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| **Title** | Lesson 3: Galileo’s Compass: Can you predict where that cannon ball is going to fall? |
| **Introduction** | In this lesson, students will be able to explore the addition of a horizontal component to the motion of a falling body. In **Lesson 2: Galileo’s Inclined Plane Experiment: Can you make gravity less?**, the horizontal component of the ball’s motion was essentially ignored, although it was the factor which resulted in the apparent reduction in gravity as observed in the ball’s slowed rate of descent. Students will take a virtual field trip to an artillery range to explore the concept of projectile motion in a way that is not normally possible in the real world. The class will be divided into groups and each group will be asked to experimentally determine the best angle for firing a projectile to maximize its range. Their collected data will be analyzed and used to show the trigonometric relationships that are essential to projectile motion. Students will be assessed on their participation and conclusions. |

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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 demonstrate the ability to conduct scientific investigations to answer questions about projectile motion.  * Students will understand two-dimensional linear motion as it relates to projectile motion. |
| **Time Required and Location** | Approximately 180 minutes (two block periods). The lesson may be adapted to three or four traditional periods by segmenting the lesson. |

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| **Materials Needed** | * Virtual Artillery Range Learning Object (Note: This learning object is currently under development.) * Pictures of artillery pieces (see resources) * A picture of Galileo’s Geometric and Military Compass (see resources) * Handouts:   + Introduction to the Virtual Artillery Range (one per group)   + Virtual Artillery Range Data Collection Form (one per group)   + Virtual Artillery Range Results Form (one per group)  Technology resources  * Interactive 3D Classroom * Computer with data projector (or other means of displaying graphical material) |
| **Safety** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge** | * Students should have completed **Lesson 1: Galileo’s Ball Drop Experiment: What would he have learned—if he had done it?** * Students should have completed **Lesson 2: Galileo’s Inclined Plane Experiment: Can you make gravity less?** |
| **Facilitator Preparations (Required)** | Teacher should procure materials ahead of time, and have materials set out for student use. |
| **Activities** | * Introduce this lesson by telling the students that Galileo’s interest in falling bodies naturally led to an exploration of how the military weapons of the day worked.   + Show them the picture of the 16th Century Artillery, explaining that these were the types of weapons that existed in Galileo’s time.   + Show them the picture of the Ballistic Quadrants and Aiming the Cannon. Ask them what they think is going on in the picture. The discussion should lead to the idea that the cannon was being aimed based on some angular measure.   + Then show them the picture of Galileo’s Geometrical and Military Compass, explaining that his research into projectile motion resulted in his invention of a device that made the “hit-or-miss” (pun intended) method of aiming cannons much more accurate. * Show the students a series of pictures of artillery pieces.   + Ask the question “What do you notice about how all the guns are aimed?” Give students time to offer their observations and it should come out that they are all aimed at an angle above the horizontal.   + Ask the question “Why are all the guns aimed upward—wouldn’t it make sense just to shoot straight at your target?” The discussion should be that the projectile would fall to the ground very quickly unless it was aimed up at some angle. This will give you the opportunity to introduce the concept of horizontal and vertical components of the object in motion. Compare and contrast these with the horizontal and vertical components of forces acting at angle to the motion of an object.   + Tell the students that they are going to take a field trip to an artillery range where they will be able to fire cannons and collect data on the motion of the projectiles—and that they are going to be able to do it without leaving their own school! (Note: This activity requires that the class have access to an i3D Classroom. In the absence of this technology, students can use the University of Oregon’s Virtual Laboratory Cannon, available at <http://jersey.uoregon.edu/vlab/Cannon/>. This is an acceptable substitute for the i3D activity, but it does not provide the same immersion experience.) * Break the students into groups of four and ask them to read the handout describing the Virtual Artillery Range.   + Ask the students to develop a strategy that will allow them to determine the angle of inclination that results in the maximum range for their cannon.   + Ask them to think about what data they will need to collect to be able to verify their results mathematically.   + Circulate through the room and observe what each group is doing. Try not to interfere with the groups’ creativity. If you observe that a group is having difficulty, ask them a leading question or two (“don’t you need to try a range of angles” or “how will you know if the range has reached its maximum?”) to help them get on the right track.   + Allow students to ask you questions if they want to, but try to lead them in the right direction, rather than just giving them a definitive answer to their questions.      * Take the class as a group to the i3D Classroom.   + You should have previously started the Virtual Artillery Range program and have it running, adjusting the audio level to give an impressive (but not too loud) boom when you fire the artillery.   + Give each student a pair of 3D glasses, making the point that one should always use eye (and ear) protection when firing artillery!   + Demonstrate how the program works, specifically indicating how to select a type of artillery and showing them how to adjust the angle of inclination.   + Point out the telemetry panel and show them the various parameters that are displayed on it.   + Fire the artillery! The students should be totally engaged at this point.   + Allow each group in turn to select an artillery type and fire ten rounds at various angles while collecting data. Other students in the class can observe the firing, but should not offer suggestions to the active group. Encourage each group to select a different type of artillery, because each type has a different muzzle velocity. This will allow the students to discover that the angle of inclination that produces the maximum range is not dependent on muzzle velocity.   + After all groups have had their turns at firing, you may return to your classroom. * Give each group a Virtual Artillery Range Results Form.   + Have them complete the graph and answer the questions in their groups.   + The students should be able to draw some conclusions about angle of inclination and maximum range by observing the shape of the curve.   + Lead a discussion of the class asking them to share their observations and conclusions. This discussion should bring out the idea that 45 degrees is the optimum angle for maximizing range.     - Ask them if the muzzle velocity had any effect on their results.     - Ask them if the results would be different if the value of gravity were more or less.     - Ask them if the results would be different if the value of gravity was zero (as in space).     - Ask them about the shape of the curve (parabolic) and whether or not they have seen this shape before (refer to Lesson 2: Galileo’s Inclined Plane Experiment).   + Collect and evaluate the Data Collection and Results form forms. * The final activity in this lesson should be a traditional exploration of the mathematics associated with projectile motion. This activity may be drawn from whatever textbook you are using in your classroom. Presentation and assessment of this activity is at the teacher’s discretion. For your reference, a thorough and understandable discussion of the general solution for projectile motion may be found at Zona Land Education’s website: <http://zonalandeducation.com/mstm/physics/mechanics/curvedMotion/projectileMotion/generalSolution/generalSolution.html> |
| **Assessment** | * The discussion activity after completing the Results Form should be used as a formative assessment of the class’s understanding of the relationship between angle of inclination and maximum range. 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:     - How is a projectile similar to a free-falling body?     - How is a projectile different from a free-falling body?     - Did projectile range increase with angle of inclination?     - Was there a point at which the range began to decrease as the angle of inclination increased? If so, what was the angle at which this occurred?     - What is special about this angle?     - Did the muzzle velocity of your chosen artillery piece have an effect on maximum range?     - Did the muzzle velocity of your chosen artillery piece have an effect on the angle that produced the maximum range?     - What would have happened if gravity were more? less?     - What would have happened if there were no gravity?     - Did you recognize the shape of the curve produced by the projectile? What was it? * 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** | * Angle of Inclination: the angle above the horizontal at which an artillery piece is aimed. * Artillery: large-caliber weapons, such as cannon, howitzers, and missile launchers. * Ballistics: the study of the dynamics of projectiles. * Gravity: the force of attraction between all masses in the universe; the force that causes objects to fall on earth. * Maximum Altitude: the highest point a projectile reaches in its travel. * Maximum Range: the farthest distance measured horizontally traveled by a projectile. * Muzzle Velocity: how fast a projectile is moving as it exits the barrel of a gun. * 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). |

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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** | An excellent book by Galileo’s preeminent biographer:  Drake, Stillman. (1978). Galileo at work: His scientific biography. Chicago: The University of Chicago Press.  This is a link to four scholarly essays describing Galileo’s work in general and his interest in ballistics in particular.  <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.15.1139&rep=rep1&type=pdf>  A journal article on Galileo’s work with ballistics:  Rose, Paul-Lawrence (1968). Galileo's theory of ballistics. *The British Journal for the History of Science*, 4(2), 156-159. Download from <http://www.jstor.org/stable/4025144>. This resource may require you to pay a fee unless you have a journal subscription or access through a university library.  Short essays on the following topics are appropriate for extra credit assignments:   * Galileo’s persecution by the church * Galileo’s beliefs about planetary motion * Galileo’s work with pendulums * Galileo’s work with telescopes * The historical impact of artillery on warfare |
| **Comments** | This lesson was inspired in part by a workshop conducted for the Kenan Fellows Class of 2012 by the Center for Inquiry Based Learning (CIBL).http://www.ciblearning.org/ |
| **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. |