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| **Title** | **Follow the Bouncing Ball: A Data-Driven Investigation of Complex Models through Basic Newtonian Mechanics** |
| **Introduction** | Bouncing a ball is quite simple. You can let go of a ball and let the force of gravity pull it down or you can exert a force on the ball yourself and throw it to the ground. Either way, the predictions regarding the motion and interactions are quite simple: the ball will hit the ground and reflect back in the direction it came from. While the behavior of a single bouncing ball is straightforward, this simple element can be used to view a bigger picture. This model can yield complex and interesting dynamics with connections to advanced topics and applications. Students will investigate the bouncing ball from multiple perspectives based on their units of study in the course. They will start by discussing the energy and momentum transfers, and motion of the ball and will further their understanding by applying these concepts to much more complex situations.  In this project, the students will have the opportunity to investigate these questions and ideas with some teacher led suggestions. But overall, they will be developing their own questions and investigating them using computer-based simulations and their own lab set ups. In the end, these students will create a poster for their independent research and present in a format that is typical of undergraduate research. |
| **Real Science Application** | Research has been done on how a bouncing ball reacts with an oscillating plate using computer programs to simulate the interactions. Students will be going through this same process. They are getting the opportunity to observe interactions and think critically about what is really happening in this small model as well as apply it to more complex collisions. As they explore this particular situation they will be prompted to ask their own scientific questions and investigate how they relate to applications such as molecular dynamics within chemistry, granular materials, and structural interactions through the use of doable calculations and computers to extend the data analysis. This is a typical process for those in the statistical and physics fields. |

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| **Curriculum Alignment** | Objectives for AP Physics C: Mechanics (Grades 11-12):  A.1.b) Students should understand the special case of motion with constant acceleration, so they can:  1) Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities  2) Use the [kinematic] equations to solve problems involving one-dimensional motion with constant acceleration.  C.3.a) Students should understand the concepts of mechanical energy and of total energy, so they can:  2) Describe and identify situations in which mechanical energy is converted to other forms of energy  3) Analyze situations in which an object’s mechanical energy is changed by friction or by a specified externally applied force  C.3.b) Students should understand conservation of energy, so they can:  1) Identify situations in which mechanical energy is or is not conserved  D.3.a) Students should understand linear momentum conservation, so they can:  2) Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved  3) Apply linear momentum conservation to one-dimensional elastic and inelastic collisions and two-dimensional completely inelastic collisions  NCSCOS Essential Standards: High School Physics (Grades 11-12)  Phy1.1 Analyze the motion of objects.  Phy1.1.1 Analyze motion graphically and numerically using vectors, graphs and calculations  Phy1.1.2 Analyze motion in one dimension using time, distance, displacement, velocity, and acceleration.  Phy1.3 Analyze the motion of objects based on the principles of conservation of momentum, conservation of energy and impulse.  Phy1.3.1 Analyze the motion of objects involved in completely elastic and completely inelastic collisions by using the principles of conservation of momentum and conservation of energy.  Phy2.1 Understand the concepts of work, energy, and power, as well as the relationship among them  Phy2.1.2 Compare the concepts of potential and kinetic energy and conservation of total mechanical energy in the description of the motion of objects  Next Generation Science Standards: High School Physical Science (Grades 9-12)  Students who demonstrate understanding can:  HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.  HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). |
| **Learning Outcomes** | Participants will:   * express their ideas clearly both verbally and in writing * apply all previous knowledge to investigate inquiries in the lab * extend their physical intuition/conceptual understanding * utilize mathematical calculations * investigate topics beyond the curriculum such as chaos theory and synchronization * work through the scientific method * gain basic coding and computer skills * experience a physics conference * gain research and questioning skills * facilitate group learning and group roles * utilize time management skills * seek out connections from basic content to complex applications * prepare a presentation and organize work |
| **Time Required and Location** | * 16 class periods (90 minutes each) * Science Classroom * Will need laptops or computers so depending on what is available, students may need to relocate to a computer lab or media center if laptops cannot be obtained for the classroom * Physics Conference: If participant size exceeds comfortability in a classroom, the use of the auditorium may be required |

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| **Materials Needed** | Facilitator List:   * Bouncy balls * Paddle ball * Teach background information papers (attached at the end)   Participant List:   * Laptop or computer (minimum 1 per 2 participants) * Participant Worksheets and Rubrics (1 per participant, attached at the end) * Access to lab equipment such as motion detectors, meter sticks, timers, etc |
| **Safety** | Facilitator and Participants should wear eye protection when conducting any experiments or demonstrations using projectiles. |
| **Participant Prior Knowledge** | These activities are designed to be part of a unit on research and scientific literacy. Participants should be familiar with major concepts within the motion, energy, and momentum units as it is a review of the physics content. If the facilitator chooses to use these activities while teaching each of these units, the students should have a small base understanding of each unit before they are to complete pieces of this project. |
| **Facilitator Preparations** | Facilitators should be prepared to:   * Become familiar with Octave coding procedures * Download Octave on school computers * Reserve computers or laptops for the entirety of the unit/project * Upload Octave code on a website for easy participant access * Prepare bouncing ball demonstration * Complete individual research on chaos theory, synchronization, coupling, or any other topics they are unfamiliar with |
| **Activities** | Day 1:   * Introduce the idea of a bouncing ball (use tennis balls) * Have students get in groups of 3-4 to investigate a bouncing ball scenario * Students should be prepared to collect qualitative data on the follow topics:   + motion and kinematics   + types of energy, conservation of energy, transfer of energy   + types of collisions * After collecting data, follow a *Think, Pair, Share* model   + groups collected data for think   + groups will pair up with a new group for pair   + pairs will share out in the class for share * Identify any misconceptions or patterns in the student’s thoughts and observations * Bring their attention to anything critical they may have missed through facilitative questioning * Ask the class how they may be able to determine the max height of the first bounce of the ball through calculations * Provide them with the worksheet entitled “*When does the ball hit the plate?”* and allow them to fill in the information on the top diagram * Walk through the first few steps of the kinematics calculations and depending on how the students are doing, either allow them to attempt to finish them, or continue working through them as a class * To end the class, pose the question: *What if the ball was bouncing on an oscillating table/plate instead of on the ground?* * Have them return to their original groups of three or four and write up their ideas and thoughts to turn in as an exit slip and “pre lab” for tomorrow’s investigation.   Day 2:   * Return their exit slips with feedback * Identify good ideas by having specific groups share out pieces of their thoughts * Have students investigate the paddle balls and have them complete the same type of qualitative data collection from the previous day but apply it to the new situation * After collecting data, provide them with the worksheet entitled “*The Oscillating Plate”* and allow them to sketch a graph of the ball’s motion as time progresses as well as a separate graph of the plate’s motion as time progresses * Have students come to the board to draw out the different graphs and have more students add their graphs if they don’t see their graphs represented * Have students defend their graphs and have the group ask each other questions to lead to identifying which graphs are correct * Once graphs are completed, walk through the mathematics of how to determine where the ball will hit the plate by asking the students prompting questions such as:   + What equations will be necessary to use?   + How will we be comparing the motion of the two objects?   + How do they interact? and how can we relate those interactions mathematically?   + What pieces of information are important and why? * Have students complete an exit slip answering the following questions:   + What do I still have questions about?   + Where am I still struggling?   + What do I want to learn more about?   + What was the best part of today?   Day 3:   * Complete computer tutorials on Octave (see attached worksheet “*Octave Tutorials”)*   Day 4:   * Complete Octave data analysis   Day 5:   * Introduce how to ask a good question * Provide students with an opportunity to get in groups of 2-3 and develop questions they would like to investigate   Day 6:   * Groups pick a question to investigate and create an outline for a procedure * Students present their investigation proposal to the entire class * Other groups ask questions and give feedback on their procedure and question to help fine tune the question   Day 8 and beyond:   * Students work in groups to collect and analyze data through their own experiments   Last day:   * Students present their research in a poster session to their peers, teachers, and community members |
| **Assessment** | Rubrics will be provided for each of the following steps/pieces outlined below:   * Exit slip from day 1 (formative) * Exit slip from day 2 (formative) * Group question brainstorming * Group proposal * Task Outline with roles * Abstract submission * Poster * Poster Presentation |

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| **Critical Vocabulary** | Chaos Theory: A field of study on the complexity of behavior of dynamical systems that are highly dependent upon their initial conditions.  Dynamical Systems: A mathematical model or description of motion of objects.  Synchronization: A phenomenon that occurs when two or more systems couple together.  Coupling: The interaction of two systems, more specifically two or more oscillating systems.  Conservation of Energy: A fundamental law of physics which states that the total energy of a system remains constant.  Conservation of Momentum: A fundamental law of physics which states that the momentum of a system is constant (conserved) if there are no external forces acting on the system.  Kinematic Equations: A set of equations used to describe and represent the motion of objects. See attached worksheet for equations themselves.  Collision: When one object comes into contact with another. There are two main types of collisions that students deal with: elastic and inelastic.  Elastic: momentum and energy are conserved  Inelastic: momentum is conserved, energy is dissipated  Impact: The action of one object coming into contact with another causing a transfer of momentum.  Coefficient of Restitution: The ratio of the velocity of an object after a collision to the velocity of the object before a collision, reflecting the level of conservation of energy.  For a list of the Octave coding terms please see attached document: *Octave Coding Terms* |
| **Community Engagement** | * Presentations to peers, teachers, and community members through a poster session format * Sharing participant work or projects through promotion around school * Guest speakers to come talk at their physics conference |

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