Electric Fields

Concept covered in activity

We will explore what a field is in general as well as the properties of electric fields, specifically.

Grade level or other prerequisites for activity

This lesson is designed to fit into a high school physics unit on electricity. Students should have already been introduced to static electricity, charges, and electric force (Coulomb’s law).

Standards

Colorado Department of Education High School Physical Science Standard 5: Energy exists in many forms such as mechanical, chemical, electrical, radiant, thermal, and nuclear, that can be quantified and experimentally determined.

National Physical Science K-12 Content Standard: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes: Evidence, models, and explanation, and Constancy, change, and measurement.

Learning objectives:

Students should be able to demonstrate their understanding of electric fields by effectively and accurately describing what an electric field is using words and sketches.

Materials

- One guide sheet for each student
- Computer with simulation downloaded
- Science Notebook

Instructional planning

The EJS Coulomb Force simulation can be downloaded from the comPADRE National Digital Library: http://www.compadre.org/OSP/items/detail.cfm?ID=9683

Like any activity involving computers, proper preparation and testing is a must.

Procedure/activity

<table>
<thead>
<tr>
<th>Student Activity</th>
<th>Teacher Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engage</strong></td>
<td>Begin to develop an idea of what a field is in a physics context as well as what properties a field has.</td>
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<tr>
<td><strong>Explore</strong></td>
<td>Explore the simulation. Generate curiosity. Familiarize themselves with the interface.</td>
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<tr>
<td><strong>Explain</strong></td>
<td>Experiment with the simulation to uncover answers to the guide. See the Electric Field Worksheet below for more detailed explanation.</td>
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<tr>
<td><strong>Elaborate</strong></td>
<td>Consolidate acquired knowledge of electric fields. Convey this knowledge through sketching and writing.</td>
</tr>
<tr>
<td><strong>Evaluate</strong></td>
<td>Students will be able to use the thorough feedback from their</td>
</tr>
</tbody>
</table>
Assessments are completed and stapled into the science notebook. The science notebook will be collected for grading.

| Assessment |
| --- | --- |
| All of the assessments in this lesson are designed to be formative in the context of the electronics unit plan, which will end with a formal summative assessment. The three assessments are the Introduction: The “Stink” Field prompt, the Electric Field Simulation work sheet, and the written/sketched description of an electric field. All of these are meant to be returned with meaningful feedback. Please find the “Stink” Field prompt, and the Electric Field Simulation work sheet below. | Anticipated misconceptions/alternative conceptions |
| The concept of a field is often difficult for students to wrap their heads around. It can be especially difficult to develop a concept of what a field is when it is not interacting with anything. | Accommodations/modifications of activity for any special needs students (special education, ELL, and gifted/talented) |
| The instructor should have the opportunity to address students who are in need scaffolding individually while they are working with the simulation. At this time, the instructor may give extra help as it is deemed necessary. Advanced students can be asked to explore the simulation further than what is required to complete the work sheet. | |

This lesson was adapted by Ben Thompson from the lesson plan, Electric Field Simulation, written by Anne J Cox and edited by Mario Belloni and Wolfgang Christian.
Introduction: The “Stink” Field

(analogy from Physics Classroom Tutorial, Lesson 4a: Electric Field; Action-at-a-Distance)

Imagine you have just entered a room where there is a rotten egg. How can you tell it is there? What happens if you get closer to it? Describe what you would be able to determine about the rotten egg just from being in its “stink” field:

________________________________________________
________________________________________________
________________________________________________
________________________________________________

Does your detector (nose) change the properties of the source of the “stink” field? Explain.

________________________________________________
________________________________________________

This is analogous to an Electric Field and your nose in the “stink field” is analogous to an electric field detector (or test charge).

Introduction: The “Stink” Field- Answer Key

(analogy from Physics Classroom Tutorial, Lesson 4a: Electric Field; Action-at-a-Distance)

Imagine you have just entered a room where there is a baby with a rotten egg. How can you tell it is there? What happens if you get closer to it? Describe what you would be able to determine about the egg just from being in its “stink” field:
answers will vary: stink is stronger closer to source, moving slightly tells the direction of the source, a more rotten egg smells worse (a bigger “stink” field), don’t have to see it to detect it

Does your detector (nose) change the properties of the source of the “stink” field? Explain.

answers will vary: nose just detects, but doesn’t change the amount of stink, just “records” the information

This is analogous to an Electric Field and your nose in the “stink field” is analogous to an electric field detector (or test charge).

Activity Guide: EJS Electric Field Simulation

In this simulation, there is a point charge at the origin that is the source of the electric field. The colored arrows represent electric field vectors. There is also an electric field detector that you can move around. For further analysis, you can record data in a data table and use a data analysis tool to fit the data to an equation.

1. Run the Applet file on-line OR run the simulation by double-clicking on the ejs_electric_sampler.jar and then navigating to the Electric Field: Point Charge simulation and run the simulation by double-clicking on the green arrow.
2. Drag the detector around and notice the direction of the electric field as well as the size (magnitude of the field). If the detector is the same distance away from the point charge, is the field the same size? In what direction does the field point? This is the direction that a positive charge would feel a force if it were at that spot.

3. The arrows are like a bunch of little electric field detectors and they point in the direction of the electric field. What does the color indicate? Is red a stronger field than blue? Weaker?
4. Try changing the slider and see what happens. If you double the charge, does the value at the detector double? At all points? How does the color change?
Quantitative Analysis:

5. Keep the value of the point charge fixed. Push the Record Data button on the Data Table and notice that it records the position of the Detector and the value of the electric field. Move the detector around and record the value of several points (at least 5) in the table and record them in the table below:

<table>
<thead>
<tr>
<th>$x$</th>
<th>$y$</th>
<th>$r$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

6. In the table, $r$ is the distance between the Detector and the point charge. Show that $r = \sqrt{x^2 + y^2}$ for one of the entries in the table:

_________________________

Explain why $r = \sqrt{x^2 + y^2}$ is the distance between the point charge (at the origin) and the Detector (make a diagram if necessary):
7. Now you are going to use your data to determine the equation for $E$ (electric field) as a function of $r$. Clicking on the Wrench (🔧) button opens up a data analysis tool (DataTool) with your data.
   
a. DataTool automatically draws lines between nearby points and you may find this confusing. Click on the checkbox with a line through it (above the data) to remove the connecting lines.

   ![DataTool interface]

   uncheck this

   b. If you want DataTool to Fit the data, click the Fit checkbox.

   ![Data Tool interface with Fit and Plot options]

   Click on Auto-fit to let the computer complete the best Line fit. Is this a good fit? Explain.

   __________________________________________
   __________________________________________

   c. Since the electric field decreases as you get further away, you will need to try an equation not in the list by editing the current equation in Fit Builder. For example, if you want to fit the data to $a/r^3$ (and have the program automatically find the value of $a$), first, double-click on the equation of the line ($E=a*r+b$)

   ![Double-click to open Fit Builder]

   double-click to edit

   d. This to automatically opens the Fit Builder. In this case, since you only want to fit one parameter, first delete parameter "b" (from the parameter list)
and then type your new Line1 = a/r^3 in the equation box.

Click to select b and then use “cut” button

and then type your new Line1 = a/r^3 in the equation box.

<table>
<thead>
<tr>
<th>Name</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-116.5136944067159</td>
</tr>
<tr>
<td>b</td>
<td>89.29534994523621</td>
</tr>
</tbody>
</table>

- Try E = a/r, E=a/r^2 and E=a/r^3. Which is the best fit? How can you tell?

Best equation: ___________________________________________

8. If r is very large (the Detector is far away), what should happen to the field (be large or small)? Is this true for your equation?

_________________________________________________________
9. If \( r \) is measured in meters and \( E \) is measured in N/C, what is the charge of the yellow point charge at the origin when the slider for \( q \) is set to 1? Show your work:
Activity Guide: EJS Electric Field Simulation—Answer Key

In this simulation, there is a point charge at the origin that is the source of the electric field. The colored arrows represent electric field vectors. There is also an electric field detector that you can move around. For further analysis, you can record data on a data table and use a data analysis tool to fit the data to an equation.

1. Run the Applet file on-line OR run the simulation by double-clicking on the ejs_electric_sampler.jar and then navigating to the Electric Field: Point Charge simulation and run the simulation by double-clicking on the green arrow.

2. Drag the detector around and notice the direction of the electric field as well as the size (magnitude of the field). If the detector is the same distance away from the point charge, is the field the same size? In what direction does the field point? This is the direction that a positive charge would feel a force if it were at that spot. ______ field is the same if the detector is same distance away; direction is along a line connecting the detector and point charge and points away from the point charge ____________________________

3. The arrows are like a bunch of little electric field detectors and they point in the direction of the electric field. What does the color indicate? Is red a stronger field than blue? Weaker? ___ color indicates field strength: red is stronger and blue is weaker ___

4. Try changing the slider and see what happens. If you double the charge, does the value at the detector double? At all points? How does the color change? ___ double charge results in double the field; color gets ‘redder’ _______
Quantitative Analysis:

5. Keep the value of the point charge fixed. Push the "Record Data" button on the Data Table and notice that it records the position of the Detector and the value of the electric field. Move the detector around and record the value of several points (at least 5) in the table and record them in the table below:

Answers will vary—typical values for q=1

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>R</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.500</td>
<td>0.000</td>
<td>0.500</td>
<td>8.546</td>
</tr>
<tr>
<td>0.250</td>
<td>0.385</td>
<td>0.459</td>
<td>10.139</td>
</tr>
<tr>
<td>0.645</td>
<td>0.680</td>
<td>0.937</td>
<td>2.432</td>
</tr>
<tr>
<td>-0.310</td>
<td>0.740</td>
<td>0.802</td>
<td>3.319</td>
</tr>
<tr>
<td>-0.650</td>
<td>-0.360</td>
<td>0.743</td>
<td>3.870</td>
</tr>
<tr>
<td>-0.055</td>
<td>-0.130</td>
<td>0.141</td>
<td>107.277</td>
</tr>
</tbody>
</table>

6. In the table, \( r \) is the distance between the Detector and the point charge. Show that 

\[ r = \sqrt{x^2 + y^2} \]

for one of the entries in the table:

Answers will vary: for 2\(^{nd}\) row of table: \((.25^2 + .385^2)^{1/2}=.046\)

Explain why \( r = \sqrt{x^2 + y^2} \) is the distance between the point charge (at the origin) and the Detector (make a diagram if necessary):

Answers will vary: length of vector; Pythagorean theorem...
7. Now you are going to use your data to determine the equation for $E$ (electric field) as a function of $r$. Clicking on the Wrench (🔧) button opens up a data analysis tool (DataTool) with your data.

a. DataTool automatically draws lines between nearby points and you may find this confusing. Click on the checkbox with a line through it (above the data) to remove the connecting lines.

b. If you want DataTool to Fit the data, click the Fit checkbox.

Click on Auto-fit to let the computer complete the best Line fit. Is this a good fit? Explain.

__Not a good fit since $E$ decreases with $r$ while a line increases with $r__


c. Since the electric field decreases as you get further way, you will need to try an equation not in the list by editing the current equation in Fit Builder. For example, if you want to fit the data to $a/r^3$ (and have the program automatically find the value of $a$), first, double-click on the equation of the line ($E=a*r+b$)
d. This to automatically opens the Fit Builder. In this case, since you only want to fit one parameter, first delete parameter "b" (from the parameter list)

![Fit Builder interface](image)

(you may need to increase the size of window if you don't see both a and b)

Click to select b and then use "cut" button

and then type your new Line1 = a/r^3 in the equation box.

![Functions interface](image)

e. Try $E = a/r$, $E = a/r^2$ and $E = a/r^3$. Which is the best fit? How can you tell?

<table>
<thead>
<tr>
<th>Equation</th>
<th>Fit</th>
<th>RMS Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E = a/r$</td>
<td>$a = 8.3$</td>
<td>13.3</td>
</tr>
<tr>
<td>$E = a/r^2$</td>
<td>$a = 1$</td>
<td>$3 \times 10^{-15}$</td>
</tr>
<tr>
<td>$E = a/r^3$</td>
<td>$a = 0.1$</td>
<td>6.2</td>
</tr>
</tbody>
</table>

___ $E = a/r^2$ works the best—goes through the points and the rms deviation is the smallest ___

Best equation: ___ $E = a/r^2$ fit $a = 1$ ___________________________
8. If \( r \) is very large (the Detector is far away), what should happen to the field (be large or small)? Is this true for your equation?
   \( \text{if } r \text{ is large, the field should be very small; true for any of the equations above} \)

9. If \( r \) is measured in meters and \( E \) is measured in N/C, what is the charge of the yellow point charge at the origin when the slider for \( q \) is set to 1? Show your work:

   \[
   E = k \frac{q}{r^2} = \frac{q}{r^2}
   \]

   \( a = 1 \)

   Then \( kq = 1 \) N m\(^2\)/C

   Since \( k = 9 \times 10^9 \) N m\(^2\)/C\(^2\)

   \[
   q = \frac{1}{9} \times 10^{-9} \text{ C} = \frac{1}{9} \text{ nC}
   \]