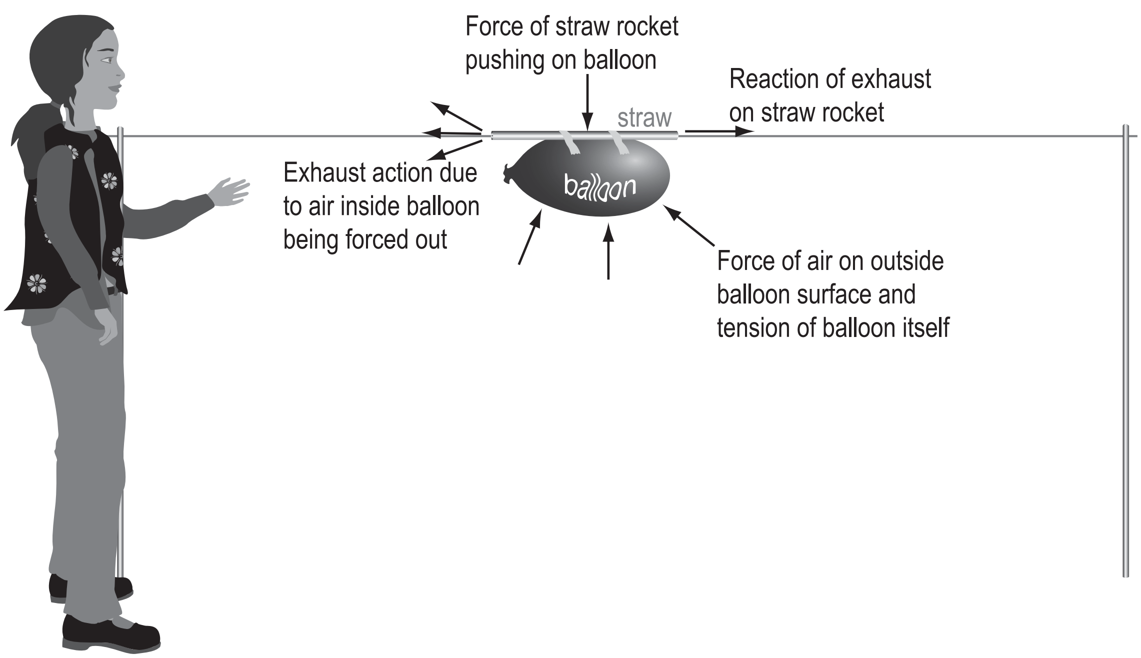

Post-activity Discussion:

Remember, Newton's Third Law of Motion says that whenever one object exerts a force on another object, the second object exerts an equal and opposite force on the first object. However, note that the two forces do not act on the same object.

Were the forces acting on the rocket equal and opposite? Why or why not?

Optional (for advanced students): Compare and contrast this "rocket" to the one that launched Swift into orbit.

Answers to Post-Activity Discussion:

No, the forces were not equal and opposite. If they were, then by Newton's Second Law, there would be no net force on the rocket and it would not accelerate. Note that when one considers forces, the forces are all acting on the same object. When one considers actions and reactions, the actions are on one object, while the reactions are on a different object.

Optional: Swift's rocket launched vertically, and was affected by the force of gravity. It is obviously much larger and heavier, and carried fuel that burned to create the exhaust. In both cases, the exhaust exiting the back of the rocket provided the action that pushed the rocket forward.

Assessment:

Points	A Day at the Races
4	A) Team is able to correctly construct and operate the rocket balloon. B) Individual student is able to provide a correct and thoughtful analysis of why the rocket moved. C) Individual student can correctly identify how Newton's third law is illustrated by this experiment. D) Student is able to explain the difference between forces and actions/reactions.
3	Student is part of a team that achieves objective A and can also correctly answer B) and C) above.
2	Student is part of a team that achieves objective A and can also describe the actions and reactions that made the rocket move.
1	Student is part of a team that achieves objective A above.
0	Student achieves none of the objectives above.

Student Handout:

Newton's Third Law: Actions and Reactions

Name: ________________________

Date: ______________

Period: ________

In this activity, you will learn about Newton's Third Law of Motion: how do the actions and reactions in a moving system relate to forces and acceleration?

In this experiment you will create a balloon and straw rocket! You will figure out how to shoot the balloon from the back of your classroom and hit the blackboard with it at the front of the room. You will do this using a fishing line as a track for the balloon to follow.

Procedure: A Day at the Races

This is a race. The race will be timed and a winner determined.

1. Divide into groups of at least five students.

2. Attach one end of the fishing line to the blackboard with tape. Have one teammate hold the other end of the fishing line so that it is taut and roughly horizontal. The line must be held steady and may not be moved up or down during the experiment.

3. Have one teammate blow up a balloon and hold it shut with his or her fingers. Have another teammate tape the straw along the side of the balloon. Thread the fishing line through the straw and hold the balloon at the far end of the line.

4. Assign one teammate to time the event. The balloon should be let go when the time keeper yells "Go!" Observe how your rocket moves toward the blackboard.

5. Have another teammate stand right next to the blackboard and yell "Stop!" when the rocket hits its target. If the balloon does not make it all the way to the blackboard, "Stop!" should be called when the balloon stops moving. The timekeeper should record the flight time.

6. Measure the exact distance the rocket traveled. Calculate the average speed at which the balloon traveled. To do this, divide the distance traveled by the time the balloon was "in flight." Fill in your results for Trial 1 in the table below.

Materials:
- balloons (one for each team)
- plastic straws (one for each team)
- tape (cellophane or masking)
- fishing line, 10 meters in length
- a stopwatch
- a measuring tape

7. Each team should conduct two more trials and complete the sections in the table for Trials 2 and 8. Calculate the average speed for the three trials to determine your team's race entry time.

The winner of this race is the team with the fastest average balloon speed.

Explain:

1. What made your rocket move?

2. How is Newton's Third Law of Motion demonstrated by this activity? What is accelerating? what provided the force?

3. *Optional for advanced students:* Draw pictures using labeled arrows to show the action and reaction forces acting on the balloon before it was released and after it was released.

	Distance (m)	Times (sec)	Speed (m/sec)
Trial 1			
Trial 2			
Trial 3			
			Average:

Standards for all Four Posters:

National Science and Mathematics Standards for the Newton's Laws Materials (all activities)

PHYSICAL SCIENCE (Grades 5-8, 9-12)
- Motions and Forces

UNIFYING SCIENCE CONCEPTS AND PROCESSES
- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

SCIENCE AS INQUIRY
- Understanding of scientific concepts
- Understanding of the nature of science
- Skills necessary to become independent inquirers about the natural world

ALGEBRA (Grades 6-12)
- Understand patterns, relations, and functions
- Represent and analyze mathematical situations

MEASUREMENT (Grades 6-12)
- Understand and use measurable attributes of objects
- Apply appropriate techniques, tools, and formulas

DATA ANALYSIS (Grades 6-12)
- Select, create, and use appropriate graphical representations of data
- Develop and evaluate inferences and predictions that are based on data

MATHEMATICS PROCESS STANDARDS
- Reasoning
- Problem Solving
- Representing Mathematical Relationships
- Connections to Science and the Outside World
- Communication of Mathematics and Science

References for all Four Posters:

Copies of these materials, along with additional information on Newton's Laws of Motion and Law of Gravitation, are available on the Swift Mission Education and Public Outreach Web site:
http://swift.sonoma.edu/

- NASA Web sites:
  NASA's official Web site - *http://www.nasa.gov*
  Swift Satellite - *http://swift.gsfc.nasa.gov*

- NASA Education Resources:
  The Space Place - *http://spaceplace.nasa.gov*
  Imagine the Universe! - *http://imagine.gsfc.nasa.gov*

- NASA's Central Operation of Resources for Educators (CORE):
  http://education.nasa.gov/edprograms/core/home/index.html
  Check out these videos:
  "Liftoff to Learning: Newton in Space" (1992), $15.00
  "Flight Testing Newton's Laws" (1999), $24.00

- NASA's Space Science Education Resource Directory:
  http://teachspacescience.org

- Newton's Laws of Motion:
  http://www-istp.gsfc.nasa.gov/stargaze/Snewton.htm
  http://www.grc.nasa.gov/WWW/K-12/airplane/newton.html
  http://www.grc.nasa.gov/WWW/K-12/TRC/Rockets/rocket_principles.html

- Newton's Law of Gravitation:
  http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html

- Newton in the Classroom:
  http://www.physicsclassroom.com/Class/newtlaws/newtltoc.html
  http://www.glenbrook.k12.il.us/gbssci/phys/Class/newtlaws/u2l1a.html

- The Nine Planets:
  http://seds.lpl.arizona.edu/nineplanets/nineplanets/nineplanets.html
  http://seds.lpl.arizona.edu/nineplanets/nineplanets/data1.html