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| **Title** | Lesson 6: Galileo’s Compass: Can you predict where that cannon ball is going to fall (if the wind is blowing)? |
| **Introduction** | In this lesson, the students reflect upon a virtual experiment they carried out to determine the range of a projectile. This lesson explores one of the variables that was completely ignored in that experiment—the wind! Does the wind have an effect on projectiles? And, if so, what is that effect? |

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| **Curriculum Alignment** | North Carolina Essential Standards   * Physical Science.   + PSc.1.1.1 Explain motion in terms of frame of reference, distance, and displacement.   + PSc.1.1.2 Compare speed, velocity, acceleration, and momentum using investigations, graphing, scalar quantities, and vector quantities.   + PSc.1.2.1 Explain how gravitational force affects the weight of an object and the velocity of an object in freefall.   + PSc.1.2.2 Classify frictional forces into one of four types: static, sliding, rolling, and fluid.   + PSc.1.2.3 Explain forces using Newton’s three laws of motion. * Physics, Grades 9-12.   + Phy.1.1.1 Analyze motion graphically and numerically using vectors, graphs and calculations.   + Phy.1.1.2 Analyze motion in one dimension using time, distance, and displacement, velocity, and acceleration.   + Phy.1.1.3 Analyze motion in two dimensions using angle of trajectory, time, distance, displacement, velocity, and acceleration.   + Phy.1.2.3 Explain forces using Newton’s laws of motion as well as the universal law of gravitation. |
| **Learning Outcomes** | * Students will be able to describe the effects of wind on a projectile. |
| **Time Required and Location** | Approximately 45 minutes (one-half of one block period). The lesson may be taught in one traditional period. |

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| **Materials Needed** | * A ping pong ball. * A 1000 ml beaker or a similarly-sized container. * An electric fan (a box-type fan works best, but any fan can be made to work). * Handout for group activity—*Galileo’s Compass: Can you predict where that cannon ball is going to fall (if the wind is blowing)?* * Answer Key for group activity—*Galileo’s Compass: Can you predict where that cannon ball is going to fall (if the wind is blowing)?Answer Key.* * Rubric for group activity—*Assessment Rubric for Galileo’s Compass: Can you predict where that cannon ball is going to fall (if the wind is blowing)?* |
| **Safety** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge** | * The teacher should set up and practice the demonstration described below to determine the appropriate location and speed for the fan prior to the students’ arrival. * Students should have completed “Galileo’s Compass: Can you predict where that cannon ball is going to fall?” |
| **Facilitator Preparations** | Teacher should procure materials ahead of time, and have materials set out for student use. |
| **Activities** | * Introduce the lesson by asking students to think back to what they learned when they did the Galileo’s Compass experiment. * Ask if the wind was blowing when they did the experiment. Of course, no mention was made of wind, so you can expect to receive any range of answers from “yes” to “no” to “how are we supposed to know?” * Select a student volunteer to come forward and assist you (this should be a fairly competent and confident student as some skill is required; this is not a good time to involve a shy or fragile student). * Tell the student to place the beaker on the floor and drop the ping pong ball into it from chest height. This may take several attempts, but let the student keep trying until he can consistently hit the target. * Then turn on the fan (placed to blow across the ball’s path of motion) and ask the student to repeat the task. It should be very difficult to accomplish. Give him a few attempts, but it is not necessary to have a successful attempt. * Ask the class to break into small groups (3-5 students) and discuss what just happened. Give each group a copy of the handout and have them answer each question.   + During this phase of the lesson, you should circulate through the room observing individual participation in the group discussions. Make notes as necessary so that you can evaluate each individual and group using the rubric for this activity.   + If you see students getting off track, ask them leading questions such as:     - Why do you think projectiles are pointed on the front?     - Which would be easier to push—the pointy front or the flat back of a projectile?     - Which is larger the area of a projectile viewed from the front, or the area viewed from the side?     - Would a tail wind assist or resist a projectile?     - Would a head wind assist or resist a projectile? * Bring the groups back together and ask for a volunteer from each group to present their findings. During the presentations, the following conclusions should become apparent:   + Wind has an influence on a projectile.   + A head wind would hinder a projectile’s motion.   + A tail wind would aid a projectile’s motion.   + A cross wind would cause a projectile to be “off line.”   + Projectiles are designed to minimize wind effects. * Be sure to take up the handouts from each group so that they can be used as a reference during your evaluation of each student according to the rubric for this activity. |
| **Assessment** | * The discussion activity at the end of the lesson should be used as a formative assessment of the class’ understanding of the effect of wind on projectiles. If you become aware of any general misconceptions or misunderstandings, be sure to address these during the discussion or in future lessons.   + Specific questions to ask to check for understanding may include:     - Is wind direction important to the accuracy (hitting a target) of a projectile?     - Can wind affect both the horizontal and vertical components of a projectile’s motion?     - Would vector addition be a good way to calculate the influence of wind on a projectile?     - If we define a projectile as moving in a positive direction, would a tail wind be positive or negative? How about a head wind? How about a cross wind?     - Of the three wind directions, which would likely have the greatest effect on a projectile’s range? * Student learning will be summatively assessed using the rubric provided. The rubric provides both the means of assessment and the standards by which the students are to be assessed. |

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| **Critical Vocabulary** | * Projectile: an object that is fired, thrown, or otherwise propelled, such as a cannon ball that has no capacity for self-propulsion. * Projectile Motion: the motion of a body (the projectile) given an initial velocity and then following a path determined by the effect of gravitational acceleration (and in some instances, by air resistance). * Wind: the perceptible natural movement of the air, esp. in the form of a current of air blowing from a particular direction. * Head wind: a wind blowing in the direction opposite to a projectile’s motion. * Tail wind: a wind blowing in the same direction as a projectile’s motion. * Cross wind: a wind blowing across a projectile’s path. |

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| **Modifications** | This lesson is particularly suited to classrooms with students of differing learning styles and abilities. Most special audiences can be accommodated through the careful selection of groups. Whenever possible, each group should contain a representative cross-section of the class, including gifted and talented students, standard level students, and students with learning disabilities. If possible, English language learners should be placed in a group with a bilingual student or a student who is studying the ELL’s language. |
| **Alternative Assessments** | The rubric used to assess this lesson has sufficient latitude to accommodate a range of learners. Much of the grade is based on the group’s performance, and the teacher may consider an individual student’s abilities when awarding the individual participation points. |
| **References** | Cannons at Skansen:  <http://upload.wikimedia.org/wikipedia/commons/3/34/Cannons_at_skansen_050701.JPG>  French De Bange Cannon:  <http://upload.wikimedia.org/wikipedia/commons/9/9b/French_De_Bange_cannon_from_1877_.jpg>  World War I railroad artillery:  <http://upload.wikimedia.org/wikipedia/commons/e/e3/Guerre_14-18-Four_great_english_guns-vers_1914.JPG>  16 inch Howitzer:  <http://upload.wikimedia.org/wikipedia/commons/4/49/16inch-howitzer.gif>  Modern French CAESAR artillery piece:  <http://upload.wikimedia.org/wikipedia/commons/d/da/French_CAESAR_artillery_piece.jpg>  Virtual Artillery Range Learning Object for the i3D Theatre (when available):  <http://www.explorethelor.org/>  Galileo's geometrical and military compass in Putnam Gallery: http://upload.wikimedia.org/wikipedia/commons/4/48/Galileo%27s\_geometrical\_and\_military\_compass\_in\_Putnam\_Gallery%2C\_2009-11-24.jpg  16th Century Artillery  <http://upload.wikimedia.org/wikipedia/commons/3/3a/16th_Century_Artillerie.jpg>  Ballistic quadrants and aiming the cannon  <http://upload.wikimedia.org/wikipedia/commons/f/f0/Fotothek_df_tg_0000132_Ballistik_%5E_Quadrant_%5E_Kanone.jpg>  A discussion of the general solution for projectile motion: <http://zonalandeducation.com/mstm/physics/mechanics/curvedMotion/projectileMotion/generalSolution/generalSolution.html>  The University of Oregon’s Virtual Laboratory Cannon  <http://jersey.uoregon.edu/vlab/Cannon/>.  This is a website created (under the auspices of the Oracle ThinkQuest Educational Foundation) by students for students under the age of 19. The authors are from a school in Hong Kong, so the English is not perfect, but the science is good.  <http://library.thinkquest.org/28388/Mechanics/Motions/Projectile.htm> |
| **Supplemental Information** | This resource may be used by the teacher as background reading, or for student research. It has an excellent discussion of the forces associated with a projectile, including wind.  Wikipedia. External Ballistics.  <http://en.wikipedia.org/wiki/External_ballistics>  This resource is a fascinating study of how projectile motion is perceived by people. It offers valuable insight into the types of misconceptions that students may have, and can be of benefit to the teacher as background reading.  Hecht, H. and Bertamini, M. (2000). Understanding projectile acceleration. Journal of Experimental Psychology: Human Perception and Performance, Vol. 26, No. 2, 730-746. Retrieved October 8, 2011, from:  <http://psycho.sowi.uni-mainz.de/abteil/aep/hecht/pdf/2000_Hecht_Bertamini.pdf>  This resource may be used by the teacher as background reading. It offers a detailed mathematical explanation of projectile motion including wind effects and a link to a computer simulation of a catapult.  The Secondary Education in Computational Science (SPECS) Project. University of Minnesota.  *Catapult: Using Computers to Solve Seemingly Simple Problems.*  <http://www.lcse.umn.edu/specs/labs/catapult/index.html>  This is an excellent resource for use in grouping students.  Tools for Teaching by Barbara Gross Davis; University of California, Berkley.  *Collaborative Learning: Group Work and Study Teams*.  <http://teaching.berkeley.edu/bgd/collaborative.html> |
| **Comments** | This lesson was inspired in part by a conversation with Dr. Carl Howald (see Author Info below) concerning the desirability of making students aware of the real-world implications of the idealized experiments they see in the physics laboratory. |
| **Author Info** | **Fred Morris** is a technology education teacher at Richmond Senior High School in Rockingham (Richmond County), NC. He teaches Principles of Technology and Computer Networking to students in grades 10-12. Although Mr. Morris received his AB in Education (Secondary Mathematics) in 1973 while attending the University of North Carolina at Chapel Hill on a Morehead Scholarship, he did not become a public school teacher until 2002. From 1973 until 2002, he pursued a career in business and industry, ultimately establishing and managing an international technical training center for a Fortune 500 Company. As a result of a change in the company’s business model, Mr. Morris closed down the technical training center and took a job teaching. He became a National Board Certified Teacher in Technology Education in 2006. Mr. Morris was named the 2008 North Carolina High School Teacher of Excellence by the International Technology and Engineering Educators Association (ITEEA). He received his MS in Technology Education from North Carolina A&T State University in 2009.  This project was developed as result of research conducted during a Kenan Fellows Externship at Richmond Community College in Hamlet, NC. The focus of the externship was to develop a unit plan that would incorporate the use of i3D technology. The majority of the research focused on the software and hardware used in the development of learning objects for the i3D system, under the guidance of mentor Dr. Randy Henson. The subject matter for the unit plan was suggested by Dr. Carl Howald, who was the other mentor for the externship. The resulting lesson plans were designed to provide a fresh approach to the study of projectile motion. Some, but not all of the lessons in the unit, incorporate the use of i3D technology, and may be used in any science classroom.  **Dr. Randy H. Henson** is a professor of Mechanical Engineering Technology at Richmond Community College in Hamlet, NC. He received his MS from the University of Arizona and his PhD from North Carolina State University.  **Dr. Carl D. Howald** is a professor of Physics and the Dean of Instructional Services at Richmond Community College in Hamlet, NC. He received his AB from Kenyon College and his MA and PhD from Duke University. |