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| **Title** | Lesson 5: Galileo’s Inclined Plane Experiment: Did we really make gravity less? |
| **Introduction** | In this lesson, students will reflect upon an experiment they designed to replicate one of Galileo’s experiments. They began with certain assumptions, and reached certain conclusions. In this lesson we revisit those assumptions and reflect on the validity of the conclusions, as well as considering how the lessons learned during the study of projectile motion can be used to analyze the experiment. |

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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 their knowledge that the inclined plane experiment did not really reduce gravity, but instead used an inclined plane to redirect part of the vertical force exerted by gravity in a horizontal direction, thereby reducing the vertical acceleration. |
| **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** | * Flip chart or dry erase board with markers. * Handout for group activity—*Galileo’s Inclined Plane Experiment: Did we really make gravity less?* * Answer Key for group activity—*Galileo’s Inclined Plane Experiment: Did we really make gravity less? Answer Key.* * Rubric for group activity—*Assessment Rubric for Galileo’s Inclined Plane Experiment: Did we really make gravity less?* * A simple inclined plane and two marbles or similar small balls (the inclined plane can be just a board elevated on one end by a stack of books; it is not necessary to use the large inclined plane from the original experiment). |
| **Safety** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge** | * Students should have completed “Galileo’s Inclined Plane Experiment: Can you make gravity less?” * 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** | * Ask the students to recall what they did and what they learned from the Galileo’s Inclined Plane Experiment. * Write any key ideas or thoughts they may have on the flip chart or board. * Hopefully, someone will mention that the inclined plane was used to make measuring the ball’s descent easier. If this does not come out, ask why we used the inclined plane and gently guide them to this answer. * Point out the inclined plane and ask a student to assist you (this is a very good opportunity to engage a student who “hangs back” or a special needs student).   + Ask the student assistant to hold one marble at the top of the inclined plane and the other marble at the same height just off the end of the inclined plane.   + Tell the student to release both marbles simultaneously.   + The free falling marble will hit the table before the other marble reaches the end of the inclined plane.   + Ask the class to think about the following question but not to respond to it: “The rolling marble ‘fell’ slower than the free-falling marble—did the inclined plane reduce gravity?” * 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:     - Is gravity a constant?     - Can you change a constant?     - If gravity is directed toward the center of the earth, why does the ball roll sideways down the inclined plane?     - If the ball is moving horizontally, does there have to be a horizontal force?     - Where would a horizontal force come from?     - How is a ball rolling down an inclined plane similar to a projectile.     - How is it different from 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:   + Gravity is a constant for a specific location, and cannot be changed. Therefore, the inclined plane does not actually reduce gravity.   + Forces exerted by the inclined plane caused the gravitational force to be resolved into horizontal and vertical forces.   + The same concepts used to analyze projectile motion can be used to analyze the inclined plane experiment.   + This experiment alters certain factors while not completely eliminating them. * 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’s understanding of the effect of gravity and air resistance on falling bodies. 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 gravity a constant for a specific location?     - What influences gravity?     - Gravity made the ball go down the incline, but what made the ball go sideways?     - Does the ball have horizontal and vertical forces acting on it?     - Does the ball have a horizontal and vertical component to its motion?     - Does a projectile have horizontal and vertical forces acting on it?     - Does a projectile have a horizontal and vertical component to its motion? * 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** | * Acceleration: the rate of change of speed of a moving object. * Distance: the length of the path of an object moving through space. * Gravity: the force of attraction between all masses in the universe; the force that causes objects to fall on earth. * Inclined plane: a plane set at an acute angle to the horizontal. * Speed: a measure of the distance an object moves in a specific period of time. * X-component: the portion of a force acting in a horizontal direction. * Y-component: the portion of a force acting in a vertical direction. |

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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 inclined planes.  The Physics Classroom. Forces in two dimensions.  <http://www.physicsclassroom.com/class/vectors/u3l3e.cfm>  The following resource is a Java-based simulation of a ball rolling down an inclined plane from the Tel-Aviv University Science and Technology Education website. It can be used to demonstrate the effect of angle of inclination and length on the time of descent  <http://muse.tau.ac.il/~museum/java/pc/LawOfFall/english/act_inclined_eng.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. |