Lesson Title	Statistical Design of Experiment with a Catapult
Length of Lesson	1 Day
Created By	William Funderburk
Subject	Physics
Grade Level	10-12 (Physics)
State Standards	Physics: 1a, g
DOK Level	DOK 4
DOK Application	Design, Apply Concepts, Analyze
National Standards	9 – 12: B (physical); E (technology)
Graduate Research Element	Statistical treatment of data

Student Learning Goal: This lesson was prepared for a 12th physics class taught at the Mississippi School for Mathematics & Science, but it can be implemented in any high school science classroom. This lesson is designed to provide a DOK 4 level of understanding for Mississippi State Science Standards Physics: 1a, g; with Advanced Enrichment.

Physics: 1. Apply inquiry-based and problem-solving processes and skills to scientific investigations: (a) Use current technologies such as CD-ROM, DVD, Internet, and on-line data search to explore current research related to a specific topic; (g) Collect, analyze, and draw conclusions from data to create a formal presentation using available technology (e.g., computers, calculators, SmartBoard, CBL's, etc.)

National Science Education Standards of Content 9 – 12
A (Inquiry): identify questions and concepts that guide scientific investigations.

E: (Science and Technology): abilities of technological design; understanding about science and technology

Materials Needed (supplies, hand-outs, resources): Small toy catapult with variable angle of release, meter tape, wood balls / ping pong balls or plastic (practice) golf balls

Lesson Relevance to Performance Task and Students:
These lessons and performance tasks will increase students' interest in the subject through the use of technology resources (programming language, PowerPoint, internet) to generate a data set and create a presentation of their design process and result.

Anticipatory Set/Capture Interest:
The teacher will set up the catapult and make tosses with two different projectile types. Have the students brainstorm for factors that determine horizontal distance of the tosses. They might include environmental factors as well as 1. Angle of release and 2. Projectile type. Then have them discover that these two factors are the factors that the designer can control.

Have the students organize themselves into the following engineering teams:
Field Engineers: set up engineer, shooter, inspector, data recorder
Design Engineers: project manager and staff

Now introduce the following scenario:
Imagine we are asked by Nissan North America to design a large catapult of the same design (but larger) for the purpose of tossing Toyotas. In order to optimize the horizontal throw of the catapult, it will be necessary to gain data concerning the yield while varying the factors which determine yield. But cars are expensive. Each data point will cost approximately $30,000. How do we gain the most empirical information about the catapult while minimizing the cost of the experiment?

Guided Practice:
The worst option is called OFAT (One Factor at a Time) where one factor is held constant while varying all the others, and in turn, holding each factor constant while varying all others. (This method isolates independent variables only, and cannot account for interactions between factors.) OFAT will be too expensive for our purposes.

A better option is called Factorial Design and requires one run per projectile type, maximum to minimum. This will total four runs.

Next use leading questions to "tease-out" the issue of replication to average out random errors. At least one replication will be required to satisfy the issue and minimize cost.

Next use leading question to "tease-out" the issue of apparatus degradation. The catapult string tension will degrade with repeated use. This degradation will introduce variance for yield which will depend upon the order of throw. Without randomization of trial order, the variance will be systematic. Then have the students devise their own method of randomization of the order of trials. This will total four runs with two trials each, for a total of eight (8) trials, each costing approximately $30,000.

Have the student "engineers" carry out the experiment. Each trial costs the "project" about $30,000 so re-enforce the idea that they only have only eight "cars" to throw.

Independent Practice:
With the experiment designed, have the students graph yield vs. angle of release for each projectile type on the same graph, where the legend is the projectile type, i.e., big Toyota and little Toyota.

A parallel "shape" on the graph for the two projectile types would indicate that the two factors / variables are independent. A non-parallel "shape" on the graph for the two

projectile types will indicate an interaction between the two factors / variables. This graph is called an "Interactions Plot."

With the graph, you have given the students their first statistical discovery of interaction between multiple factors (where it is not possible to isolate independent variables.)

Remediation and/or Enrichment: individual IEP; partner help throughout lesson; shorten parts of assignment; focus upon smaller elements of the process

Enrichment/Extension:
Have the students prepare a Power Point presentation of their design of experiment. Set up a seminar which includes students from other science classrooms as an audience for the student team design presentations. Have the panel of teachers offer suggestions for improvement for student presentations.

Check(s) for Understanding:
Do the students understand the need for minimal costs? (OFAT vs. Factorial Design) Do the students understand the need for replication? Do the students understand the need for randomization?

Do the students understand how to generate the Interactions Plot and the meaning of its "shape?"

Closure:
What do engineers spend most of their efforts actually doing? In truth, engineers spend much of their professional lives designing experiments in competition with other engineers and engineering firms to maximize efficiencies and to minimize costs of experiments. This activity allows students to discover the process of "the design of experiment" to maximize the efficiency of a Toyota Tossing Catapult and minimize the cost of empirical discovery. Welcome the students to the world of engineering.

Possible Alternate Subject Integrations:
*Math – can manipulate mathematical expressions to isolate needed variables

*Programming/Computer Science – can use a programming language to generate computations over a range of variables

*Language Arts – (with Advanced Enrichment) can use PowerPoint to deliver a public presentation of an engineering design