A COMPARISON OF COMPUTER SIMULATED AND PHYSICAL DC CIRCUIT LABORATORY INVESTIGATIONS ON CONCEPTUAL UNDERSTANDING

A RESEARCH PAPER

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BY

CASEY WILLIAM KOOPMANS

DR. JOEL BRYAN – ADVISOR

BALL STATE UNIVERSITY

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I. INTRODUCTION

Physics teachers are in constant pursuit of instructional strategies that will maximize student learning, as well as correct false presumptions that many students have even before they enter the classroom. Direct current (DC) circuits is an area in which students have many misconceptions. According to The Physics Classroom (http://www.physicsclassroom.com/class/circuits/u9l2e.cfm), some common misconceptions are:

1. Batteries and power plants “produce” electrons.
2. Batteries store electrons.
3. Charge is used up by light bulbs.
4. Charge flows at very high speeds.
5. Batteries produce a constant current – once the battery runs out of current the battery is dead.
6. Components of a circuit can be treated individually.
7. Greater resistance results in brighter light bulbs.
8. Confusing potential difference with current.

These misconceptions can be difficult to overcome as the relationships between current, potential difference and resistance are abstract (Liégeois 551-553). Students must develop their conceptual framework of these relationships based on things they cannot observe directly. Many students learn by seeing and feeling, which is very difficult in this case, as opposed other physics concepts, such as centripetal force or Newton’s Laws, which are more easily demonstrated (Taber, et. al. 156).

One method of overcoming this problem is through the use of simulated experimentation on a computer. Simulations allow students to go at an appropriate pace, give students immediate feedback on performance, give them more control over their learning experience, and often they find it more enjoyable (Bayrak 54). It is necessary, however, that simulations be well designed and well integrated into the curriculum so that they are both supported by and also support other learning activities. Often, simulations with inquiry-based objectives have been found to have a positive impact on student learning. A technique known as P-O-E, or Predict, Observe, & Explain has been determined to be very effective at increasing students' learning of physics in conjunction with computer simulation (Zacharia 1742).

Physics researchers from the University of Colorado and the Physics Education Technology (PhET) Project (http://phet.colorado.edu/) have developed over 70 interactive computer simulations specifically geared for physics content. Finklestein and colleagues from the University of Colorado conducted a study with undergraduate students in an introductory physic class using the PhET Circuit Construction Kit (DC only). Their goal was to see if this simulation could be used instead of actual equipment. They examined if students learned the concepts and learned them as well as students using real equipment, and what, if anything was lost by having students only use computer simulation. The students were split into two groups – those that used actual equipment, and those that used the simulation. Students were given a pre-test and a post-test, and those that used the simulation outperformed those who used actual equipment on the assessment as well as other circuit related tasks they were asked to do (Finklestein, et. al. 1-6).

The Circuit Construction Kit is very robust and comprehensive in terms of capabilities. Students can add light bulbs, other types of resistors, batteries, switches, and wires just as they could using actual equipment. In addition, it is possible to vary the voltage of the batteries, the resistance of the resistors, and the internal resistance of the wires, light bulbs and batteries. Students can use computer generated voltmeters and ammeters to make measurements just as they would in a real lab. Furthermore, and one of the greatest advantages to using this simulation, students have the ability to see the behavior of the electrons in the wires, as shown in Figure 1. This visibility with the PhET simulations is what allows students to bridge the gap between their present understanding and the underlying physics concepts.

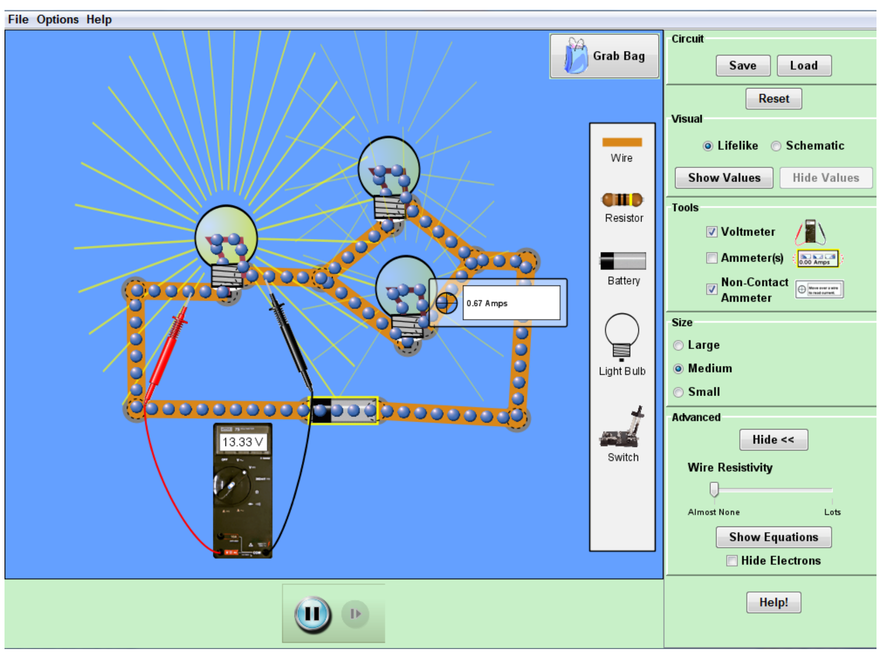


Fig. 1 – A snapshot of the PhET Circuit Construction Kit (DC only)

This study utilized the Circuit Construction Kit in order to extend previous work and answer the following research questions:

1. Does computer simulation result in an increase in conceptual understanding of simple DC circuits for high school students?
2. Does exposing students to both types of laboratory experience provide any additional gain in conceptual understanding?
3. Does the order in which students are exposed to the laboratories affect students' conceptual understanding? Are they best used as stand-alone activities or to be used in support of one another?
4. Does computer simulation provide a more time effective way of doing a laboratory?
5. What are the students' attitudes in regards to both laboratory experiences?
6. What are the advantages and disadvantages of each laboratory experience?

II. EXPERIMENTAL DESIGN

A. Participants & Classroom Environment

The study was conducted at a small town public high school in Michigan. There were 43 students who participated in the study, all of which were either juniors or seniors and enrolled in a two semester introductory physics course.

Of the participants, 27 (nine boys, eighteen girls) were enrolled in two sections of Conceptual Physics (CP) – an introductory physics course where mathematical computation is minimized. These students were accustomed to assignments and assessments with conceptual questions where they were asked to rank things from greatest to least, or respond with answers such as "increases, decreases, remains unchanged". All but six of these students were juniors, taking this course instead of chemistry to fulfill a graduation requirement. Most are college bound, but are not likely to pursue a science related degree.

The other 16 students (thirteen boys, three girls) came from a single section of a course called Physics (P), an algebra/trigonometry based introductory physics course. This group was accustomed to assigned work and given assessments in which mathematical computation was used very frequently, although conceptual understanding was also highly emphasized. This group included 14 seniors. All are college bound, most of which are likely to pursue a science related degree.

Classes met for 85 minute periods on an every other day basis (two or three times per week depending on the week). The courses did not have designated lab periods, as they were embedded into the schedule where appropriate. All classes had been exposed to other PhET simulations, as well as other Java Applet simulations, through entire class demonstrations or other laboratory experiences.

B. Procedure

Prior to the lab, all classes were given similar instructions about circuits including the following:

1. battery, resistor, current – water pump, clog, water flow analogy,

2. Ohm's Law & Kirchoff's Point Law,
3. series vs. parallel circuits,
4. compound circuits,
5. computing overall resistance, current through the battery, current through the resistors, and voltage drop across a resistor,
6. how to build circuits using actual equipment,
7. how to use a multimeter, and
8. how to use the PhET Circuit Construction Kit.

Prior to the lab, all students took a thirty question inventory (Appendix 1) in order to measure their current level of understanding. Twenty-three of the questions were close variations of or came directly from the Determining and Interpreting Resistive Electric Circuits Concepts Test - DIRECT (Engelhardt, P.V., and Beichner, R.J. 98-115), five questions were close variations of or came directly from the Electric Circuits Concept Evaluation – ECCE (Sokoloff and Thornton) and one question was written by the instructor. For a sample question, see Figure 2.

Compare the brightness of bulbs A, B, and C in these circuits. Which bulb or bulbs are the BRIGHTEST?

(A) A

(B) B

(C) C

(D) A = B

(E) A = C

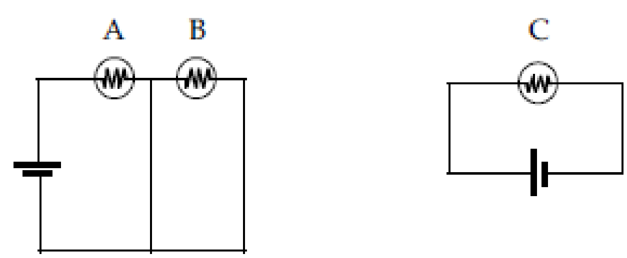


Fig. 2: Sample question from inventory

Students from the three classes were split into four groups to complete the lab (Appendix 2), which was conducted over two consecutive class periods. Each class completed the lab separately from the other classes. Attempts were made for each group to be composed evenly of students from all three classes and to make the group sizes approximately equal with a similar ratio of males to females in each group. The groups were as follows:

AA: Actual equipment on both Day 1 and Day 2 (4 boys, 5 girls; 5 CP, 4 P).

AS: Actual equipment on Day 1 and simulation on Day 2 (6 boys, 4 girls; 6 CP, 4 P).

SA: Simulation on Day 1 and actual equipment on Day 2 (7 boys, 5 girls; 7 CP, 5 P).

SS: Simulation on both Day 1 and Day 2 (5 boys, 7 girls; 9 CP, 3 P).

The lab was conducted in the school library. Students using actual equipment built circuits on large tables in the library, while those using the computer simulation did so in an adjoining computer lab. Approximately six to eight students were exposed to one of the lab experiences at a given time. Students who worked with the actual equipment built their circuits with one or two other people, while students using the computer simulation built their circuits individually. The students in all groups worked simultaneously for 60 minutes in two consecutive class periods. The lab consisted of 25 circuits in which the students were to build circuits, make predictions, take measurements, make observations, and rank and record results. The lab progressed students through series, parallel, compound, and other miscellaneous circuits – increasing in complexity. The number of circuits students built each day was recorded and students continued with the lab from where they left off previously. All students created identical circuits regardless of whether they were using actual materials or the computer simulation.

III. RESULTS

A. Improvement

After the lab, students were asked to retake the 30 question inventory. Figure 3 displays the average number correct per group on both the first and second time taking the inventory, as well as the improvement.

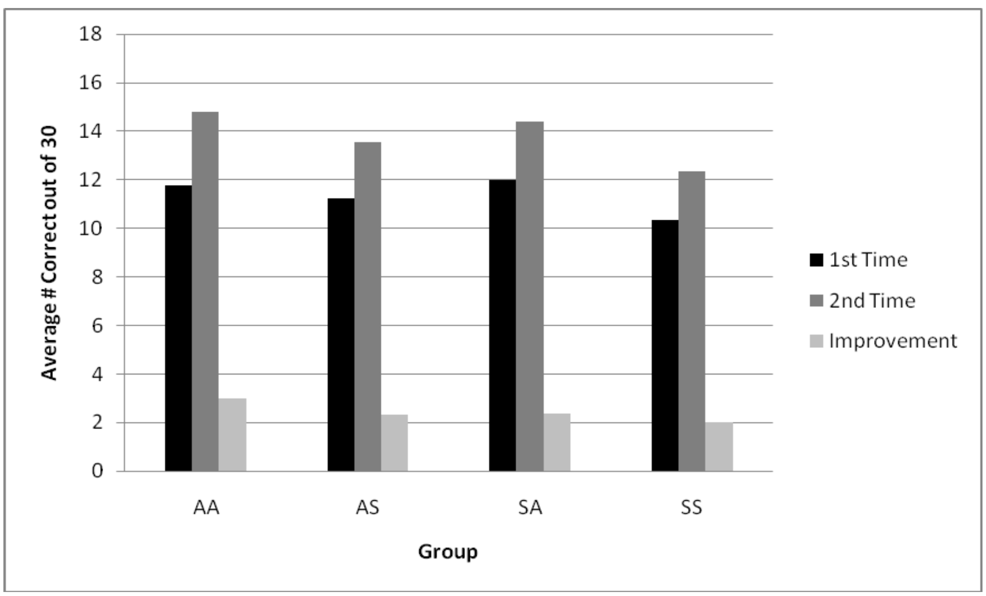


Fig. 3: Average number correct by group on inventory

It appears AA had the most improvement. With such a small amount of data, these results are very inconclusive, however. It is noteworthy in Figure 4 that the standard deviation of the students scores increased for every group from the first time they took it to the second time.

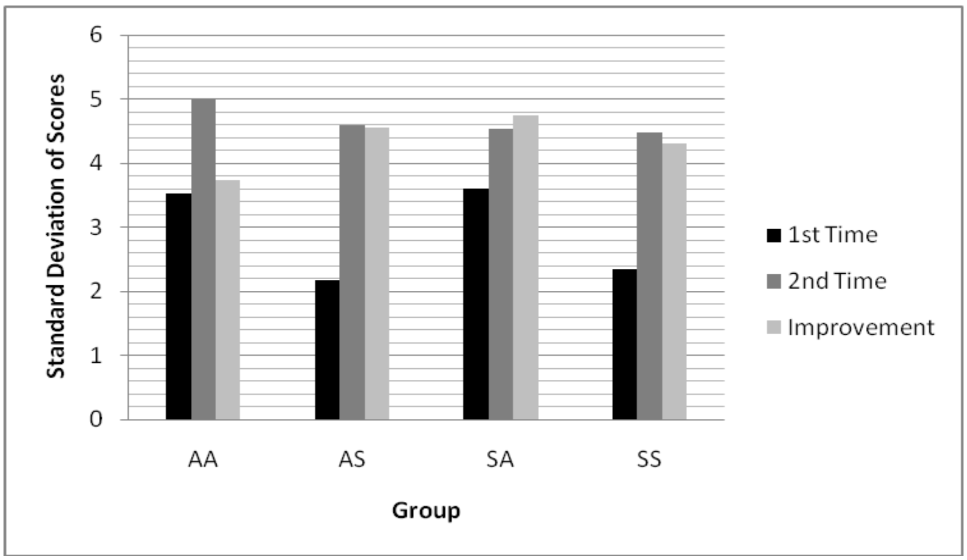


Fig. 4: Standard deviation of scores by group on inventory

This suggests, as some of the students also made it known to the instructor, that some students did not make an honest effort on the 30 question inventory the second time around. Figure 5 shows revised results in which the scores of 11 students who scored worse on the inventory the second time around were thrown out.

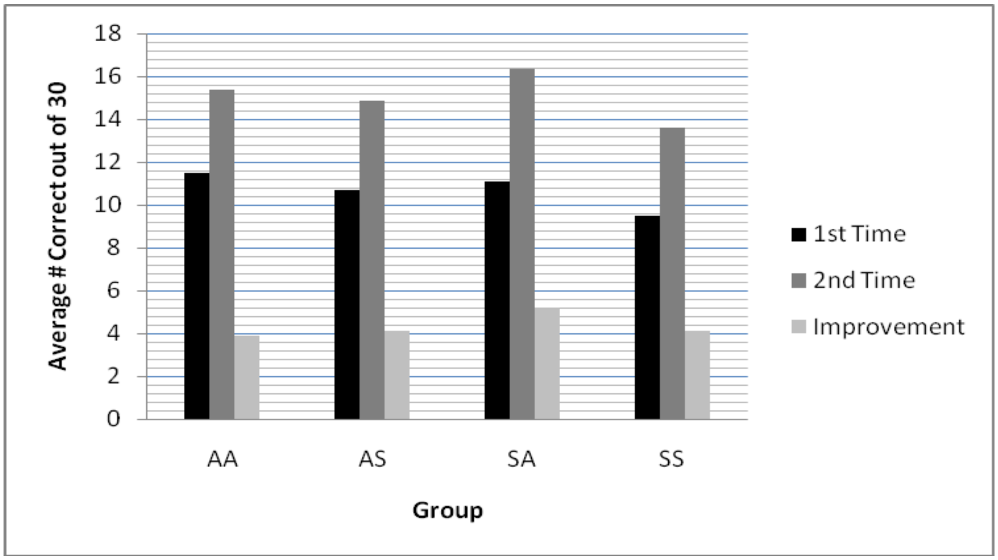


Fig. 5: Revised average number correct by group (decreases thrown out)

Figure 6 shows the data from Figures 3-5 in a tabular format.

	Average # Correct			Std. Deviation			Avg. # Correct (Decreases thrown out)		
Group	1st Time	2nd Time	Improvement	1st Time	2nd Time	Improvement	1st Time	2nd Time	Improvement
AA	11.78	14.78	3.00	3.53	4.99	3.74	11.50	15.38	3.88
AS	11.22	13.56	2.33	2.17	4.59	4.56	10.71	14.86	4.14
SA	12.00	14.38	2.38	3.61	4.54	4.75	11.11	16.33	5.22
SS	10.33	12.33	2.00	2.35	4.48	4.31	9.50	13.63	4.13

Fig. 6: Data in a tabular form

The revised results, while they may suggest that the SA group had slightly more improvement, are still not striking. With such small sample sizes and outside factors such as student motivation and attitude, the results clearly do not have any statistical significance.

On the inventory, there were five questions that asked about realistic circuits. These questions have drawings of what an actual circuit would look like as opposed to schematic diagrams (Figure 7).

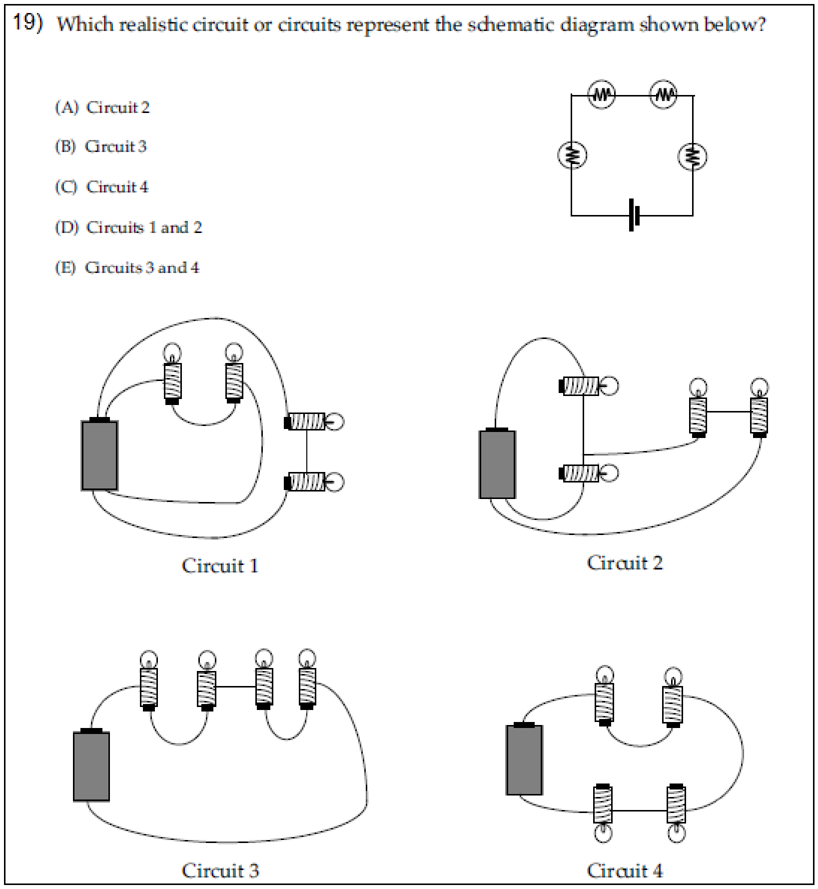


Fig. 7: An example of a realistic circuit question

It is worth noting that group AA, as one would predict, had the highest scores on these five questions the second time they took the inventory (Figure 8).

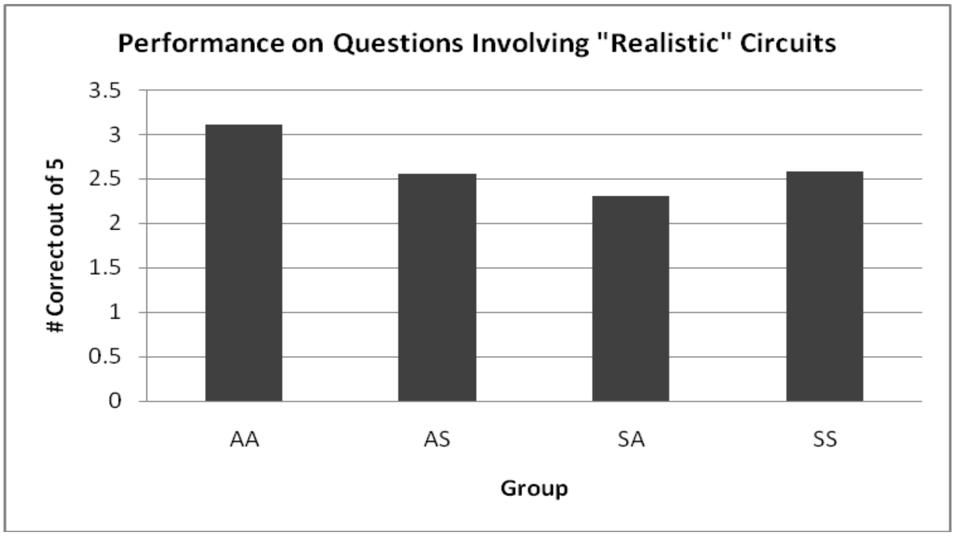


Fig. 8: Average number correct on realistic circuit questions by group

B. Building Circuits

Which laboratory experience was a better use of class time? Which laboratory experience allowed students to build circuits more quickly and accurately? It is worth pointing out that while the instructor was able to observe students in both lab experiences simultaneously, he spent an estimated 90% of his time helping students work with the actual equipment. Beyond simple series circuits, many students had trouble translating the schematic circuit diagram into an actual circuit. Some groups of students would not have gotten very far if the instructor was not there helping them correctly build the circuits and use the multimeters to make measurements.

The only problem the instructor had to troubleshoot with a few students using the simulation occurred when students would hook two wires to the same terminal of a light bulb, as illustrated in Figure 9. As a result, the light bulb would not light up, and initially, students did not understand why.

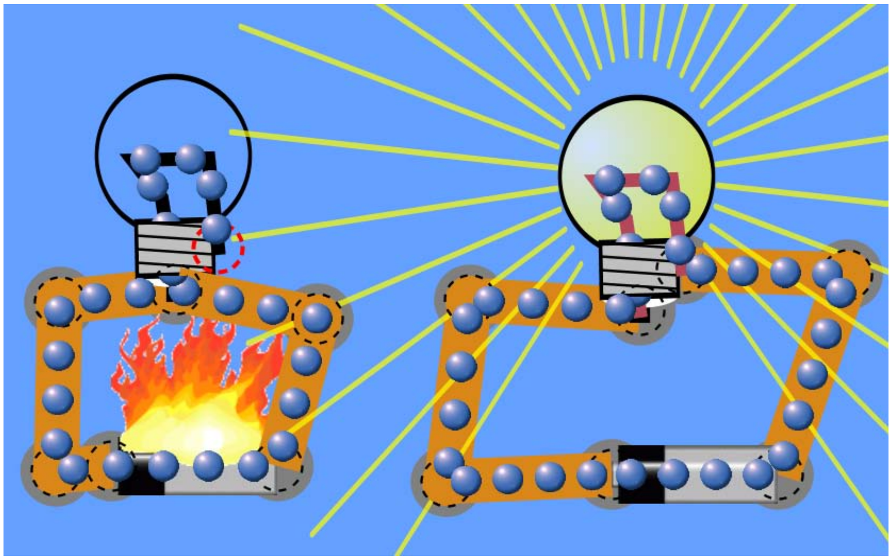


Fig. 9 – Incorrect vs. correct use of light bulb terminals

Using the simulation, students had a much easier time translating the schematic diagram of the circuit in order to build them. This was likely because they could make the circuits they were building look much more like the diagram than with actual equipment. With the simulation, it is possible to use wires that are always straight. It was also more intuitive for the students to figure out how to make current split at a junction in parallel and circuits because they can build a circuit that more closely resembles the circuit diagram (Figure 10).

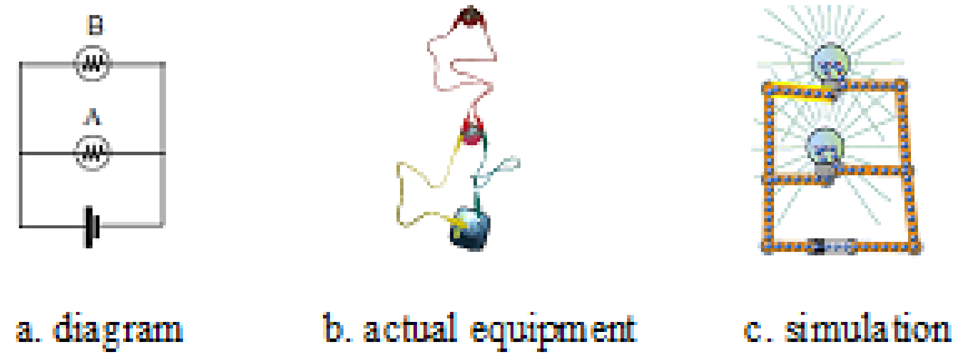


Fig. 10 –Parallel circuit using a schematic diagram, actual equipment, and simulation

As a result, students that used the simulation were able to build more circuits in the same amount of time than students using actual equipment (Figure 11). In addition, they were able to do this individually (as opposed to in groups) and, for the most part, independent of any assistance from the instructor. This was particularly true on the second day of the lab as students were building more complex compound circuits that involved several light bulbs as well as switches. Very few of the groups involved in using actual equipment were able to construct any of the compound circuits accurately without assistance. In addition, if they were able to construct a difficult circuit accurately, it was often because one of the students took charge and built it while the others in the group looked on, not completely understanding why he or she built it that way.

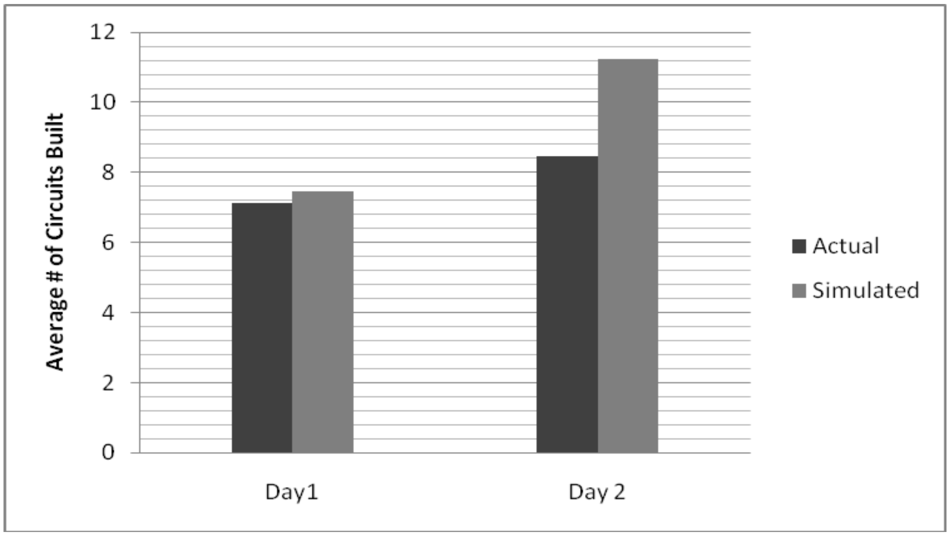


Fig. 11 – Number of circuits built

C. Student Attitudes & Perceptions

After the conclusion of the laboratory experience, the students in the two groups that used both actual equipment and the computer simulation (AS and SA) were asked to respond to two prompts:

1. What experience did you enjoy participating in more? Why?
2. What experience do you feel you learned more from? Why?

Of the 19 responses to the first prompt, 5 out of the 7 girls and 6 out of the 12 boys said they enjoyed using the simulation more. Reasons given for enjoying the simulation more included:

- the equipment always worked
- the results were cleaner and less confusing

- you did not have to worry about breaking things
- the circuits were easier to build
- I got to build the circuits myself instead of watching somebody else do it
- it was easier to understand; it was easier to change things around

Reasons given for enjoying the actual equipment more included:

- they had the help of other people to explain things
- it is more enjoyable to put things together with your hands than clicking a mouse
- I like working with real materials
- it provided more of a challenge to build the circuits – you had to think it through
- I sit at a computer enough as it is

Of the 19 responses to the second prompt, 3 out of the 7 girls, and 9 out of the 12 boys said they learned more from the simulation. Reasons given for learning more from the simulation included:

- you could see the electrons
- it was easier to understand what was going on
- your results always made sense
- I could actually make the circuit properly
- straight wires made the circuits easier to look at
- I felt more confident in the conclusions I drew
- it was more like our homework

- it gave more accurate measurements

Reasons given for learning more from the actual equipment included:

- I got a better grasp on how to build an actual circuit
- I paid attention to it more; it stuck with me more
- there were other people to explain things to me

It appears the simulation helped students learn more about the concepts, while using the actual equipment gave students a better grasp of how to build a circuit. In addition, of the 19 that responded, only 7 thought they learned more from the experience in which they enjoyed less. This seems to be in agreement with the thought that there is a positive correlation between students' enjoyment and student learning.

IV. INSTRUCTOR PERSPECTIVE

A. Actual Equipment - Advantages & Disadvantages

For the portion of the lab using actual equipment, students had the following limited resources at their disposal: Six 6-Volt heavy duty batteries, 40 wires with alligator clips, 5 multimeters, 30 mini light bulb holders, 30 mini light bulbs, and 5 switches.

The main advantage of this lab experience is that the students physically got to build the circuits, which excited quite a few of them. They were also able to collaborate more freely with other students in the class to overcome challenges such as translating the circuit diagram into an actual circuit. Using actual equipment exposed the students to real world experimental physics in which many tangible concepts and laboratory skills can be learned. This is in contrast to the ideal world of physics that takes place in many classrooms where the results are clean and follow along nicely with the equations from the textbook.

This last advantage, however, can also be a major disadvantage for many students because it can cause some of the learning objectives and the major concepts involved to become blurred. For example, suppose a student connects two identical light bulbs in series to a 6 Volt battery. In the simulation, the student would put the voltmeter on each terminal of a light bulb and see that it reads 3 V for both bulbs. When a student does this same procedure using the actual equipment, he or she may get something like 2.4 V for potential drop across the first bulb and 2.1 V for the potential drop across the second bulb. He or she may not recognize that these results are essentially the same, nor is the student likely to recognize that the results add to the voltage of the battery. Some of the students may realize that the voltage drops are supposed to add to the voltage of the battery and wonder why they do not in real life. The battery has 6 V stamped right on it. Why do they only add to 4.5 V? (The battery is not brand new or ideal.) Others may also realize that the potential drop across identical resistors in series should be the same. Why is this not the case? (The wires have a non-negligible internal resistance.)

Another example of the learning objectives becoming blurred comes from a parallel circuit with two bulbs. If two bulbs are wired in parallel, and one of them burns out or is unscrewed, what happens to the other bulb? The “correct physics answer” is that the brightness of the other bulb remains unchanged. In doing the lab, however, as a result of the internal resistance of the wires, many students saw the other bulb get slightly brighter. Additionally, actual light bulbs are not perfect Ohmic resistors. The resistance of the light bulbs increases with temperature, thus affecting the brightness of the bulbs. This could have further contributed to students getting ‘non-ideal” results. As a result of these “non-ideal” results, many students had a hard time seeing patterns and generalizing them in order to make meaning and construct connections between the relevant physics concepts and the lab experience.

Another major disadvantage of using actual equipment was the actual equipment itself. It was in limited supply, some of it was dated, parts were not uniform, and at times it broke or did not function properly. Additionally, some students were not very actively involved with the actual construction, instead watching others build the circuits. Without enough equipment for every student to build their own circuit, they were forced to work together and sometimes had to wait to borrow equipment from other groups. This was especially true the second day as the circuits became larger and more complex. Furthermore, as equipment breaks or begins to malfunction, it needs to be replaced, which is not free, nor can it occur immediately. At other times, students had two light bulbs in their circuit that should have been uniform in terms of brightness, but because they were not exactly identical bulbs, the students did not observe that. On top of that, parts of students’ circuits would not work properly, and it took time to troubleshoot the issue. Did a bulb burn out? Did something become disconnected? Is the battery still functioning properly? Lastly, how to properly use the multimeters took a lot of instruction and practice. Students had to be both patient and consistent in how they held the probes onto the terminals of the mini bulb holders. As a result, students did not always get reliable data.

The last disadvantage with using actual equipment is that the students became much more dependent on the instructor. At times, groups did not know how to build their circuit and had to wait until the instructor could come assist them. Students had a very difficult time, particularly with compound circuits, accurately building a circuit from a circuit diagram. They had difficulty understanding that current could split at the terminals of the mini bulb holders, and many overcame that by connecting 3 alligator clips together to form a junction. Furthermore, if the circuit had too large of a resistance or the current got split multiple times, some of the bulbs had so little current going through them that many students thought they were not lit at all. All of this resulted in a lot of trouble shooting on the part of the instructor. If the students were unsure how to build a circuit, they would be directed how. Yet on the next circuit, they were often still unable to build it independently. The students using actual equipment would not have been able to build nearly as many circuits as they did without the direct assistance from the instructor.

B. Simulated Equipment – Advantages & Disadvantages

The advantages to the simulated lab are many. First and foremost, students can literally see a visual representation of the movement of the electrons through the wires! This visual aid helps students to conceptualize what current is and what it means for current to split. It provides a dynamic visualization of both Kirchhoff's 1st Law (current into a junction equals the current leaving it) and Ohm's Law (voltage equals current times resistance). In addition, students are able to see the direct relationship between the current going through a light bulb and its brightness.

The second major advantage to the circuit simulation is that students are able to work much more independently – both from other students and from the instructor. Students rarely ran into problems that they could not overcome themselves. They were very capable of building complex circuits from the diagrams because they were able to make them with straight wires and junctions that looked exactly as the diagram appeared. As a result, students were able to build circuits quickly and accurately.

Additionally, while working in a virtual environment the supplies are free and limitless, the components are uniform and controlled, and the results are ideal. If a user needs another light bulb or another battery, it is only a mouse click away. The equipment does not break or malfunction. The batteries can be made ideal, and the wires can be made to have zero internal resistance. Users have the ability to control both the voltage of the batteries and the resistance of the light bulbs and resistors. As a result, students obtain results in which they can take meaning from and make connections with more easily. It was obvious to students, for example, that in a parallel circuit the voltage drop across each branch is the same as that of the battery and the current through each branch adds up to the current that goes through the battery. Many students using actual equipment, on the other hand, did not make this connection unless the instructor was there to point it out to them.

While the simulation experience was valuable, it also has its share of disadvantages. First of all, students do not get to do true experimental physics. At some point, physics becomes valuable because of its utility – things like actually building circuits that work and people can use. Many students involved with using actual materials learned the important skill of how to read a circuit diagram and turn it into an actual circuit. Students exposed to just the simulation missed this valuable experience, as well as things such as the proper technique in using a voltmeter and the important difference between conducting and insulating materials in building circuits.

In addition, using the circuit simulation requires computers - which are neither cheap nor infallible. While the simulation itself never malfunctioned, there were times when a student's computer or the school's server malfunctioned and the student had to restart the simulation. Additionally, allowing students access to the Internet can cause problems in productivity by being a distraction. Some students, even when monitored closely, would find opportunities to get off task and surf the Internet while doing the lab. Many students using the simulation probably could have built many more circuits if this distraction was not available to them. While not necessarily a bad thing, other students became distracted from building specific circuits by just playing around with all the functionality the simulation provided. This also led to a decrease in productivity in terms of circuits built, but may have still had some educational benefit.

C. Classroom Use of Simulation & Actual Equipment

With such a small sample size, it is impossible to make any statistically significant statements regarding the difference in educational value between the four lab experiences. That said, there is definitive value obtained from both laboratory experiences. When properly channeled, both laboratory experiences can and should be used to maximize student learning.

Classroom instructors need to take the following factors into account to help them make these decisions in terms of how to optimally incorporate a circuit lab into their curriculum:

1. The amount of circuit supplies available – if there is not enough functioning equipment for the students in your class, utilizing computer simulation becomes necessary.
2. The number of students in the classroom – if the student to instructor ratio is too large and the students are unable to work independently, many students will have down time as they wait for the instructor's help in working with the actual equipment.
3. The number of computers available – if you are forced to have three or more students sharing a computer, then it is likely that one or more students will not actively participate or pay attention to what the computer operator is doing.
4. The ability of the students to work independently and stay on task – if the students can't be trusted to stay on task and avoid distractions such as the Internet, the actual equipment may be the better option.
5. The learning objectives – instructors need to weigh the value of the experimental physics knowledge gained by using actual equipment with the value of the idealized concepts that they want them to learn.

6. The time available to meet the learning objectives – if an instructor can dedicate multiple days to meet this objective, then exposing the students to both experiences should be considered.
7. The personality and past experiences of the students – the instructor needs to consider what experience may engage the students at a deeper level.
8. How is it going to fit into the curriculum – if the intent of the laboratory is an exploratory lab that is conducted prior to any direct instruction (opposed to what was done in this study) the computer simulation is an ideal instructional tool as the results would seem very obscure and difficult to generalize to students using actual equipment.

Not every classroom is the same, and instructors need to take these factors into account in designing their DC circuit curriculum. Comparing the different students in this study, both experiences provided some value to all students, but the students from the section of Physics probably gained more knowledge regarding ideal physics concepts from using the actual equipment than did the students from Conceptual Physics. When voltage drops in a series circuit did not add to the voltage of the battery, for example, they seemed much more able to grasp that it should have as well as understand the reasons that it did not.

The power of computer simulation in the modern high school physics classroom cannot be ignored. The majority of schools simply do not have the resources to equip their classrooms with all the materials necessary for all physics labs. That said, there is still great value and a place for using actual equipment when available and appropriate. In addition, instructors need to consider the proper place for using both computer simulation and actual equipment in their classroom; computer simulation in particular does not always need to be used as a laboratory experience.

In the future, at a school where a majority of students have Internet access at home, it makes sense to have the students use the Circuit Construction Kit (DC only) as part of an assignment or pre-lab they complete at home. Since the students are able to work on this fairly independently, it leaves more class time to do other things. Due to the fact that some students will get stuck, it makes sense to allow them two nights to complete it. After the first night, the instructor would allow his or her students to ask questions in order to clear up any problems they may have had running the simulation. The students would then be able to go back home the second night and finish the assignment.

If exposed to both laboratory experiences, there seems to be added benefit for the students when using the computer simulation first. First of all, it is easier for students to build the circuits properly. Secondly, it gives students a model with which to visualize what is going on inside an actual circuit when they get to that laboratory experience. Lastly, the computer simulation provides clearer data for the students to use, which in turn allows them to make better generalizations and stronger connections to the physics concepts.

Once these concepts are clear, it makes sense to have the students use the actual equipment. It is in this experience that the students gain valuable laboratory skills such as how to actually build a circuit. In addition, they are able to develop an understanding for why actual results do not exactly match up with the ideal results from the simulation due to things like internal resistance. In order for this to occur, however, they first must have a good grasp on what the results should be.

In summary, it makes the most sense to teach the students how to use the computer simulation and have them use it at home first. Its design and user friendliness will allow most students to find success apart from the instructor. Once students have the concepts down, it is time for them to gain the ability to build actual circuits. With most classes, limiting the number of students building actual circuits at one time to under nine would be to the instructor's advantage as most students are not able to do this independently. For Physics students – in contrast to Conceptual Physics student - this maximum number of students working at one time may be allowed to increase. If it is not possible to keep the number of students building actual circuits this small, limiting students to building simple series and parallel circuits (as opposed to compound circuits with 4-5 light bulbs) will help alleviate the problem of instructor dependency. With the actual equipment, students need monitoring nearly the entire time. They are not quite sure how to build a circuit, nor do they use the multimeter consistently enough to get reliable results.

If it is important that students learn the physics concepts related to circuits, as well as how to actually build a circuit, then the assessments should reflect that. For example, rather than relying solely on a written exam to assess students, individual students could be asked to demonstrate their knowledge of circuit construction by actually building circuits in the presence of the instructor. It is also important for teachers to emphasize the difference between the ideal results the simulation gives and the results obtained for using actual equipment. This also needs to be reflected in assessments, particularly with higher functioning students.

D. Limitations of Study

This study clearly had limitations in regards to statistical significance because the sample sizes were so small. As a result, it was impossible to conclude with any level of confidence which laboratory experience was best for the students. In addition, the instructor, being that his job was to help all his students learn, was unable to both ignore and sufficiently meet the demand of requests for help that he received from students using the actual laboratory equipment. That said, it is impossible to tell how much more or less those students would have learned if there would have been more instructors available or if the instructor forced them to work independently.

Other problems encountered included periodic shortages of actual supplies. There were a few instances where the class needed more batteries or wires and students either had to share or wait. In addition, some students did not make a serious effort on the multiple choice inventory assessment, particularly the second time around. Some students verbally conveyed this lack of effort to the instructor, while other students finished it in such a short amount of time that it was obvious that a full effort was not given. It being so close to the end of the school year, combined with the general aloof attitude some students have toward school, clearly affected the results. It was impossible to know for sure which students and for what portion of the inventory they did not give a serious effort.

E. Recommendations for Future Study

There are many variations to this study that could be done to further extend it or improve it. In order to minimize problems associated with student effort, it would be worthwhile to imbed some of the inventory questions into an assessment such as a final exam. While difficult, researchers may want to avoid having multiple groups in the same classroom. With students from both the AA group and the SS group in the same class, the AA group was exposed to some of the benefits of the computer simulation and the SS group was exposed to how to build circuits. This occurred as a result of the instructor showing the entire class how to use and the equipment for each laboratory experience. As a result, all groups were exposed to both laboratory experiences to some extent.

In order to extend the study further, it may be worthwhile to do a more in depth study regarding students' perceptions and attitudes of both experiences. In addition, a study could be conducted where students use the same four groups and complete an exploratory lab (prior to any instruction about Ohm's Law, Kirchhoff's 1st Law, and generalizations about voltage and current for series and parallel circuits). Other possible areas of extension could come from seeing how gender plays a role in simulation in terms of both attitude and understanding, as well as looking at the use of computer simulation and actual equipment with higher level high school physics students such as AP Physics.

V. SUMMARY

A. Response to Research Questions

1. **Does computer simulation result in an increase in conceptual understanding of simple DC circuits for high school students?** Yes, the computer simulation allows students to visualize how the electrons move in the circuit. In addition, it provides an ideal environment in which results are not clouded by things such as internal resistance. As a result, a conceptual understanding of circuits is better obtained here.

2. **Does exposing students to both types of laboratory experience provide any additional gain in conceptual understanding?** Yes, while most of the major concepts regarding the differences between parallel and series circuits can be well mastered with just the simulation, exposing students to both laboratory experiences does provide an additional gain in understanding and skill development. For example, students that were exposed to using actual equipment had a better understanding of how to construct a real circuits, the effects of internal resistance, how to translate a schematic diagram into an actual circuit, and the role of conductors versus insulators in circuits.

3. **Does the order in which students are exposed to the laboratories affect students' conceptual understanding? Are they best used as stand-alone activities or to be used in support of one another?** Yes, the order does matter.

It is better to expose students to the simulation first because it provides a model for them to visualize the movement of the electrons in the circuit, which enhances understanding. Students can then use this model to help them visualize what is going on inside the wires when they use the actual equipment. If done in the other order, many students would not be able to visualize the movement of the electrons in the circuit when using actual equipment, and as a result a smaller gain in conceptual understanding would occur. These two activities are best used in support of one another when the proper time and resources are available.

4. **Does computer simulation provide a more time effective way of doing a laboratory?** Yes, the computer simulation is a more time effective way of doing this laboratory. First of all, most students will be able to work on it outside of class time. Secondly, student using the computer simulation were much less dependent upon instructor assistance and were still able to build more circuits.

5. **What are the students' attitudes in regards to both laboratory experiences?** For the most part, the students seemed to enjoy both laboratory experiences. As far as which one they liked more and thought they learned more from, the results are not conclusive. Very nearly half of those exposed to both laboratory experiences said they enjoyed one experience more than the other, often for very different reasons.

6. **What are the advantages and disadvantages of each laboratory experience?** The main advantages of the simulation are that it provides students a representation of what occurs within the wires of a circuit and it gives ideal

results. In addition, the students are able to complete it more independently. Its main disadvantage is that they do not get to experience and develop the skills associated with building an actual circuit. The main advantage of using actual equipment is that students are exposed to real experimental physics. They are better equipped to build circuits and translate schematic diagrams into actual circuits. The disadvantages of using actual equipment are many. As a result of using actual equipment, many students become confused by results that are not ideal. In addition, students require much more assistance from the instructor. Lastly, equipment can be expensive and it may malfunction at times.

B. Conclusion

This study provided a good reminder that every decision an instructor makes in planning curriculum has an effect on students' understanding. In planning things such as laboratory activities, using computer simulations and actual equipment both have their benefits. The computer simulation probably allows students to gain knowledge more readily, but using actual equipment allows students to develop skills they otherwise would not have. As an instructor, it is important to strongly consider what it is that you want the students to gain from the activity. In the case of simple DC circuits, if it is conceptual knowledge, the simulation is a great tool to use, while using actual equipment is good, but a step behind. If developing skills regarding how to build actual circuits from diagrams is also a goal, than sole exposure to the computer simulation is not sufficient. It is also important for instructors to remember that what is best for one group of students may not be best for another group of students. In addition, instructors must also consider the resources available to them.

As far as my teaching goes, I will continue to use these two laboratory experiences to support each other as much as possible as they complement each other very well. With class sizes becoming larger and supply budgets becoming smaller, I may have to rely more on the simulation than I would like to with my Conceptual Physics classes. I am also likely to have students, particularly in my Physics classes, use the simulation at homes since most were able to use it independently with much success. Lastly, I plan to find and use computer simulation to supplement and enhance my curriculum in other areas.

Works Cited

Bayrak, Celal. "Effects of Computer Simulations Programs on University Students' Achievement in Physics." Turkish Online Journal of Distance Education 9 (2008): 53-62.

Engelhardt, P.V., and Beichner, R.J. "Students' understanding of direct current resistive electrical circuits." American Journal of Physics. 72:1 (2004): 98-115

Finklestein, N. D., et al. "When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment." Physical Review Special Topics – Physics Education Research 1 (2005): 010103-7.

Ligéois, Laurent. "High schools students' understanding of resistance in simple electric circuits." International Journal of Science Education 24 (2002): 551-564.

Zacharia, Zacharias, C. "The Impact of Interactive Computer Simulations on the Nature and Quality of Postgraduate Science Teachers' Explanations in Physics." International Journal of Science Education 27 (2005): 1741-1767.

Sokoloff, David & Thornton, Ronald. "The Electric Circuits Concept Evaluation."

Taber, Keith S., et al. "Conceptual Resources for Constructing the Concepts of Electricity: The Role of Models, Analogies, and Imagination." Physics Education 41 (2006): 155-160.

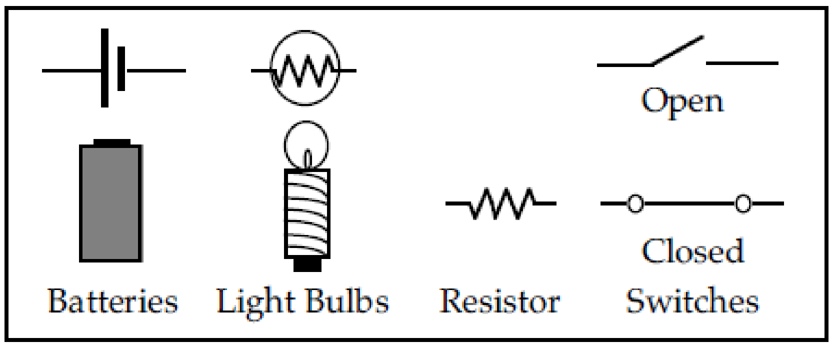
The Physics Classroom. Tom Henderson. 2010. 4 May 2010 <http://www.physicsclassroom.com/class/circuits/u9l2e.cfm>.

Appendix 1 Name: ___________________

Direct Current Circuit Conceptual Inventory

Note:

1. Assume all light bulbs have the same resistance unless told otherwise.
2. Assume all batteries provide the same voltage and are ideal.
3. Assume the wire have no internal resistance.
4. Below is a key to symbols used on the test. Study them carefully before you begin.



1. How does the current through resistor A change when resistor B is added to the circuit? The current in resistor A ____________________.

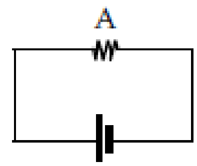
(A) Quadruples (4 times)

(B) Doubles

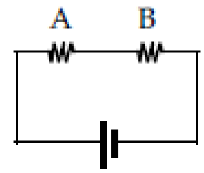
(C) Stays the same

(D) Is reduced by half

(E) Is reduced to one quarter (1/4)



Before



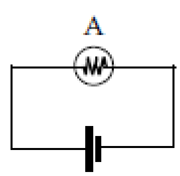
After

2. Refer to the “After” diagram in the previous question:
Suppose resistors A and B are light bulbs. If light B burns out, light bulb A will:

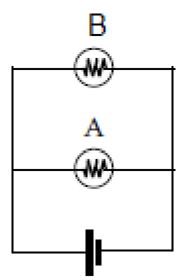
a. be brighter
b. be dimmer
c. go out as well
d. remain unchanged

3. How does the current through light bulb A change when light bulb B is added to the circuit? The current in light bulb A ____________________.

a. increase
b. decrease
c. remain the same



Before



After

4. Refer to the “After” diagram in the previous question:
If light B burns out, light bulb A will:

a. be brighter
b. be dimmer
c. go out as well
d. remained unchanged

5. Which circuit or circuits has the greatest current through the light bulbs:

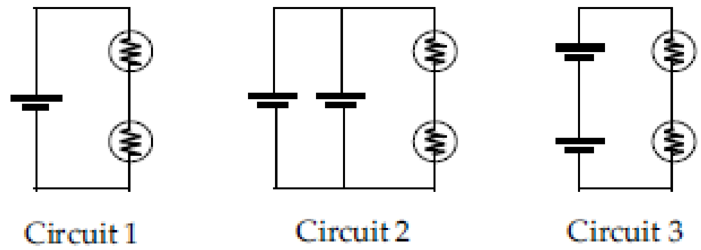
(A) Circuit 1

(B) Circuit 2

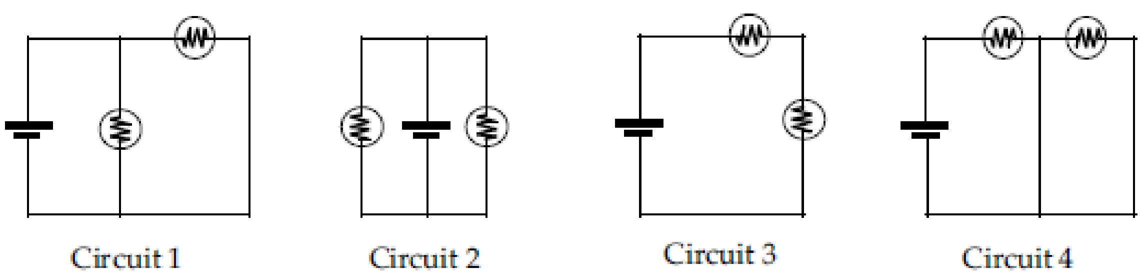
(C) Circuit 3

(D) Circuit 1 = Circuit 2

(E) Circuit 2 = Circuit 3



6. Which circuit of circuits below represents a circuit consisting of two light bulbs in parallel with a battery?



(A) Circuit 1

(B) Circuit 2

(C) Circuit 3

(D) Circuits 1 and 2

(E) Circuits 1, 2, and 4

7. Compare the resistance of branch 1 with that of branch 2. A branch is a section of a circuit. The resistance of branch 1 is __________ branch 2.

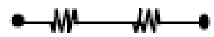
(A) Four times

(B) Double

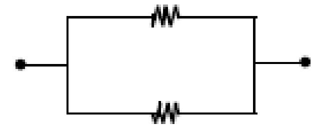
(C) The same as

(D) Half

(E) One quarter (1/4)



Branch 1



Branch 2

8) Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown below from HIGHEST to LOWEST.

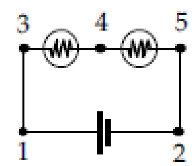
(A) 1 and 2; 3 and 4; 4 and 5

(B) 1 and 2; 4 and 5; 3 and 4

(C) 3 and 4; 4 and 5; 1 and 2

(D) 3 and 4 = 4 and 5; 1 and 2

(E) 1 and 2; 3 and 4 = 4 and 5



9) Compare the brightness of the bulb in circuit 1 with that in circuit 2. Which bulb is BRIGHTER?

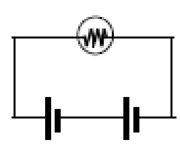
(A) Bulb in circuit 1 because two batteries in series provide less voltage

(B) Bulb in circuit 1 because two batteries in series provide more voltage

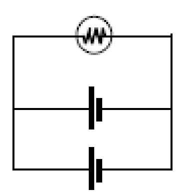
(C) Bulb in circuit 2 because two batteries in parallel provide less voltage

(D) Bulb in circuit 2 because two batteries in parallel provide more voltage

(E) Neither, they are the same



Circuit 1



Circuit 2

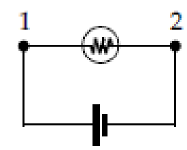
10) Compare the current at point 1 with the current at point 2. At which point is the current LARGEST?

(A) Point 1

(B) Point 2

(C) Neither, they are the same. Current travels in one direction around the circuit.

(D) Neither, they are the same. Currents travel in two directions around the circuit.



11) Which circuit(s) will light the bulb? (The other object represents a battery.)

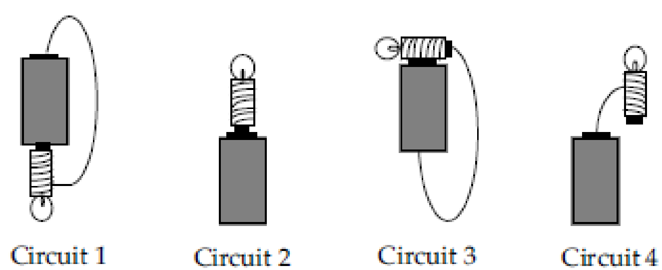
(A) Circuit 1

(B) Circuit 2

(C) Circuit 3

(D) Circuits 1 and 3

(E) Circuits 1, 3, and 4



12) Compare the brightness of bulbs A, B, and C in these circuits. Which bulb or bulbs are the BRIGHTEST?

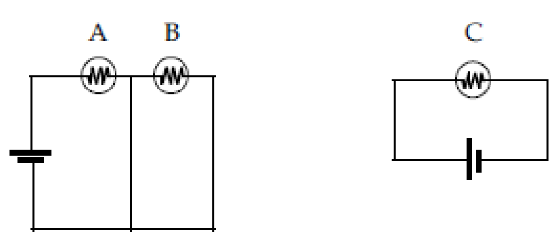
(A) A

(B) B

(C) C

(D) A = B

(E) A = C



13. Consider the current delivered to each of the resistors shown in the circuits below. Which circuit or circuits have the LEAST current going through them?

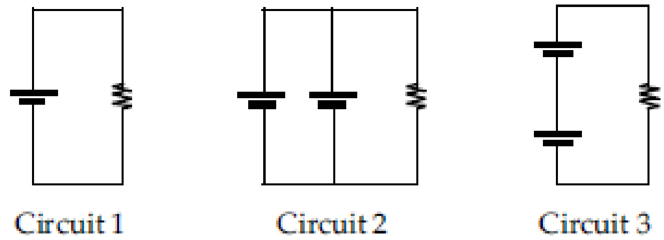
(A) Circuit 1

(B) Circuit 2

(C) Circuit 3

(D) Circuit 1 = Circuit 2

(E) Circuit 1 = Circuit 3



14) Which schematic diagram best represents the realistic circuit shown below?

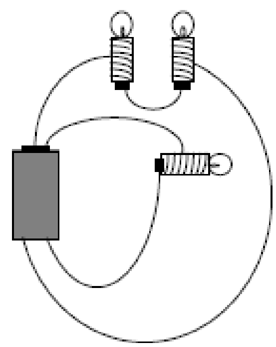
(A) Circuit 1

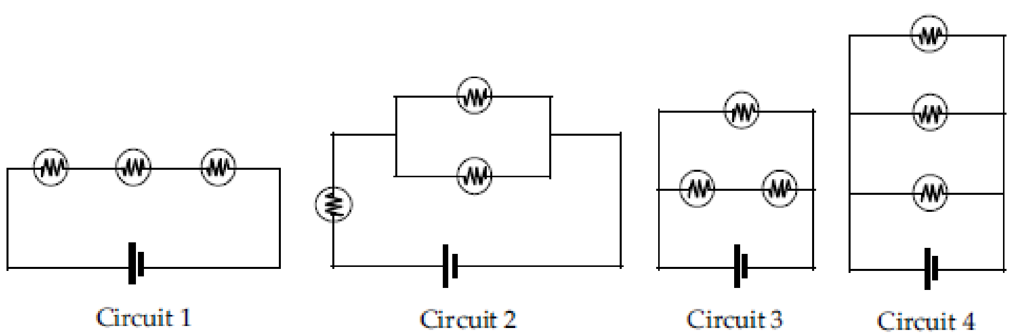
(B) Circuit 2

(C) Circuit 3

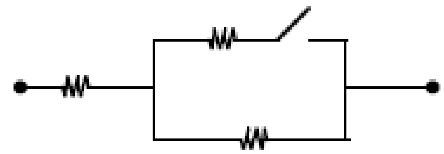
(D) Circuit 4

(E) None of the above



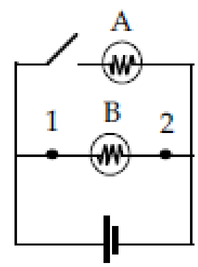


15) How does the resistance between the endpoints change when the switch is closed?



a .increase
b. decrease
c. stays the same

16) What happens to the potential difference between points 1 and 2 when the switch is closed?



(A) Quadruples (4 times)

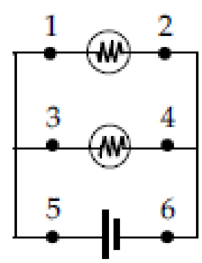
(B) Doubles

(C) Stays the same

(D) Reduces by half

(E) Reduces by one quarter (1/4)

17) Rank the currents at points 1, 2, 3, 4, 5, and 6 from HIGHEST to LOWEST.



(A) 5, 3, 1, 2, 4, 6

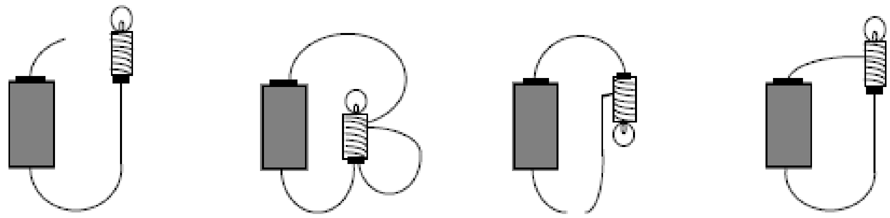
(B) 5, 3, 1, 4, 2, 6

(C) 5 = 6, 3 = 4, 1 = 2

(D) 5 = 6, 1 = 2 = 3 = 4

(E) 1 = 2 = 3 = 4 = 5 = 6

18) Which circuit(s) will light the bulb?



Circuit 1 Circuit 2 Circuit 3 Circuit 4

(A) Circuit 1

(B) Circuit 2

(C) Circuit 4

(D) Circuits 2 and 4

(E) Circuits 1 and 3

19) Which realistic circuit or circuits represent the schematic diagram shown below?

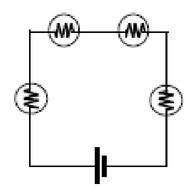
(A) Circuit 2

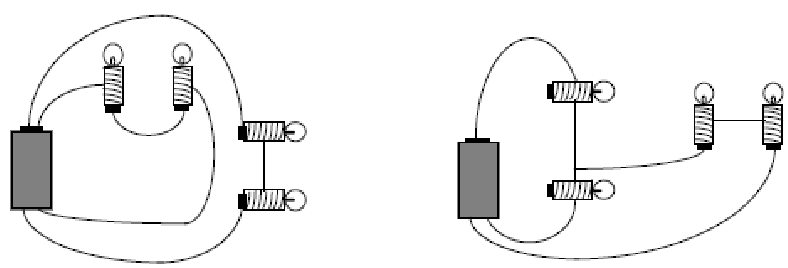
(B) Circuit 3

(C) Circuit 4

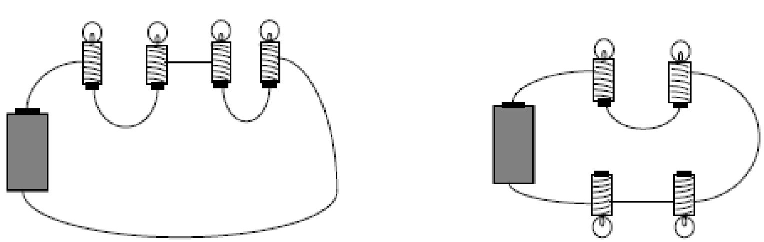
(D) Circuits 1 and 2

(E) Circuits 3 and 4



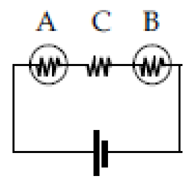


Circuit 1 Circuit 2



Circuit 3 Circuit 4

20) If you increase the resistance C, what happens to the brightness of bulbs A and B?



(A) A stays the same, B dims

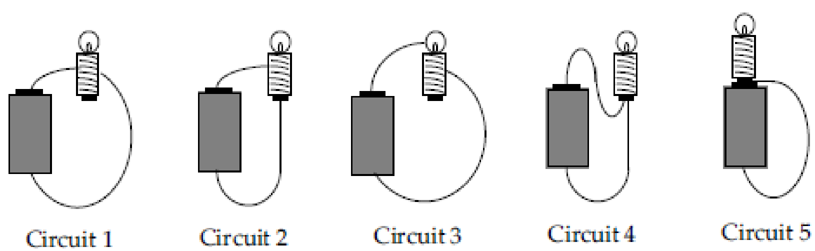
(B) A dims, B stays the same

(C) A and B increase

(D) A and B decrease

(E) A and B remain the same

21) Will all the bulbs be the same brightness?



(A) Yes, because they all have the same type of circuit wiring.

(B) No, because only Circuit 2 will light.

(C) No, because only Circuits 4 and 5 will light.

(D) No, because only Circuits 1 and 4 will light.

(E) No, Circuit 3 will not light but Circuits 1, 2, 4, and 5 will.

22) What is the potential difference between points A and B?

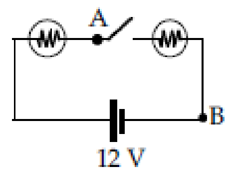
(A) 0 V

(B) 3 V

(C) 6 V

(D) 12 V

(E) None of the above



23) What happens to the brightness of bulbs A and B when the switch is closed?

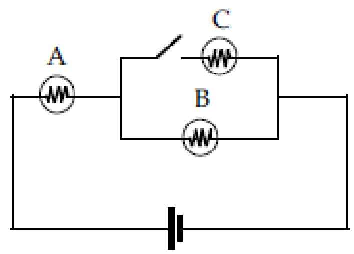
(A) A stays the same, B dims

(B) A brighter, B dims

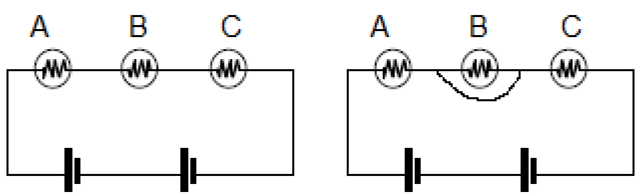
(C) A and B increase

(D) A and B decrease

(E) A and B remain the same



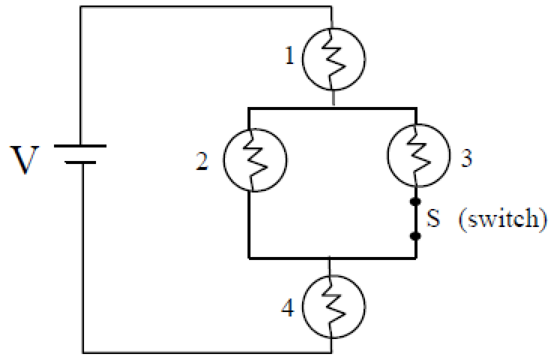
24) Consider the following circuit. As a result of the changes in the "After" picture, what happens to Bulb B?



Before After

a) It becomes brighter
b) It becomes dimmer
c) The brightness of Bulb B does not change

In questions 25 – 28, refer to the circuit below in which 4 identical bulbs are connected to a battery. The switch, S, is initially closed as shown in the diagram.



25. Which correctly ranks the bulb brightness from greatest to least?

   a. All bulbs are equally as bright.
   b. 1, 2, 3, 4
   c. 1, 2 = 3, 4
   d. 1 = 4, 2 = 3
   e. 2 = 3, 1 = 4

26. Which correctly ranks the potential difference (or voltage) across each bulb from greatest to least?

   a. The potential across all bulbs are the same.
   b. 1, 2, 3, 4
   c. 1, 2 = 3, 4
   d. 1 = 4, 2 = 3
   e. 2 = 3, 1 = 4

27. What happens to the current through bulb 1 if the switch, S, is opened?

   a. It increases
   b. It remains the same
   c. It decreases
   d. Not enough information to tell

28. What happens to the current through bulb 2 if the switch, S, is opened?

   a. It increases
   b. It remains the same
   c. It decreases
   d. Not enough information to tell

29 . Bulbs 2 and 3 are connected:

a. in series
b. in parallel
c. in series and parallel
d. neither in series nor parallel

30. Bulbs 1 and 3 are connected:

a. in series
b. in parallel
c. in series and parallel
d. neither in series nor parallel

Appendix 2 Name: ___________________

Circuit Construction Lab (DC only)
Parallel & Series

<u>This lab will have 2 formats in which it is completed:</u>

1. With actual equipment
2. With simulated equipment on a computer

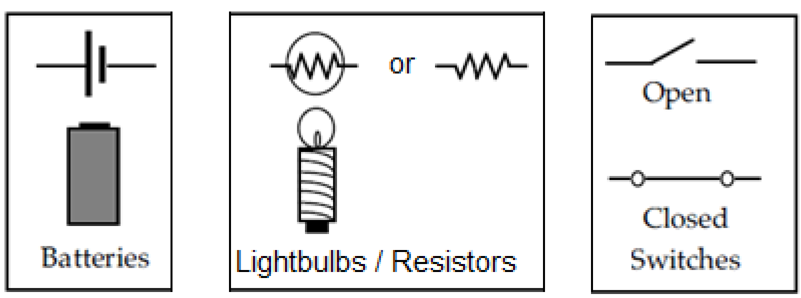
<u>You will be split into 4 groups and complete the lab over a 2 day period.</u>

	<u>Day 1</u>	<u>Day 2</u>
Group 1:	Actual,	Actual
Group 2:	Actual,	Simulated
Group 3:	Simulated,	Actual
Group 4:	Simulated,	Simulated

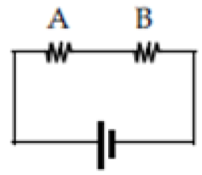
<u>To access the simulated lab:</u>

1. Google: Colorado phet
2. Click on the top search result
3. Click on "play with sims"
4. Click on physics
5. Scroll down and click on "Circuit Construction Kit (DC only)"
6. Click "Run Now"

Here are the symbols for the 3 types of components in the circuits we'll be dealing with

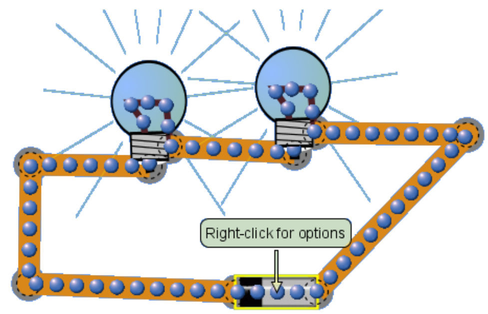


Consider the following circuit diagram:



Actual:

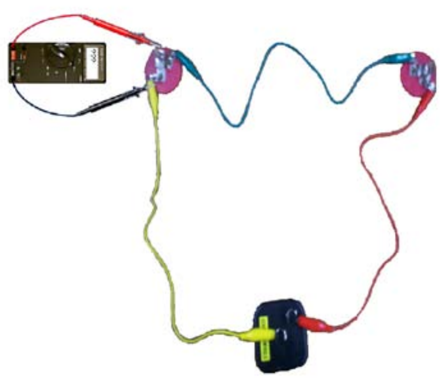
Simulated:



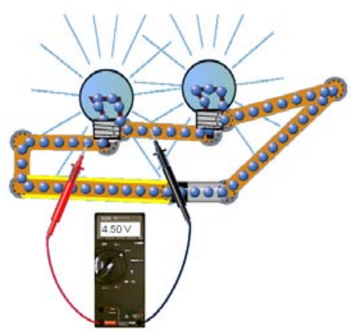
2 things you will be asked to do:

A) **Measuring "voltage drop" or "potential difference"** across a resistor (light bulb).

Actual:



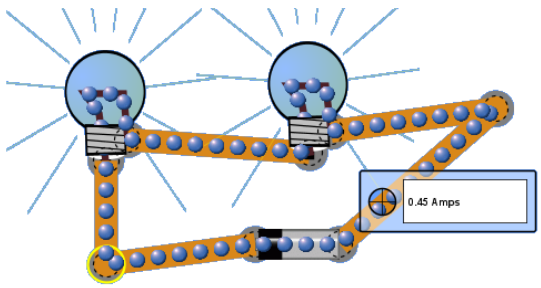
Simulated:



B) **<u>Measuring current through a wire or light bulb</u>**

<u>Actual</u>:
Assume resistance of each bulb is 10 Ω (ohms)
Measure the voltage drop across the bulb.
Use Ohm's Law: V=IR, so I = V/R to solve for I.
(take the voltage across and divide by 10)

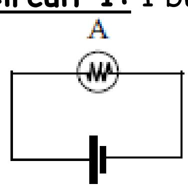
<u>Simulated</u>: Use the Non-Contact Ammmeter and hold it over the wire.



Directions: Build the following circuits and answer the corresponding questions

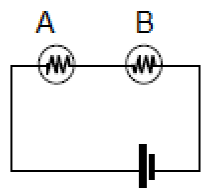
SERIES CIRCUITS

<u>Circuit 1:</u> 1 bulb



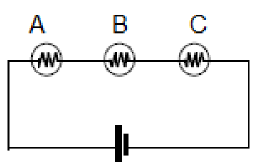
a. Voltage of battery: _______________
b. Resistance of light bulb: _____________
c. What is the voltage drop across the light bulb?___________
d. What is the current in the wire/light bulb?_______________

Circuit 2: Adding a 2nd bulb in series



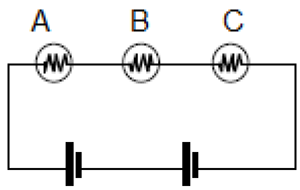
a. Voltage of battery: ______________
b. Resistance of 1 light bulb: ____________
c. What is the voltage drop across Bulb A? ____________
d. What is the voltage drop across Bulb B? ____________
e. How do your answers to parts c and d compare to the voltage of the battery?_____________
f. Did adding Bulb B in series cause Bulb A to be (brighter, dimmer, or remain unchanged)
g. What is the current through Bulb A?______________
h. What is the current through Bulb B? ______________
i. Total resistance of circuit: ________________
j. Current through the battery: ________________
k. What is the same about the battery and one of the light bulbs?: (voltage across OR current through)
l. Disconnect or unscrew one of the light bulbs. What happens to the other one? Why?

Circuit 3: Adding a 3rd Bulb in series



a. What happens to the brightness of Bulb A and Bulb B when you add Bulb C in series? Why?
b. What is the voltage drop across Bulb A? Bulb B? Bulb C?
c. How do these compare to the voltage of the battery?
e. What is the current through the battery? Is this bigger or smaller than Circuit 2?
f. How is current related to brightness?
g. Did adding a third bulb increase or decrease the overall resistance?
h. Did adding a third bulb increase or decrease the current through the circuit?
k. What is the same about the battery and one of the light bulbs?: (voltage across OR current through)
i. Disconnect or unscrew one of the bulbs. What happened to the other two? Why?

Circuit 4: Adding a 2nd battery



a. What did adding a 2nd battery do to the brightness of the bulbs? (increase, decrease, or remain unchanged)?

b. What is the voltage drop across Bulb A? Bulb B? Bulb C?

c. How do your answers to part b) compare to the total voltage of the batteries?

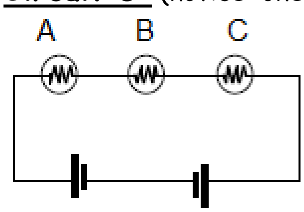
d. What is the current through each of these bulbs?

e. What is the current through the batteries?

f. How does the current now compare to when there was only one battery?

g. What is the same about one of the bulbs and the battery? (voltage across or current through)?

Circuit 5: (notice: one of the batteries is flipped around)



a. What happens? Why?

SERIES CIRCUIT SUMMARY:

1. What does adding light bulbs in series do to the overall resistance? (increase, decrease, remain unchanged)
2. What does adding light bulbs in series do what to the current through the battery (increase, decrease, remain unchanged)
3. What does adding light bulbs in series do to the brightness of the other bulbs (increase, decrease, remain unchanged)

4. Circle the true statement:
   a. The **voltage** drop across a bulb is the same as the **voltage** of the battery.
   b. If you add the **voltage** drop across each bulb, it equals the **voltage** of the battery.

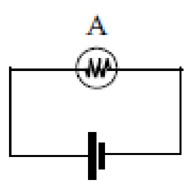
5. Circle the true statement:
   a. The **current** through a bulb is the same as the **current** through the battery.
   b. If you add the **current** through each bulb, it equals the **current** through the battery.

6. **TRUE** or **FALSE**: If one bulb breaks, goes out, or is disconnected the other bulbs are AFFECTED?

7. If one bulb is brighter than another identical bulb, what can we say about the current going through it?

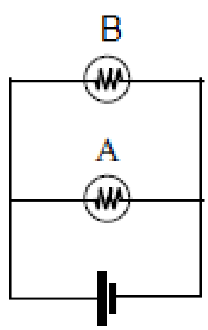
PARALLEL CIRCUITS: each terminal of the bulb has a direct path to the battery

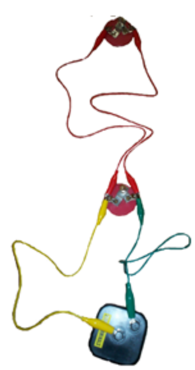
Start with a circuit just like Circuit 1:

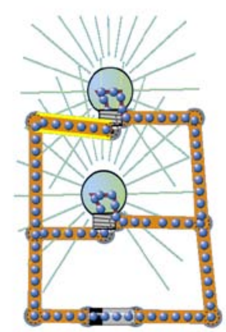


a. What is the voltage drop across the bulb?
b. What is the current through the circuit?

Circuit 6: Add a 2nd bulb in parallel

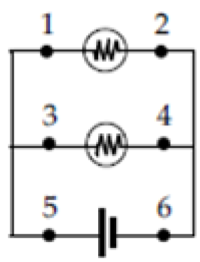




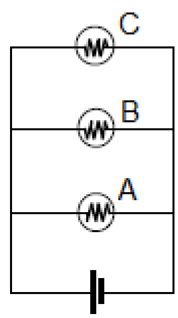


a. Voltage of battery: _______________
b. What is the voltage drop across Bulb A? ____________
c. What is the voltage drop across Bulb B? ____________
d. Did adding bulb B in parallel cause Bulb A to be (brighter, dimmer, or remain unchanged)
e. What is the current through Bulb A?_______________

f. What is the current through Bulb B? ______________
g What is the current through the battery? ____________
h. How are your answers to e, f, and g, related?
i. By adding Bulb B, the current through bulb A (increase, decrease, remain unchanged).
j. By adding Bulb B, the current through the battery (increase, decrease, remain unchanged).
k. By adding Bulb B, the total resistance of the circuit (increase, decrease, remain unchanged).
l. What is the same about the battery and one of the light bulbs?: (voltage across OR current through)
m. Disconnect or unscrew one of the light bulbs. What happens to the other one?
n. Rank the current at the following points from greatest to least (use "=" to indicate a tie)



Circuit 7: Add a 3rd Bulb in parallel



a. Voltage of battery: ______________
b. What is the voltage drop across Bulb A?   Bulb B?   Bulb C?
c. Did adding Bulb C in parallel cause Bulb A and Bulb B to become (brighter, dimmer, or remain unchanged)
d. What is the current through Bulb A?   Bulb B?   Bulb C?
e What is the current through the battery? ____________
f. How are your answers to d and e related?
g. By adding Bulb C, the current through Bulb A and Bulb B (increase, decrease, remain unchanged).

h. By adding Bulb C, the current through the battery (increase, decrease, remain unchanged).
i. By adding Bulb C, the total resistance of the circuit (increase, decrease, remain unchanged).
j. What is the same about the battery and one of the light bulbs?: (voltage across OR current through)
k. Disconnect or unscrew one of the light bulbs. What happens to the other ones? Why?

PARALLEL CIRCUIT SUMMARY:

1. Adding light bulbs does what to the overall resistance? (increase, decrease, remain unchanged)
2. Adding light bulbs does what to the current through the battery (increase, decrease, remain unchanged)
3. Adding light bulbs does what to the brightness of the other bulbs (increase, decrease, remain unchanged)

4. Circle the true statement:
   a. The **voltage** drop across a bulb is the same as the **voltage** of the battery.
   b. If you add the **voltage** drop across each bulb, it equals the **voltage** of the battery.

5. Circle the true statement:
   a. The **current** through a bulb is the same as the **current** through the battery.
   b. If you add the **current** through each bulb, it equals the **current** through the battery.

6. TRUE or FALSE: If one bulb breaks, goes out, or is disconnected the other bulbs are AFFECTED?

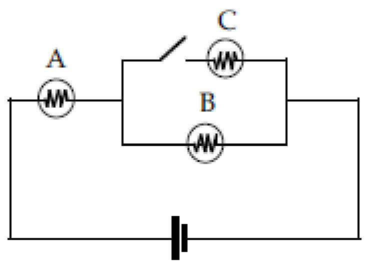
Extension:

7. What would make more sense for Christmas lights – to wire them in parallel or series? Why?

8. What do you think would drain a battery faster: Connecting 3 bulbs to it in series or in parallel? Why?

COMPOUND CIRCUITS (combination of both series & parallel)

Circuit 8:



Switch is open:

a) What is the voltage drop across Bulb A? Bulb B? Bulb C?

b) What is the current through the battery?

c) What is the current through Bulb A? Bulb B? Bulb C?

Close the switch:

d) The current in Bulb A (increases, decreases or remains unchanged)?

e) The current in Bulb B (increases, decreases or remains unchanged)?

f) The current in Bulb C (increases, decreases or remains unchanged)?

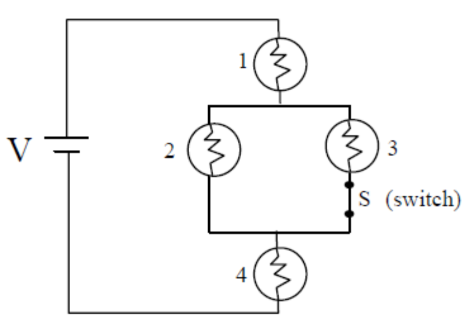
g) The current through the battery (increases, decreases, or remains unchanged)?

h) The overall resistance of the circuit (increases, decreases, or remains unchanged)?

i) When you flipped the switch closed, what bulb(s) got brighter? Dimmer? Went out?

j) What 2 bulbs are in parallel with each other?

Circuit 9:



Switch Closed:

a) Rank the bulbs from brightest to least bright (use "=" to indicate a tie)

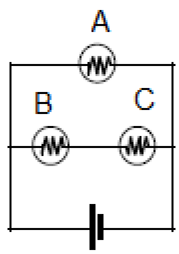
b) Rank the bulbs from greatest voltage drop to least (use "=" to indicate a tie)

Open the switch:

c) Rank the bulbs from brightest to least bright (use "=" to indicate a tie)

d) Rank the bulbs from greatest voltage drop to least (use "=" to indicate a tie)

Circuit 10:



a) Rank the current in each bulb from greatest to least (use "=" to indicate a tie)

b) Rank the brightness in each bulb from greatest to least (use "=" to indicate a tie)

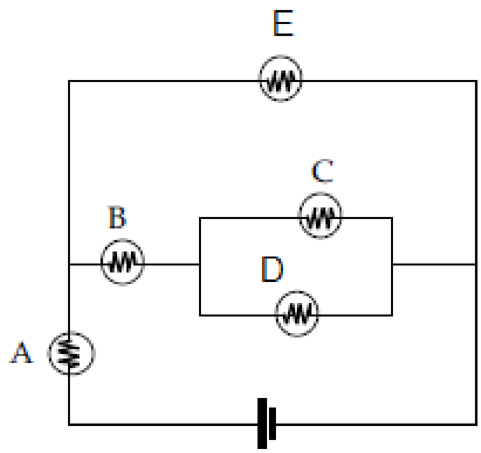
c) Rank the voltage drop across each bulb from greatest to least (use "=" to indicate a tie)

d) Disconnect Bulb A. What happens to Bulb B? Bulb C?

e) Reconnect Bulb A. Disconnect Bulb B. What happens to Bulb A? Bulb C?

f) When they are all connected, why is Bulb A the brightest?

Circuit 11:



a) Rank the bulbs from brightest to least bright (use "=" to indicate a tie)

b) Disconnect the following bulbs and describe what happens to the other bulbs. (brighter, dimmer, no change, goes out)

What happens to

Disconnect	A	B	C	D	E
A	goes out				
B		goes out			
C			goes out		
D				goes out	
E					goes out

MORE CIRCUITS:

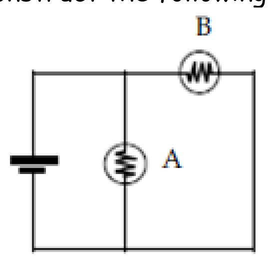
Circuit 12:

Take the following materials 1 battery, 1 wire, 1 light bulb (not in its holder) and see if you can figure out how to light the bulb.

Draw a diagram of how you did it below:

Circuit 13:

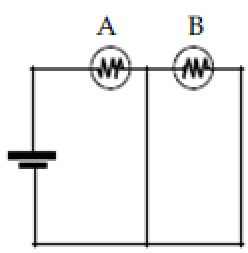
Construct the following. Make observations about current, brightness and voltage drop.



Circuit 13

Now move Bulb A to construct Circuit 14.

Circuit 14:



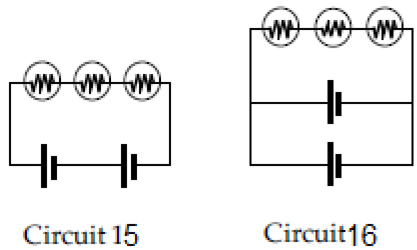
Circuit 14

Make observations about current, brightness and voltage drop.
a) What happened to Bulb A and Bulb B when you did this? Why?

b) Which is a parallel circuit: Circuit 13 or Circuit 14?

<u>Circuit 15 & Circuit 16</u>: Be sure to use identical bulbs and identical batteries.

Build the following circuits separately (unless there are enough supplies) and make observations about current, brightness, and voltage.



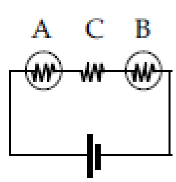
a) Which has batteries in series: Circuit 15 or Circuit 16? In parallel: Circuit 15 or Circuit 16?

b) Which circuit results in brighter bulbs? Any ideas as to why?

c) If you remove one of the batteries in Circuit 15 (and reclose the loop) what happens to the brightness of the bulbs?

d) If you remove one of the batteries in Circuit 16 (and reclose the loop) what happens to the brightness of the bulbs?

<u>Circuit 17:</u>



a) If you increase the resistance of C, what happens to Bulb A and Bulb B?
(Note: simulated users can simply change the resistance of C. People using actual equipment can try replacing C with a larger resistor, but instead could add another bulb between Bulb A and Bulb B)

Circuit 18:

Take 1 battery, 5 bulbs, and make a compound circuit of your choice. You may also use up to 2 switches:
Note: DO NOT PUT THEM ALL IN SERIES OR PARALLEL.

Make a schematic diagram of the circuit you build, using the symbols located on the title page of this document.

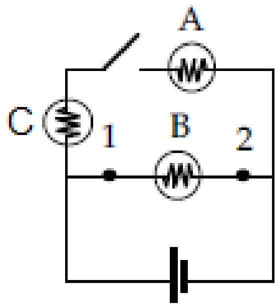
a) Label your Bulbs A, B, C, D, and E. Rank them in order from brightest to least bright.

b) If you used switches, repeat part a) with all possible combinations of the switches being opened & closed.

c) Disconnect the following bulbs and describe what happens to the other bulbs when all the switches are closed. (brighter, dimmer, no change, goes out)

	What happens to				
Disconnect	A	B	C	D	E
A	goes out				
B		goes out			
C			goes out		
D				goes out	
E					goes out

Circuit 19:



a) What is the voltage drop (potential difference) between points 1 and 2 when the switch is open?

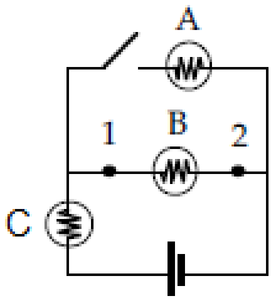
b) What is the voltage drop (potential difference) between points 1 and 2 when the switch is closed?

c) Is Bulb C in Series with Bulb A or Bulb B when the switch is closed?

d) Which bulb is brightest when the switch is closed?

Move Bulb C to form Circuit 20

Circuit 20:



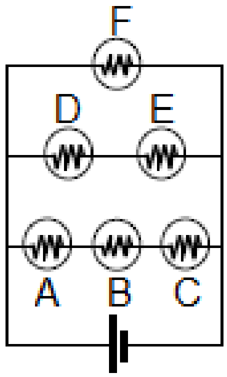
a) What is the voltage drop (potential difference) between points 1 and 2 when the switch is open?

b) What is the voltage drop (potential difference) between points 1 and 2 when the switch is closed?

c) Is Bulb C in Series with Bulb A or Bulb B?

d) Which bulb is brightest when the switch is closed?

Circuit 21:



a) Rank the brightness of each bulb from greatest to least (use "=" to indicate a tie)

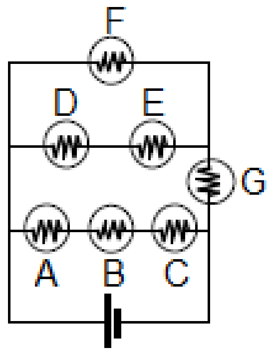
b) What is the voltage drop (potential difference) across each bulb?

Bulb A:
Bulb B:
Bulb C:
Bulb D:
Bulb E:
Bulb F:

c) Describe how each of the other bulbs change when you unscrew (disconnect) the following:

	Goes Out	No Change	Brightens	Dims
Bulb A:				
Bulb B:				
Bulb C:				
Bulb D:				
Bulb E:				
Bulb F:				

Circuit 22: Add Bulb G

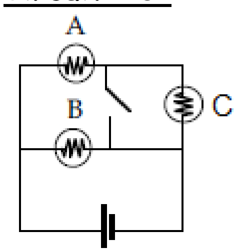


a) Which bulbs changed brightness when you added Bulb G (compared to Circuit 21)?

b) What is the voltage drop (potential difference) now across Bulb D and Bulb E?

c) Unscrew/Disconnect Bulb G. What happens to:
Bulb A:
Bulb B:
Bulb C:
Bulb D:
Bulb E:
Bulb F:
Why?

Circuit 23:



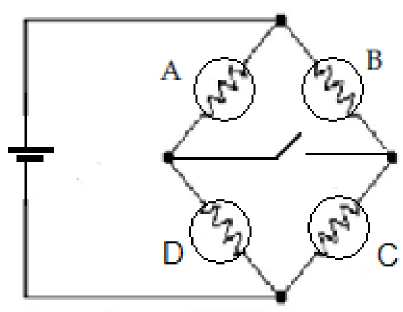
Describe what happens to the brightness of each bulb when you close the switch:

a) Bulb A: (brighter, dimmer, goes out, stays the same)

b) Bulb B: (brighter, dimmer, goes out, stays the same)

c) Bulb C: (brighter, dimmer, goes out, stays the same)

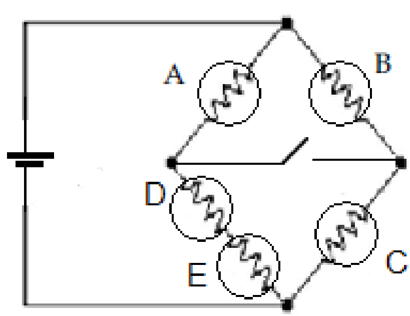
Circuit 24: The Wheatstone Bridge



a) Open & close the switch. What happens to the brightness of the bulbs?

b) Does any current seem to go through the switch?

Circuit 25: Add Bulb E



a) Open & close the switch. What happens to the brightness of the bulbs?

b) Does any current seem to go through the switch?