DC CIRCUITS VIA THE 7E LEARNING MODEL

ELICIT PHASE

Activity 1. Ohm's Law and DC Circuits

At the end of this phase, you should be able to recall Ohm's law and determine how are the circuit elements connected.

Procedure:

1. Click the battery-resistor circuit simulation to download. If a pop-up message appears that the file may harm your computer, just click on the "keep" button. Click the executable jar file to open the simulation in a separate window. Observe how are the battery, resistor, ammeter and battery connected.
2. Take note of the movement of electrons within the circuit.
3. Vary the amount of voltage by moving the glider located at the control panel (right side). Observe what happens to the electrons, the amount of current and the polarity of the battery. Write down your observations in your log.
4. Keep the voltage constant at your own desired amount. Predict what will happen to the current as you increase and decrease the resistance of the resistor. Write down your observations after verifying your prediction.
5. Tick/click the box for "show voltage calculation". This will show you how a voltmeter is used to measure the voltage across the different circuit elements. Write down your observation.
6. Close the simulation then briefly discuss your observations with your assigned group.
7. Discuss also with your group the possible answers to the following questions:
    a. What makes a parallel connection different from a series connection?
    b. What do you think will happen to the individual and total voltage, current, and resistance if the circuit elements are to be connected in series or in parallel?
    c. How are you going to determine or solve the individual and equivalent voltage, current, and resistance if the circuit elements are connected in combination of series and parallel?
8. Proceed only to the engage phase once you are done with the discussion.

ENGAGE PHASE

Activity 2. Introduction to DC Circuit Simulation Kit

At the end of this phase, you are expected to be accustomed in using the DC circuit simulation kit.

Procedure:

1. Click the Circuit Construction Kit-DC to open in a separate window. Choose the "lab" icon to load the simulation.
2. Acquaint yourself with the different circuit elements found at the left control panel. On the opposite side, the right control panel includes the option for current direction, flow of electrons, values, labels, voltmeter, ammeter, battery resistance, wire resistivity and type of view (lifelike or schematic).
3. Discover how to use the different circuit elements, change the different quantities (voltage and resistance) and use the voltmeter and ammeter.
4. Click refresh (lower right button) then proceed to the explore phase for the next activity.

EXPLORE PHASE (1)

Activity 3.1. Making Circuit Diagrams

At the end of this activity, you are expected to be able to determine the different circuit elements and illustrate circuit diagrams with power sources (cell or battery), switches, light bulbs, resistors (fixed) fuses, ammeters and voltmeters.

Procedure:

1. Make a simple circuit consisting of a 12V battery, a switch, a light bulb of zero resistance and wires. The circuit should form a rectangular loop. Close the switch (switch on) then observe the flow of electrons around the circuit (rectangular loop) and the direction of conventional current.
2. Change the bulb's resistance to 6 ohms then observe what happens. You may further change instantaneously the resistance of the bulb and voltage of the battery for more observations.
3. Set the voltage of the battery to 12V and the bulb resistance to 6 ohms. Disconnect the circuit by clicking one of the nodes (scissor symbol) before the light bulb.
4. In the disconnected node/junction, connect two (2) resistors of different resistance (8 ohms and 10 ohms) end-to-end to form a single path for the electrons to flow. Observe what will happen to the light bulbs and the flow of electrons as you close (switch on) the switch.
5. Click on the battery schematic button found at the lowest right side. This will show you the different symbols used for the different circuit elements. Familiarize yourself with these symbols including those symbols of elements that are not used.
6. Proceed to the next phase then accomplish the data and observation sheet (Activity 3.).

EXPLAIN PHASE (1)

Activity 3.1. Making Circuit Diagrams
Data and Observation Sheet

Name: ___________________________ Group No.: ____________

I. Draw the different symbols used for the following circuit elements:

Battery (indicate the + and negative terminal)	Resistor	Fuse
Bulb	Wire	Switch

II. Draw the schematic diagram of the final circuit you have created. Use the correct symbols and labels in your diagram.

III. Explain. Answer the following questions:

1. What is the direction of electron flow with respect to the terminals of the battery when the switch is on?
2. What is the direction of conventional current with respect to the terminals of the battery when the switch is on?
3. What happens to the electrons when the resistance of the light bulb is set to zero ohm?
4. What happens to the brightness of the bulb as you slowly increase its resistance?
5. What happens to the brightness of the bulb as you increase and decrease the battery's voltage?

EXPLORE PHASE (2)

Activity 3.2. Series and Parallel Circuits

At the end of this activity, you are expected to distinguish series circuit from parallel circuit connection and determine the equivalent resistance, current, and voltage in a given network of resistors.

1. Using the previously constructed circuit diagram (series connection) in activity 3.1, measure the amount voltage across the battery, across each of the two resistors and across the bulb using the voltmeter found at the right panel. Drag and drop the voltmeter in the working area then simply touch the negative and positive test probes (leads) to any two points in the circuit. The switch must always be on during this process. If a negative voltage is displayed, the probes are simply interchanged which can be corrected by switching the red and black test probes. List down the values in the data and observation sheet. Take note that the voltage supplied by the battery is the total voltage. List down the values in the data and observation sheet (Table 1).
2. After measuring the voltages, return the voltmeter to the right panel using the drag and drop process.
3. Measure the current supplied by the battery, current passing through the resistors and the bulb using the ammeter. Remember that the ammeter must become part of the circuit to obtain a reading. However, the simulation provides you the option to use the non-contact ammeter. For this activity, please use the contact ammeter, the one with connecting ends or leads. Disconnect or split the circuit in the positive end of the battery then insert the ammeter. Do the same for the bulb and the two resistors to get the current reading through these. In total, there must be four (4) ammeters in the circuit. Compare the equivalent current (battery's current) with that of the individual currents through the resistors and the bulb. List down the values in the data and observation sheet (Table 1).
4. After taking all measurements, refresh the simulation page to start a new working space. Using the same circuit elements (12V battery with no battery resistance, a switch, a bulb of 6-ohm resistance, an 8-ohm resistor and a 10-ohm resistor), make a parallel circuit. Each of the resistor, the battery and the bulb should be in separate branches. All components should be connected between the same set of electrically common points called nodes. For this part, you may discuss with your groupmates on how to come up with a parallel circuit.
5. Measure the voltage across the battery, across the bulb and across the two resistors. List down the values in the data and observation sheet (Table 2).
6. Measure the current through the battery (equivalent or total current), current through the resistors and current through the bulb using either the non-contact or contact ammeter. List down the values in the data and observation sheet (Table 2).
7. Proceed to the next phase then accomplish the data and observation sheet.

EXPLAIN PHASE (2)

Activity 3.2. Series and Parallel Circuits
Data and Observation Sheet

Name: ____________________________ Group No.: ____________

I. Series Connection

Complete the table below.

Table 1

Units	R_1 (bulb of 6Ω resistance)	R_2 (8 Ω resistor)	R_3 (10 Ω resistor)	Total/equivalent
Voltage	V_1 =	V_2 =	V_3 =	V_{eq} =
Current	I_1 =	I_2 =	I_3 =	I_{eq} =
Resistance	R_1=6 Ω	R_2=8 Ω	R_3=10 Ω	R_{eq}=24 Ω

II. Parallel Connection

A. Draw the parallel circuit you have constructed. Use correct symbols and labels.

B. Complete the table below.

Table 2

Units	R1 (bulb of 6Ω resistance)	R2 (8 Ω resistor)	R3 (10 Ω resistor)	Total/equivalent
Voltage	V_1 =	V_2 =	V_3 =	V_{eq} =
Current	I_1 =	I_2 =	I_3 =	I_{eq} =
Resistance	R_1=6 Ω	R_2=8 Ω	R_3=10 Ω	R_{eq}=2.55 Ω

III. Explain. Answer the following questions:

1. Given the amount of voltage and resistance, how is current through the loads (resistors and bulb) computed in both series and parallel connection?

2. Comparing series and parallel connection, what can you conclude about their equivalent (total) current?

3. How is equivalent (total) resistance computed in series connection?

4. How is equivalent (total) resistance computed in parallel connection?

5. The total voltage supplied by the battery is 12V for both type of connections. What can you infer about the voltages across the resistors and bulb in series connection?

6. The total voltage supplied by the battery is 12V for both type of connections. What can you infer about the voltages across the resistors and bulb in parallel connection?

7. Based on your answers in the previous questions, derive the equations for the equivalent current and resistance for both series and parallel connection. The voltage is done for you.

Series	Parallel
$V_{eq} = V_1 + V_2 + V_3 + \ldots + V_n$	$V_{eq} = V_1 = V_2 = V_3 = \ldots = V_n$

8. What happens to the current in the battery when more light bulbs are added in series connection? in parallel connection?

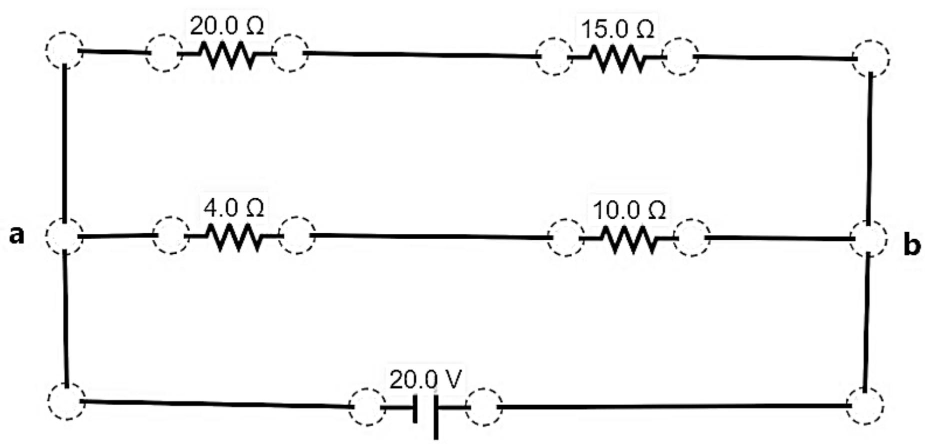
9. Suppose you are given a 12V battery and three light bulbs with a resistance of 6Ω each. In which type of connection (series or parallel) do you think the light bulbs will be brighter? Why? You may use the simulation kit to verify your answer.

EXPLORE PHASE (3)

Activity 3.3. Series-Parallel Connection

At the end of this activity, you are expected to describe the process in computing for the equivalent resistance, current and voltage in combinations of series and parallel connections.

1. Refresh the simulation page to have a new working space then plot the circuit diagram below. Letters a and b are considered nodes.



The circuit presented is a combination of series and parallel connection. It contains 3 branches, one for the location of the battery, another branch for the 4Ω and 10Ω resistor and the last branch for the 20Ω and 15Ω resistor. The 4Ω and 10Ω resistors are in series with one another. When combined, the equivalent resistance for these two resistors are in parallel with the equivalent resistance of the 20Ω and 15Ω resistors which are also connected in series.

2. Draw the circuit diagram in the data and observation sheet as Figure 1. Use the correct symbols. Label the 4Ω, 10Ω, 20Ω, and 15Ω resistors as R_1, R_2, R_3 and R_4 respectively.
3. In the data and observation sheet, make a simplified circuit diagram (Figure 2) combining resistors R_1 and R_2. Label the combined resistors in series as R_1 - R_2. Do the same for resistors R_3 and R_4.
4. Compute the equivalent resistance of the combined resistors (R_1 - R_2) using the equation you derived for series connection in the previous activity. Show your solution in the data and observation sheet.
5. Compute the equivalent voltage and equivalent current of the combined resistors (R_1 - R_2) using the equations you have derived in the previous activity. Show your solution in the data and observation sheet.

6. The diagram you made in procedure 3 can still be further simplified since the combined R_1 and R_2 resistors are in parallel with R_3 and R_4. As such, combine all the resistors to attain the simplest diagram (Figure 3) of which the current flows only around one rectangular loop. Use the label R_1-R_2//R_3-R_4 for all the combined resistors since R_1 and R_2 is parallel with R_3 and R_4, Draw the circuit in the data and observation sheet.
7. Compute the equivalent resistance of the combined resistors (R_1-R_2//R_3-R_4) using the equation you derived for parallel connection in the previous activity. Show your solution in the data and observation sheet.
8. Compute the equivalent voltage and equivalent current across the combined resistors (R_1-R_2//R_3-R_4) using the equations you derived for parallel connection in the previous activity. Show your solution in the data and observation sheet.
9. Verify your computations by measuring the current and resistance using the voltmeter and non-contact ammeter. Do this with each of the resistor and the combined resistors. List these values in the data and observation sheet (Table 1) under the column "meas" which means measured.
10. Proceed to the next phase then accomplish the data and observation sheet.

EXPLAIN PHASE (3)

Activity 3.3. Series-Parallel Connection
Data and Observation Sheet

Name: ____________________________ Group No.: ____________

I. Circuit Diagrams

Figure 1 Figure 2 Figure 3

II. Complete the table below.

Table 1.

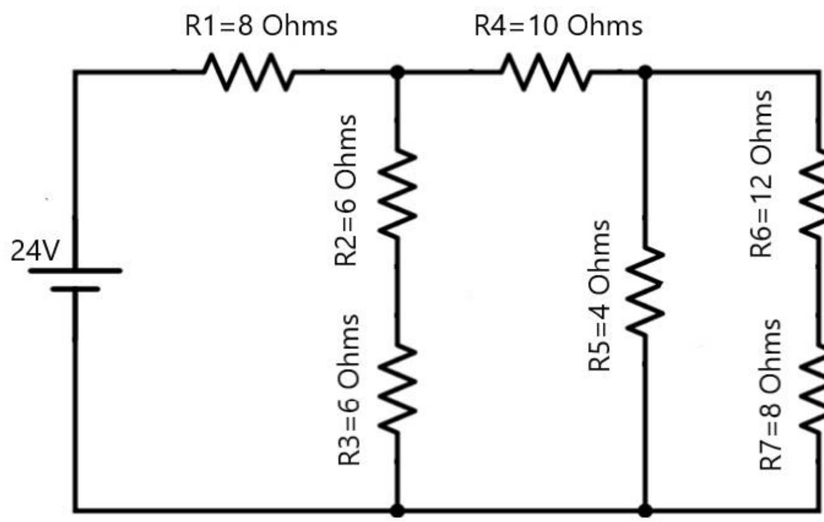
Units	R_1		R_2		R_1-R_2		R_3		R_4		R_3-R_4		Equivalent (R_1-R_2//R_3-R_4)	
	comp	meas	comp	meas	comp	meas	comp	meas	comp	meas	comp	meas	comp	meas
Voltage														
Current														
Resistance	4Ω	4Ω	10Ω	10Ω			20Ω	20Ω	15Ω	15Ω				

III. Solutions. Please show your solutions for the following computations: R for R_1-R_2, R for R_3-R_4, equivalent R (R_1-R_2//R_3-R_4), V for R_1-R_2, V for R_3-R_4, equivalent V (R_1-R_2//R_3-R_4), I (current) for R_1-R_2, I (current) for R_3-R_4 and equivalent I (R_1-R_2//R_3-R_4)

IV. Explain. Answer the following questions:

1. In the analysis of series-parallel combination, what strategy (steps) can you outline in computing for the individual or equivalent resistance, voltage and current?

2. Given the circuit below, apply the strategy you formulated in computing for the equivalent resistance, equivalent current, current through each resistor and voltage across each resistor. Draw the simplified circuits and show complete solution.

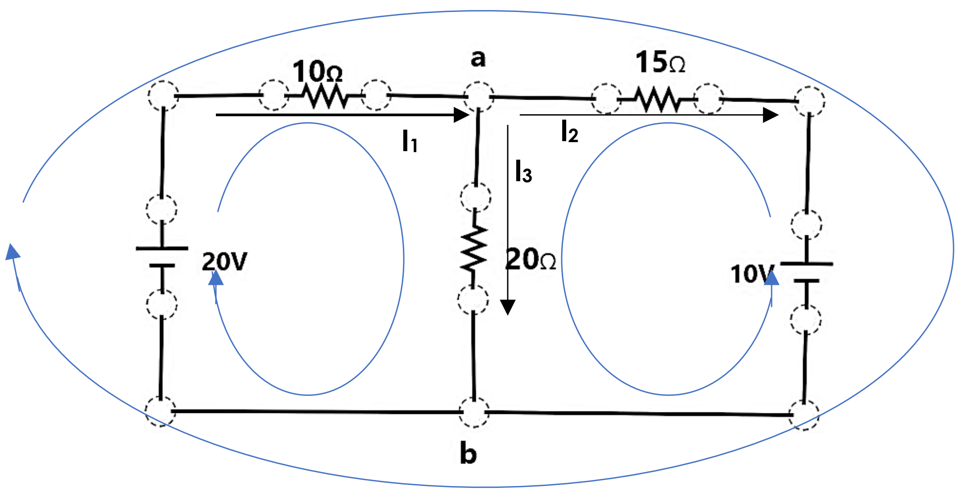


EXPLORE PHASE (4)

Activity 3.4. Kirchhoff's Laws

At the end of this activity, should be able to state Kirchhoff's current and voltage law then use these in analyzing series-parallel combinations.

1. Refresh the simulation page to create a new working space. Plot the circuit elements as shown in the circuit below then proceed to the succeeding steps to correctly analyze the circuit. The loops and arrows are merely directions needed in the subsequent steps and are not considered part of the circuit.



In the previous activity (Activity 3.3), Ohm's law can be used alone by combining the resistors and come up with the equivalent resistance to solve for voltages and currents circulating within the circuit. However, the circuit presented above cannot be simply broken down into series or parallel connections. This type of circuit requires the use of Kirchhoff's current law (KCL) which is also known as junction rule and the Kirchhoff's voltage law (KVL) normally referred to as the loop rule.

2. Draw the circuit diagram in the data and observation sheet. Label the circuit elements and use the correct symbols.
3. Measure the voltage across the resistor using the voltmeter. List the values in Table 1 under the column measured in the data and observation sheet.
4. Using the non-tact ammeter, measure the current passing through each branch. Take note that there are three branches in this circuit separated by nodes a and b. The first branch from node a to node b through the 10 Ω resistor and the 20V battery. The second branch is from node a to node b that encompasses the 20Ω resistor while the last branch is from node a to node b through the 15Ω resistor and 10V battery. List the values in Table 1 under the column "measured" in the data and observation sheet.

5. Label the current passing through the first branch as I_1, the second branch as I_2 and the last branch as I_3 in the diagram you have drawn. Doing this indicates that there are three separate values of current for each branch.
6. The values of voltage and current you have measured can be computed using Kirchhoff's laws. To solve for the current passing through the resistors in each of the branch, the junction rule or Kirchhoff's current law should be used. Applying the rule, take node a as the point where I_1 enters and leaves as I_2 and I_3. A current that enters a junction is assigned with a positive convention while a negative sign is for current that leaves the junction. Thus, the junction rule implies that $I_1-I_2-I_3=0$. At node b, the equation is $I_2+I_3-I_1=0$ which is the same with that of node a. Transforming this equation will result to $I_1=I_2+I_3$. Write this equation in your solution and label it as equation 1.
7. To solve for the voltage across each resistor, the loop rule will be used. A loop is a simple closed path in a circuit in which no circuit elements or nodes is run into more than once. In the circuit, there are a total of three loops indicated by the blue lines. The direction of the loops (clockwise or counterclockwise) can be arbitrarily chosen. You can simply choose the direction you want. In your diagram, label the loops as loop 1 (left inner loop), loop 2 (right inner loop) and loop 3 (biggest outer loop).
8. Use the loop rule to solve for the voltage/potential difference across the resistors. Accordingly, the algebraic sum of all voltages in a closed loop is zero. Using this principle, determine the equations for all loops. Start from the battery or a resistor then move around the loop making a complete loop. Take note that from Ohm's law, V=IR.

   However, use the sign conventions for battery and resistor.

   For battery: positive voltage if loop travels from – to + terminal of the battery
   negative voltage if loop travels from + to – terminal of the battery

   For resistor: positive voltage if loop travels in the opposite direction with current
   negative voltage if loop travels in the same direction with current

   Using the loop rule and sign conventions, the equation for loop 1 is derived below.

   Loop 1: $\Sigma V = 0$

   Voltage (20V battery) + Voltage (10Ω resistor) +Voltage (20Ω resistor) = 0

   $20 + I_1R_1 + I_3R_3 = 0$

   $20 - I_1R_1 - I_3R_3 = 0$ (the sign conventions were used)

   $20 - I_1R_1 - I_3R_3 = 0$

   $20 - 10I_1 - 20I_3 = 0$

   $-10I_1 - 20I_3 = -20$ (equation 2)

9. For loop 2 (right inner loop), derive the equation and label it as equation 3 in your solution. The equation should be $15I_2 - 20I_3 = -10$.
10. For loop 3 (biggest loop), derive the equation and label it as equation 4 in your solution. The equation should be $-10I_1 - 15I_2 = -10$.
11. Substitute equation 1 ($I_1=I_2+I_3$) to equation 2 to derive another equation. Label this as equation 5. The equation you should derive should be $-10I_2 - 30I_3 = -20$.

12. Add equations 3 and 5 since they have common unknown variable (I_2 and I_3). Apply the rules in simplifying equations by elimination. Eliminate I_2 to solve for the value of I_3.
13. Substitute the value of I_3 you have computed to either equation 2 or 3 then solve for the remaining unknown variable (I_1 or I_2).
14. Solve for the remaining unknown variable using the values you have derived. At this point, the current passing through the three branches are already known. Show all your solutions in data and observation.
15. Solve for the voltage across each resistor using Ohm's Law (V=IR). Show your solution in data and observation.
16. Record all the values in the table 1. Compare if the computed values are the same with that of the measured values. If there are inconsistencies, countercheck your solutions to come up with the correct ones. Take note that if a negative current is computed, the direction of the current you have arbitrarily chosen should be in the opposite direction.
17. Compute the average percentage error by using the equation

$$\%\,error = \frac{(Computed\ value - measured\ value)}{measured\ value} * 100\%$$

18. Before closing the simulation, double check if you have followed the procedure correctly. Proceed to the next phase then accomplish the data and observation sheet.

EXPLAIN PHASE (4)

Activity 3.4. Kirchhoff's Laws
Data and Observation Sheet

I. Circuit Diagram. Draw the circuit diagram with labels and values. Show also the identified arbitrary directions of the current in each branch and loop.

II. Solutions. Show all your solutions including your computation for the average percentage error.

III. Complete the table below.

Table 1

Units	**10 Ω resistor (R_1)**		**15 Ω resistor (R_2)**		**20 Ω resistor (R_3)**	
	measured	computed	measured	computed	measured	computed
Voltage						
Current						
Resistance	**10 Ω**		**15Ω**		**20 Ω**	

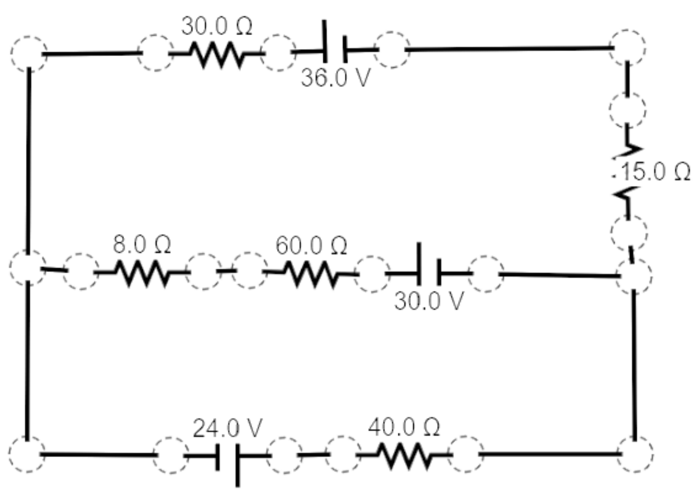
IV. Explain. Answer the following questions and problem.

1. Based on the activity you have performed, when is Kirchhoff's laws applicable to use?

2. State Kirchhoff's current law (KCL) then explain how it is used to solve for current in complex circuits. Derive your explanation from the procedures you have performed.

3. State Kirchhoff's voltage law (KVL) then explain how it is used to solve for voltage in complex circuit. Derive your explanation from the procedures you have performed.

4. Calculate the current in each branch and the voltage across each resistor of the circuit below. Use the same procedure you have learned in the explore phase to correctly analyze the circuit. Assign the arbitrary direction of currents and loops according to your preference. Show complete solution. Use additional sheets if necessary. You may use the simulation later to check your answers.



ELABORATE PHASE

Activity 4. Designing Complex Circuits

At the end of this phase, you should be able to create a functional DC circuit that can be resolve using Kirchhoff's current and voltage rule.

1. Design a complex circuit (combination of series and parallel) that can only be resolved using Kirchhoff's current and voltage rule. The circuit must satisfy the following conditions and contain the given circuit elements:
    - 3 batteries of varying voltage from 1.5V to 24V only
    - 3 branches only
    - 3 loops
    - 5 resistors of varying resistance from 10Ω to 100Ω only.
2. Refresh the simulation page to create a new working space. Plot your circuit in the simulation to verify if it is working. There must be current in each of the branch and voltage in all resistors. If your circuit is not working, modify it based on the conditions stated above.
3. Draw the schematic diagram of the working circuit you designed on the activity sheet (Activity 4)
4. Give the activity sheet where you have drawn your circuit to your partner but in return, you must accept his/her circuit.
5. Analyze the circuit you have received from your partner then solve for the unknown quantities as stated in the activity sheet. After individually solving the problem, you may discuss your solutions with your partner then come up with an agreement if both of your solutions are correct.
6. After completing the activity, refresh the simulation then proceed to the extend phase.

EVALUATION PHASE

Activity 4. Designing Complex Circuit

Activity Sheet

Name of Designer: ____________________________ Date: __________

Name of Assigned Pair: _________________________ Score: _________

Circuit Diagram

(Draw your circuit here)

Solve for the current in each branch and the voltage across each resistor of the circuit above (designed by your pair). Show your complete solution.

EXTEND PHASE

Activity 5. Solving Series-Parallel Combination Using Matrix

At the end of this phase, you should be able to discuss and solve the currents and voltages in a given complex series-parallel circuit using linear algebra.

1. Sit together as a group (3-4 members) then collectively accomplish the next steps. Group discussion is needed in this phase. The use of computer simulation is not required in this phase.
2. Refer to the circuit in Activity 3.4. Draw the same circuit with complete loop and current direction in the activity sheet (Activity Sheet 5).
3. The currents in all three branches can be determined using matrix, a concept you have learned in your linear algebra. To do this, you need to write down the first 4 equations that were derived in activity 3.4.
4. Discuss among your groups the process in solving for the currents using matrix. You may refer to your notes in linear algebra.
5. Solve for the current in each branch using the process you have discussed among your group. Show your solution in the activity sheet.
6. Compare your answers with the values you have computed in activity 3.4. If the answers are not the same or are not approximately close with one another, you need to go back to your process in using matrix.
7. Submit the activity sheets as required by your teacher (printed or through e-mail) before the deadline.

Activity Sheet 5

Solving Series-Parallel Combination Using Matrix

Names of Members: ____

Section: ___________ Date: _____________

I. Circuit Diagram

II. Solution