Lesson Title	Numerical Determination of Drag Coefficients
Length of Lesson	3 days
Created By	Jed Leggett
Subject	Physics
Grade Level	11-12 (Physics)
State Standards	Physics: 1 c, d; 2 a, b;
DOK Level	DOK 4
DOK Application	Apply Concepts, Analyze
National Standards	9-12: B (physical);
Graduate Research Element	Use of numerical techniques to approximate the solution to a differential equation.

Student Learning Goal:
Students will study the motion of falling objects experiencing drag by making videos of the motion and analyzing the motion using Logger Pro by Vernier. Students will also use a simple finite difference algorithm to calculate the acceleration of the objects. Finally students will model their acceleration data with a second order polynomial in order to determine drag coefficients that can accurately characterize the surface of the object.

Mississippi State Standards - Physics:
1. Apply inquiry-based and problem-solving processes and skills to scientific investigations: (b) Clarify research questions and design laboratory investigations; (c) Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations (e.g., hypotheses, experimental design, observations, data analyses, interpretations, theory development).
2. Develop an understanding of concepts related to forces and motion: (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 (e.g., position, distance, displacement, time, speed, velocity, acceleration, the special case of freefall).

National Science Education Standards of Content 9-12
B (Physical): Objects change their motion only when a 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 be calculated using the relationship F=ma, which is independent of the nature of the force.

Materials Needed (supplies, hand-outs, resources):
Coffee filters, large clear plastic graduated cylinders, small spheres of different masses all approximately the same size, enough soap to fill graduated cylinders, digital video cameras (phones with large enough frame-rate will work e.g. iPhone 3G and up), computers running Logger Pro and a spreadsheet software (e.g. Excel)

Lesson Performance Task/Assessment:
In this lesson, students will study the motion of falling objects experiencing drag and determine the drag coefficients needed to model the motion. Students will make a video of the motion of an object falling with drag. Students will import the video into Logger Pro and use the software to record distance and time data. Students will then export this data into a spreadsheet program, where they will use the Euler method to calculate velocity and acceleration. Finally, using their acceleration data, students will perform a second order polynomial fit to find the first and second order drag coefficients.

Lesson Relevance to Performance Task and Students:
This lesson will provide students with new methods of data acquisition and analysis. Student will be required to use multiple pieces of software to accomplish a detailed analysis of a real-world physical process. This lesson will also help move student conceptions beyond those found in the idealized world of introductory mechanics by incorporating the complication of drag forces.

Anticipatory Set/Capture Interest:
The teacher will present a physics demonstration where a penny and a feather are both dropped through a clear plastic cylinder. First, the penny and feather are dropped under normal air pressure, and of course the penny falls more quickly. After that, the teacher uses a hand pump to evacuate the majority of the air from the cylinder. Under these conditions, the two objects fall at nearly equal rates. (This apparatus can be made easily by the teacher, or can be ordered from scientific vendors such as Arbor Scientific.)

Guided Practice:
Day One:
The teacher will show a premade video of a coffee filter falling from a particular height. The teacher should make the film before class and choose a location with a dark background in order to see the coffee filter best. An object of known length should also be placed in the video for reference (a meter stick works well). The teacher will demonstrate the process of setting an origin, setting a scale, and recording data points using Logger Pro. The students will then begin making their own videos while the teacher advises individual groups of particular pitfalls they may experience.

Day Two:
The teacher will discuss in more detail the motion of the coffee filters from the previous class, noting the regions of constant and non-constant slope and explaining these regions in terms of terminal velocity and decreasing acceleration. The teacher will then demonstrate the process of dropping a steel ball through a graduated cylinder filled with soap and give tips for making videos of this motion.

Day Three:
The teacher will demonstrate how to export data from LoggerPro to a spreadsheet program. The teacher will then give a brief lecture on finite difference methods explicitly giving the formulas for the Euler method of numerical differentiation. The teacher will guide students in analyzing their data from the previous classes using numerical differentiation to determine the drag coefficients.

Independent Practice:
Day One:
Students will make videos of coffee filters falling through the air. They will vary the mass of the object by stacking multiple coffee filters. Once the students have finished making their videos, they should begin recording their data in Logger Pro.

Day Two:
Students should review their data from the previous class in light of the explanation given by the teacher. If the data does not fit the model presented by the teacher, the students should make new videos of the coffee filters. Once students are finished making videos of the coffee filters, they should begin making videos of the objects falling through the soap. Again, an object of known length should be placed in the video for reference; in this case a 1ft. ruler should suffice.

Day Three:
Students should finish making any videos that were not finished in previous classes. Students will then import their data into a spreadsheet program and begin their analysis. Students will most likely not finish all of their analysis in class, and should be assigned a report for homework.

Remediation and/or Enrichment:
R: individual IEP; partner help throughout lesson

E: There are many opportunities for enrichment in this lab. Students can use a more complicated numerical derivative formula to produce more accurate results. The first order differential equation for drag is also accessible to high school students and has a simple analytic solution.

Check(s) for Understanding:
From the graph of your data, how do you know when the object has achieved terminal velocity? Does our first order equation accurately describe the drag acting on the objects? How might we better model the motion?

Closure:
At the beginning of the next class, students should discuss problems they had and compare results among groups.

Possible Alternate Subject Integrations:
*Math – In this lesson, students are introduced to numerical approximation techniques that can be covered much more rigorously in a high school calculus class.

Teacher Notes:
The teacher should definitely perform this lab on their own before introducing it to students. There are many places to make simple mistakes.