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| **Section of Project** | **Discovering Projectile Motion: From Galileo to the i3D Experience**  What inspired Galileo’s interest in motion? How did his inquiries lead to an understanding of some of the most fundamental concepts in modern physics? And why is the study of science so boring to many of today’s students? The answers to these questions were fundamental to the development of this unit. Galileo’s inspiration was a desire to know the unknown. His inquiries gave us the basis for understanding both one-dimensional and two-dimensional motion. And science is boring to students today because we give them the answers and don’t let them discover the questions. This unit consists of a series of traditional physics experiments presented in a very non-traditional way. Rather than giving students a very well-defined lab (“do three trials each with masses of 100g, 200g, and 300g”), they are presented with an idea and are asked to formulate a means to discover its implications. Interactive 3D (i3D) technology is specifically incorporated into some lessons, but the unit may be taught using other technologies. |
| **Title** | Lesson 2: Galileo’s Inclined Plane Experiment: Can you make gravity less? |
| **Introduction** | In this lesson, students will be briefly told about Galileo’s inclined plane experiment and will be asked to come up with their version of the experiment using the same type of equipment available in Galileo’s time. The class will be divided into groups and each group will be asked to design the experiment. Groups will present their proposals to the class, and a consensus of how to conduct the experiment be reached. The experiment will be conducted and results will be analyzed. 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 design and conduct scientific investigations to answer questions about objects rolling down an inclined plane. * Students will understand two-dimensional linear motion as it relates to bodies rolling down an inclined plane. |
| **Time Required and Location** | Approximately 90 minutes (one block period). The lesson may be adapted to two traditional periods by doing the planning part of the lesson and the experimental part of the lesson on consecutive days. |

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| **Materials Needed** | * Computer with data projector (or other means of displaying graphical material). * Handouts:   + Designing an Inclined Plane Experiment Handout (one per group)   + Inclined Plane Data Collection Form (one per group)   + Inclined Plane Data Calculation Form (one per group) * A grooved inclined plane approximately 2 to 2-1/2 meters long. The angle of incline should be adjustable from 5 to 10 degrees. You can easily make this by nailing two 2” x 4” x 93” pre-cut studs together flat-side to flat-side. Pre-cut studs have slight radii on the edges, and nailing them together forms the groove. Use a piece of sandpaper wrapped around a dowel or other cylindrical object to sand the groove very smooth. Nail a ball stop to the bottom end of the incline; a piece of metal cut from a tin can gives a resounding “whack” when the ball hits it. The angle adjustment can be as simple as a stack of books. * A steel ball bearing 12 to 25mm in diameter. * A water clock (see Websites and Resources for additional information on water clocks). You can make one from a 5-gallon plastic bucket by drilling a hole as near as possible the bottom and inserting a length of 6mm plastic tubing. Use silicone tub and tile sealant to secure the tubing. Allow at least 24 hours for the sealant to dry. A tubing clamp will be used to start and stop the flow of water. * A small beaker or container to catch the water. * A triple beam balance or digital scale to weigh the water in the container. Or for even more authenticity, use a pan balance scale with a weight set. * A meter stick or other measuring device.  Technology resources  * Computer with data projector (or other means of showing students a portrait of Galileo and other visual aids). |
| **Safety** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge** | * Students should have previously learned the Scientific Method of inquiry. * Students should have completed **Lesson 1: Galileo’s Ball Drop Experiment: What would he have learned—if he had done it?** |
| **Facilitator Preparations** | Teacher should procure materials ahead of time, and have materials set out for student use. |
| **Activities** | * Introduce this lesson by showing the students of a portrait of Galileo and ask them to think about the state of technology in his lifetime (1564 – 1642).   + Ask the question “How good were clocks in Galileo’s day?” Give students time to offer their opinions and then tell them that the first mechanical clocks appeared in the first half of the 14th Century, but they were large and inaccurate. Christiaan Huygens made the first pendulum clock in 1656 that was accurate to within 1 minute a day. Interestingly enough, Galileo studied the motion of the pendulum as early as 1582 and even sketched out a design for a pendulum clock, but he never built one. The most accurate way of measuring time available to him was a water clock. Show them a picture of a water clock and explain how it works. Then point out the water clock in your classroom.   + Ask the question “How easy is it to measure how far a ball has fallen at any given point in time?” The discussion should be that it is very hard to do. Tell them that Galileo came to the insightful conclusion that a ball rolling down an inclined plane would react just like a free-falling ball, but slower. And the plane itself would provide the means of measuring where the ball was at a given time in its descent. Point out the inclined plane in your classroom. * Break the students into groups of four and ask them to design an experiment using the materials in the classroom (inclined plane & ball, water clock, small beaker, triple beam balance, and meter stick or substitutes for these items). Give them the handout to guide their discussions.   + During this discussion, circulate around the room and observe what the students are discussing. Try to interfere as little as possible, but ask leading questions to get the groups on track (“How will you measure the time—is ‘grams’ a suitable unit of time for this experiment?”; “Does it matter that the bucket is getting less and less full?”; etc.)   + 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. * After the groups have developed their proposals, give each group the opportunity to explain their process. Then have the whole class vote on which elements of the proposals to include in the actual experimental procedure. Some items to look for (or ask leading questions about):   + The experiment should include multiple trials so that an average can be taken for each measurement.   + The beaker should be weighed empty, and its empty weight should be deducted from the measured “time.”   + The same person who starts the ball rolling should start and stop the water clock.   + It is easier to start the ball at varying distances from the bottom than to stop the clock when the ball passes a certain point (this idea may not come out in the initial design, but it should become apparent as the trials are accomplished).   + The water clock should be refilled to a pre-determined level after every trial (decreasing depth of water results in reduced flow). * After the class has reached a consensus on how to do the experiment, let each group carry out a number of trials based on this consensus. The entire class will use the data from all of the groups.   + When the trials are over, have each group collaborate on averaging all trials of the same distance and then graphing the data, using distance as a function of time.   + The students should be able to draw some conclusions about the speed (distance over time) of the ball 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 the longer the ball rolls the faster it rolls. This should allow you to introduce the concept of acceleration due to gravity. It is possible that one or more students may recognize from the graph that the distance is proportional to the time squared. If not, bring this out by asking about the shape of the curve (parabolic) and whether or not they are aware of a mathematical function that has this shape. * Collect and evaluate the experiment design and data calculation forms. |
| **Assessment** | * The discussion activity at the end of the lesson should be used as a formative assessment of the class’s understanding of the acceleration of bodies rolling down an inclined plane, and by extension, free-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:     - What makes a ball roll down an inclined plane?     - Does a ball rolling down an inclined plane respond to gravity in the same way that a free-falling ball does?     - A ball rolling down an inclined plane loses height slower than a free-falling ball--what happens to the "rest of the speed?"     - Does the ball roll at a constant speed, or does it get faster as it rolls down the incline?     - How does the distance traveled by the ball relate to the length of time it is travelling?     - Did any of you recognize the shape of the graph that you plotted?     - What function produces a graph of that shape?     - What kind of assumptions can we make about free-falling objects based on what we observed for balls rolling down and inclined plane?     - Is this sound scientific reasoning, or have we "assumed facts not in evidence?" * 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. * Water clock: a device used to measure the passage of time by allowing water to flow from a small hole in a vessel. * Speed: a measure of the distance an object moves in a specific period of time. |

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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** | Galileo Galilei portrait:  http://commons.wikimedia.org/wiki/File:Justus\_Sustermans\_-\_Portrait\_of\_Galileo\_Galilei,\_1636.jpg  Leaning Tower of Pisa photo:  <http://commons.wikimedia.org/wiki/File:Leaning_tower_of_pisa_2.jpg>  Information on what a KWL exercise is:  http://www.readwritethink.org/classroom-resources/printouts/chart-a-30226.html  Information on the Scientific Method:  <http://www.sciencebuddies.org/science-fair-projects/project_scientific_method.shtml>  <http://www.sciencemadesimple.com/scientific_method.html>  http://www.buzzle.com/articles/steps-of-the-scientific-method.html |
| **Supplemental Information** | An excellent book by Galileo’s preeminent biographer and a good source of background information on his scientific work:  Drake, Stillman. (1978). Galileo at work: His scientific biography. Chicago: The University of Chicago Press.  These are two interesting websites on Galileo’s experiment, and provide additional background. The second one has quite a few links to other relevant websites.  <http://www.jimloy.com/physics/galileo.htm>  <http://www.juliantrubin.com/bigten/galileofallingbodies.html>  This website has an interactive demonstration of Galileo’s experiment, which may be downloaded for free and used in the classroom.  <http://demonstrations.wolfram.com/GalileosExperimentAtTheLeaningTowerOfPisa/>  Background information on 1-dimensional motion of falling objects may be found at:  SparkNotes Editors. (n.d.). SparkNote on 1D Motion. Retrieved December 16, 2010, from <http://www.sparknotes.com/physics/kinematics/1dmotion/>  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 |
| **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/  * If time permits, the water clock can be calibrated using a stop watch, and the time measurements in grams can be converted to seconds, allowing the students to convert the speeds to centimeters per second. |
| **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. |