Lesson Title	Projectile lab "Siege that castle!"
Length of Lesson	1 day
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Subject	Physics
Grade Level	9-12 (Physics)
State Standards	Physics: 1 a, b, c, d, e, f; 2 a, b, c
DOK Level	Physics: 3
DOK Application	Create, inquire, hypothesize, organize, collect, interpret, investigate, connect, explain, prove, draw conclusions, graph, predict, regress
National Standards	9 – 12 A: Inquiry; B: Physical Science; E: Science and Technology
Graduate Research Element	Working with excel for statistical analysis and presentation of collected data drawn from experimentation. Creation of range table and improving it using applied knowledge of basic calculus and physics. Importance of experimental design and development of critical excel skill set.

Student Learning Goal:
The purpose of this lesson is to recreate a medieval range table and learn the importance of experimental design and excel application/analysis. To utilize the range table (graphing through excel) to regress a quadratic equation useful for projectile accuracy; in other words, using the power of math to knock down a castle wall. The goal is to get students thinking about non linear multidirectional motion and to expand upon what they have learned about vectors, velocity, and acceleration due to gravity.

Mississippi State Standards
Physics: 1: (a) Use current technologies such as CD-ROM, DVD, Internet, and on-line data search to explore current research related to a specific topic; (b) Clarify research questions and design laboratory investigations; (c) Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations; (d) Organize data to construct graphs to draw conclusions and make inferences; (e) Evaluate procedures, data, and conclusions to critique the scientific validity of research; (f) Formulate and revise scientific explanations and models using logic and evidence; 2: (a) Use inquiry to investigate and develop an understanding of the kinematics and dynamics of physical bodies; (b) Analyze, describe, and solve problems by creating and utilizing graphs of one-dimensional motion; (c) Analyze real-world applications to draw conclusions about Newton's three laws of motion.

National Science Education Standards of Content 9 – 12

A: Inquiry: identify questions and concepts that guide scientific investigations

- Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding the hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and a conceptual understanding of scientific investigations.

B: Physical Science: motion and forces

- Objects change their motion only when net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.
- Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the square of the distance between them.

E: Science and Technology: understanding about science and technology

- Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.

Materials Needed (supplies, hand-outs, resources):

Pasco spring operated projectile launcher, plastic or wooden balls of standard size and mass, grid paper, carbon paper, meter stick, computer and excel program, cup or equivalent object to represent castle tower/wall.

Lesson Performance Task/Assessment:

- Ability to use pasco equipment and creation of range table
- Demonstrate ability to design and work lab using available materials
- Ability to create graph and regression equation using excel
- Showing work using carbon and graph paper and good note taking
- Ability to use equation to hit placed object at a set measured distance
- Completion of a lab write up or notes write up

Lesson Relevance to Performance Task and Students:

- To practice experimental design using specialized pasco equipment
- To understand the importance of experimental design by successful completion of range table, graph on excel, and regression of quadratic equation to meet objective of knocking down opponents wall with one calculated shot

- To gain insight back to medieval era (learn a bit of history) and importance of projectile motion and rise of physics (important application of physics through the rise of human civilization)
- To apply what they have learned, such as projectile motion equations/concept, and to connect, compare, and contrast to previously learned linear motion (free fall of objects affected by gravity)

Anticipatory Set/Capture Interest:
Each class table is a barbarian horde (or Celtic/Germanic tribe) that has recently "appropriated" a roman catapult. Your reigning warlord demands that you, the engineers, investigate and document the capabilities of this new siege weapon of war. Unfortunately the last pillaging and burning destroyed the range table created by the Romans. You will have to recreate this table through testing and documentation of results. Being the clever engineer that you are you realize the power of math and figure that you can improve upon this range table, and one up the Romans, by graphing it and regressing an equation useful for calculating precise projectile placement. If you are successful you will have revolutionized siege warfare and make seizing and pillaging territories far more efficient.
After class creates graph: Your warlord has grown tired of your restless barbarian neighbors and wishes to test your siege weapon on them to destroy the competition. Your neighbors wish to do the same to you so every shot counts as this looks like war. One shot one kill, the last barbarian encampment standing wins. Time to put your range table and equation to the test, the global conquest of the physics classroom begins!
Historical note: Castles and siege weaponry were at their height during the medieval era shortly after the collapse of the roman empire; however, the Greeks/Romans did utilize and pioneer siege weapons such as the ballista and grapeshot catapult. During the 1300's trebuchets and the use of range tables remained the primary method of siege warfare for hundreds of years until calculus was applied (component of physics) to replace the range table. This revolutionary application of physics contributed to the allied nations victory during world war II such as battleships shell trajectory or artillery bombardment on specific enemy targets.

Guided Practice:
Show how to use projectile launcher safely and demonstrate how to load, set the spring, and adjust the angle. Make it clear to only click into the first spring setting. Then show how to measure the horizontal distance up to the graphing paper (in cm's) with carbon sheet lain over top. Launch ball and have it hit carbon paper which leave a mark on the graph paper. Make it clear to lift carbon paper and label shot. Each table will fire 5 shots at a wide range of angles to avoid clustering of data. Each shot is done in triplicate (fired and recorded 3 times in a row at same angle). Explain the importance of triplicate recording concept by connecting graduate research with averaging and accuracy of data. Make it clear that the only measurements the students will be recording on to table (after the shot is fired) is horizontal distance and angle of attack. They should choose how to organize table; however, showing an example table for triplicate work would be

recommended as students may be working with excel for the first time. After the tables are created walk through a class demonstration of creating a graph using excel and regression of a quadratic equation from the data. Briefly explain how the formula can be used to calculate the angle or horizontal distance when one variable is known. Explain for the war scenario that each team will place their cup (castle) at any linear distance from the catapult. The team operating the catapult will measure the distance to castle and plug in distance measured into their equation. If their equation is good the projectile should hit the cup in the first shot; however, it is most likely to take a few shots due to other variables at play.
Either before or after the range table generation explain to the students that they will also calculate the muzzle velocity (initial horizontal velocity) of their projectile launcher. They must set it to zero degrees, record the horizontal distance, and record the vertical distance from floor to middle of the barrel. Give them the two projectile equations to calculate time and initial velocity in the horizontal direction. Explain that they will manipulate the first given equation to substitute time into the second equation. This way they won't have to know the time and they can plug in vertical and horizontal measured distances to calculate initial muzzle velocity. This will be homework because range table creation is more important. Especially if they are to compete in the war scenario described earlier.

Independent Practice:
Calculation of muzzle velocity and other components of projectile motion if needed, such as change in vertical direction or vertical initial velocity.

Remediation and/or Enrichment:
Remediation: individual IEP, partner with helpful student, make lesson more walk through intensive.

Enrichment: Ask for calculated vertical projectile components using their horizontal data. Have students further explain and connect applied concepts to the lab they have just completed. Have them use equations to hit more difficult targets.

Check(s) for Understanding:

- Successful completion of range table and quadratic equation
- Ability to hit target castle using equation
- Correct calculation of muzzle velocity
- Ability to explain in a report what they did and why it was important, to connect what they have learned in previous lectures about projectile motion, free fall, Newton's laws of motions, and affect of gravity

Closure:
Mention historical note stated previously or end will class discussion on Newton's laws of motion and other material that the class will be moving into beyond projectile motion.

Possible Alternate Subject Integrations:

Calculus: Regression models, line equations, and formula/algebraic calculations

Teacher notes:
Pick an open room, place launchers in areas that will avoid potential damage to the computers/other breakables, and do not use ammunition that has a lot of bounce to it. Keep an eye on the students because they can hurt themselves if safety procedures are not followed.