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| **Title** | Lesson 4: Galileo’s Ball Drop Experiment—what did we leave out? |
| **Introduction** | In this lesson, students will reflect upon an experiment they designed and carried out—a version of Galileo’s ball drop experiment. They will be asked to engage in a thought experiment to consider alternative outcomes to their results if various changes are made to the experiment. The idea is to get students to think about some of the assumptions that are generally made in an introductory physics course–and to learn a little about air resistance and drag. |

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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 analyze a completed experiment and speculate on what the outcomes might have been if the conditions of the experiment were altered. * Students will be able to describe the reasoning behind making certain assumptions when designing an experiment. * Students will construct a cause and effect relationship for air resistance as force acting on a falling body. |
| **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. * Triple beam balance or digital scales. * Modeling clay. * A large feather (think turkey, not peacock), or even a section of a feather boa. * Handout for group activity—*Galileo's Ball Drop Experiment: what did we leave out?* * Answer Key for group activity—*Galileo's Ball Drop Experiment: what did we leave out? Answer Key*. * Rubric for group activity—*Assessment Rubric for Galileo's Ball Drop Experiment: what did we leave out?* |
| **Safety** | Students should follow typical lab safety procedures. |
| **Participant Prior Knowledge** | * Students should have completed the Galileo’s Ball Drop Experiment lab. * This lesson should be taught following the unit on air resistance. * The teacher will need to make a small ball of modeling clay that has the same mass as the feather. |
| **Facilitator Preparations** | Teacher should procure materials ahead of time, and have materials set out for student use. |
| **Activities** | * Begin the lesson by asking the students to call out words related to the Galileo Ball Drop Experiment, and write them on a flip chart or dry erase board. Words that may be mentioned will include: gravity, weight, mass, acceleration, balls, force, data, hypothesis, theory. It really doesn’t matter what the words are; this is merely an exercise to get the students thinking about the experiment. * Then ask why these words are not on the list: friction, air, vacuum, shape, resistance, drag. * Tell them that these are all “inconvenient” factors that we (and scientists throughout history) totally ignored. * Show them that the clay ball and the feather have the same mass (weigh them in front of the class), and then drop the two items simultaneously from above your head. The clay ball will hit the floor first every time. * 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 as a group.   + 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:     - What is the most apparent difference between the feather and the ball?     - Why does shape matter?     - Would shape matter in a vacuum?     - Is there anything wrong with eliminating extraneous variables from an experiment?     - Can you even do an experiment without eliminating some variables? * 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:   + The demonstration does not prove that objects of the same mass fall at different rates, because mass is not the only factor in the demonstration.   + The shape of the objects (specifically surface area and aerodynamics) influenced their rates of fall.   + Only balls were chosen for the ball drop experiment to specifically eliminate the influence of shape.   + There is nothing wrong with designing an experiment that eliminates certain factors; in fact an experiment that contains extraneous factors can often lead to incorrect conclusions.   + If the experiment were performed in a vacuum, you could change the shapes of the objects.   + Whether or not the students would change the experiment in any way and their reasoning behind it is more philosophical than scientific, and can be used as a springboard to a broader discussion of science and society in general. Let students talk and express their opinions! * 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:     - If gravity works in a downward (negative) direction, in which direction does air resistance work?     - Can air resistance ever be greater than gravity?     - Is it "cheating" to design experiments that eliminate some variables?     - How does a parachute work?     - Why do rockets/trains/airplanes/bullets have rounded noses? * 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 velocity of an object * Air resistance—a force caused by air acting in the opposite direction to the movement of an object through the air. * Drag—the force caused by air resistance * Gravity— the force that attracts a body toward the center of the earth, or toward any other physical body having mass * Mass—the amount of matter that an object contains * Weight—the force of gravity on an object; weight equals mass times the acceleration of gravity (w = m x g) * Vacuum—an absence of matter; an empty space completely devoid of anything, including air * Velocity—the rate of change of the position of an object |

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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 is an excellent discussion of the forces affecting a falling object (including air resistance) and can be used by the teacher as background reading on content or for student enrichment.  NASA. Forces on a falling object (with air resistance).  <http://www.grc.nasa.gov/WWW/k-12/airplane/falling.html>  This resource may be used by the teacher as background reading, or for student research.  The Physics Classroom. Elephant and feather – air resistance.  <http://www.physicsclassroom.com/mmedia/newtlaws/efar.cfm>  The Free Fall Air Resistance Model (written by Andrew Duffy) is a ready-to-run Java archive file that illustrates two falling objects, one affected by air resistance and one not affected. It is available from comPADRE, an online physics and astronomy education community at:  <http://www.compadre.org/Repository/document/ServeFile.cfm?ID=10002&DocID=1641&DocFID=2835&Attachment=1>  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. |