Interacting with Simulated Charges and Fields via Augmented Reality

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Abstract

Electric and magnetic fields can be difficult for students to understand because they cannot directly see the fields or physically manipulate individual charges. Computer simulations and videos have helped, however they have been limited to a 2D screen. Using recently developed augmented reality devices it is possible to assign real world objects a simulated charge or current, and to see the changes in the fields as those values are changed or as the objects are moved around the room. The user can walk around the charges and currents to see the fields from any direction, as well as introduce simulated test charges. The intent is that student understanding will improve if the students can control the simulation intuitively and see the fields and forces in all three dimensions. Mixed reality recordings of the simulation will be shown and the limits and possibilities of the underlying technology will be briefly discussed.

The Simulation

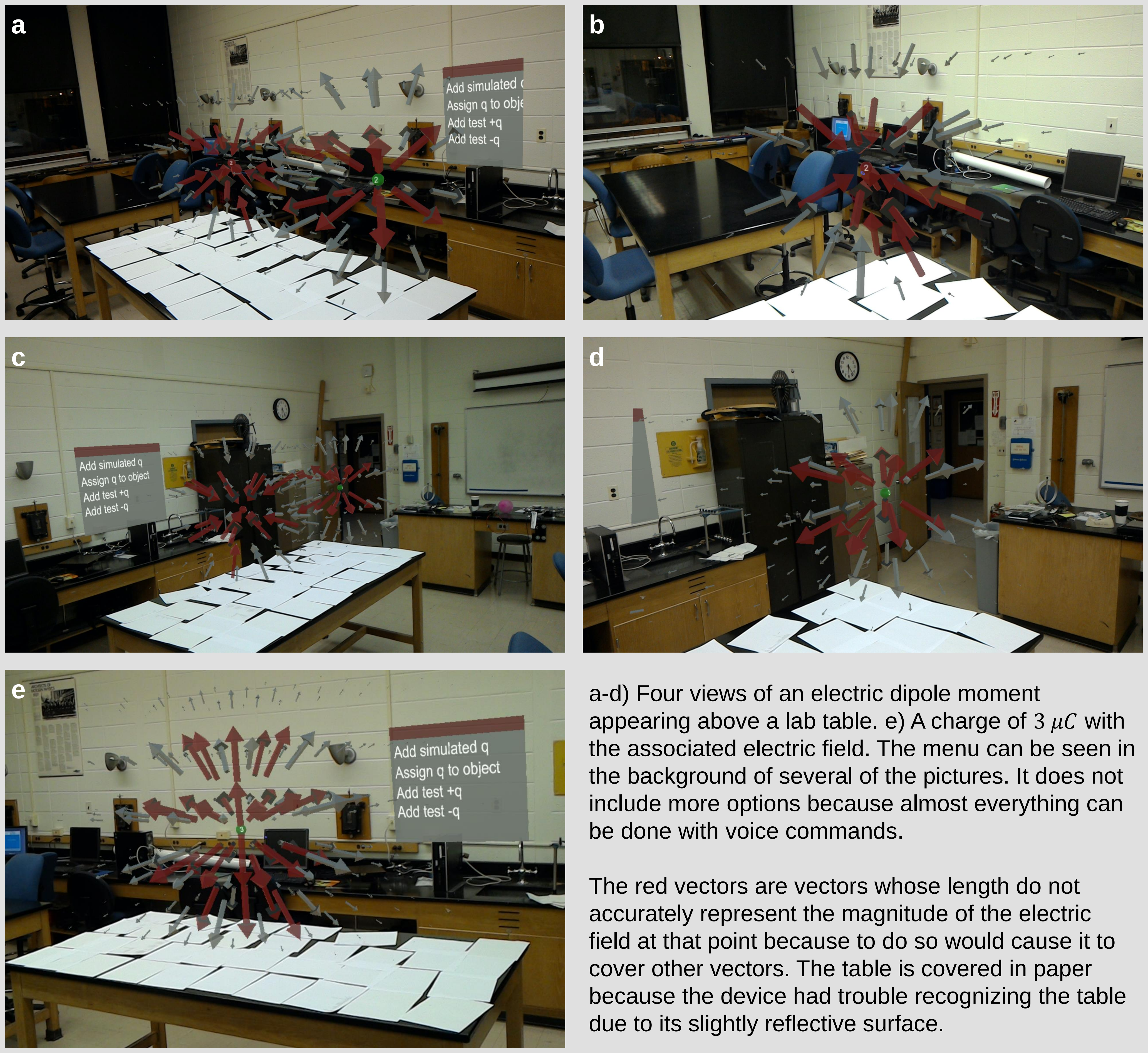
The simulation has been developed for the Microsoft HoloLens but should work on any device supporting Microsoft's Holographic API. It begins with the user selecting the area of the room where they want the electric field to be displayed by selecting the four corners of a rectangle. The program will then place a grid of electric field vectors 1 meter high with the vectors spaced by 20 centimeters in each of the x-, y-, and z-directions. The user can then place simulated charges anywhere they want in the room as well as either positive or negative test charges. This can be done either by selecting choices on the menu or by using voice commands. "Create" will place a simulated charge of 1 μC 2 meters in front of the user, which they can then place by walking around the room and looking where they want the charge to be. The value of the charge can be increased and decreased simply by looking at a charge and saying "increase" and "decrease", respectively. "Delete" removes the charge and saying "picture" will record a mixed reality picture of what the user is looking at. Mixed reality pictures include both the real world as well as the 'holograms' inserted by the device, see the figures for examples.

Test charges are designed to move in the fields at a rate that can be easily observed, thus they have a charge of $10^{-15}\ C$ and a mass of 0.1 grams. The test charges are taken into account when calculating the electric field but their charge is so small it is almost always negligible. Since the augmented reality device is aware of the surroundings in the room, charges cannot be placed inside physical objects and the test charges will collide with tables, walls, and any other large stationary object.

The vectors point in the direction of the electric field and get larger as the field increases, exactly as one would expect. However, to strike a balance between number of vectors, vector size, and the user being able to see all of the vectors, a maximum vector size is enforced. Vectors that reach their maximum size are turned red to alert the user that that vector is only indicating the direction of the electric field since the vector cannot become any larger without obscuring other vectors. Vectors smaller than a millimeter are not shown, as small 'holograms' tend to sparkle and may be distracting.

To navigate around the simulation the students need only look in different directions and walk around. Several different views of an electric dipole are shown in figures a-d.

Places the Electric Field in the Room



a-d) Four views of an electric dipole moment appearing above a lab table. e) A charge of 3 μC with the associated electric field. The menu can be seen in the background of several of the pictures. It does not include more options because almost everything can be done with voice commands.

The red vectors are vectors whose length do not accurately represent the magnitude of the electric field at that point because to do so would cause it to cover other vectors. The table is covered in paper because the device had trouble recognizing the table due to its slightly reflective surface.

Student Reactions

Two students used the current version of the program and provided general feedback in areas of usability, interest, and usefulness. The students were self-selected, thus having an interest in trying new technology; one of them (Student A) had used an unknown virtual reality system in the past and had already completed both semesters of algebra based introductory physics. Student B is currently taking the algebra based introductory course that covers electrostatics. The experience lasted approximately forty minutes with the first 10 minutes dedicated to introducing the students to the device, its interface, and what to expect in the simulation. After the brief introduction they were given the device in its 'desktop' mode and given instructions on how to start the device's calibration and gesture training programs to give them some practice with the interface. The students spent the last 20 minutes using the simulation where they did not have a particular goal beyond just exploring the simulation and its commands.

Usability

The device has a very different user interface than most other computers, however the students seemed to come to understand the basics of the controls within 30 minutes of using it. Neither student had previous experience with the device. Student B had some trouble with the interface but was still able to try out all parts of the simulation while Student A described the interface in the simulation as "Simple to use."

Interest

Both students enjoyed the experience with Student B saying "It is so awesome" and "I wish we had this in lab." When asked what part of the experience was "awesome", the student said both the device and the simulation. Student A wrote: "I'd describe the experience as fun, interactive, immersive, and interesting".

Usefulness

When using student self-reporting it is often extremely difficult to accurately determine how helpful the experience actually was for the students, however both saw it as useful in helping them learn about electric fields. Student B said "This is actually real, you can control it" and "3D makes it much more real". Student A expressed similar thoughts: "I'd also say it allows students to see an actual representation of a difficult concept to visualize such as electric fields right in front of their eyes that they can play with, which would have helped me when I was studying physics".

Expected Benefits

- The 'holograms' are in 3D and appear in the room with the students so the simulation is giving them a more concrete and realistic model of electric fields, which should improve understanding.[1,2]
- Help students see the difference between electric field lines and particle trajectories, a point of confusion.[3]
- Students will be actively engaged with a topic that is generally abstract, helping students learn the material.[4]
- Simple interface will limit time spent learning the controls, leaving more time and focus for exploring physics concepts.

Modern AR Hardware Overcomes Previous Limitations [5]

- A single mass market device
- Comfortable enough to be worn for an hour
- Battery lasts at least 3 hours
- Multi-purpose devices
- VR and AR devices are becoming more common, increasing student familiarity with the technology and its interfaces.

But Some Remain

- Difficult to monitor and help more than one group of students
- Cost (though it is decreasing)
- Viewing area
- Pedagogical Issues
- Fractured device ecosystem

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