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Table 1

Demographics of students

	Number of students	Gender[i]	Major[ii]	Grade Level[iii]	Average GPA[iv]
1st Semester	18	17 M, 1 F	9 (CSC) 2 (PHY) 2 (CHM) 2 (MTH) 1 (AC) 1 (BIO)	6 (FR) 6 (SO) 3 (JR) 3 (SR)	3.41/4
2nd Semester	21	13M, 8 F	9 (CHM) 9 (CSC) 1 (NEUR) 2(UNK)	2 (FR) 11 (SO) 6 (JR) 1 (SR)	3.02/4
3rd Semester	21	14M, 7 F	12 (CSC) 5 (CHM) 2 (MTH) 1 (PSY) 1 (POL)	2 (FR) 10 (SO) 5 (JR) 4 (SR)	3.17/4

[i] Gender- (male: M, female: F)
[ii] Major- CSC: Computer Science, PHY: Physics, CHM: Chemistry, MTH: Math, BIO: Biology, AC: Accounting, PCIS: Pre-Computer & Information Science, NEUR: Neuroscience, POL: Politics, PSY: Psychology, UNK: Unknown
[iii] Grade Level- FR: Freshman, JR: Junior, SO: Sophomore, SR: Senior
[iv] GPA: Grade Point Average

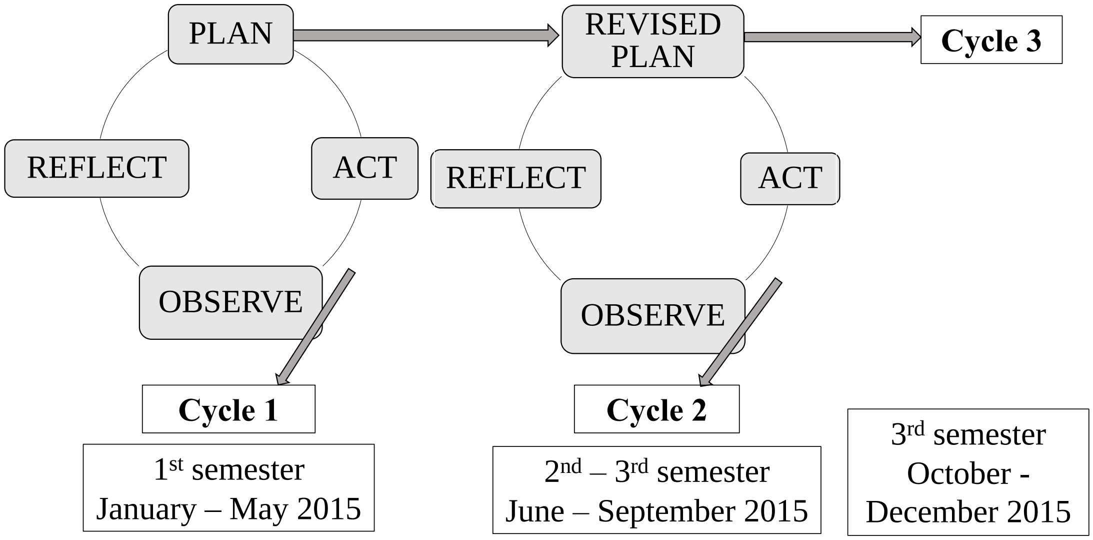


Figure 1. Timeline for the cycles of action research

Supplementary Material- Lesson Plan

Phase 1: Engage (10 minutes)

The teacher tries to find out what students know and how to build on new concepts on their knowledge; students have the opportunity to realize their existing ideas and compare them with those of others.

Learning activity: Students work on the debate problems in groups. They discuss these problems in groups, come up with some ideas, and share their ideas in whole class discussion (The sample debate problem is at right).

Scientific practices: communicating information through arguing from evidence, constructing explanations

Phase 2: Explore (50 minutes)

After students engage in ideas, they also need to conduct activities for exploration. Students interact with materials and ideas; observe, describe, record, compare, and share their ideas and experiences through small-group discussions. The teacher has a facilitator role.

Learning activity: Students explore “electrical interactions” by sticky tape and try to identify whether different or same type of pairs attract or repel each other. They will use “a plastic rod” and “a piece of wool” to identify the types of charges as negative or positive.

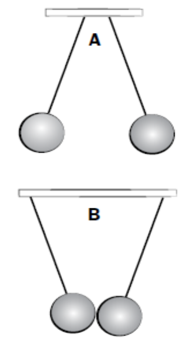
Students work on the questions related to “Charge” concept from *Tutorials in Introductory Physics* (McDermott et al., 1998) on page 71-76.

Sample question: Press a tape onto the table and write a B (for bottom) on it. Then press another tape on top of each B tape and label it T (for top). Pull each pair of tapes off the table as a unit. After they are off the table, separate the T and B tapes and describe the interaction between two T tapes, two B tapes, and a T and a B tape.

Scientific practices: making observations, modeling, constructing explanations

Debate problem (Keeley & Harrington, 2014)

Does the Example Provide Evidence?



Students in Mr. Miller’s class watched a demonstration on electric charge. In the first example of an interaction, Mr. Miller brought two plastic balls together. The balls moved apart when they got near each other, like this (A). In the second example of an interaction, the balls moved toward each other, like this (B). Mr. Miller asked the students if the two examples of interactions provided convincing evidence that both balls in each example were electrically charged. Here is what some students said:

Faith: I think both examples provide evidence that all of the balls in both interactions were electrically charged.

Milo: I think only the first example provides evidence that both balls in an interaction were electrically charged.

Judd: I think only the second example provides evidence that both balls in an interaction were electrically charged.

Fran: I think neither example provides evidence that both balls in an interaction were electrically charged.

With whom do you agree the most? _______________
Explain why you agree.

My idea is that …

The evidence I would use to convince somebody is that …

Phase 3: Explain (15 minutes)

The teacher builds on the important points of engagement and exploration phases. After students are asked to share their ideas, the teacher makes summaries based on the data collected in the exploration section to explain basic concepts.

Scientific practices: communicating information, constructing explanations

Figure 2a. An example for integrating scientific practices into the 5E instructional model

Phase 4: Elaboration (90 minutes) (Sample questions provided)

Elaboration activities provide students' further experiences that contribute their learning. Students involve in hands-on activities as part of their laboratory assignment. In this phase, the teacher gives frequent feedbacks for students' activities and students have opportunity to share their ideas in group work and revise them through discussions. Students continue investigations on the type of charges, interactions between charged and uncharged objects, and the concept of electric force, and working with an electroscope.

Learning Activity: Create T and B tapes approximately 10 cm long. Complete the following investigations.

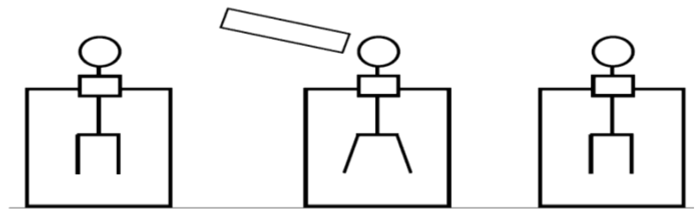
1. Bring a few charged objects toward the tapes and record whether they are attracted/repelled/nothing.

Material	T type tape	B type tape
Charged plastic rod, rubbed with wool		
Charged glass rod, rubbed with silk		

2. List types of materials that are clearly T-type or B-type.

	Is the charge T or B or none?	Is the charge T or B or none?
Glass rubbed with silk	Glass is	Silk is
Glass rubbed with wool	Glass is	Wool is
Plastic rubbed with silk	Plastic is	Silk is
Plastic rubbed with wool	Plastic is	Wool is

3. You are provided an electroscope as in the figure. Touch the metal sphere once with your finger. Then bring the charged plastic rod rubbed with wool toward the metal sphere of the electroscope and observe the behavior of leaves.



4. Draw + and – charges on the diagram to represent the distribution of charge on the rod and the electroscope when the rod brought close to the electroscope.
5. What happens to the electroscope when you take the charged rod away? Explain why?

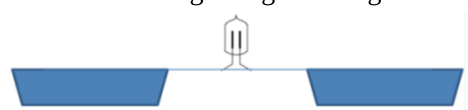
Scientific practices: designing experiments, data collection and analysis, modeling, engaging in argument from evidence

Precautions: Extend the rubbed objects away from your body so that your body does not influence your observations made with hanging tapes. In humid conditions, the electric charge on the pieces of tape can leak off causing them to become discharged. You may have to recharge or replace your T- and B-strips from time to time.

Phase 5: Evaluation (15 minutes)

Students' understanding of concept is assessed. Students are asked to design an experiment in order to show whether moving charges can light the bulb. In addition, students work on a quiz related to charge concept.

Materials: two aluminum pie pans, two short wires, and a neon bulb, Styrofoam board



1. Assemble the objects as shown in the figure.
2. In a darkened room, vigorously rub the Styrofoam board with a cloth to charge it. Then, wave the foam board in various ways above one of the pie pans while carefully observing the bulb. What did you notice?
3. What is the correlation between the behavior of the bulb and the motion of the board? What is happening in the activity?

Scientific practices: designing experiments, engaging in argument from evidence, communicate information

Figure 2b. An example for integrating scientific practices into the 5E instructional model

References

Keeley, P., & Harrington, R. (2014). *Uncovering student ideas in physical science,* vol. 2. Arlington, VA: NSTA Press.

Example on the use of different type models

The instructor modified the lesson plan to incorporate the qualitative, mathematical, and physical models.

Engagement:
The instructor prepared the question in Figure 3 to encourage students to make predictions about the brightness of identical bulbs in different circuit designs and explain their reasoning.

Exploration:
Tutorial guided students to set up the physical models of these circuits to compare the brightness of the bulbs by considering the amount of current passing through each bulb.

Explanation:
The instructor discussed students' responses from the engagement and exploration phases and asked, "What if you have unidentical bulbs? How will the brightness of bulbs change?"

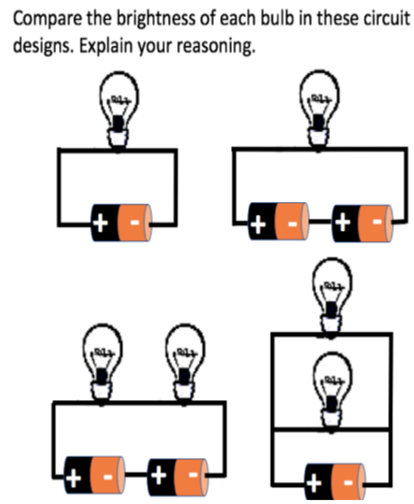


Figure 3. Question utilized in the engagement and exploration phases

Elaboration:
Students used two different light bulbs in series and parallel circuits to predict and test how the brightness changed. They were also expected to derive an equation related to Kirchhoff's Loop Law based on their measurements (Figure 4)**.**

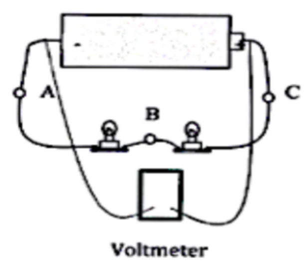
Record the voltmeter reading, $\Delta V_{battery}$=

Predict: If you connected the voltmeter across each bulb (unidentical) would you expect

a. The readings to be equal to each other?
b. The readings to be equal to battery or power supply voltage?
c. Another result such as .....

Connect the voltmeter across each of the two bulbs in the circuit, and measure voltages across each bulb.

ΔV_{B1}	ΔV_{B2}	$\Delta V_{battery}$



Based on your measurements about potential differences across the bulbs and the battery voltage write down an equation connecting ΔV_{B1}, ΔV_{B2} and $\Delta V_{battery}$ for the series circuit. This is the Kirchhoff's loop law applied to the series circuit.

Figure 4. Question used in the elaboration phase

Evaluation: The instructor evaluated students' understanding of concepts by asking for a comparison of the brightness of different light bulbs in a complex circuit including both parallel and series connections (Figure 5).

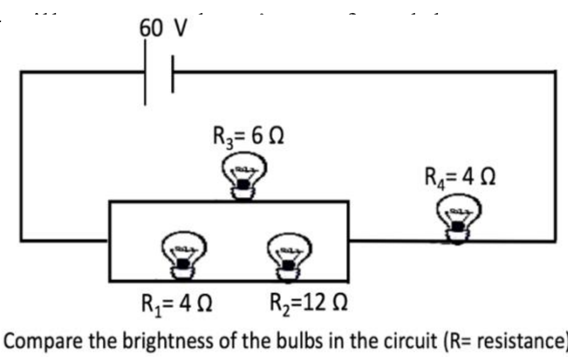


Figure 5. Complex circuit to assess students' understanding

Table 2

Sample class discussion on "Light Rays" from the engagement phase

The instructor posed an engaging question on Light Rays from Osborne et al. (2001). She asked the students to "Please discuss these two theories and provide the evidence for your claims." **Theory 1:** Light rays travel from our eyes to the objects and enable us to see them **Theory 2:** Light rays are produced by a source of light and reflect off objects into our eyes, so we can see them
A student facilitated class discussion by asking a question about the evidence that "Light travels in straight lines." **Student A**: If the idea that "Light travels in straight lines." is correct, can this evidence support *Theory-1*? **Instructor**: Can you explain why? **Student B**: Light does not travel. It is just there. **Student C** (from another group): "Light travels in straight lines" is a general definition, technically it should support both of theories. **Student B** (asked to another student from another group): What is your position for "Light travels in straight lines"? **Student D**: It is relevant for both of them, it supports Theory 1 or Theory 2. **Instructor:** What happens if a light ray meets a medium? **Student D**: It bends through refraction. *This discussion was an indicator of students' conceptions about light rays before starting the activity. This example shows the students' preconceptions before starting to explore the phenomena.*