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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 1: Galileo’s Ball Drop Experiment: What would he have learned—if he had done it? |
| **Introduction** | In this lesson, students will be briefly told about Galileo’s most famous experiment (which he most likely did not conduct) and will be asked to come up with their version of the experiment. The class will be divided into groups and each group will be asked to design and conduct the experiment. Groups will present their findings to the class, and a consensus outcome will be developed. 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 (Required)** | * Students will demonstrate the ability to design and conduct scientific investigations to answer questions about falling objects. * Students will understand one-dimensional linear motion as it relates to falling bodies. |
| **Time Required and Location (Required)** | 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 (Required)** | * Computer with data projector (or other means of showing students a portrait of Galileo). * Dry erase board or flip chart with markers (for KWL exercise). * Galileo and the Leaning Tower of Pisa Handout (one per group of 4 students). * Lab Report Form Handout (one per group of 4 students). * Rubric for Lab Report * An assortment of balls of different sizes and masses (basketballs, baseballs, softballs, golf balls, steel ball bearings, marbles, etc.—low density balls such as ping pong balls and beach balls may be made available but be prepared to explain why their use resulted in incorrect conclusions). * (Optional) Stopwatches, triple beam balance or digital scale, meter sticks, 25’ measuring tape. Students may propose to use these items, but none of them are necessary to complete the experiment. * Locations from which the balls can be dropped: small balls do well in the classroom, but you should be prepared for some groups to want to go on top of the building or to the top of the gym bleachers!  Technology resources  * Computer with data projector (or other means of showing students a portrait of Galileo). |
| **Safety (required)** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge (Required)** | * Students should have previously learned the Scientific Method of inquiry. * Refresh the students’ memory of the steps in the Scientific Method (see resources). Be sure to include a review of the Critical Vocabulary.   + Note: In the interest of time, this lesson omits the Background Research step of the Scientific Method; however, the information given in the handout serves the purpose of background research for this lesson. Additionally, conducting extensive background research on this topic would lessen the discovery component of the lesson. |
| **Facilitator Preparations (Required)** | Teacher should procure materials ahead of time, and have materials set out for student use. |
| **Activities (Required)** | * Begin the lesson by showing the students a portrait of Galileo Galilei (see resources) and asking if they know who it is. * Then conduct the KW part of a KWL exercise (see resources) about Galileo (note: this exercise is done with the group, not individually). * If the Leaning Tower of Pisa Experiment myth comes out in the KWL exercise—great! In any case, divide students into group of four and give each group a copy of the handout. * Ask each group to discuss the handout and to design an experiment that would meet the requirements of the handout. * 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 use different size objects?” or “how will you know if they are falling at the same speed?”) 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. * As each group completes its experimental design, review their proposal to be sure each major category has been filled in and look for evidence the following essential elements:   + Does the design call for using balls of different masses?   + Does the design call for multiple trials?   + Does the design call for observing the balls hitting the ground at the same (or different) times? * After you are satisfied with a group’s design, allow them to perform the experiment. This may require some time and space management, as some groups may want to go to other locations in the school or on campus to perform their experiments. Use your best judgment in this situation, follow school policies, and be aware of safety considerations (the roof of a building without parapet walls might not be a good location for dropping things!). One option would be to have the groups decide on a drop location by consensus, and then go to that location as a class when all groups are ready. * After the experiments are completed, bring the groups back together, and allow them to share their results in a class discussion, completing the L part of the KWL exercise. The goal of this discussion should be to reinforce the concept that objects of different masses fall at the same rate. Additionally, the discussion should clear up any erroneous conclusions or ideas that the students may have. (Note: If you are pressed for time, this activity may be omitted or preferably saved for the next class period.) * Collect and evaluate the lab report forms. |
| **Assessment (Required)** | * The discussion activity at the end of the lesson should be used as a formative assessment of the class’s understanding of the Scientific Method and the nature of 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:     - Why do balls fall when you drop them?     - Is gravity the same everywhere?     - Do balls of different masses falling from the same height strike the ground at the same time?     - Do balls of different sizes falling from the same height strike the ground at the same time?     - Why wouldn't a feather and a ball hit the ground at the same time?     - Did you notice some balls that did not strike the ground at *exactly* the same time? What do you think caused this?     - What was the hypothesis for our experiment?     - What was the research question?     - How do a hypothesis and a research question differ? What do they have in common? * 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 (Required)** | * Conclusion—the answer to the research question and how you know that it is the answer. * Data—information collected as the result of doing an experiment. * Experimental design—what the experiment will be like. * Hypothesis—what you propose the outcome of the experiment will be. * Mass—the property of matter that causes it to have weight in a gravitational field. * Procedure—what you will do in the experiment. * Research question—the question that is to be answered through experimentation. |

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| **Modifications (Optional)** | 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 (Optional)** | 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**  **(Optional)** | 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 (Optional)** | 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 (Optional)** | 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. |