Lesson Title	Trebuchet lab "Part 1"
Length of Lesson	1 week
Created By	Henry Stauffenberg IV, Matthew Lee
Subject	Physics
Grade Level	9-12 (Physics)
State Standards	Physics: 1 a, b, c, d, e, f, g; 2 a, b, c
DOK Level	Physics: 3
DOK Application	Create, inquire, hypothesize, optimize, collect, interpret, investigate, connect, explain, prove, draw conclusions, graph, predict, test
National Standards	9 – 12 A: Inquiry; B: Physical Science; E: Science and Technology
Graduate Research Element	Optimization using limited material resources and limited parameters. Using academic resources to design and fabricate an optimized trebuchet with independent research and group work. Meeting a deadline and producing working results that will be used in a competition.

Student Learning Goal:
The purpose of this lesson is optimization and understanding potential and kinetic energy by calculating work output of trebuchet. Optimization using limited parameters and resources to maximize distance. To understand Newton's laws in action and gain perspective into medieval history. To strengthen teamwork skills, group and independent research, and healthy competition. To build a trebuchet that works better than the standard non optimized trebuchet built by teacher.
Note: It will take 3 classes (1.5hrs each) of lab time to design and build. Some time may be needed outside of class to tweak and build trebuchets. Normally not a problem for students who like hands on stuff and instruments of war. Launch day will have to be an open afternoon after class time or on weekend. There is a part 2! Designed by Mr. Lee as leading author, that is factored into 3 week time period with mathematical calculations and optimization design.

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.
- Conservation of energy. All energy can be considered to be either kinetic energy; potential energy, or energy contained by a field.

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):

1 trebuchet: Four 2x4x96 inch blocks of wood, one 5/8x2x2 inch particle board, one 5/8x3 inch weld steel rod, Irwin 5/8 inch wood boring auger drill bit, one power drill and tool box, angle cutter, one regular saw, one saw that cuts metal, handheld power saw, one roll twisted mason line, 1 box 4inch and 5 inch screws, 1 box 3 inch screws, 1 bottle wood glue, 1 pack assorted sand paper, a couple long nails (release mechanism), 100ft rope, 20 common red brick with holes in center, large and small C clamps, 1 tube grease, truck to transport trebuchets, spare wood, half a brick as standard ammunition, other ammunition such as pumpkins, footballs, ect. See attached handout for standard trebuchet photos and notes.

Lesson Performance Task/Assessment:

- Ability to research and find workable design for trebuchet (keep simple)

- Demonstrate ability to design and work in lab using available materials
- Inquiry about optimizing length or weight ratio for maximizing range
- Completion of trebuchet one section at a time over 3 weeks and ability to show math behind their calculations
- Development of a testable hypothesis for optimized trebuchet

Lesson Relevance to Performance Task and Students:

- Importance of research first prior to fabrication
- Utilization of available resources and inquiry
- Maximization of a complex problem with multiple solutions
- Understanding parameters and the purpose of optimization
- Teamwork and meeting the deadline skill focus
- Application of physics and math to produce real life siege weapon (appreciation for ancient history and perspective)
- Following scientific process starting with creation of a hypothesis that involves maximizing throwing distance

Anticipatory Set/Capture Interest:

They are building an ancient instrument of war and will throw large objects across an open field. If that does not do it show a few internet videos of huge trebuchets in action. Any excuse to break the boring routine of the classroom students will take; to relive and gain insight into medieval history by application of physics. It gives Newton's laws purpose to the students. Also their are catapult competitions that schools such as Old Miss sponsor every year.

Historical note: Castles and siege weaponry were at their height during the medieval era shortly after the collapse of the roman empire. Using gravity 300 pound boulders could be launched hundreds of yards using 20,000 plus pounds of counterpoise weight, often more rocks. Trebuchets were originally invented by the Chinese and was later perfected by the French. They were so effective and reliable that Napoleon (16th century) continued to use the trebuchet for siege purposes despite the invention of the early cannon. Physics is power showing that people of the medieval era were smarter than we give them credit for.

Guided Practice:

Build a trebuchet (non optimized) for the students to look at and model after. Keep it simple and no bigger than 4ft tall and no more than 12 bricks counter weight. See photos attached to lesson plan to get idea of simplicity, bricks for counter weight, and how the mentioned materials tie together. Students will have to optimize the length of the throwing arm and the weight ratio between ammunition and counter weight. They will inquire using math, internet, and other resources which is more important?; a long throw arm, high weight ratio, increasing distance which counter weight falls, or angle of attack? What is the balance between them (optimized) to yield the greatest distance for half a brick. Ask for their hypothesis and reasoning behind their research before they build. Stress measure twice and cut one.

Don't let their trebuchet frame exceed 6ft or counter weight exceed 20 bricks. Albeit the parameters are the limited wood and 4ft height, it is possible to use the available wood to increase height beyond 4ft through optimization. After all, the standard trebuchet is not meant to maximize distance potential. Students will have to tweak the standard design based on researching other designs, using calculus to find the optimal launch angle, and calculating launch arm length an weight ratio described in part two of this lesson. The teacher will use the power saw (skill saw) for wood cuts to avoid legal issues. Safety first must be maintained at all times.

Watch students as they build and be present to answer all trebuchet related questions. Make sure progress is made by pushing students not to stay too long designing or on any other single task. The simple trebuchet can be made is 2.5 hours time, students will need to be guided to meet the time deadline and stay focused; in other words, don't let them get lost in details. Some homework will have to be assigned and having students think about the design plan before the build (1 week in advance) is always helpful.

Independent Practice:
Independent research to present to group about trebuchet math and design.

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

Enrichment: Introduce more parameters and ask questions that require students to calculate the conservation of energy produced from machine at launch day. Ask what they could have done to increase optimization after results from launch day and explain it using more advanced math and physics.

Check(s) for Understanding:

- Successful completion of optimized trebuchet
- Ability to use trebuchet and achieve a greater throw distance than standard trebuchet
- Ability to defend why they built their trebuchet they way they did and what components were optimized
- Answering hypothesis and questions specific to what is more important in trebuchet design with respect to optimization
- Ability to utilize results to explain what is going on with respect to what they have learned and optimized

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

work, and projectile motion. Launch fun materials such as pumpkins and test the limits of the trebuchets to the breaking point (assuming they have no more use and need to be recycled).

Possible Alternate Subject Integrations:

Calculus: Regression models, graph equations, and formula/algebraic calculations
Geometry: Angle and projectile motion
Engineering: Optimization and mechanical design/work
History: Insight into ancient siege weapon that influenced history, understanding by design and gaining of perspective, enhancement of a academic report detailing warfare history and Isaac Newton

Teacher notes:
Students will have to spend some free time finishing trebuchets because 3 weeks is a tight deadline. Allow 3 hours for launch day that is after school. Stay with groups of 4 per trebuchet.