

Multimedia Applications in Studio Physics Courses

K. Min,* M. Malak† P. Casabella, J. Haus, and J. Wilson
Department of Physics, Applied Physics and Astronomy
Rensselaer Polytechnic Institute
Troy, NY 12180, USA

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Abstract

In the studio format of introductory physics courses at Rensselaer Polytechnic Institute, a unified teaching method is used in which a mini-lecture on a specific topic is followed by various classroom activities related to the topic, such as hands-on experiments, computer simulations, and spreadsheet exercises. We will illustrate this approach using Gauss's Law of electrostatics as an example.

Overview

At Rensselaer Polytechnic Institute, the introductory physics courses, Physics I (mechanics) and Physics II (electricity and magnetism, including optics) are taught in a studio format[1]. The studio format of teaching differs from the traditional lecture-based format in the assumption that students learn more effectively from each other and from doing carefully-chosen small-group activities. Short lectures, recitations, and class activities are integrated in a single class session of 110 minutes. There are two class meetings per week for each of Physics I and II. One faculty member, one graduate teaching assistant, and one undergraduate teaching assistant staff each studio class. Students work together in groups of two

to four in a special studio classroom equipped with 24 personal computers loaded with Windows applications and Internet browsers.

A typical studio class is conducted according to the following schedule:

- Solving homework problems (30 minutes.)
- Mini-lecture (20 minutes)
- Classroom exercises (60 minutes)

The students work on the homework assignments individually and hand in the solutions at the beginning of class before classroom discussion. The professor or a TA presents a short “mini-lecture”, perhaps using a PowerPoint presentation. The mini-lecture outlines the important points of a new topic, but avoids any long derivations. The students then perform a class exercise. There are various kinds of exercises; they include hands-on experiments which may use the computer to gather data via the Universal Laboratory Interface, computer simulations using Java applets[2], spreadsheet calculations, symbolic mathematical exercises, and paper and pencil worksheet problems. The teachers walk about the classroom during the exercise helping the students, answering their questions, and offering suggestions. The students work on the class exercise in groups, and hand in a group report at the end of class.

We will illustrate this approach using Gauss's Law from electrostatics as an example. Gauss's Law states that the electric flux through a closed surface (the “Gaussian surface”) is proportional to the net charge inside the surface.

*Email: mink@rpi.edu

†Email: malakm@rpi.edu

1 Mini-Lecture

The mini-lecture introduces the concept of electric flux, and presents the mathematical formulation of Gauss's Law, $\Phi_E \equiv \oint \mathbf{E} \cdot d\mathbf{A} = q/\epsilon_0$, and discusses its physical interpretation. To prepare the students for the computer simulation exercise that follows, it is emphasized that the flux integral is independent of the shape of the Gaussian surface and also of the location and distribution of charges enclosed within the surface. The mini-lecture includes the discussion of a simple but important application of Gauss's Law, the case of a uniformly charged sphere. Once again, in preparation for the computer simulation exercise, it is shown that the electric field within a uniformly charged sphere is proportional to the radial distance, but at points outside of the sphere, it is inversely proportional to the square of the distance.

2 Computer simulation

(<http://links.math.rpi.edu/devmodules/electromagnetism/Gauss/html/gldemo.html>)

This Java applet opens a rectangular area on the screen in which are hidden several infinitely long charged objects. Some are infinitely thin lines, and some are extended cylinders. By using combinations of modifier keys and mouse-button clicks, students can do the following:

1. Draw electric field lines.
2. Draw rectangular Gaussian surfaces, and evaluate and print the electric flux through them.
3. Draw cylindrical Gaussian surfaces, and evaluate the flux.
4. Drop arrows indicating the direction and the strength of the field.

An arrow moves with the mouse pointer and shows the direction and the relative strength of the electric field. After exploring the rectangular area, the students are asked to hand in a report answering the following questions:

1. How many charged objects are in the rectangular area?

2. Give the coordinates, magnitudes, and signs of all the hidden charges. For a charge that is not a point charge, give the coordinates of the approximate center of the distributed charge. The coordinates of the point where the cursor is located appear in the browser's status line at the bottom of the window. If you manage to put the cursor directly on a line charge, the arrow will disappear, and a small circle will appear there.
3. Indicate which charges are point charges and which are spread out over some finite area.
4. For each of the non-point charges, indicate the shape of the charge distribution. Is it square, circular, or something else?
5. At how many points in the area is the electric field equal to zero?
6. Give the coordinates of those points where $E = 0$.

The main features of this simulation exercise are shown below.

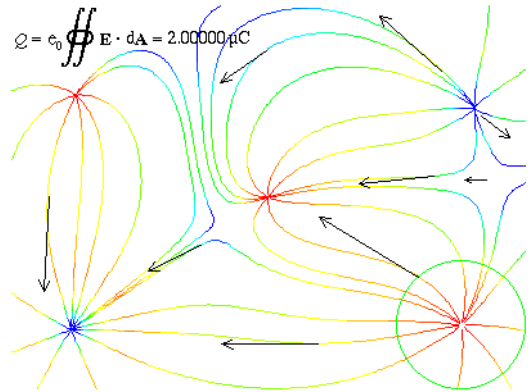


Figure 1: Gauss's Law Simulation Exercise. The green circle is the footprint of a cylindrical Gaussian surface; the surface encloses $2 \mu\text{C}$ of charge. The length of an arrow or the color of a fieldline indicates the strength of the electric field at a point; red is strong field, and blue is weak field. The arrows are tangent to the field lines and indicate the direction of the electric field.

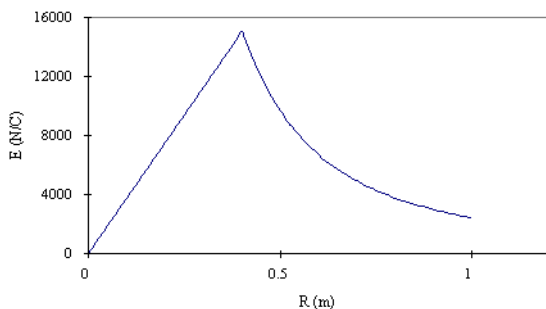


Figure 2: Electric Field of Uniformly Charged Sphere

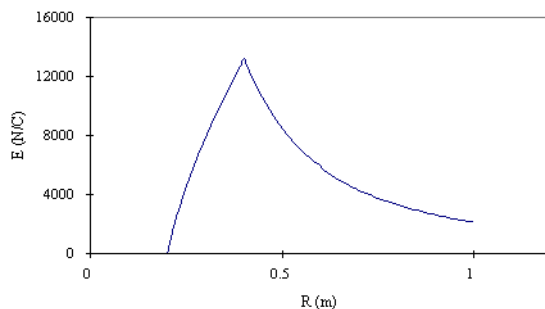


Figure 3: Electric Field of Hollow Sphere

3 Spreadsheet Exercise

(<http://links.math.rpi.edu/devmodules/electromagnetism/Gauss/html/esphere.html>)

The Excel spreadsheet named “E-sphere.xls” uses Gauss’s Law to calculate and graph the strength of the electric field due to a spherically symmetric charge distribution. It will calculate the electric field from the center of the spherical distribution out to the distance designated as R_{\max} ; in the spreadsheet, $R_{\max} = 1.0$ m. When the spreadsheet opens, there is a uniform positive charge density of 1.0×10^{-6} C/m³ from $R = 0$ to $R = 0.4$ m and no charge beyond that. The electric field for this charge distribution is shown in Figure 2.

The program sums the charge over spherical shells of thickness dR , which is given as 0.01 m in cell B3. There are 100 shells. The radii of the surfaces of the shells are listed in cells A10 through A110. In cells B10 through B109, the relative charge density is listed for each shell, next to the value of the radius. If the values of the relative charge density in any of the cells B10 through B109 are changed, everything is recalculated automatically, and the graph is redrawn.

Students are asked to do spreadsheet calculations and turn in the following report:

1. A sketch of the graph of E vs. R for a hollow sphere with no charge from $R = 0$ to $R = 0.2$ m, and a uniform charge density from $R = 0.2$ m to $R = 0.4$ m. (See Figure 3.)
2. The constant relative charge density for the inner region ($R = 0$ to 0.2 m) that produces a field of

zero for $R > 0.4$ m.

3. A sketch of the graph of E vs. R for a sphere with a negative charge from $R = 0$ to $R = 0.2$ m, and positive charge from $R = 0.2$ m to $R = 0.4$ m, such that $E = 0$ for $R > 0.4$ m. (See Figure 4.)

4 Classroom Discussion

In the previous spreadsheet exercises, most students can answer the questions even with only a qualitative understanding of Gauss’s Law. For example, they are asked to find the constant charge density for the inner region ($R = 0$ to 0.2 m) that produces zero electric field for $R > 0.4$ m. If the student understands from Gauss’s Law that the total charge inside $R = 0.4$ m has to be zero, he can see that the required charge density in the inner region ($R = 0$ to 0.2 m) must be negative. Most students then try various negative values while looking at the E vs. R plots, until the correct value $\rho = -7\rho_0$ is obtained.

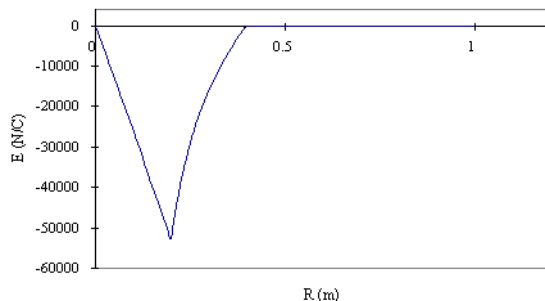


Figure 4: Electric Field of Nonuniform Sphere

After the spreadsheet exercise, we ask the students to obtain this charge density and the corresponding electric field as a function of distance analytically.

Summary

In the studio teaching method illustrated above, we attempt to use different kinds of activities to illustrate one major physics topic in one integrated studio class.

We have developed similar applets and spreadsheet exercises for other topics in Electricity and Magnetism as well as other physics classes. Further developmental work and classroom applications are also in progress.

References

- [1] Jack M. Wilson, “The CUPLE Physics Studio”, *Physics Teacher* **32**, 518–523 (1994).
- [2] William E. Boyce, John B. Brunski, Michael M. Chen, Kevin Craig, James A. Fairweather, Joseph W. Haus, Joseph Porter, and William L. Siegmann, “Interactive Multimedia Modules in Mathematics, Engineering, and Science”, *Computers in Physics* **11**, 151–156 (1997). An introduction to Project Links.

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