Computation and Coulomb – Aaron Oppenheimer

Purpose

Coulomb’s Law is a fundamental aspect to the general physics curriculum, and is an excellent step to understanding how many physical phenomena are linked in an abstract mathematical context. Basic electrostatics also present an apt environment to utilize computation and simulation to provide students with a “hands-on” feeling for behaviors that are difficult to appreciate, certainly at the scale at which Coulomb’s Law originates. This lesson is aimed at allowing students to relive Coulomb’s experience of discovering electrostatic interactions, and to go through the scientific method toward empirically developing a law to explain said interactions.

Overview

The focus of this lesson is to deliver Coulomb’s Law to the students through simulation-driven discovery. Since the intended goal is for students to develop Coulomb’s Law independent of prerequisite knowledge, it is crucial to frame the activity in the context of the scientific method. The lesson has two primary aspects to reach this goal.

The class should open with a discussion framed toward recalling and detailing the scientific method. The method applied here is simplified, in that to adequately recreate Coulomb’s experience, students should be dissuaded from pursuing background research (which should still be presented as a crucial step in the process). Mainly, it should be impressed upon that in discovering new phenomena, students should ask a question, pose a hypothesis, performed a controlled experiment, and finally revisit their hypothesis to evaluate its validity. There should be a few details with heavy emphasis, namely how to properly construct a hypothesis, and how to perform a controlled experiment to analyze the dependence of one variable upon another. After this discussion, if the students are unfamiliar with NetLogo, it is helpful to demonstrate the basic functionalities associated with the simulation environment. So as to not give anything away, it is sufficient to show the students how to setup and start a simulated experiment, and further how to interact with the simulated world.

Following the discussion and potential demonstration, students should group together to work through the simulated experiments using the NetLogo program provided. The worksheet provided gives a brief introduction to the experiment that Coulomb ran, and walks students through the discovery process. The worksheet provides students with the questions necessary to start the scientific method, but it should be emphasized that each experiment should have its own hypothesis. After the activity is completed, which should take around 30 minutes, call the students back for a brief discussion; if the period is longer than an hour, a prolonged discussion in which students can discuss their results and finally compare their forms of Coulomb’s Law is highly suggested. Additionally, the students’ attention should be directed at one point or another to the analog between the electrostatic force they worked with in this activity and the gravitational force put forth by Newton. The connection between these two phenomena (that occur on massively different scales) is very helpful in introducing interesting research avenues in later topics like wave functions and optics.

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Student Outcomes

- Students will be able to construct hypotheses aimed at elucidating nonlinear relationships.
- Students will be able to demonstrate and utilize Coulomb's Law from a fundamental, empirical perspective.

Standards Addressed

This lesson addresses the following science and engineering practices:

- Asking questions and defining problems – Asking a pertinent question is the start of the scientific method, and this lesson seeks to teach by example. The questions in the formal assessment part of the lesson guide the experimental design process toward discovery.
- Planning and carrying out investigations – since the lesson focuses heavily on the scientific method and experimental design, this standard is heavily emphasized. Students need to be aware that to gauge causal relationships requires a large amount of control, which is obtained well using a simulated environment.
- Constructing explanations – Students will need to justify the relationships they obtain between simulation parameters using graphical evidences.
- Developing and using models – The primary task for the simulation assignment is for students to build a model of Coulomb's Law in much the same way that he went about it originally. It is suggested to bolster this model by confirming and validating it, and reinforcing its form with homework or in-class examples.

Time

Lesson is intended to fit within a 45-50 minute period. A follow-up lesson to allow students to discuss their results and present the formal law is highly suggested.

Level

This lesson is meant to coincide with the physics curriculum at the high-school level, and can be used in regular, honors, AP or physical science classes.

Materials and Tools

- NetLogo is necessary for this lesson and should be available on any computers the students are using.
- The NetLogo simulation for this lesson is available here.
- Computation and Coulomb Worksheet.

Preparation

NetLogo is readily available for free download at http://ccl.northwestern.edu/netlogo/. The program runs on Java, which should be already installed but may be downloaded at http://www.java.com/en/ if necessary. The associated NetLogo simulation for this lesson may be downloaded before hand, or may be made available to the students through a communal site (BlackBoard, moodle, etc.).

Prerequisites

Students should have previously engaged in the scientific process several times with any other lab they have conducted in this class or another. Apart from that, there are no prerequisite skills that the students need to navigate this material.

Background
You should be familiar with the scientific method so that the initial discussion proceeds smoothly. Additionally, you should be comfortable with the concept of electrical charge, the idea of electrostatic interaction (similar and dissimilar charges), and lastly with graphical interpretation.

Teaching Notes
The associated simulation is fairly robust, and allows for a lot of room to play and explore. It may be necessary to remind students to stick to the questions for this simulation rather than attempting to change the simulation in the "Code" tab of the program. It's best to familiarize yourself with the simulation beforehand, to facilitate the students with any difficulties they may encounter.

Assessment
As per usual, a consistent dialogue with the students as they conduct their experiments will serve as the foundation for dynamic assessment. Separate of that, the worksheet associated with simulation will allow you to gauge how well the students can pose a hypothesis, evaluate the graphical results of their experiment, and finally how well they can construct an empirical law from several observations. Between the dynamic, formative assessment, and this summative assessment, you should be able to discern how well the students understand the use of the scientific method, and to what degree they understand Coulomb's Law.

Additional Information
The plots in the NetLogo simulation yield information (force, potential energy, distance, etc.) against time, while the worksheet asks for direct relationships between force and charge, permittivity and distance. It may be difficult for students to connect between the graphical data available and what they are supposed to report, so it may be necessary to include that aspect in the preliminary discussion on the scientific method.