Investigation 2 – What are factors that affect the interactions between objects?

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INVESTIGATION 2: What are factors that affect the interactions between objects?

Overview

Students build upon their model of electrostatic interactions from Investigation 1 by including electric fields to explain how attraction and repulsion can occur through space. Students will define electric fields by analyzing the space around charged objects and representations that depict the electric field. In addition, to develop a conceptual understanding of Coulomb's law, students will investigate how the amount of charge on two objects and the distance between them affect the strength of the force between those objects. Students will continue to characterize interactions involving charged Scotch tape, rods, and balloons to develop a conceptual understanding of the factors that affect the strength of the force between charged objects. In upcoming investigations, students will revise their model of electrostatic interactions to include the effect that the electric field of charged objects has on neutral objects.

The Performance Expectations (NGSS)

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

Elements from NGSS (NGSS Lead States, 2013, p. 94 - 95)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Types of interactions: • Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. • Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.	Students build a conceptual model to explain how the distance between charged objects and the amount of charge on those objects affects the strength of the force between them—a qualitative understanding of Coulomb's law. Having a conceptual understanding of these relationships prepares students to use a mathematical model to predict the forces between objects.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept

Patterns: • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	When charged objects are brought near each other, they may attract or repel each other. Distance and the amount of charge on each object are factors in how strong the force between the two objects will be. Students will apply these patterns in explaining phenomena.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Using mathematics and computational thinking: • Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. ○ Use mathematical representations of phenomena to describe explanations.	Throughout this investigation, students will use simulations to collect data about the relationship between the amount of charge and/or the distance between the charges on the interaction. In addition, they will develop and revise their own models to explain observations of phenomena. Students use data they collect as evidence to support claims about the relationship between the amount of charge or distance between objects and the interaction between the objects. This will help students understand the underlying concepts so they can use mathematics and reasoning.

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Elements from NGSS (NGSS Lead States, 2013, p. 97 - 99)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas

Relationship between energy and forces: • When two objects interacting through a field change relative position, the energy stored in the field is changed.	Students build on their model of electrostatic interactions by including electric fields to explain how electric forces can act through space. In Unit 2, students will build on their understanding of fields to explain changes in energy when charged particles interact and atoms form bonds.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Cause and effect: • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller-scale mechanisms within the system.	When charged objects are brought near each other, they may attract or repel each other. Students begin to use electric fields to explain how objects can interact without touching.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Developing and using models: Modeling in 9-12 builds on K-8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	Students learn to interpret and generate representations of the electric field surrounding charged objects to explain attraction and repulsion. In addition, students use simulations and develop and revise their own models to explain observations of phenomena throughout the investigation.

Objective: Target Model

What should the students' conceptual model include?

- *Objects can be positively charged (+), negatively charged (-), or uncharged (neutral). (At this point, students are not expected to know and use the term* neutral.*)*
- *Objects with the same charge repel each other; oppositely charged objects attract each other.*
- *The distance between charged objects affects the interactions between them. The closer they are, the stronger the interaction.*
- *The amount of charge on charged objects affects the interactions between them. The greater the charge, the stronger the interaction.*
- *Charged objects generate an electric field in the region around them.*
- *It is through the electric field that charged objects interact with each other.*

Background Knowledge

Two objects can interact through electric forces even though those objects are not in contact. The idea of an electric field can be used to explain how charged objects can interact without being in contact. An electric field exists around all charged objects and exerts a force on the charged objects within the field. The direction of the electric field at any point is defined as the same as the direction of the force experienced by a positively charged object at that point. The ***direction*** *of the electric field is away from a positive charge because a positive charge repels another positive charge and toward a negative charge because a negative charge attracts a positive test charge.*

The ***strength*** *of an electric field at any point is related to the force experienced by a positive charge introduced at that point. The force on the positive charge is equal to the magnitude of the charge times the electric field, so a larger charge will experience a bigger force than a smaller charge in the same electric field. The strength of an electric field is always strongest close to the charged object and decreases as distance from the charged object increases.*
Different types of representations can be used to depict the nature of electric fields.

Key aspects of the idea of electric fields include the following:

(1) Charged objects create an electric field around them.
(2) Multiple charged objects contribute to one field.
(3) The field view helps us understand the forces another object would feel in that field.
(4) Objects apply forces on each other through the field generated by the objects, which is how they affect each other at a distance.
(5) The vectors (arrows that represent direction and magnitude), often used to represent fields, are not force vectors, but they are proportional to the force that a positive charge would experience at that point in space.
(6) The rule that opposite charges attract and like charges repel helps explain the forces that occur between objects, but the rule can be difficult to apply when many charged objects are present. The concept of an electric field extending through a region of space and producing forces on charged objects helps us understand and explain those forces.

Activities

Activity 2.1	*How can charged objects have an effect on each other without touching?*	*60 min.*
Activity 2.2	*How do factors like distance and amount of charge affect the interactions between objects?*	*90 min.*
Activity 2.3	*How does our model of charge interactions connect with a variety of phenomena?*	*60 min.*

Activity 2.1 : *How can charged objects have an effect on each other without touching?*

SUMMARY

In the last investigation, students observed charged objects interacting without touching. To help students understand how electrically charged objects can interact through space, this activity introduces the concept of the electric field. Students will observe the effect of the electric field around the Van de Graaff generator and learn how to represent the field around a charged object.

LEARNING GOAL

Students will develop a preliminary model of an electric field by describing the direction of the force acting on a charged object in the presence of the electric field. (Clarification: The region of space surrounding an electrically charged object that has an effect on another object contains an electric field. The concept of an electric field helps explain how electric force acts at a distance.)

- Representations of electric fields will be depicted using pointers to show the direction of force that a positive charge would experience. The color intensity of the pointers represents the strength of the field at that point in space.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types of interactions: Forces at a distance are explained by fields (gravitational, electrical, and magnetic) permeating space that can transfer energy through space. (NGSS Lead States, p. 95)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Analyzing and interpreting data:* Analyze data using tools, technologies, and/or models (e.g. computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (NGSS Appendix F p. 57)

POINTS FOR CONSIDERATION

- Students' everyday experience with forces typically involves the objects being in contact with each other (i.e., a push or a pull). They may struggle with the concept of forces acting between objects (in this case charged objects) that are not in contact.
- Students may have difficulty conceptualizing an electric field. An electric field is an abstract concept and cannot be seen; only its effects can be observed. At each point in space, an electric field has a strength (magnitude) and a direction.
- Students may have trouble differentiating between electric fields and electric forces. These concepts are closely related but not identical. An electric field is always present around a charged object, while there must be at least two objects interacting in order for a force to be exerted on the objects. During discussions, be sure to ask students to be clear about whether they mean *field* or *force* when they are using these terms.

Activity 2.1 – Teacher Preparation

PREPARATION

Class Time: 60 min.

Materials

- Van de Graaff generator
- Pointer (see instructions below)

Activity Setup

- Make the pointer for the demonstration - the point needs to be able to pivot and rotate freely
    - Cut a triangle out of the bottom of an aluminum pie pan
    - Poke a hole near the center of gravity of the triangle (It can be found it by trying to balance the flat triangle on the point of a pencil)
    - Flatten out a paper clip and thread it through the hole in the aluminum triangle
    - Tie a thread to each end of the flattened paperclip (this is easier if there is a bend at each end of the paperclip)
    - Tape the thread to a wooden dowel

SAFETY ISSUES

A Van de Graaff generator will only be hazardous if it is handled carelessly or if correct procedures are not followed. Do not let students use it unsupervised.

A large amount of electrical charge builds up on a Van de Graaff generator. **Touching or approaching the Van de Graaff generator while it is on or before it has been discharged will result in a large shock. Never use the Van de Graaff generator without having a discharger nearby.**

In particular, a Van de Graaff generator may be harmful to people with pacemakers or those dependent on other electrical medical equipment (cochlear implants, etc.). **Do not let students with electrical medical equipment near the Van de Graaff generator**. See additional safety issues in the Appendix.

HOMEWORK

Reading for Activity 2.1: How Can Charged Objects Interact Without Touching?

Activity 2.1 – Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction

    a. Discussion to review ideas about charged objects so far

2. Van de Graaff generator

    a. Demonstration indicating space around Van de Graaff generator

    b. Initial model of space around charged objects

    c. Discussion of initial models and benefits of standard representations

3. Standard representation of space around a charged object

    a. Simulation

    b. Discussion of simulation

    c. Questions and revised models

    d. Concluding the lesson

Activity 2.1 (Student materials): How can charged objects have an effect on each other without touching?

Introducing the Lesson

Review the homework: *Why do we revise our models?*

Possible questions:

- *Why do models change?*
- *What are some examples of models that changed did you think of? Any other ones?*
- *How have our models changed in this class?*
- *Do you think our models are done at this point?*

Lead a short class discussion that reviews students' models of the rules about how charged objects interact. Introduce the activity-level driving question: *How can charged objects have an effect on each other without touching?*

Possible questions:

- *What have we discovered about charged objects so far?*
- *What questions do we still have?*
- *Did the charged objects have to touch in order for them to interact? How is that possible?*

Page title:
Introduction

In the previous investigation, you developed some principles that you can use to help explain and predict how two charged objects will interact with each other. As you observed, attraction and repulsion can occur without the objects touching. How can that be?

Safety Guide
The Van de Graaff generator is only hazardous if correct procedures are not followed. Only use it under the supervision of your science teacher. ***DO NOT*** *touch the Van de Graaff generator!*

Page title:
Van de Graaff generator

Discussion

Holding the pointer so it is hanging freely, bring it near the Van de Graaff generator and slowly move it around the Van de Graaff to all sides including above the dome. The pointer should be free to pivot and rotate so that it always pulled in toward the Van de Graaff. View this video if you need a sense of how the demonstration should work.

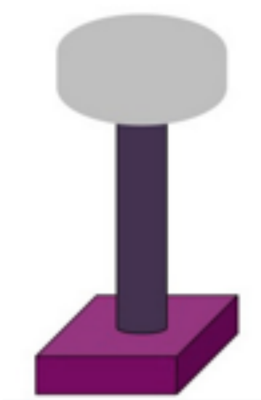
Note: the metal pointer is being polarized by the field around the Van de Graaff generator, it does not have its own charge. Which ever point is closest to the Van de Graaff in the beginning will be pulled toward the Van de Graaff as the pointer moves around.

Possible questions:

- *Does standing on a different side of the Van de Graaff generator affect the direction of the force on pointer?*
- *Are there any regions around the Van de Graaff generator where the pointer does not experience a force?*

Watch as your teacher demonstrates with a metal triangle ("pointer"), moving it around all sides of the Van de Graaff generator.

1. [Draw prompt] Draw a model to represent the pattern of how the pointer interacts with the Van De Graaff generator as it is moved around to different sides of the generator. .
[Text prompt] How does your model explain your observations?



Student responses: This question is to elicit students initial attempts to represent the area around a charged object and to motivate the need for developing a standard representation. Students' responses should not be evaluated; instead, students should be encouraged to develop their own representations.

- Students may draw wavy lines around or emanating from the VDG.
- Students may draw what they observed rather than representing the area around the VDG.
  - *Ask students if they can include in their representation the observation that there was an interaction on all sides.*
- Students may draw a circle or bubble around the VDG
  - *Ask students if they think there is any interaction outside that line. Is there a boundary where the objects interact or does the interaction change with distance?*

Answers will vary. For example, students may draw concentric circles around the Van de Graaff dome or waves coming out of the Van de Graaff dome. Alternatively, they may draw a diagram of a hand with tape and the Van de Graaff generator.

Discussion

Students' models will vary. Display several models in front of the class.

Possible questions:

- *What do you notice when comparing the models?*
- *What are some different ways that you represented the region of space around the Van de Graaff generator?*

Follow-up Discussion

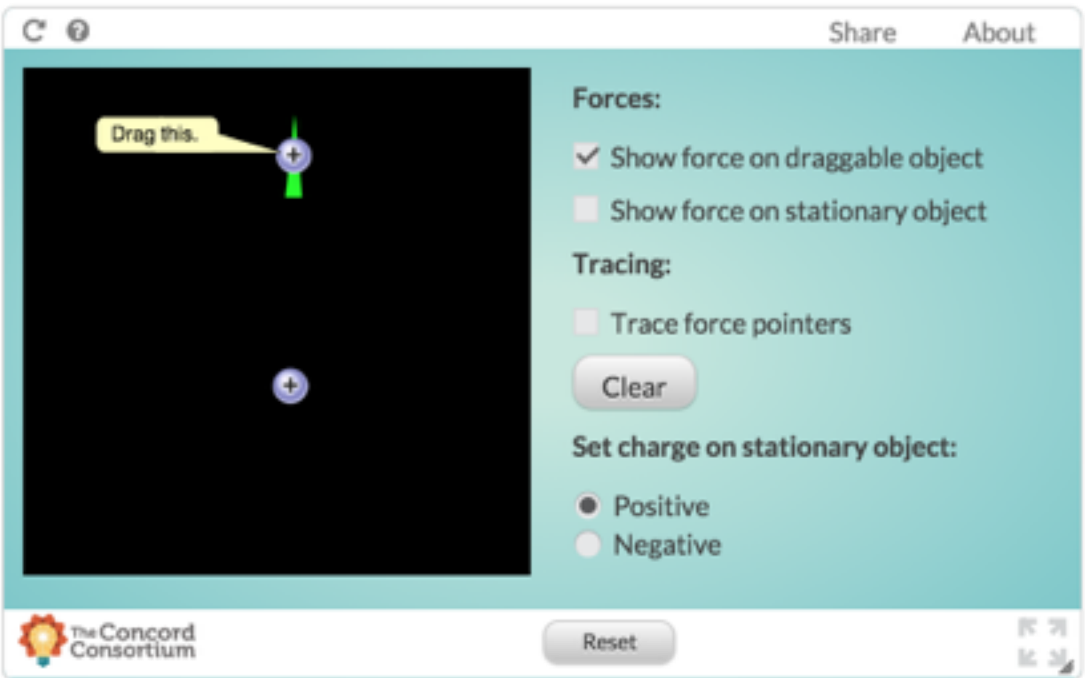
Note that students developed different and creative ways to represent the space around the Van de Graaff generator. It is important to emphasize that students are not "incorrect" for using different representations, but their representations need to have enough information to be easily understood. While students' creativity is good, it is useful to have standard ways to represent ideas to make it easier to communicate with each other. In this curriculum, we will be using pointers to represent the electric field.

Page title:
Standard representation of space around a charged object

Your class came up with several ways to represent the forces around the charged Van de Graaff generator. In addition to developing your own representations, it is also important to interpret standard representations.

In the simulation, drag a charged object around another one and observe the direction of the green pointer (representing the force felt by the object).

Then use the “Trace force pointers” checkbox to track the pattern of forces around the object.



Simulation link:
http://lab.concord.org/interactives.html#interactives/interactions/forceDirection.json

Discussion

This simulation and those that follow begin to be more complex. Ask students to recall the three aspects of modeling from the Investigation 1 reading "Aspects of Scientific Models" (Investigation 1, Reading 1 for Activity 1.2). Use the three aspects of modeling to discuss the simulation. Below is a possible template to use when helping students evaluate and understand the simulation. To help guide the discussion, you might put this table on the board and fill it in as a class.

What are the components/variables shown in simulation? What are the relationships between those components? (What are you trying to test?)

What are some connections between the simulation and the phenomenon? (For example: the metal pointer and Van de Graaff machine)

2. Describe what you see when you use the "Trace force pointers" option.

Supplemental content: The physics community agreed to define electric fields by indicating what force a massless positive "test" charge would experience at any given point in the field. For that reason, the convention is that electric field lines and vectors are always shown pointing toward negative charges and away from positive charges. In the simulation, the strength or magnitude of the interaction is not represented, but the "point" does show the direction of the field according to this convention.

Clarification - students just need to note the pattern (they all point in toward the negative particle, or out away from the positive particle). Students do not need to explain why.

Student responses:

- The arrows always point out (or vise versa: the arrows always point in)
- The arrows point in or out depending on the charge (of the stationary object)
- It shows that energy goes out of positive and into negatives
    - *Clarify for students that the direction is just a convention.*

3. In this simulation, what do you observe when the charge of the stationary object is positive versus when it is negative?

Supplemental content: As mentioned above, by convention, the pointers always point toward negatives and away from positives.

Clarification - students should state the pattern they observe in the simulation.

Student responses:

- The direction of the pointer changes
- *The pointer points toward negatives and away from positives.*
- *The interaction changes from repulsive to attractive interactions.*

4. How is this simulation related to what you observed in the demonstration with the Van de Graaff generator?

Supplemental content: The simulation uses pointers to trace the interaction between a positive test charge and a central charged object. This is building toward a standard representation of an electric field - the idea that in the space all around a charged object, other charged objects will interact with it. Since the Van de Graaff generator builds up a large amount of static charge, it also develops a strong electric field around it. The pointers representation can be used to represent that field.

Clarification - students do not need to use the term electric field nor understand the development of the electric field. Students should just connect the pointers as one way to represent the space around the Van de Graaff where it has an impact on other objects.

Student responses:

- The pointers show that objects would interact with a charged object, like the Van de Graaff, without being in contact.
- The pointers always point toward the charged object.

Discussion

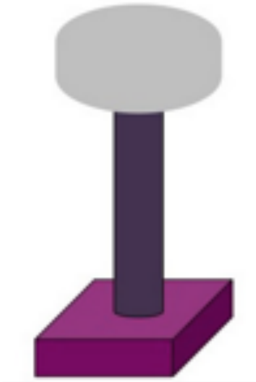
Display the simulation and ask students to share what they observed.

Possible questions:

- *What patterns did you notice?*
- *What is being represented in the model? What does that representation communicate?*
- *How could you use this to explain what we observed with the Van de Graaff generator?*

Be sure to ask students to support their answers with evidence. If students have different opinions, have them try to support their opinions by using the projected simulation as evidence. Have the class discuss whether the various opinions are supported by the evidence.

5. [drawing prompt] Think back to your model of the Van de Graaff generator from the beginning of this Activity. Using pointers to represent the force around the generator, show how an aluminum pointer would be affected if it were placed in different areas around the generator. [text prompt] Explain your drawing.



Supplemental content: Depending on the charge of the Van de Graaff generator that you used, the pointers representing the electric field would either all point in toward the VDG (if negative) or out from the VDG (if positive). A full representation of the electric field would also indicate that the field would get weaker in magnitude as the distance from the VDG increased.

Clarification - students are not expect to represent the magnitude in their representation. Students should use pointers to indicate that other charged objects would interact with the VDG in the area all around the VDG.

Student responses: It is tedious and complicated to draw a full electric field, so students may include a few arrows and words to indicate that the arrows spread everywhere.

- Student draws arrows pointing in toward (or out from) the VDG in all directions.
- Student states that there would be arrows all pointing in toward (or out from) the VDG.
- Student may be uncertain about the representation because they are not sure what charge the VDG is.
  - *If you have not yet tested the charge of the VDG, work with the class to develop a test to determine the charge of the VDG.*

6. How does your original model compare to your new model? Be sure to explain the ideas that are shown and how they are represented in each model.

Student responses: The goal here is that students' diagrams will be more consistent. Individual representations are great, but since part of the role of models in science is to communicate ideas and build consensus it is important that others interpret representations in similar ways.

- Students may describe how they represented the field/area around the Van de Graaff in each case.
- Students may note similarities between the revised models and the simulation.

Concluding the Lesson
Display students' revised models. Have them discuss how their models have changed and how the new representation of force has been illustrated by different students.

Possible questions:

- *What do you notice about these new models?*
- *[referring to a sample model] What is this model representing?*
- *How do these models compare to the first set of models we looked at?*

As a class, come to a consensus about some example models to add to the DQ board.

Review the idea that there is a region all around a charged object in which other charged objects will interact with it, and that pointers are one way to represent that charged objects will feel forces when placed in that area. Relate this back to the activity-level driving question: *How can charged objects have an effect on each other without touching?* Also make connections to the investigation-level driving question: *What are the factors that affect how strongly objects interact with each other?*

Possible questions:

- *What did this activity tell us about how charged objects interact without touching?*
- *Do you have any new questions that might help us answer the driving question for the investigation?*
- *Is the strength of an interaction always the same?*
- *What are some of your predictions about factors that may affect the strength of the interaction between two charged objects?*

Homework: Reading for Activity 2.1
How Can Charged Objects Interact Without Touching?

Activity 2.2: How do factors like distance and amount of charge affect the interactions between objects?

SUMMARY

In Investigation 1, students identified patterns in the way that two charged objects attract and repel each other. Here, students begin to establish the factors that affect the strength of the interaction. Students will observe a teacher demonstration using the Van de Graaff generator and balloon, then they will use a computer simulation to explore how changing the distance between charged objects affects the interaction.

LEARNING GOALS

- Students will qualitatively explain and predict how the amount of charge and the distance between two charged objects affects the strength of the electric force between them.

Disciplinary core idea	**Crosscutting concept**	**Science and engineering practice**
Types of interactions: Forces at a distance are explained by fields that and can be described in terms of the arrangement and properties of the interacting objects and the distance between them. These forces can be used to describe the relationship between electrical fields. (NGSS Lead States, p. 95)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. (NGSS Appendix G p. 85)	*Analyzing and interpreting data:* Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (NGSS Appendix F p. 57)

- Using an electric field model, students will explain the relationship between the distance separating two charged objects, the amount of charge on those objects, and the strength of the forces experienced by those objects. (Clarification: The strength of the electric force decreases with increasing distance. The electric force can be described by direction and the strength [magnitude]).
    - Students will identify the direction and qualitative strength of an electric field surrounding a charged object. However, students do not need to calculate the magnitude of fields based on distance.

Activity 2.2 - Teacher Preparation

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types of interactions: Newton's Law of Universal Gravitation and Coulomb's Law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (NGSS Lead States, p. 95)	*Cause and effect:* They [students] also use models and simulations to predict the behavior of a system and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. (NGSS Appendix G p. 85)	*Developing and using models:* Develop revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

POINT FOR CONSIDERATION

Students may have difficulty relating the concepts of electric field and electric force. An electric field occupies the region of space around a charged object. When another charged object is brought into the electric field, there is an electric force between the two objects.

PREPARATION

Class Time: 90 min.

Materials

- Van de Graaff generator
- wooden rod
- tape
- balloon
- fur
- string

SAFETY ISSUES

A Van de Graaff generator will only be hazardous if it is handled carelessly or if correct procedures are not followed. Do not let students use it unsupervised.

A large amount of electric charge builds up on a Van de Graaff generator. **Touching or approaching the Van de Graaff generator while it is on or before it has been discharged will result in a large shock. Never use the Van de Graaff generator without having a discharger nearby.**

In particular, a Van de Graaff generator may be harmful to people with pacemakers or those dependent on other electrical medical equipment (cochlear implants, etc.). **Do not let students with electrical medical equipment near the Van de Graaff generator**.

See additional safety issues in the Appendix.

HOMEWORK

Reading for Activity 2.2: How Do Bees Find Flowers?

Activity 2.2 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Discuss homework
    b. Introducing the lesson
2. Testing the effect of distance
    a. Demonstration of distance and amount of charge
    b. Discussion of demonstration
3. Factors that affect the strength of electric force between charged objects
    a. Simulation
    b. Discussion of simulation
4. Interpreting representations
    a. Questions
    b. Discussion

Activity 2.2 (Student materials): How do factors like distance and amount of charge affect the interactions between objects?

Review Homework
Review the homework reading from the previous activity.

Possible questions:

- *In the last activity, we described how objects were affected when brought within the space around the Van de Graaff generator. What did you observe?*
- *What is an electric field?*
- *How can we tell if there is an electric field present?*

Discuss the idea that multiple charged objects will contribute to one electric field. Figure 3 in the reading is a good illustration of this idea.

Possible questions:

- *In the reading, what happens in the part inside the pink oval of Figure 3?*
- *Does each object have it's own electric field, or do the electric fields of the two objects cancel out/build up to one field?*

Ask students to support their claims using the image in Figure 3.

- *Why would electric fields be a useful addition to our model of interactions between charged objects?*

Introducing the Lesson
Lead a short class discussion that reviews the previous work about electric fields, and introduce the driving question for this activity: *How does the distance between charged objects affect the strength of the interaction between them?*

The purpose of this discussion is to allow students to share their ideas, so do not evaluate students' responses at this point. Encourage students to offer different ideas. and to make connections with their daily life experiences.

Possible questions:

- *Why did we feel an electric force at a distance from the Van de Graaff generator?*
- *What factors do you think might affect the amount of force you can feel from a charged object like the Van de Graaff generator?*
- *What predictions do you have about the relationship between distance and the strength of the electric field/interaction?*
- *What other variables do you think you could change to make the electric force between two charged objects stronger or weaker?*

Page title:
Introduction

In the following activity, you will investigate the effect that the distance between two charged objects has on the strength of the electrical force between them.

Safety Guide
The Van de Graaff generator is only hazardous if correct procedures are not followed. Only use it under the supervision of your science teacher. ***DO NOT*** *touch the Van de Graaff generator!*

Page title:
Testing the effect of distance

Observe the demonstration and note how the tape interacts with the Van de Graaff generator and the charged balloon.

Demonstration:
Pull a long piece of tape off the roll (about 6 inches) and stick it to the end of the wooden dowel. The tape should be charged from pulling it off the roll. (If not stick it to a table and pull it up similar to the procedure from Activity 1.1).

Hold the wooden dowel so the strip of tape is hanging down and move it closer and farther from the Van de Graaff generator. Students should be able to observe that the tape bends more when it is closer to the Van de Graaff and less when it is farther from the Van de Graaff.

Blow up and charge a balloon using the fur (or have a student charge it). Hang the balloon using some string.

Use the tape hanging from the wooden dowel to test the balloon as well. Students should observe that the tape does not bend as much when it is near the balloon.

Possible questions:

- *What interactions do you observe?*
- *What relationships do you see?*
- *What do you think could cause these observations?*

1. What pattern did you observe when the tape was at different distances from the Van de Graaff machine?

Supplemental content: The electric field around a charged object is always strongest close to the object. Officially, the field continues forever, but the strength of the field drops off rapidly as distance increases. Since the field gets weaker as distance increases, at a certain point interactions will no longer be noticeable. Therefore, if it is far enough away no interaction between the tape and VDG will be visible. As the tape is brought closer to the VDG, it will bend more due to the stronger forces and stronger field present closer to the VDG.

Clarification - Students only need to record their observations. They do not need to explain the observations at this point.

Student responses:

- The tape bends more when it is closer to the VDG.

2. How did the Van de Graaff generator make the tape bend?

Supplemental content: Both the VDG and the tape are charged and interact with each other through the electric field they generate around themselves. The interactions within the electric field create forces causing the tape and VDG to either pull toward each other or push away (depending on the charge of the tape and VDG).

Clarification - Students may refer to either the electric field or forces, it is not expected that they include both. Additionally, students may talk about the tape being pushed or pulled. According to Newton's third law, the two objects exert equal and opposite forces on each other, but that is not a focus of this curriculum.

Student responses:

- The Van de Graaff generator must be pushing/pulling on the tape when it is closer.
- The Van de Graaff generator must be exerting a force on the tape.

3. What patterns did you notice when comparing the interactions between the tape and Van de Graaff generator to the tape and charged balloon?

Supplemental content: Objects with more charge generate a stronger electric field. The Van de Graaff generator builds up a large amount of static charge and therefore a strong electric field. Rubbing the balloon with fur also builds up static charge, but not the same magnitude of charge. Therefore, the field around the balloon is weaker and any forces between the balloon and another charged object will be weaker compared to forces between that object and the VDG.

Clarification - Students only need to record their observations. They do not need to explain the observations at this point.

Student responses:

- The tape bends more when it is closer to the VDG.
- The tape bends less when it is interacting with the balloon.

Discussion

Review the experimental setup and have students observe what happens to the tape at different distances from the Van de Graaff generator. Ask students to summarize the relationship between distance and the strength of the force between the Van de Graaff generator and the tape. Be sure to ask students to support their claims with evidence. Also, ask students to relate the variations in the strength of the force between the two objects (balloon versus Van de Graaff) back to the idea of electric fields that was introduced in the previous activity.

Possible questions:

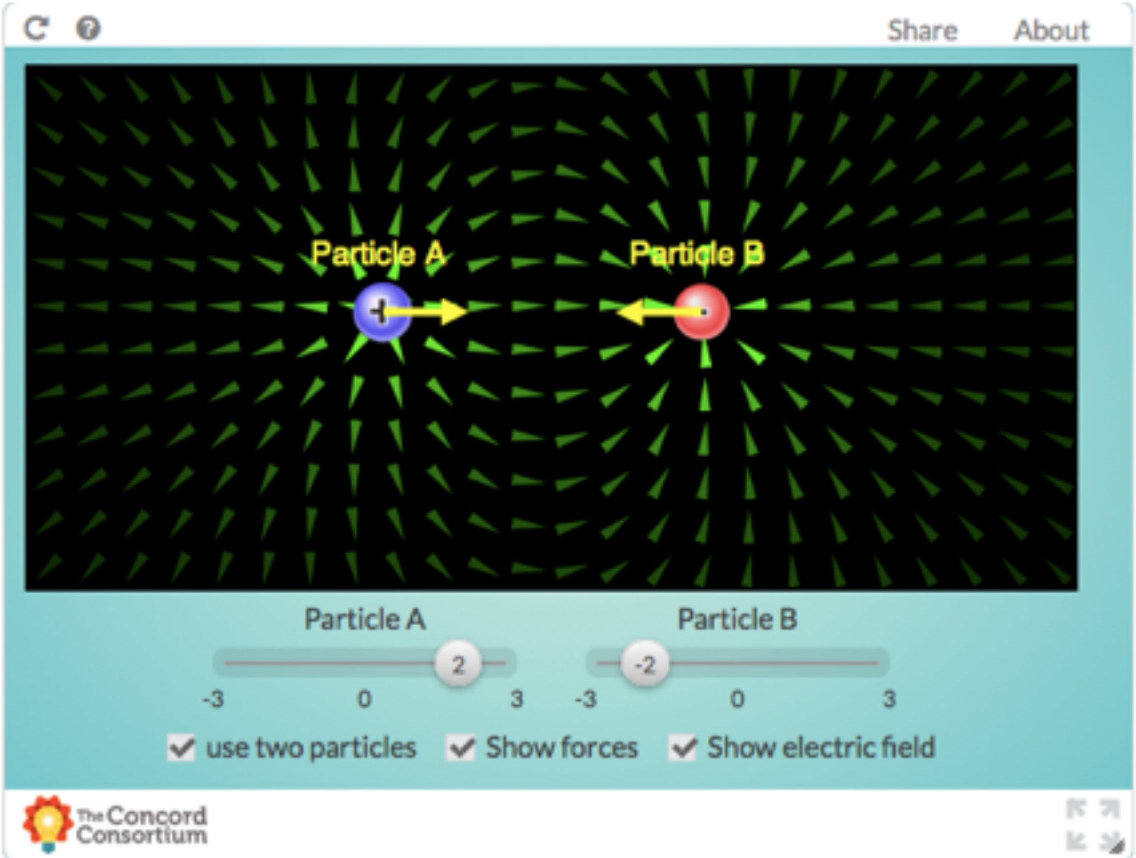
- *Where was the tape most affected by the electric field?*
- *Based on your observation, can you explain the relationship between the distance and the force? What is your evidence?*
- *How does the interaction between the tape and Van de Graaff compare to the interaction between the tape and the balloon? What do you think could cause these differences?*
- *In the last activity, we observed that when the Van de Graaff generator is on, the region of space around its dome contains an electric field that other objects can interact with. We just saw that the strength of the electric force experienced by an object changes based on its distance from the generator. Do you think the strength of the electric field changes, too? (Be sure to ask students to support their answers.)*
- *How do you think the electric field around balloon compares to the electric field around the Van de Graaff generator? Why?*
- *What questions do you have about the interaction you observed?*

Page title:
Factors that affect the strength of electric force between charged objects

Arrows can represent not only the *direction* of the force but also the *strength* of the force. In this illustration, the lengths of the arrows represent the relative strengths of the forces. The longer arrows represent a stronger force.

The following simulation will help you explore how electric fields and electric forces relate to each other.

- The computer simulation uses green pointers to indicate the electric field and its direction. The brighter the green arrows become, the stronger the electric field at that location.
- Yellow arrows represent the direction and strength of the electrical force between the charged objects. The longer the yellow arrows, the stronger the force.



Simulation link:
http://lab.concord.org/interactives.html#interactives/interactions/amount-charge-2.json

Components

4. List the components you see in the simulation. Identify any components that you are able to change.

Supplemental content: The simulation shows one or two charged objects, the electric field, and electric force between the two objects.

Clarification - Students may mention what they see instead of what it represents (yellow arrows) or additional components that are not necessarily relevant given the focus (words, labels, etc.)

Student responses:

- Charged objects (can change: amount of charge, location), the electric field, electric forces
- Charged objects, green pointers, yellow arrows
  - *These are acceptable answers as these are components that are seen in the simulation, but push students to describe what these components are representing*
- Students may identify some components but miss some key components (charged objects, electric field, forces)
  - *Encourage students to test the different buttons and see if they can find any additional components*

Relationship between components

5. When the distance between the two objects changes, what do you notice about the strength of the electric force between the two objects? Be sure to describe what you observe in the simulation to support your answer.

Supplemental content: When charged objects are closer, the strength of the force between the two objects increases. The electric field is strongest close to each charged object. When there are multiple charged objects, those objects create one electric field. When the charged objects are close, the strong regions of the electric field around each individual object overlap and the forces are stronger.

Clarification - students only need to note the pattern, they do not need to explain why or the relationship between fields and forces.

Student responses:

- When two charged objects are closer together, the amount of force increases
- The force changes when the distance between charged objects changes
  - *Push students to be specific, how does the force change?*
- The force depends on both the distance and the amount of charge
  - *Make sure students are focused on just the distance and changing only the distance.*

6. When the charge on one object is increased (either positive or negative), what happens to the forces on both objects?

Supplemental content: The electric field is stronger around objects that have a larger magnitude of charge. Since forces are due to the interactions between two or more objects, the forces between those objects will always be equal. This is reflected in Newton's third law of motion: when an object exerts a force on a second object, the second object always exerts an equal and opposite force back on the first.

Clarification - Newton's third law is often misunderstood and not a focus of this curriculum. Students should just note that the forces increase when the amount of charge is increased.

Student responses:

- The force on both objects is bigger when the amount of charge increases.

Connection to phenomena

7. How does this simulation help explain your observations of the interaction between the tape that was attached to the wooden rod and the Van de Graaff generator?

Supplemental content: As shown in the simulation, the electric field around a charged object is always strongest close to the object. As the tape is brought closer to the VDG, it will bend more due to the stronger forces and stronger field present closer to the VDG.

Clarification - students should be able to connect the relationship shown in the simulation with their observations

Student responses:

- The simulation shows that an electric field is strongest close to a charged object. The tape bent more when it was close to the VDG because the field is strongest close to the VDG.
- The simulation matches the observations
  - *Push student to be specify the observation and the simulation*

8. How does this simulation help explain your observations of the interaction between the tape and the Van de Graaff generator compared to the tape and the balloon?

Supplemental content: As shown in the simulation, the electric field around a charged object is stronger if the magnitude of the charge is increased. As the tape is brought closer to the VDG, it will bend more due to the stronger forces and stronger field present closer to the VDG compared to the the weaker field and force around the balloon which has a smaller charge.

Clarification - students should be able to connect the relationship shown in the simulation with their observations

Student responses:

- The simulation shows that an electric field is stronger around a charged object that has a larger charge. The tape bent more when it was close to the VDG because the field around the VDG is stronger than the field around the balloon which has less charge.
- The simulation matches the observations
  - *Push student to be specify the observation and the simulation*

Discussion: After students have a few minutes to explore the simulation, display the simulation and discuss. In this simulation students are able to manipulate both the distance between charged objects and the amount of charge. Be sure to discuss the need to control one variable while testing another.

Possible questions:

- *What components are in this simulation?*
- *Which components are you able to adjust?*
- *What are some relationships demonstrated in this simulation? Ask students to support their answer.*
- *If you want to determine the relationship between amount of charge and amount of force, how could you test this? What about distance and amount of force?*
- *Why is it important to keep the distance the same when testing the amount of charge (and vise versa)?*

9. When you start with two objects and remove one, what happens to the field and the forces?

Hint: *The "Show electric field" and "Show forces" buttons are only used to hide or reveal the field or forces that are present. Clicking these buttons does not change the field or force, just whether or not the pointers or arrows are visible.*

Supplemental content: Any charged object has an electric field around it; however, forces are the interaction between two or more objects. Therefore one charged object will have an electric field around it but no electric force.

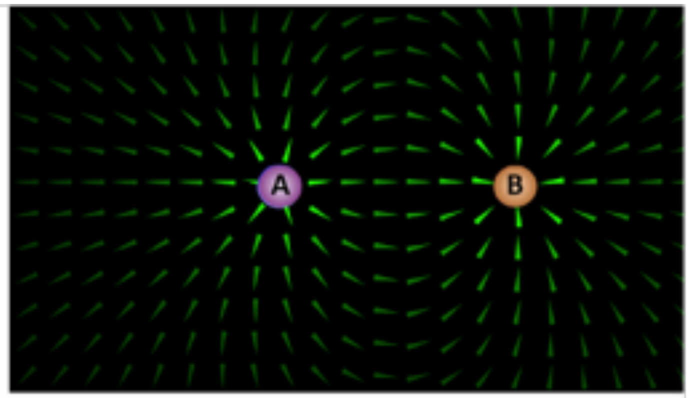
Clarification - students only need to notice what happens they do not need to explain why.

Student responses:

- The field stays, but the force goes away
- One charged object has no electric force
    - *Make sure students are aware of the difference between when no force is there and when the forces are not being shown*

Page title:
Interpreting representations

Use the figure to the right to answer the next two questions. In the figure, the pointers represent the electric field around two charged objects.



10. What kind of charge does each object have?

___ Both are negatively charged.
___ Both are positively charged.
___ A is positively charged, and B is negatively charged.
___ A is negatively charged, and B is positively charged.

11. Explain why you selected that choice for your answer.

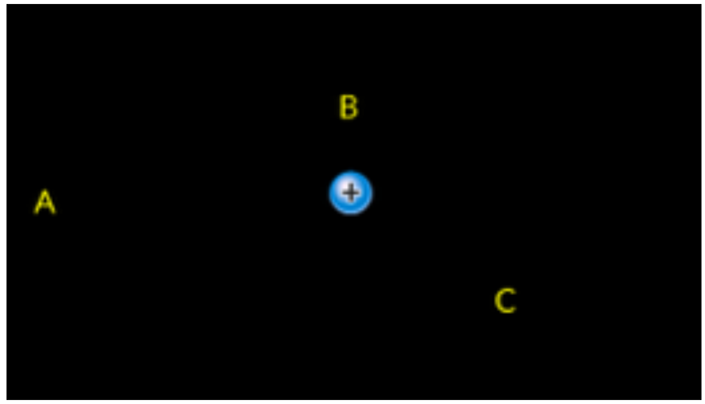
Supplemental content: By convention, arrows used to illustrate or represent electric fields always point towards towards negative charges and away from positive charges. Electric field arrows are defined according the the force a mass-less positive test charge would experience at any given point. Since the test charge is positive (due to an arbitrary decision) the test particle would attract toward any negative charges and repel from positive charges. Given this pattern, the pointers in the figure indicate that object A is positive, since the pointers are all pointing away from it, and object B is negative, since the pointers are all pointing towards it.

Clarification - Students only need to cite the pattern to support their choice, they do not need to explain the source of the the pattern.

Student responses:

- The pointers always point away from positives and toward negatives

Use the figure to the right to answer the next four questions. In the figure, there are three points (A, B, and C) around a charged object (the blue circle).



12. At what point is the electric field around the positive charge the strongest?
A. Point A
B. Point B
C. Point C

13. Explain why you selected that point, using observations from the simulation.

Supplemental content: As demonstrated in the simulation, the electric field is always strongest close to charged objects. Point B is closest to the charged object and therefore is the point where the charge is the strongest.

Clarification - Students do not need to explain why, but should refer to the patterns or simulation to support their answer

Student responses:

- Forces are strongest when charged objects are close
- The electric field is always strongest close to a charged object

14. If you could place a negatively charged object at any of these points, where would you place it to create the weakest force between the negatively charged object and the positively charged object?
A. Point A
B. Point B
C. Point C

15. Explain why you selected that point, using observations from the simulation.

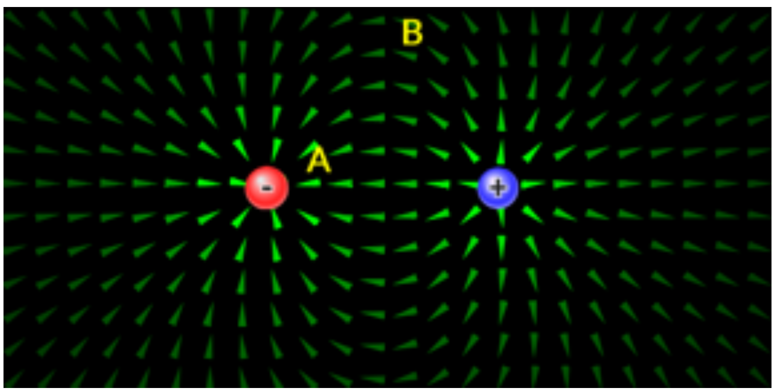
Supplemental content: As demonstrated in the simulation, the strength of the electric field dissipates as the distance away from the object increases. Point C is the point that is the point that is the farthest away from the charged object in the figure. Since point C is farthest away, at the point where the field is weaker, the force will be weaker compared to points A and B.

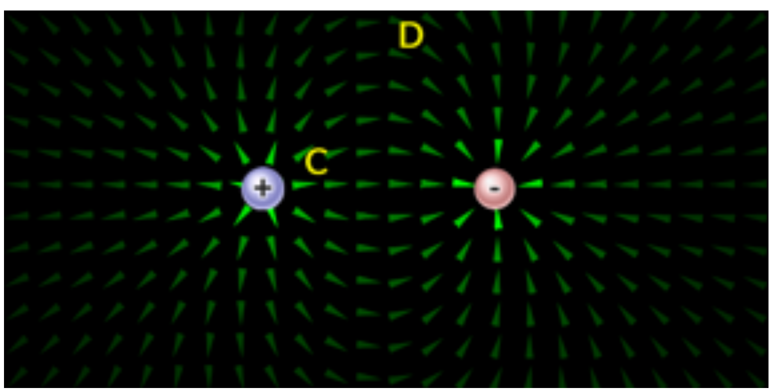
Clarification - students only need to support their answer with the pattern, they do not need to explain the pattern.

Student responses:

- The field is always weakest far away.
- The forces are always weakest when the objects are far apart.

Use the figures below to answer the next question. The green pointers represent the electric field around the objects.





16. Consider the strength of the electric field at points A, B, C, and D. Compare the strength of the field at two of these points.

Supplemental content: The pointers in the image with points A and B are brighter, this indicates that the objects in this image have larger magnitude of charge. The strength of the field is stronger closer to the objects compared to the points that are farther away. Using these relationships you can conclude that: B is stronger than D, A is stronger than C, B is weaker than A, D is weaker than C. Some comparisons are unclear. For example, C is closer to a charged object than B, but B is in a field that is created by objects with larger amount of charge. Depending on the differences between the magnitude of the charged objects in the two images, the field at either B or C could be stronger.

Clarification - students do not need to compare all points

Student responses:

- A is stronger than B because A is closer to a charged object
- A is stronger than C because A is close to an object with more charge
- B is stronger than D because B is in a field created by objects with more charge
- C is stronger than D because C is closer to a charged object
- B and C cannot be compared

Discussion

There are several comparisons that can be made. This is a good point to push students to build on and add to each other's responses. Establishing that there are multiple acceptable responses helps build a classroom environment where students are comfortable sharing their ideas.

Possible questions:

- *Which points did you pick? How do they compare? How do you know?*
- *Did someone else have a different comparison?*
- *Does anyone disagree?*
- *What about points __ & __? How do they compare?*

Note: Some students may confuse electric field and force. Be sure students have noticed the following:

- The electric field is always stronger close to each charged object, even if the two charged objects are far apart.
- There must be at least two objects present in order to have an electric force, but an electric field exists around a single charged object.
- The electric force acts on both objects with same magnitude. Some students confuse action and reaction between two objects.

Page title:
Game 1

In the game below, the goal is to shoot the charged particle past the barrier to hit the target. **You will take a snapshot of your first try at the game and a snapshot of your winning game to record your progress.**

Game link:
http://lab.concord.org/embeddable.html#interactives/interactions/targetGameCharge.json

21. [image prompt] Take a snapshot of your first try.

22. [image prompt] Take a snapshot of your winning game.

[text prompt] Compare your winning game to your first try. Using your knowledge of interactions between charged objects, explain what you did to win the game.

Student responses: Students' responses will vary depending on what the did the first time and what changes they made. Push students to use their ideas and understanding of charge to explain the changes.

- I had to make Object A negative so it would attract the positive particle down around the wall, then make Object B negative so it would repel the positive particle and push it back towards the target.
- In the first one it crashed into the wall, in the second one I won.
    - *Ask student to use their understanding of charges to explain why the winning set-up worked.*

Concluding the lesson
Share students' finding with the class. Project the simulation so you or volunteer students can manipulate it during the discussion.

Possible questions:

- *Describe how the electric field changes with distance from a charged object.*
- *Did anyone notice a different pattern?*
- *When there are two charged objects, how does the electric field around each object change as the distance between the two objects changes?*
- *How does the electric force between two objects change as the distance between the two objects changes?*
- *What is the general relationship between distance and the strength of the electric force felt by charged objects?*
- *How many objects are needed to create an electric field? How many objects are needed to create an electric force?*

*A key difference between electric fields and electric forces is as follows: an electric field surrounds one charged object, but at least two objects must interact in order to create a force.

Revisit the driving question for this activity: *How does the amount of charge on two objects affect the strength of the interaction between them?* Also make connections to the driving question for the investigation: *What are the factors that affect how strongly objects interact with each other?*

Possible questions:

- *What does this activity tell us about how the amount of charge on two objects affects the strength of the interaction between them?*
- *What else affects the strength of the interaction between two objects?*

Ask all students to support their claims with evidence.

Homework: Reading for Activity 2.2
How Do Bees Find Flowers?

Activity 2.3 : How does our model of charge interactions connect with a variety of phenomena?

SUMMARY

In previous activities, students developed conceptual models of electrostatic interactions that include an understanding of how a charged object interacts with other objects. In this investigation, students will revisit a phenomenon from Investigation 1 to revise their model of electrostatic interactions by incorporating ideas they have learned about fields and forces. In addition, they will apply their models of electrostatic interactions in new ways.

LEARNING GOAL

Students will apply their models of electrostatic interactions that illustrate the principles about how objects become charged and about how charged objects interact with other objects to explain phenomena and make predictions.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types of interactions: Forces at a distance are explained by fields (gravitational, electrical, and magnetic) permeating space that can transfer energy through space. (NGSS Lead States, p. 95)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. (NGSS Appendix G p. 83)	*Developing and using models:* • Develop, revise and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F p. 53)

PREPARATION

Class Time: 60 min.

Materials

- Van de Graaff generator
- piece of wire stripped on both ends
- 2 soda cans
- pith ball (or other small object that can act as a clapper, such as the tab from one of the soda cans)
- stand from which to hang pith ball
- thread
- tape
- scissors

Activity Setup

- Construct a Franklin's bells apparatus. This link will guide you in its construction.

Notes

- In the video, the apparatus is constructed using a straw across two cans. However, we strongly suggest using a stand instead of a straw, as shown in the figures below, to remove the possibility that students will think the charge is being transferred via the straw connecting the two cans.
- Using the simplest version of the apparatus, without the grounding wire back to the Van de Graaff generator, is fine. Without the grounding wire, the bells will stop ringing when the system reaches equilibrium and both cans have approximately the same amount of charge. Once this happens, if you ground the can NOT attached to the Van de Graaff generator (Can 2) by touching the can, the bells will start ringing again (see Ringing "bells" demonstration).

SAFETY ISSUES

****Do not let students with electrical medical equipment near the Van de Graaff generator. In particular, a Van de Graaff generator may be harmful to people with pacemakers or those dependent on other electrical medical equipment (cochlear implants, etc.). Be very careful if touching the Van de Graaff generator while it is running, *or* before it has been discharged. A Van de Graaff generator will only be hazardous if correct procedures are not followed. Do not let students use it unsupervised. See additional safety issues in the Appendix.**

HOMEWORK

Reading for Activity 2.3: Detecting Oncoming Thunderstorms

Activity 2.3 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Applying your knowledge
    a. students apply the ideas they developed in previous lessons to explain and make predictions
2. Ringing the bells
    a. Franklin's Bell Demonstration
    b. Initial discussion of observations
3. Explaining Franklin's bell
    a. Students explain and model demonstration by breaking into smaller steps
    b. Discussion of demonstration and students' models
4. Revising your pie pan models
    a. Students revise their models of the pie pans and Van de Graaff generator
    b. Discuss of the driving question

Activity 2.3 (Student materials): How does our model of charge interactions connect with a variety of phenomena?

Discussion
Review the homework: *How do bees find flowers?*

Possible questions:
- *What surprised you in this reading?*
- *How does the electric field around a flower change when a bee has recently visited? How would the electric field change after the bee has been gone for awhile and the plant is ready for a new bee to visit?*

Introduce the lesson. Review the ideas the students have developed and how those help answer our driving questions.

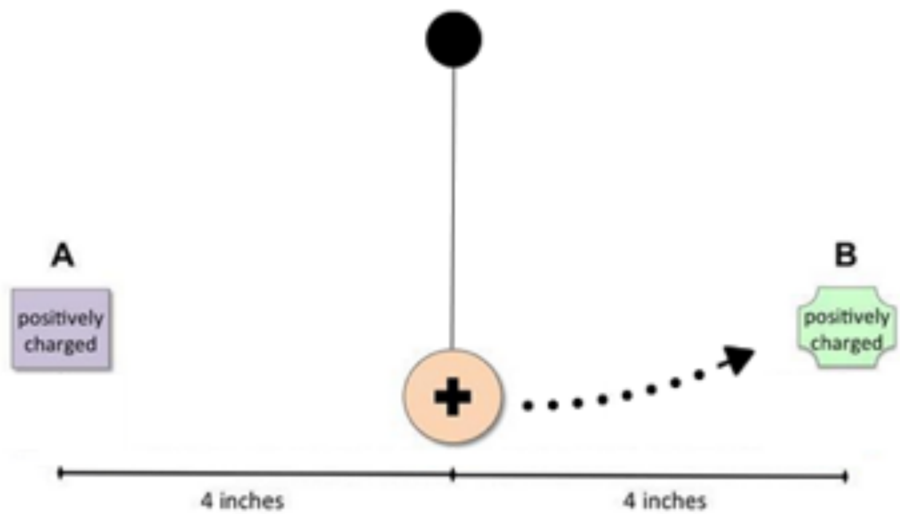
Possible questions:
- *What do we know about what makes some things stick together and other things push apart?*
- *What do we know about how objects can interact without touching?*
- *What do we know about how objects become charged (note: this question still has not been answered, but it is good for students to recognize this).*
- *What unanswered questions do we still have?*

In this activity, students will apply their ideas to new situations.

Page title:
Applying your knowledge

1. Two positively charged objects (Object A and Object B) are 8 inches apart. When a positively charged ball is hung at an equal distance between the two positively charged objects, the ball moves toward object B (see figure).

What can you conclude about the relative amount of positive charge on Object A and Object B? Provide support for your claim.



Supplemental content: Since all objects are positively charged, A must have a larger charge than B. The ball is repelled by both object A and object B since they are all positive. However, if the ball moves toward the right, it must be more repelled by object A than object B which means object A must have a stronger field due to a larger magnitude of charge.

Clarification - students may not refer to fields or other specific ideas, but they should be able to determine that object A must have more charge and support this with some of the rules that have been developed through the investigation.

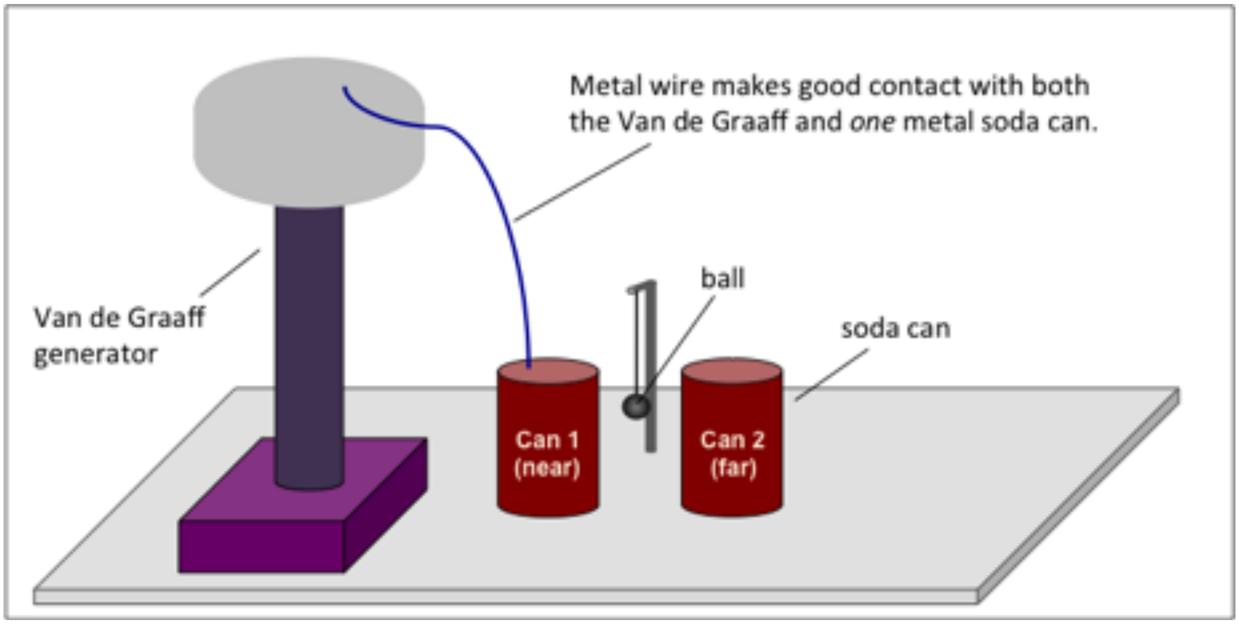
Student responses:

- Object A must have more charge because it is pushing more on the ball.
- The ball is more repelled by A than B showing that object A has more charge.

Page title:
Ringing the bells

A Van de Graaff generator can make “bells” ring. The apparatus for this demonstration is illustrated in the figure below.

- Two soda cans act as the bells. One of the cans is connected to the dome of the Van de Graaff generator.
- A ball hanging between the cans acts as the clapper that rings the bell.



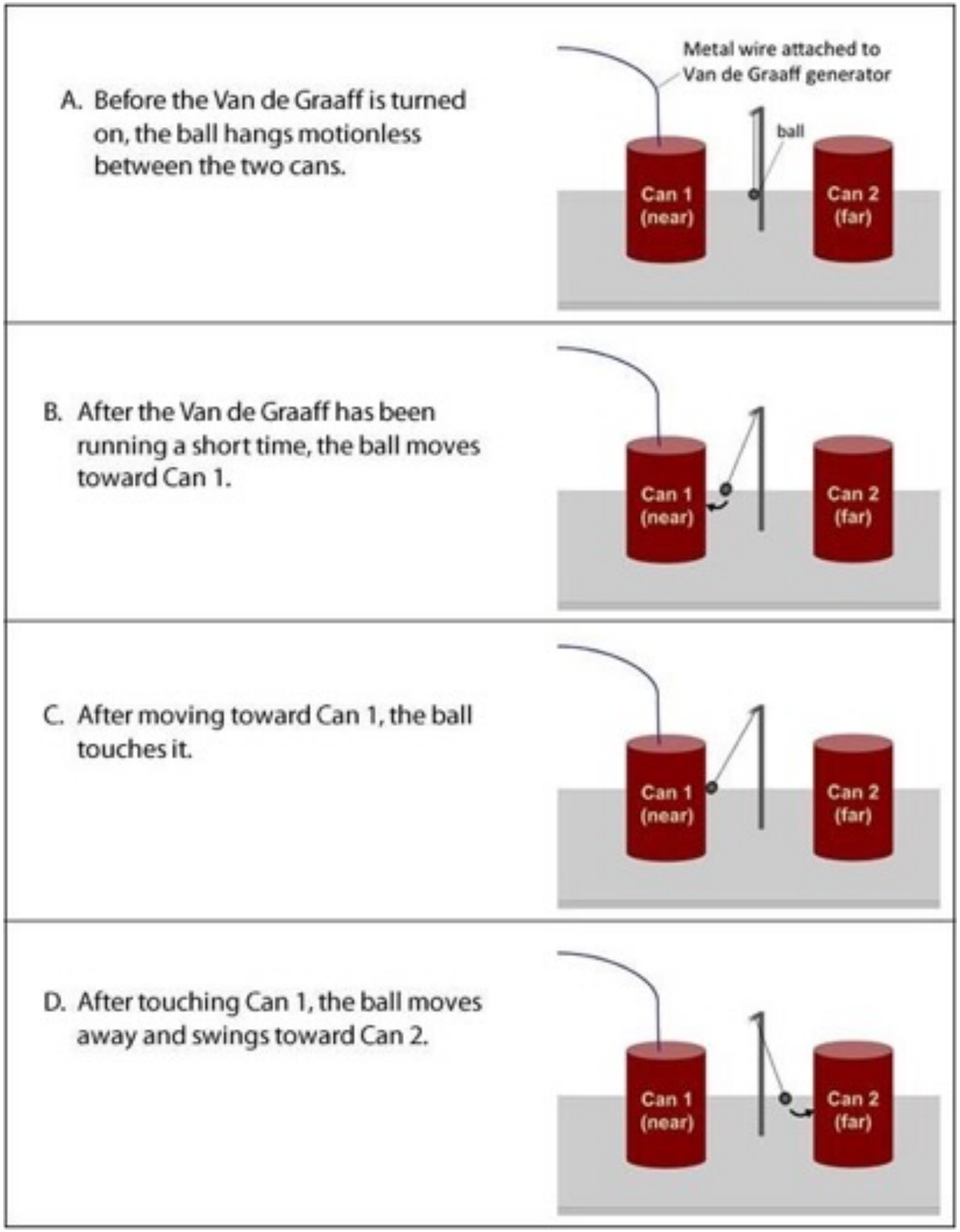
Safety Guide
Van de Graaff generators produce a large amount of static electricity. ***DO NOT*** *touch the Van de Graaff generator!*

Discussion
The Franklin’s bells apparatus provides a real-world extension of the demonstrations at the beginning of the unit. Explaining this phenomenon will require students to apply all that they have learned in Investigations 1 and 2.

Run the Franklin’s bells demonstration for about a minute and then unplug the VDG, allowing the bells to continue ringing until the pith ball comes to a stop. Have students record their observations. Then ask students to share some of their observations.

Page title:
Explaining Franklin's bells

The four panels (A, B, C, D) of this figure break down what is happening in four steps as the Franklin's bells apparatus starts to ring. Use the figure to answer Questions 4–12. If you want to see the demonstration again, watch the following video: [Ringing Bells Demonstration].



2. In panel B, what causes the ball to move toward Can 1?

Supplemental content: Can 1 is attached to the Van de Graaff generator and therefore gets charged when the VDG is turned on. The pith ball is neutral. Neutral objects and charged objects attract.

Clarification - students do not need to explain why, but should be able to use their observations and the patterns they have developed to make inferences about the interaction.

Student responses:

- Neutral objects are attracted to charged objects. The can is charged by the VDG so the neutral pith ball is attracted to it.
- The can and the pith ball have opposite charges
  - *Ask students if this can explain all their observations of the cans and the pith ball*

3. What is the charge on Can 1 at the moment shown in panel B?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- **A. same as Van de Graaff**
- B. opposite of Van de Graaff
  - *Ask students how the can is getting charged, or they could compare the can with the pie pans that were stacked on top of the VDG.*
- C. neutral
  - *Ask students to compare the can to other aluminum objects when they are in contact with the VDG (pie pans.)*

4. What is the charge on Can 2 at the moment shown in panel B?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- A. same as Van de Graaff
  - *Point out that Can 2 is not in contact with the VDG, how could it become charged?*
- B. opposite of Van de Graaff
  - *Point out that Can 2 is not in contact with the VDG, how could it become charged?*
- **C. neutral**

5. What is the charge on the ball at the moment shown in panel B?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- A. same as Van de Graaff
    - *Point out that the ball is not in contact with the VDG, how could it become charged?*
- B. opposite of Van de Graaff
    - *Point out that the ball is not in contact with the VDG, how could it become charged?*
- **C. neutral**

Note: Students may have difficulty following the transfer and buildup of charge through this process.

6. In panel D, the ball moves away from Can 1 and swings toward Can 2. What causes the ball to move away from Can 1?

Supplemental content: Metals conduct charge, meaning charges move freely through metal objects such as the aluminum can and the pith ball. Therefore, when the pith ball and Can 1 hit, some of the charge from Can 1 is transferred to the pith ball. The pith ball and Can 1 now have the same charge and therefore they repel each other and the pith ball swings away. At the same time, Can 2 is neutral, so the now charged pith ball and the neutral Can 2 attract.

Clarification - students do not need to discuss conduction or the role of metals. Students should be able to infer that since the interaction between Can 1 and the pith ball changed, the charge must have changed.

Student responses:

- Can 1 and the pith ball now repel because the charge from Can 1 moved to the pith ball and they have the same charge.
- The pith ball swings back and forth
    - *Ask students to use their rules about charges to explain why the interactions would change.*

7. What is the charge on Can 1 at the moment shown in panel D?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- **A. same as Van de Graaff**
- B. opposite of Van de Graaff
  - *Ask students how the can is getting charged, or they could compare the can with the pie pans that were stacked on top of the VDG.*
- C. neutral
  - *Ask students to compare the can to other aluminum objects when they are in contact with the VDG (pie pans.)*

8. What is the charge on Can 2 at the moment shown in panel D?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- A. same as Van de Graaff
  - *Point out that Can 2 is not in contact with the VDG, how could it become charged?*
- B. opposite of Van de Graaff
  - *Point out that Can 2 is not in contact with the VDG, how could it become charged?*
- **C. neutral**

9. What is the charge on the ball at the moment shown in panel D?

A. same as Van de Graaff
B. opposite of Van de Graaff
C. neutral

Student responses:

- **A. same as Van de Graaff**
- B. opposite of Van de Graaff
  - *Students should be able to use their observations to make an inference here. What is the interaction between the ball and Can 1? What do we know about the charge of Can 1?*
- C. neutral
  - *Students should be able to use their observations to make an inference here. What is the interaction between the ball and Can 1? Have we observed repulsion between a charged object and a neutral object?*

Note: Students may have difficulty following the transfer and buildup of charge through this process.

Discussion

Have students share their conclusions about each step of the process, and make sure they provide evidence to support their conclusions. Ask if any students have a different conclusion, and have them justify it. Students should be able to explain that since the pith ball moves away from Can 1, the pith ball and Can 1 must have the same charge. If students do not suggest this idea, use questions to guide them toward it.

Possible questions:

- *Was the pith ball attracted to Can 1?*
- *Why would it move away from Can 1?*
- *What are the rules for electrostatic interactions?*
- *What can we conclude about the charge on the pith ball and Can 1 now?*

Students should be able to make claims about the strength of the electric field around each object and the amount of charge on each object during each step of the process.

Possible questions:

- *Can we determine anything about the relative strength of the electric field around each object?*
- *Can we determine anything about the relative amount of charge on each object?*
- *What evidence supports that conclusion?*

Optional Challenge Questions

After the ball continues to move back and forth, ringing the bells for a while, what are the charges on Can 1, the ball, and Can 2?

Answer:

- *Can 1: same as VDG*
- *Can 2: same as VDG*
- *ball: same as VDG*

After the bells ring for a while, the ball will stop swinging back and forth as shown in this demo video. Why does the ball stop swinging back and forth?

Answer: *After so many transfers of charge, Can 1 and Can 2 have the same charge and the same magnitude of charge.*

Touching Can 2 will make the bells start ringing again. Why does this work?

Answer: *Grounding Can 2 removes the charge and allows the process to continue starting with panel D. Can 1 and the pith ball have the same charge, so they repel and some charge is then transferred to Can 2.*

To challenge students to apply their understanding in a different way, make the following modification to the Franklin's bells apparatus:

- Move the pith ball relative to Can 1. Sometimes the apparatus will work, while other times it won't—depending on the distance. Have students make predictions about whether or not the apparatus will work, and have them explain their thinking.

10. Our Driving Question for this unit is: Why do some clothes stick together when they come out of the dryer? In order to answer this, we have explored what make some things stick together and others push apart. Summarize what you have learned so far to help answer the driving question.

Student responses: Students should be able to summarize some of the ideas that the class has agreed upon at this point. Push students to connect those ideas to the Driving Question.

- Opposite charges attract, the pieces of clothes could be oppositely charged.
- Neutral and charged objects attract, one piece of clothing could be charged and it sticks to clothes with opposite charges or to clothes that are neutral.
- The clothes could get an electric field from the dryer making them interact and stick together.

11. What additional questions could we answer in order to develop a more complete explanation for our Driving Question?

Student responses: At this point students can explain the interaction, but not the mechanism that causes the interaction in the first place. Students may have a difficult time realizing that there is more to explain. It might be helpful to refer them to the Driving Question board and ask, what have we answered and what is unanswered.

- Where do the charges come from?
- Why do neutrals attract to charged objects?
- Why does the dryer make clothes charged?

Concluding the Lesson

Return to the DQ board and the unit-level driving question: *Why do some clothes stick together when they come out of the dryer?*

Possible questions:

- *What progress have we made toward answering the driving question for the unit?*
- *What additional information might help us answer the driving question? (What additional questions need to be answered?)*

Point out that so far, the class has left the following questions unanswered:

- *Why are neutral objects attracted to both positively and negatively charged objects?*
- *How do objects get charged?*

Later in this unit, students will develop a nuclear model of atoms that will help them to answer these questions and develop a more sophisticated model of electrostatic interactions.

Homework: Reading for Activity 2.3
Detecting Oncoming Thunderstorms

Optional Discussion and Activity
After students have finished this investigation, you may wish to return to the Franklin's bells apparatus with students and test the charge of each object at the various points in the process.

Ask students what they would need to know in order to figure out the charge of each object in the Franklin's bell apparatus. Once they reach the conclusion that they need to know the charge of the Van de Graaff generator, discuss how to determine the charge.

One possibility is to make T and B tape strips following the same procedure that was used in Investigation 1. Bring each piece of tape close to the VDG and have students observe what happens. Remind students that they determined the charge of the T and B tape strips in Activity 1.4.

Note: The charge produced by the VDG differs depending on the machine. The VDG and both cans should all have the same charge after the bells have been ringing, provided there is *no* grounding wire back to the base of the VDG.