INSIDE SCIENCE TV: Ping Pong Balls Break The Sound Barrier

STEM Lesson Plan / Adaptable for Grades 7–12

Lesson plan developed by T. Jensen for Inside Science and the American Institute of Physics

About the Video **(click here to see video)**

Purdue University students, led by their mechanical engineering technology professor, designed an hourglass-shaped nozzle like those found in the engine of F-16 fighter planes for their air-cannon. The cannon accelerates a ping-pong ball to supersonic speeds, propelling it with incredible momentum through wood, soda cans, and even denting steel.

Related Concepts

acceleration	energy	momentum
aerodynamics	force	sound barrier
air pressure	linear motion	speed
continuity equation	mass	vacuum

Bell Ringers

Use video to explore students' prior knowledge, preconceptions, and misconceptions. Have students write or use the prompts to promote critical thinking.

Time	Video content	Students might…
0:00–0:05	Series opening	
0:06–0:13	What can travel at supersonic speed and shatter plywood?	Have students make written predictions about what might travel at supersonic speed and can blast through plywood. Predictions should be supported with physics concepts. (You can play the video at full screen without the label *Ping Pong Balls Break The Sound Barrier* showing by keeping your cursor out of the screen.)
0:14–0:25	Purdue mechanical engineering and technology students build an air-powered cannon.	Students might put on their engineering hats and make annotated drawings that depict how they would propel a ping-pong ball to supersonic speeds.
0:26–0:32	Students determine how fast the ping-pong ball is traveling and makes comparisons.	Have students outline the procedure they would follow to determine how fast the ping-pong ball was going when it hit the metal grid.
0:33–0:49	Mechanical engineer Mark French used his experience with the U. S. Air Force to design the cannon.	Have students calculate the momentum with which the speeding ball hits the metal grid, using Craig Zehrung's proclamation that the ping-pong ball left the tube at 919 miles per hour and the mass of the average ping-pong ball, which is 2.7 grams.

0:50–1:07	How the hourglass-shaped nozzle helps the cannon work.	Students could label a diagram that explains how the hourglass-shaped nozzle accelerates the ball to supersonic speeds, propelling it with incredible momentum through wood and soda cans
1:08–1:21	The ping-pong ball and its high rate of acceleration and a safety caution	Have students compare and contrast the lab environments shown in the video with their own.
1:22–1:35	Even researchers can have a little fun with science	Students could identify subsequent problems these engineers might try to solve based on their findings and offer explanations on how to solve them.
1:36-1:55	Closing credits	

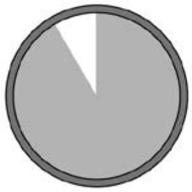
Explore and Challenge

After prompting to uncover prior knowledge, use video for a common background experience and follow with a minds-on collaboration.

1. Explore readiness to learn from the video with the following prompts:
- One experience I have had with linear motion is….
- I can understand what went on in the tube because the continuity equation….
- Force and acceleration are related by….
- Observations I've made about momentum include….
- Things that affect momentum include….
- The fog coming out of the end of the tube….
- Aerodynamics and the sound barrier impact each other….
- The force required for a ping-pong ball to break through a given material can be determined by….
- Constraints that limit the speed at which a ping-pong ball can travel are….
- Constraints that might limit how hard a ping-pong ball can be pushed are….

2. Show the video and allow students to discuss what they observed.

3. Challenge students, in groups, to devise a method to determine the impulse of force required for a ping-pong ball to break through a list of class agreed on materials. Each group should be able to explain and justify their solutions using concepts and math previously covered in class.



Investigate, Compare, and Revise

Use video as a springboard for students to apply engineering design processes and science concepts to answer questions and solve problems.

Identify Problems

Challenge students to ask questions based on the video that can lead to problems they can solve through an engineering design process. For example: ***How could we propel a ping-pong ball through a taut piece of tissue paper?*** Encourage a wide range of questions and allow students to choose.

Guide students to restate their questions in the form of a statement that outlines the problem to be solved. For example: ***We will design and build a device that will propel a ping-pong ball through a taut piece of tissue paper from a distance of 30 centimeters.***

Possible Equipment and Materials

- ping-pong balls
- marshmallows
- rubber bands
- PVC pipe
- materials to push, hit, or pull the ping-pong ball
- materials to guide the ping pong ball to its target
- material such as tissue or butcher paper, chosen through consensus, to serve as a target through which the ping pong ball must have enough momentum to pass through
- video camera or cell phone camera with slow motion filming capabilities
- equipment to hold the ‘target’ during the investigation.

Allow students a brief period of time to examine and manipulate available materials. Doing so often aids students in refining the direction of their investigation or prompts new ones that should be recorded for future exploration. Since conversation is critical in the science classroom, allow students time to discuss which materials they will choose and why.

Safety Considerations: Review safe use of tools and measurement devices as needed. Augment your own safety procedures with NSTA’s Safety Portal at http://www.nsta.org/safety/. Make certain students understand that they must NOT

attempt experiments at home “just for fun or to see what will happen.” Do not make assignments that require students to carry out any experiments at home. Only supervised activities in the school setting and directed by the teacher should be done.

Set the Stage

Use prompts to get students thinking about how they will solve their problem:

- One way we can propel a ping-pong ball without the use of compressed air is….
- Not using compressed air to propel the ping-pong ball brings in the constraints of….
- The physical characteristics of the ping pong ball present specific constraints such as….

- It will be necessary for the ping-pong ball to impact the target at a given angle because….
- The optimal location of the target can be determined by….
- This task is manageable because I understand….

Investigate

Determine the appropriate level of guidance you need to offer based on your student's knowledge, creativity, ability levels, and available materials. Review safe use of tools and measurement devices as needed. Augment your own safety procedures with NSTA's Safety Portal at http://www.nsta.org/safety/.

Students might split rubber bands of different thicknesses and attach them to the frame holding the tissue paper. The ball could be held in each rubber band and, in turn, the bands are drawn back 30 centimeters and released at the suspended tissue paper. Alternatively, the ball might be fired from a slingshot or catapult.

A major constraint in any design investigation is time. Give students a clear understanding of how much time they will have to find a solution to their problem.

Compare/Revise

After demonstrating and communicating claims backed by evidence about their solution to the class and reflecting on the solutions of other groups, allow teams to go through a redesign process to improve their solutions. Encourage students to identify limitations of the design and testing process. Students should also consider additional variables that they did not identify earlier that impacted their designs. Students should quickly make needed revisions to their solutions. You might modify the problem so that it is more difficult, such as using two pieces of tissue papers instead of one, to increase the challenge.

Build Science Literacy through Reading and Writing

Use the video as engagement to spark interest in science, engineering design, and careers. Related resources help build science literacy.

Related Resources

- http://www.popularmechanics.com/adventure/a8683/behold-the-900-mph-supersonic-ping-pong-bazooka-15097897/
- http://arxiv.org/ftp/arxiv/papers/1301/1301.5188.pdf
- https://www.youtube.com/watch?v=HFj4efBPoyc

Reading Strategy: Close Reading As students read have them number each paragraph. Students could make comparisons the texts with notes they took on the video. Have students underline portions of the texts that present the science of how the cannons work. Students might circle passages that raise questions for them. In the margins to the left of each paragraph or on sticky notes, students might demonstrate their understanding by writing a short summary of the paragraph. The margins to the right of each paragraph could be used to write questions that are raised by the information presented in the paragraph.

Writing Strategy: CRAFTS After students have read and watched the material closely, give them a writing assignment that allows them to integrate and evaluate the texts and video in order to examine the science behind the air cannons while offering ideas for a more efficient design. For example: ***You are an engineer at a company who wants to build a competing air cannon. You've been asked to figure out how this one works and offer suggestions for changing and improving the design. Write a summary of your findings and suggestions to present at the next team meeting. Be sure to include evidence from the video and readings to support your claims.***

Special Thanks To the American Association of Physics Teachers and its members for their help:
Beth Cunningham, Executive Officer, American Association of Physics Teachers
Robert Hilborn, Associate Executive Officer, American Association of Physics Teachers
Diane Riendeau, Deerfield High School (Illinois)
Daniel Crowe, Loudoun County Public Schools (Virginia)
James Lincoln, Tarbut V'Torah High School (California)

NATIONAL STANDARDS CONNECTIONS

Next Generation Science Standards

Visit the URLs to review the supportive Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts for these connected Performance Expectations.

MS-PS2 Motions and Stability: Forces and Interactions
http://www.nextgenscience.org/msps2-motion-stability-forces-interactions
MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS3 Energy
http://www.nextgenscience.org/msps3-energy
MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

MS-ETS1 Engineering Design
http://www.nextgenscience.org/msets1-engineering-design
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

HS-PS2 Motion and Stability: Forces and Interactions
http://www.nextgenscience.org/hsps2-motion-stability-forces-interactions
HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

HS-PS3 Energy

http://www.nextgenscience.org/hsps3-energy
HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-ETS1 Engineering Design
http://www.nextgenscience.org/hsets1-engineering-design
HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Common Core State Standards for ELA & Literacy in Science and Technical Subjects

Visit the URLs to find out more about how to support science literacy during science instruction.
College and Career Readiness Anchor Standards for Reading
http://www.corestandards.org/ELA-Literacy/CCRA/R/
1. Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.
6. Assess how point of view or purpose shapes the content and style of a text.
7. Integrate and evaluate content presented in diverse formats and media, including visually and quantitatively, as well as in words.
8. Delineate and evaluate the argument and specific claims in a text, including the validity of the reasoning as well as the relevance and sufficiency of the evidence.

College and Career Readiness Anchor Standards for Writing
http://www.corestandards.org/ELA-Literacy/CCRA/W/
Visit the URL to review the supportive Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts for these connected Performance Expectations.
1. Write arguments to support claims in an analysis of substantive topics or texts using valid reasoning and relevant and sufficient evidence.
2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.
7. Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation.
8. Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.
9. Draw evidence from literary or informational texts to support analysis, reflection, and research.

Feedback

Inside Science welcomes your feedback on this STEM lesson plan. Please send your comments to Laleña Lancaster of Inside Science at ldlancas@aip.org.