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Robotic Sunflower Lesson 1: Measuring Voltage Using a Microcontroller

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DESCRIPTION: In this lesson students will be introduced to series circuits, resistors, a photoresistor and a microcontroller. There's a lot here, but it boils down to making a voltage divider circuit and measuring the voltage at different points. A second circuit includes an RC component. Teachers can edit this down to just a photoresistor if time and/or student ability will not permit exploring each of the optoelectronic sensors.

GRADE LEVEL(S): 9, 10, 11, 12

SUBJECT AREA(S): electricity, electronics, applied physics, computer science

ACTIVITY LENGTH: 2 hours, 30 minutes

LEARNING GOAL(S):
1. Students will apply Ohm's Law.
2. Students will use a multimeter to measure current, voltage, and resistance.
3. Students will use a breadboard to set up a series circuit.
4. Students will read circuit diagrams.
5. Students will calculate times for an RC circuit to change state.
6. Students will prove that resistors in series have an equivalent resistance equal to their individual sums.
7. Students will program the Basic Stamp to measure voltage levels in a voltage divider and RC circuit.

STANDARDS MET:
Common Core:
- CCSS.ELA-Literacy.RST.11-12.9. Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
- CCSS.ELA-Literacy.RST.9-10.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

- CCSS.ELA-Literacy.RST.9-10.7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Next Generation Science Standards:

- HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem-based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Student Background:

This lesson was developed as the first in a unit that culminates in the construction of a robotic sunflower that tracks the sun. While it will provide a lot of the foundational knowledge that the rest of the unit will be built on, it is helpful if students have some understanding of basic electricity concepts, including voltage, current, resistance, how a diode works and how to use a multimeter.

Educator Background:

Students will build three simple circuits, the first of which is called a voltage divider and the second, an RC circuit. The circuit diagrams are below.

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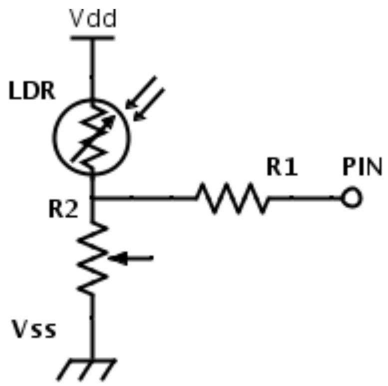
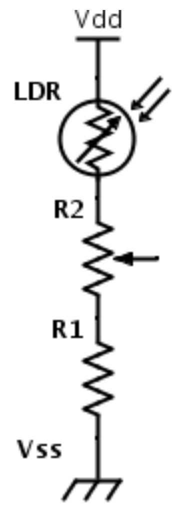
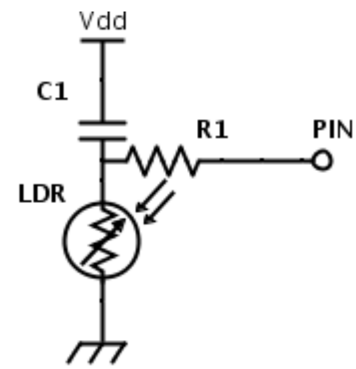


Circuit 1: Voltage divider.



Circuit 2: RC circuit w/ pin hookup.



Circuit 3: Voltage divider w/ pin hookup.

Students will measure voltage differences with a multimeter between R1, R2 and the LED in the voltage divider circuit in Circuit 2. The potentiometer is a source of varying resistance. When light is incident on the photoresistor, the resistance drops, allowing more current to pass. When the photoresistor is in a shadow or dark, the resistance increases. The photoresistor is in series with the other resistors, meaning that the voltage drops across each resistor will sum to 5V. This is why this circuit is called a voltage divider. The voltage divider divides the voltage in steps from the source voltage to 0V. Vdd on the Basic Stamp represents 5V and Vss represents the ground, or 0V. Moving along from Vdd the potential drops as the current goes through the photo resistor. The amount depends on the value of the resistance in the photo resistor and the current. Ohm's Law allows us to calculate this drop using V = IR. This happens for each resistor along the way until the potential ends at 0V. Basics Stamps will be used to monitor voltage levels between the capacitor and the photo resistor in Circuit 3 and between the photo resistor and R2 in Circuit 4. When this voltage drops below 1.4V, the Basic Stamp returns a logic value of zero. The potentiometer will allow students to adjust the circuit sensitivity to varying lighting conditions by varying its resistance, thereby changing the voltage drop over itself and the other components.

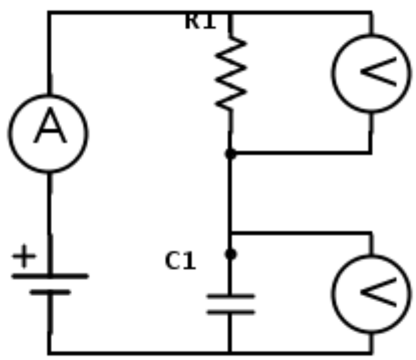
Circuit 3 is an RC circuit. In this circuit the capacitor will be discharged by setting the pin it is hooked up to on the Basic Stamp to high or 5V. This in effect discharges the capacitor because the voltage on each plate is the same. Keep in mind that the voltages across and current through the components in an RC circuit grow or decay exponentially. This is described by the formulas: $V_c = V\left(1 - e^{-\frac{t}{RC}}\right)$ and $V_r = Ve^{-\frac{t}{RC}}$ for the capacitor and resistor respectively. High on the Basic Stamp is 5V. (It would be a worthwhile endeavor to have students set up an LED circuit with the Basic Stamp pulsing the LED on and off for 1 second intervals. Students can then monitor the oscillation of the voltage drop of 5V across the circuit with a multimeter.) To measure the circuit, the Basic Stamp will toggle the pin from an output (5V) to an input (0V). Then the microcontroller will monitor the pin until the value of the voltage decays to 1.4V through the RC circuit, at which point the microcontroller will return a logic value of 1. Since the pin is measuring the voltage on the lower plate of the capacitor through the resistor we'll use the second equation from above: V = 5V and Vr = 1.4V.

Equation 1 $\frac{t}{RC} = \ln\left(\frac{5V}{1.4V}\right) sec$

Equation 2 $t = \ln(3.75)\, RC\, sec$

Equation 3 $t = 1.322RC\, sec$

In this way we'll use the Basic Stamp to measure the time, in 2 micro-second intervals, required for the voltage to rise to 1.3V. The Basic Stamp does all of the above effortlessly, using the RCTIME command. (If you have access to an oscilloscope you can show students the growth and decay of the RC circuit. A multimeter could be used as well or Vernier probes with Loggerpro. Circuit 5 shows the circuit diagram.)



Circuit 4: RC circuit measurements.

Worth noting with regard to programming techniques is the comment. In pBasic, the programming language for the Basic Stamp, an apostrophe precedes a comment. Encourage your students to document their code with comments. This allows them and others to open the code and understand what is happening.

Science Kit Materials List:

- LED (1 per group)
- Multimeter (1 per group)

Other Materials List:

- "Robotic Sunflower: Lesson 1 — Student Guide"
- "Robotic Sunflower: Lesson 1 — Reflection Questions" student handout
- "Token CDS Light-Dependent Photoresistors" handout
- "Simple Circuits Worksheet"
- Photoresistor (1 per group)
- 220 Ohm resistor (1 per group)
- 440 Ohm resistor (1 per group)
- 2k Ohm resistor (1 per group)

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- 10K Ohm resistor (1 per group)
- uF Capacitor (1 per group)
- 5k Ohm potentiometer (1 per group)
- Basic Stamp Homework Board (1 per group)
- Jumper wires (1 set per group)

Vocabulary:

- Resistor
- Photoresistor
- Potentiometer
- Voltage
- Current
- Ohm's Law
- Multimeter
- Capacitor
- Basic Stamp HWB
- Ohm's
- Amps
- Volts
- RC circuit
- Voltage Divider circuit
- Breadboard
- VAR
- CON
- PIN
- DEBUG
- DO…LOOP
- HIGH
- LOW
- INq
- BIN1
- Comment
- Directives
- RCTIME
- CLS
- CRSR

……

Lesson Details:

Planning

Ensure that there are enough materials for each group. In addition, students should be able to access a computer. If not already there, download pBasic 2.5 onto the computers for programming the Basic Stamps (It's a free program available at: www.parallax.com). Assign the

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following web sites as reading homework for this lesson. The websites below go over the basics that will be used in this lesson and those following. A student worksheet with the links is provided in the student materials folder.

- Resistors
- Photoresistors
- MAKE presents: The Capacitor
- Microcontrollers
- Collin's Lab: Schematics
- MAKE presents: The Multimeter
- MAKE presents: Ohm's Law

As an alternate approach you may want to have students access the website: http://www.allaboutcircuits.com. This site has a large volume of material on circuits with worksheets the students can go through to learn various topics.

Class Sequence

- *Day one* will have students in groups build circuit 2.
- Prior to building the circuit, have students use a multimeter to measure the resistance of the photoresistor while exposed to sunlight and various other light sources. They should record this in their engineering journal. Have them do this with the potentiometer in several marked positions and the fixed resistor as well.
- Using whatever voltage source you prefer, keeping in mind joule heating effects, have students use two multimeters to monitor the circuit. One will be for current and the other will be used to measure voltages across each component. Have students do this in different light sources. (If you have a light sensor and can record light intensities it would add more data for the students to consider.) Again, have students record their measurements in their engineering journals.
- Now it's time for some board work. For a given light intensity and potentiometer position, use the resistance values from the above step to guide students through the voltage drops via Ohm's Law. Now have the students compute the same with measured values and compare those to the calculated values.
- Now look at the overall effects. Have students explore the net resistance and how each component contributes to the net resistance. Ask, "Assuming the pot is fixed, which means the pot and resistor have a constant value, what effect does the variable resistance of the photoresistor have on the voltage across itself and the pot/resistor combination?" Give students time to explore this first with calculations and then measurements. Again, this process should be documented.
- At this point, get student data on the board, summarize and discuss the voltage divider circuit with students. Students could have a data table similar to table 1a or 1b. Table 1a assumes you are pegging the photo resistors resistance in both directions and recording the min and max resistance values. It also assumes you are doing the same for the potentiometer as well. * Table 1b shows an alternative using the recorded values for the photo resistor at varying light intensities and the potentiometer at set points.

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**As a side note, it would be interesting to explore the behavior of a photo resistor or potentiometer with the students. For example, knowing the max and min resistance values, can we assume they vary linearly between those values? Can an appropriate model be developed for their behavior within those boundary values? Can they develop an experiment to determine a model? If you have time and student capabilities, this would be a worthwhile exploration.

	Lighting	Current	V1	V2	V3	Vtotal
Photoresistor Max resistance/Min resistance						
Potentiometer Max resistance/Min resistance						
Resistor						
Total resistance						

1a

Light Intensity				
	R	I	V	
LDR				
Pot				
R1				

1b

Table 1: Sample Data Tables

- Get student data on the board and lead students to the idea that resistors in series have a total resistance equal to their individual sums.
- *Day two* will be spent exploring the RC circuit.
- This can be as involved as you want it to be. The most straightforward approach is to set up the circuit on the Basic Stamp and show the students how to code the Stamp to read the charge values. Encourage students to comment their code. Program 1 shows a sample to display the values time values from the command RCTIME.

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```
' {$STAMP BS2}
' {$PBASIC 2.5}

'single light sensor program
'this program will calculate the resistance of a single photo resistor using the RCTIME
command.
'the circuit has the photoresistor in series with a capacitor going from neg to pos.
'a pin is connected via a safety resistor at the junction between the cap and photoresistor.
'the pin is set high to set both sides of the cap at the same voltage, 5V.
'when the program encounters the RCTIME command the microcontroller sets the pin low and
measures 'how long,in 2 microsecond intervals, it takes for the voltage on the low plate of the
cap to drop TO 1.3V.
'the basic stamp has a number limit of 65535, therefore if the interval count exceeds this
RCTIME will
'return a value of 0.


'constants and pin assignments--------------------------------------------------------------------------------

sensor PIN 14                'assigns the word sensor to a pin number. this allows the user to
change the pin
                              'assignmentfor different circuit configurations without change
multiple occurrences in
                              'the program.

'variables--------------------------------------------------------------------------------------------------------

rct VAR Word                 'variable for the RCTIME count. is declared as a word to handle
higher number counts


'initializations----------------------------------------------------------------------------------------------

HIGH sensor                  'sets the pin to high, 5V, thus setting both plates of the cap to 5V. this
allows
'the RCTIME command to time the fall of the voltage to 1.3V when the pin goes low.

'main program----------------------------------------------------------------------------------------------------

DO                          'main loop

 DO                         'loop to verify that rctime interval count is not outside range of 65535
  RCTIME sensor,1,rct         'rctime arguments include pin number, initial state, and variable to
store time.
'initial state indicates whether the capacitor starts high, 5V, or low, <1.3 V.
  HIGH sensor                'cap has discharged so needs to be recharged
 LOOP UNTIL (rct<> 0)       'ensures that the decay time doesn't exceed the measurement
capability.

 DEBUG CLS                   'clears the previous value in the debug window.
 DEBUG DEC rct 'displays sensor value, as a decimal, on debug screen,
 PAUSE 500                   'slows the program down to see values better

LOOP
```

Program 1: Sample RC controlled program.

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- Students can use the above program or a variation to then explore lighting conditions with the decay values given in those conditions. If time permits students can use equation 1 with measurements of the resistance on the photo-resistor and capacitor values to compare predicted decay times to actual. Again, they should record this in their engineering journals.
- As an assessment, you could assign as homework or as a class starter for the next day the following questions: How would the programming change if the capacitor and the resistor were reversed in the order that they appear in the circuit? Would it change at all?
- *Day three* will come back to the voltage divider circuit, but this time hooked up to the Basic Stamp.
- Have student groups build the circuit in Figure 6.
- You can use the program 2 to monitor the state of the circuit. Change the pin assignment in the command IN2 to match the pin each group used with their circuit.

```
' {$STAMP BS2}
' {$PBASIC 2.5}

'this program will display the state of a photoresistor connected to the basic stamp
'the state will be either a 1 or 0 depending on whether or not the value of the
'voltage is above or below 1.4 V respectively.
'this program was adapted from the BS-Robotics with Basic Stamps book.


DEBUG "PHOTORESISTOR STATE", CR, 'sets up a table for the values in the debug window.
"Pin State", CR,
"---------"

DO
  DEBUG CRSRXY, 0, 3,        'moves the cursor to the location 0,3
  BIN1 IN2,                  'displays the binary number of the pin 2 state
  PAUSE 100
LOOP
```

Program 2: Measuring Light w/ a Voltage Divider, Sample Program

- Have the groups record in their journals what light intensity changes the state of the pin with given resistor values. Also recorded should be the max and min values that the photoresistor gives in sun light and dark.

Assessment

For assessment, have students brainstorm how the RC and voltage divider circuit could be used to control a servo or motor. How would these circuits be useful in controlling a sunflower head? Students should record their answers in the journals. Assessing programs can be done with the following rubric:

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Program	Maximum Points	Points Earned	Grading Criteria	Instructor Initial
RC Circuit	3		Circuit is wired correctly. ___/1 Program entered correctly, downloads and runs as specified. ___/2	
Voltage Divider	3		Circuit is wired correctly. ___/1 Program entered correctly, downloads and runs as specified. ___/2	
Document	2		Documentation and comments. ___/2	
Teamwork	2		Worked well and contributed. ___/2	
	Total:			

Table 2: Programming Rubric

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