AC 2012-3301: A PHYSICS LABORATORY ACTIVITY TO SIMULATE THE OPERATION OF THE TOUCHSCREEN ON A SMARTPHONE

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A Physics Laboratory Activity to Simulate the Operation of the Touchscreen on a Smartphone

Abstract

We use cell phones as a context to teach important concepts in introductory physics. Our activities are based on an innovative hands-on, inquiry-based curriculum. We have modified the curriculum to incorporate additional activities.[1] This paper will describe a physics laboratory experiment to simulate the operation of the touchscreen on a smartphone.

A detailed description of the activity will be provided. The simulator is fabricated using common office and laboratory supplies and is inexpensive enough that students can keep the model. We describe how the simulator is used in two different courses. One course is designed for high school students attending a university enrichment program, the other is a second-semester undergraduate general physics laboratory course.

In addition we present the results of an open-ended assessment of student learning. Students are engaged to write to a specific prompt and we assess the writing in a pre- and post-activity format. The results of the assessment indicate that the experiment helps students understand how the touchscreen on a smartphone functions.

Introduction

The low cost of mass-production, driven by fierce competition among a large number of manufacturers and product lines has made wireless electronic devices ubiquitous. People in a wide range of economic groups have access to extraordinarily complex and advanced electronic devices in the form of cellular and cordless telephones, infrared television remote controls and wireless pointing devices (e.g. a mouse). In addition, low cost wi-fi networks enable tablet computers, smartphones, internet televisions and similar devices to be increasingly powerful and popular.

Students seem to have a particular interest in instantaneous communication as evidenced by the popularity of social networking websites and texting. They are very familiar with the functionality of communication devices but generally lack any knowledge of their operation. We believe that this situation provides a unique opportunity to exploit common electronic products for pedagogical purposes. In particular, cellular telephones provide a useful context in which to teach important concepts in physics and engineering. An innovative, inquiry-based curriculum has been developed to do this.[2] We will present evidence that our simple, inexpensive touchscreen simulator for a smartphone is a useful device to include in laboratory activities.

The motivation for the development of our touchscreen simulator arose from experience with the aforementioned curriculum developed for wireless communications. Physics education research is useful to help design curriculum and innovative pedagogical strategies.[3] One of the first activities in the curriculum is for students to write down questions that they would like to answer by the end of the course. During the summer of 2011 a couple of students asked how smartphones worked. This is, of course, a challenging question to answer. The answer depends on the level of knowledge of the person who asked the question, as well as the specific functionalities to be addressed. We took a somewhat simple approach and assumed that the inquirers were referring to the operation of the touchscreen on the phone; not the complete range of communication, computing, and data functions these devices are capable of performing. Over the next few days, we developed, what we believe, is a simple, inexpensive device that simulates the operation of the touchscreen on a smartphone. Students can see not only how the device registers information about the position on the screen where it is touched, but also how information about the motion of the finger contact is captured.

We recognize that the operation of touchscreens is valuable proprietary knowledge specific to various manufacturers. We also recognize that no touchscreen actually works exactly like our simulator. Nonetheless, we believe that the simulator allows students to construct mental models regarding the operation of these complex devices that convey essentially correct physical principles. Students can determine how the device *knows* where it is touched and which way the finger is moving. This method of instruction, where students construct models of physical systems is known as *interactive engagement* and has been studied extensively.[4]

This paper is structured in the following manner. First, we describe the student populations that participated in the activity. Next, the device is described and we provide detailed instructions for building the touchscreen simulator including parts and supply lists. Many of the required items are common office supplies and the rest can be purchased from electronics suppliers. Subsequently, we describe the activities that incorporated the simulators in two distinct cohorts of students; high school students in a summer enrichment program, and university students in a second-semester general physics laboratory course. Finally, the results of an assessment given to all students in a pre-test, post-test format are presented. The assessment required students to respond to an open-ended writing prompt. Student responses were evaluated by the authors according to a predetermined scoring rubric.

Student Populations

The touchscreen activity was conducted with two distinct groups of students. The first cohort consisted of a group of 24 high school students participating in a summer enrichment program. The College of Engineering & Science at the University of XXX supports the UNinitiates Introduction to Engineering (UNITE) program in conjunction with the Junior Engineering and Technical Society (JETS) and the U.S. Army Research Office.[5] The curriculum is designed to simulate a freshman engineering experience. About 79% of UNITE graduates nationwide are later enrolled in college. Our program, the oldest in the nation, has been described in previous publications.[6] The students in the program are all from the Detroit area and half are female.

The simulator activity was developed over the summer. After completing it, we felt it could be modified in such a way as to make it suitable for students in a second-semester general physics laboratory course. Subsequently, we adapted the activity and completed it with about 50 students during the fall semester. This second group consisted of students enrolled in the College of Engineering & Science as either engineering or science majors. About half of the students take a calculus-based physics sequence while the others take an algebra-based one. No distinction between the two was made for the purposes of this paper. Findings and observations from the two trials will be discussed later.

Touchscreen Simulator

Our touchscreen simulator uses vertical and horizontal strips of aluminum foil, separated by a plastic insulator, to define an x-y array of individual circuits. The circuits are powered by AAA battery packs. Completion of a circuit (or circuits) causes the LED at the corresponding x-y position to light up. It is readily apparent to students that completing a circuit at a specific location immediately provides information, in the form of an illuminated LED, as to where on the screen the touch occurred. The temporal sequence of completing circuits indicates the direction the finger is swiped across the screen and students can observe the corresponding temporal sequence of LED illumination.

A photograph of a student constructed simulator is shown below in Figure 1. Figure 2 shows a student pressing at the intersection of a row and column of foil strips to complete a circuit and cause an LED to glow. The next figure, Figure 3, shows that the simulator can be touched at two places at the same time causing two LEDs to glow simultaneously.

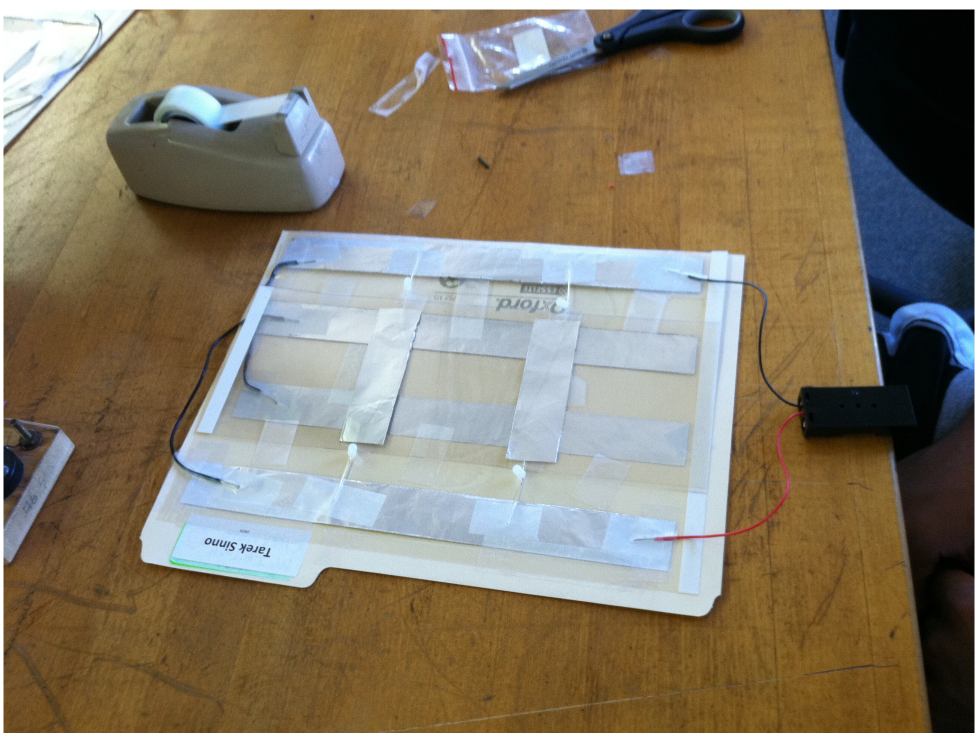


Figure 1. Student constructed touchscreen simulator.

Figure 2. A student is using the simulator to activate an LED. It really works.

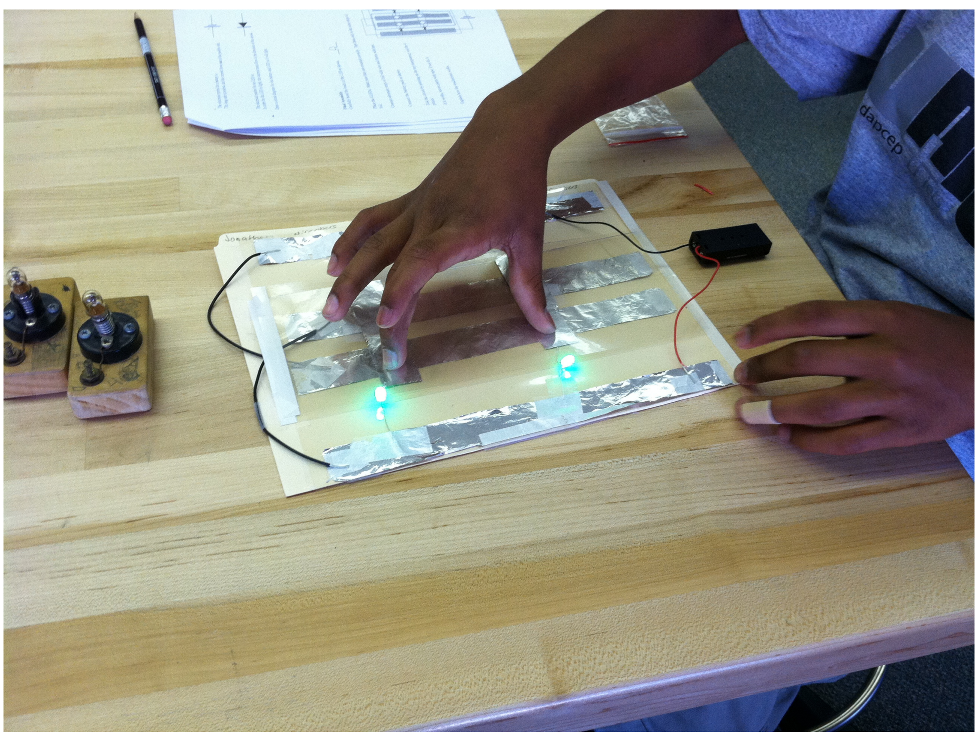


Figure 3. Illuminating two LEDs simultaneously.

Parts List, Construction and Assembly

Most of the required parts consist of common office supplies. We used aluminum foil, transparent tape, 8.5" x 11" blank overhead transparencies and one-half of a manila file folder as a substrate to hold the assembly. The aluminum foil was cut into six strips: 1" x 10" (4 required for the vertical, y, sections), 1" x 3.75" (2 required for the horizontal, x, sections). The UNITE high school students each used four LEDs (Super Bright LEDs, Inc.: RL5-G20-360, 5mm Green LED (360 degree) $0.55). Each student was provided two AAA batteries and a battery holder (Newark: 34M2184 $1.28). The assembly requires two 6" pieces of wire stripped at both ends. We used #18 wire but the choice is certainly not critical to the operation (stranded wire would be recommended).

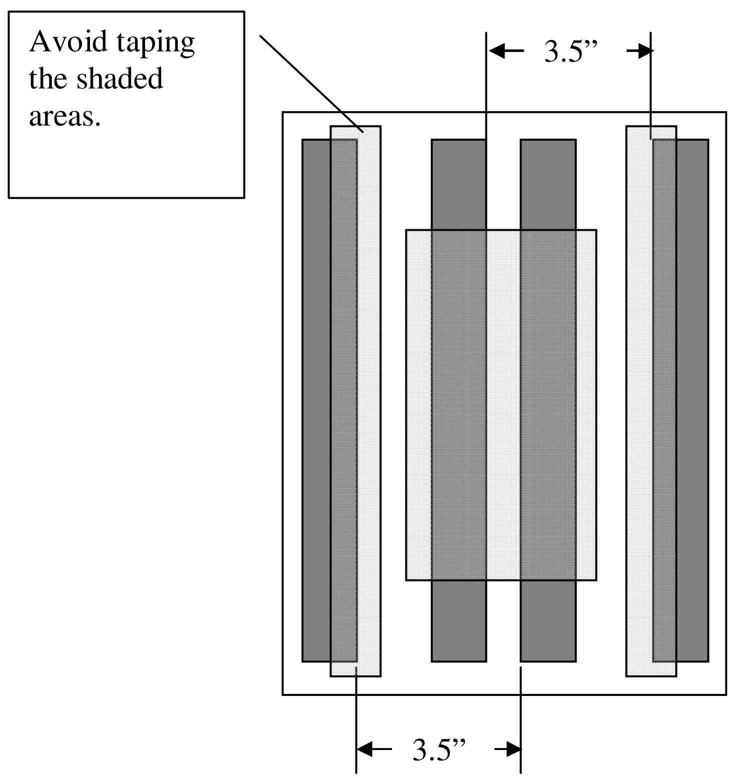
Directions

1. Tape one 8.5" x 11" transparency to the manilla folder. The transparency should be completely inside the folder.

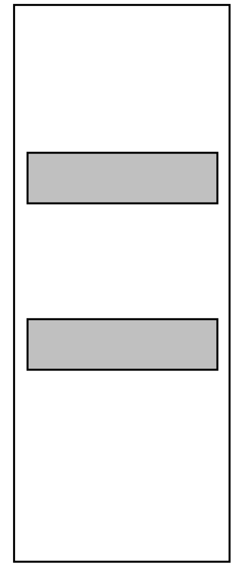
2. Cut the 6 strips of aluminum foil to the required lengths. Take care to keep them flat and straight.

3. Tape the 10" strips to the 8.5" x 11" transparency as shown. Use the tape sparingly and avoid taping the shaded areas.

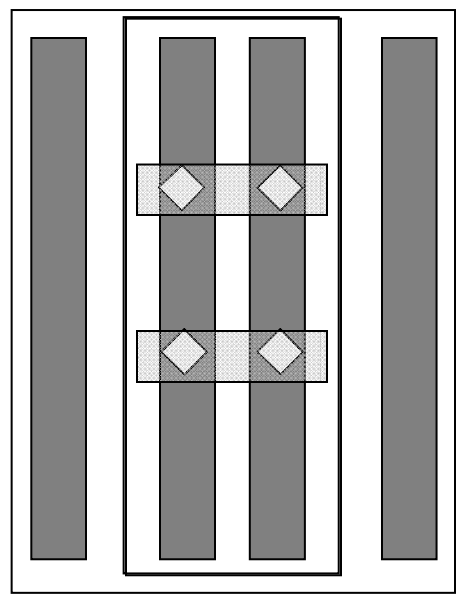
4. Cut one transparency in half lengthwise so it is 4.25" x 11".



5. Tape the 3.75” foil strips to one of the 4.25” x 11” transparencies as shown. Keep the tape away from the ends.



6. Stack the two 4.25” x 11” transparencies on top of the large one with the blank one on top. Use a marker and draw 4 diamond shapes on the blank transparency at the intersections of the foil strips as shown.



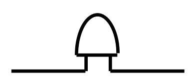
7. Cut holes in the transparency along the diamond-shaped lines. Do not crease the plastic.

   (On the following page, Fig. 4 shows a student cutting holes in the transparency used as an insulator. We found that diamond-like shapes can easily be cut using scissors without creasing the plastic. Circles require the use of a hobby knife, the risks of 14 year olds using X-acto blades needs no further discussion.)

8. Assemble the touchscreen by placing the transparency with the 4 holes between the other two. The top transparency, with the 2 horizontal foil strips, should be foil-side down.

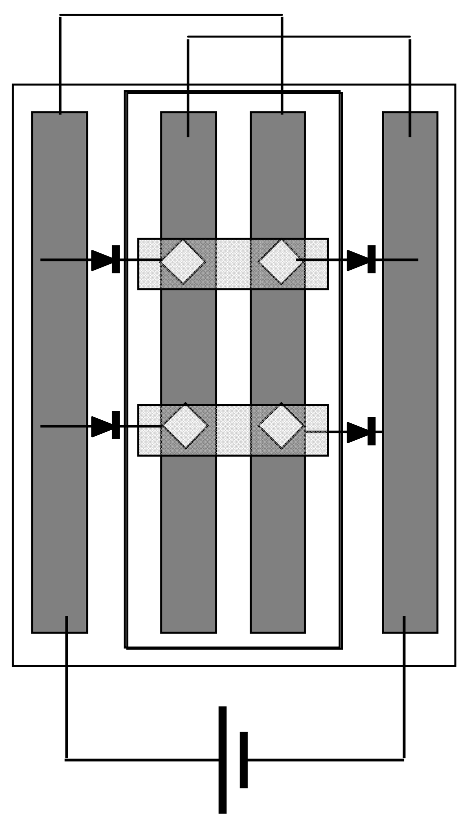
Figure 4. Student cutting diamond shapes out of a blank overhead transparency used as an insulator in the touchscreen simulator.

9. Carefully bend the leads of the LED as shown.



10. Place the 4 LEDs in the simulator as shown. Make sure they are oriented correctly. Tape them only to the outer strips of foil.

11. Connect alternate vertical strips of foil with wire and fasten with tape. Connect the battery pack as shown in the schematic drawing.



Please refer back to Fig. 1 to view a completed touchscreen simulator. It has been our experience that each student is successful in completing a working device. Sometimes an instructor needed to provide help when a diode was reversed or if the wires failed to make adequate electric contact to the aluminum foil strips.

The UNITE students were asked to use the battery pack to light a #40 flashlight lamp and then to switch the leads and observe what happens. They recognized that the lamp had no polarity associated with it. They were then directed to light the LED and to reverse the leads. They recognized that the LED had an associated polarity and the diode symbol was related to the direction of current flow.

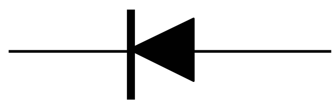


Figure 5. Schematic symbol for a diode where the direction of current flow is represented by the arrow.

After completing this activity with the high school students in the UNITE program we felt that it could also be useful in a second-semester general physics laboratory course if it was suitabley adapted to make it more rigorous. Our reasoning was along the following lines. The battery pack provides a constant emf of about 3V. The operating parameters of a typical LED are about 2.2V at 20mA. Different color LEDs (Newark: 18M1287, Green $0.183; 93K6779, Red $0.53; 93F3520; Yellow $0.183) have somewhat different operating parameters. We decided to have students measure the operating parameters and determine how to configure a circuit to drop the excess voltage. A series resistance of about 40Ω would work. Subsequently, a we purchased a large supply of 20Ω resistors (Newark: 26R3976 $0.026) and planned to have students configure these to provide an appropriate voltage drop. This turned out to complicate the construction of the simulator without adding much educational value. The combination of series and parallel resistors turned out to be very awkward to incorporate in the structure, and in fact, all of the diodes could operate with the full 3V forward drop. In the future we plan to have students measure these operating parameters and determine the appropriate circuits to drop the excess voltage, but to use LEDs that operate at 3V and not put the resistors in the circuits. This is also in response to a question given to students at the end of the activity asking how it could be improved-leave out the resistors. We believe that even without the resistors, the laboratory activity increases student understanding of the operation of the touchscreen on a smartphone. We provide evidence for this conclusion in the following section.

Assessment

It is important to measure student learning when developing new curriculum. This activity is not simple to assess due to the divergent student background knowledge of physics and the technical nature of the device being simulated. For this reason we felt that trying to develop an objective, multiple choice test would be too difficult. There are simply too many factors affecting student responses and we had no way to develop a robust assessment in a short period of time.

Our strategy was to devise an open-ended, free response writing assessment to be administered in a pre- and post-test format. To make the assessment valid, we developed a rubric for assigning numerical values to student responses. The authors decided on the rubric before grading and subsequently assigned numerical values to sets of student responses.

The high school students in the UNITE program were asked to respond to the following writing prompts:

1. Explain, in your own words, how a touchscreen on a smartphone can tell where your finger is located.

2. Explain, in your own words, how a touchscreen on a smartphone can tell which way your finger is moving.

The rubric used to provide numerical values to the first question was: 0-blank, 1-any response, 2-almost correct, 3-touching the screen completes a circuit and provides location information. The rubric used to provide values to the second question was: 0-blank, 1-any response, 2-almost correct, 3-touching the screen completes circuits in a sequence, the sequence provides directional information. The average values of the authors' (MM, JR, RR, CT) results for the UNITE students are shown below in Table 1.

Pre-test		Post-test	
Question 1	Question 2	Question 1	Question 2
1.01	1.07	2.02	1.81

Table 1. Average values of grades assigned to UNITE student responses.

Upon review of the UNITE student responses, we decided to modify the writing prompt. Several students indicated that the touchscreen can determine the position and motion of a finger by using a touch sensor. While this is technically correct, it does not provide any insight into what students are thinking about the operation of the device. We decided that on subsequent assessments we would ask students not to use the word 'sensor'.

The writing prompts given to the students in the second-semester general physics laboratory course were:

1. Explain, in your own words, how a touchscreen on a smartphone can tell where your finger is located. Do not use the word "sensor."

2. Explain, in your own words, how a touchscreen on a smartphone can tell which way your finger is moving. Do not use the word "sensor."

The assessment rubric was the same as the one used previously. The average values of the authors' (GH, MM, JR, RR, CT) results for the general physics students are shown below in Table 2.

Pre-test		Post-test	
Question 1	Question 2	Question 1	Question 2
1.63	1.58	2.80	2.69

Table 2. Average values of grades assigned to second-semester general physics student responses.

Our evaluation of student responses shows two significant findings; neither of which is particularly surprising. First, the university students demonstrate a higher level of understanding of the operation of a touchscreen on a smartphone both before and after performing the activity. It is argued that this provides evidence that the open-ended, free response writing prompt assessment has validity; at least in this limited context. Second, in each case students demonstrated an increased ability to explain the operation of a highly complex, technical device after constructing a simple simulator.

Conclusion

A simple and inexpensive device that simulates the operation of the touchscreen on a smartphone has been developed. The device can be constructed during a typical laboratory period for a few dollars per student. We believe that it helps students develop a mental model of how such a screen works. In particular, students are able to explain how a smartphone can locate a touch and also how it can determine which way a finger is swiped across the screen. We believe this activity improves student understanding of a complex electronic device and provides a valuable context in which to engage students in the study of physics and engineering.

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