

The Big Question: How can objects push or pull on one another when they don't touch?

Student Learning Goals:

1. Explain how objects apply forces to one another, even when the objects do not touch. Justify your explanation with diagrams (screenshots) and words.
2. Write 2 or 3 scientific questions that are "testable" with the simulation.
3. Evaluate another person's questions to determine if they are testable, relevant, and can be investigated in the classroom or with the simulation.

Specific NGSS related learning goals for this lesson (lesson level performance expectations)

1. Ask and evaluate clarifying questions about "action at a distance". (That is, how objects can apply forces to one another when they do not even touch.)
2. Evaluate questions (testable, relevant, and can be investigated at school or with sim).
3. Frame and evaluate a hypothesis about the mechanism for "action at a distance" from questions and explorations.
4. Use a model to make and illustrate qualitative claims regarding the relationship between force and field.

Evidence of Understanding (the student will be able to):

1. Explain the mechanism for action at a distance? (How can objects apply forces to one another, even when they are not touching?)
2. Write 2 or 3 scientific questions that are "testable" with the simulation, and explain how to would use the sim to test/investigate them.
3. Trade and grade - use the sim and evaluate someone else's questions. Write 2 or 3 suggestions or clarifying comments about their list of questions
4. Frame a hypothesis reflecting our scientific understanding of how forces can be applied when objects are at some distance from one another..

NGSS goals related to performance expectations HS-PS2-4, HS-PS2-5, HS-PS3-2, and HS-PS3-5

DCI: Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. (HS-PS2-4), (HS-PS2-5)

Practices: Asking questions and defining problems, constructing explanations, and develop and use a model

Crosscutting Concepts: Cause and effect

CCSS-ELA/Literacy WHST.11-12.7 - Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

CCSS-Mathematics MP.2 - Reason abstractly and quantitatively.

Background - for a high school physics class.

Students generally do not wonder how forces can be applied by objects that do not touch each other. This curiosity will need to be developed in the lesson set-up. Most students do not understand the concept of "the field" but they may have heard the name. Students often confuse field with force. Students will have learned, either qualitatively or quantitatively about

- the gravitational force between masses
- perhaps about electric force between charges, and magnetic force between poles
- Newton's 3 laws
- mechanical energy and conservation of energy
- there are positive and negative charges
- like charges repel and opposite charges attract

Electric Field Hockey - Fields and Forces 1 - NGSS Aligned,

In this lesson, students will develop an understanding of the electric field as a mechanism for applying a force at a distance. They will practice asking and evaluating questions, constructing explanations, and using a model. The crosscutting concept to emphasize is cause and effect; that is, what causes a force at a distance? What is the effect of placing a charge in a field?

Ideally, each student will have his or her own computer, but they should process in pairs so they can discuss findings with each other.

Pre-Lesson Introduction and Exploration

1. Opening statement - connect to prior learning. Example: "We have seen that there is a gravitational force between masses. There is also an electrical force between charges, and a magnetic force between poles. **How can objects push or pull on one another when they don't touch?**" (Write bold question on the board)
2. Students explore the simulation Electric Field Hockey.
 - a. Up to 15 minutes. Exploration time is long because this is a "game" that students enjoy.
 - b. Call the black object the puck (to stay consistent with the simulation).
3. Questions to ask as you observe their explorations. (Use these questions during the follow-up class sharing time.)
 - a. With E-field off, notice the arrows on the black puck. What do they represent?
 - b. What else did you discover?
 - c. In addition to the puck, let's decide on a name for the red and blue charges to differentiate them from the puck (later we call them source charges).
 - d. With E-field on, what do you think the black arrows represent? (Can mention that they are not forces). Are they vectors?
 - e. Forces push or pull, causing a change in velocity. Did you see changes in velocity? Where did the kinetic energy come from? Was it stored energy? Recall the conservation of energy. Where might potential energy be stored? Is it possible to transfer energy without touching?
4. Model how to ask scientific questions. (Guided practice - whole class - whiteboards if available)
 - a. Why do scientists ask questions (Curiosity deserves an explanation, testable, relevant questions lead to experiments which lead to understanding)
 - b. What are some specific, testable, questions you could ask about how forces are applied when objects do not touch each other? (List on board.) The questions should lead to potential experiments that could provide answers. Teacher could differentiate between experiments that can be done with the sim and experiments needing a high tech physics lab, by putting them in two different lists on the board.
 - c. Example questions
 - i. Do masses, magnets, and charges send out particles that push or pull?
 - ii. Are there invisible strings of force across space?
 - iii. Are the forces instantaneous or do they take time to have an effect?
 - iv. Is there something like light that goes between the particles?
 - d. Which of our questions are relevant? Can any be tested with the simulation?
 - e. Summarize - Through experiments we can't do in class, scientists have developed a model to answer the question of how forces can be applied when objects do not touch. They usually call it "force at a distance". Your job is to understand the model and (later) be able to explain how it does/does not answer our primary question. In your lesson you

will need to write relevant and testable questions about how energy is transferred over a distance.

Student Activity - Key concepts

Part A. Effect of a single charge on the surrounding space.

- Arrows are darker near the source charges (where field is stronger) and not as dark farther away (where field is weaker).
- Arrows (field) extend to the edges of the page (and actually to infinity).
- Arrows (field) points away from positive source charges and toward negative source charges.
- When the source charge moves, the arrows (field configuration) change.
- Arrows continue to point toward or away from the source charge, even when the charge moves.
- Arrows (field) is associated with the source charges and not with the puck (puck can be gone and if there is no source charge, then there is no field, even if the puck is there).

Part B. The effect of a single charge on a victim (puck)

- Red and blue arrows on the puck represent forces because
 - the puck accelerates in the net direction of the arrows,
 - direction of arrow on puck is away from a like charge, toward unlike charge,
 - arrow gets longer when puck is closer to charge indicating a greater force.
- The black arrows are not force vectors because
 - they are there even when the puck is not,
 - they do not seem to push or pull on the blue and red charges,
 - they point toward and away from the charges in all directions.
- Possible hypothesis:
 - The (positive and negative) source charges cause the black arrows. The black arrows show the size and direction of a force that would be applied to the puck if a positive puck were at the arrow position. The direction of force on a negative puck is in the opposite direction.
- Possible observations and evidence to support the hypothesis:
 - Force arrows are parallel to the black arrows when the puck is positive, force arrows are antiparallel to the black arrows when the puck is negative.
 - When there are no black arrows, there are no force arrows.
 - When the black arrows are light in color, the force arrows are smaller
 - When the black arrows change direction (by moving blue or red charge) the force arrows move also, still lining up with the black arrows.

C. Investigate Energy

- Possible questions
 - From where does the puck get its kinetic energy?
 - Where is the potential energy stored (that transforms into kinetic energy of the puck)?
- Possible evaluation of the above questions
 - Valid questions - relevant to understanding the relationship between the arrows and energy.
 - Could be tested by removing all source charges so there are no arrows. Does the puck gain KE? Adding more charges so the arrows are darker (stronger field). Does the puck gain more KE now than with a weaker field?
- Possible answers and evidence
 - Answers: The puck gets its energy from the distortion of the arrows. This means the potential energy must be stored in the pattern or distortion of the arrows.
 - Support: The darker the arrows, the more kinetic energy the puck gains when placed in the region of those arrows. The puck gains no energy when there are no arrows.

Electric Field Hockey - Fields and Forces 1 - NGSS Aligned,**Post-Lesson**

Students share their findings.

Teacher defines the black arrows as the **field**, specifically the electric field when caused by charges.

Summarize that an electric field

- surrounds all charged objects (but in the sim the puck is thought to have such a small charge that it does not significantly influence the field)
- can be thought of a pattern in space that extends from the charges to infinity
- is the cause of the force that is exerted on other charges (the “victims”).
- the force on the “victim” charge pushes a positive victim away from the cause of the field and pulls a negative victim toward the cause of the field (students will look at field patterns in their next lesson)
- the pattern of the field stores the potential energy that is transmitted to the “victim” when the “victim” is present (ask - is there potential energy in the field when the victim is not there? Answer is yes)

Teacher introduces the idea that a magnetic and a gravitational field work in the same way.