Overview:	**Goals:**
In this TI-Nspire™ CX II lesson, students will learn how to use an analog output on the TI-Innovator™ Hub to control the speed of a Small DC Motor. The TI-Innovator Hub does not produce enough electric current to drive a motor directly; instead, an analog output from the TI-Innovator Hub is used to control a TTL Power MOSFET connected to an external 4-AA Battery Holder power supply to drive the motor. Ohm's law will be used to calculate current through the motor.	1. Build a circuit containing a TTL Power MOSFET and an external 4-AA Battery Holder power supply to drive a Small DC Motor. 2. Write a Python program on the handheld that uses analog output to control speed. 3. Apply Ohm's Law to calculate current from a given voltage and resistance.

Background:

An electric car has motors that are driven by huge batteries. A set of computer chips, that are programed by software engineers, are used to control the speed of the car's electric motors.

When the driver presses the throttle pedal in the car, the pedal sends a small electrical signal to the computer chip that has a program running in it that senses the throttle pedal's position. The chip makes a decision of how much power the motors should deliver to the wheels.

Next, the chip sends a small electrical control signal to a motor drive circuit that has the car's batteries and electric motors connected into the circuit. The signal from the chip determines how much current the motor drive circuit delivers from the car's batteries to the car's electric motors. In this way, the chip gets input from the driver's foot and then makes decisions on how much power to deliver to the motors.

In this activity, a similar method will be used to drive a Small DC Motor. The handheld will be used like the throttle pedal; the TI-Innovator Hub is the control chip; the Python program will make sense of the user's input; and the TI-Innovator Hub will send an analog output signal to a motor drive circuit made up of a TTL Power MOSFET. When the TI-Innovator Hub sends a larger voltage to the TTL Power MOSFET using analog output, the TTL Power MOSFET sends more electrical current to the motor. When the motor receives more current, if spins faster!

Analog output is different from digital output. The digital output signal that was used in Unit 1, can be either on, generating 3.3 Volts or off, generating 0 Volts. In contrast, the analog output of the TI-Innovator Hub can produce any voltage between 0 and 3.3 Volts, not just on or off. The variable voltage of the analog output is required to control the speed of the motor smoothly. If a digital output were used, the motor would be either off or full-on. That would make it very difficult to drive the car!

To help understand the relationships between current and voltage, an understanding of Ohm's law is required. Early in the 19th century, German physicist Georg Ohm investigated how electrical current flows through a conductor, such as a wire, when a voltage is applied. His investigations into electricity produced one of the most important laws in physics known as Ohm's Law.

This law relates three important quantities in electricity: voltage, current and resistance. Electrical current is actually the drift of electrons through a conductor such as a piece of metal. Voltage is the "push" the electrons "feel" that causes them to drift through the conductor. Resistance is how difficult it is for the electrons to move through the conductor.

Some materials produce more resistance that others. Materials that produce little resistance are called conductors while those that produce much resistance are called resistors.

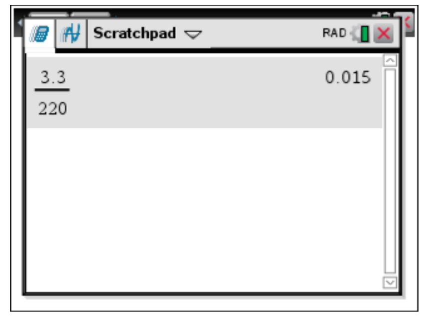
- V is the electrical potential across the conductor and is measured in Volts (V).
- I is the current through the conductor and is measured in Amperes (A).
- R is the resistance of the conductor and is measured in Ohms (Ω).

Ohm's Law

$$V = IR$$

Practice:

What is the current flow through a small DC motor that has 220 Ohms of resistance when 3.3V is applied to the motor?



$$I = \frac{V}{R}$$

Try a few more problems.

a) Calculate the current flow through a 100Ω motor when a 5.0 Volts is applied.
Answer: **5/100=.05**

b) Calculate the voltage needed for .20 amps to flow through a 500Ω motor.
Answer: **2*500=100**

c) Calculate the resistance needed to limit current flow to .15 amps when 12V is applied.
Answer: **12/.15=80**

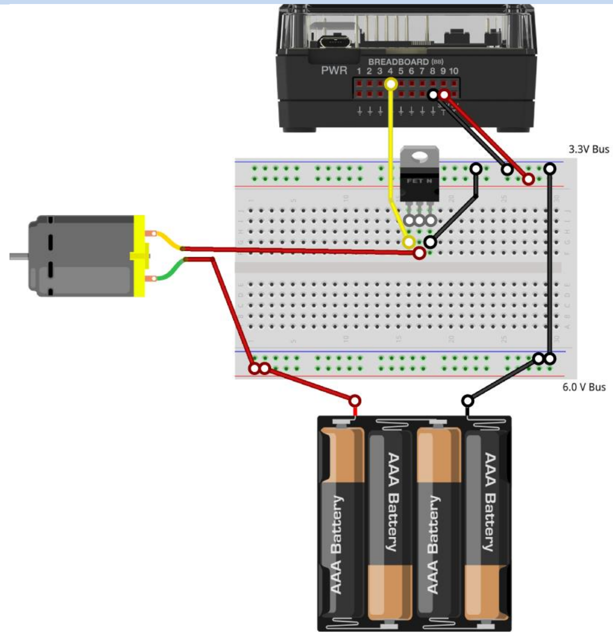
Materials and Tools

- TI-Nspire CX II Technology
- TI-Innovator Hub with USB Cable
- 4 AA batteries
- TI-Innovator Breadboard Pack:
  - Breadboard
  - Male to Male jumper wires
  - TTL Power MOSFET
  - Small DC Motor
  - 4-AA battery holder

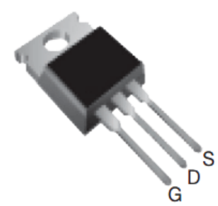
Build the Hardware:

Assemble the circuit in the diagram by following these steps:

1. Insert the TTL Power MOSFET into the breadboard as show in the diagram.
2. Use a red Male to Male Jumper Cable to connect the red 3.3V breadboard bus to the 3.3V pin on the TI-Innovator Hub.
3. Use a black Male to Male Jumper Cable to connect the blue ground bus on the breadboard to any ground pin on the TI-Innovator Hub.
4. Connect a yellow Male to Male Jumper Cable from BB4 (analog output) on the TI-Innovator Hub to the far left leg (Gate) of the TTL Power MOSFET.
5. Insert one of the stripped wire leads of the Small DC Motor into the breadboard column common with the middle leg (Drain) of the TTL Power MOSFET.
6. Connect the other stripped wire lead of the Small DC motor into the positive (red) 6.0V battery bus on the breadboard.
7. Connect a black Male to Male Jumper Cable going from either ground bus to the far right leg of the TTL Power MOSFET (Sink).
8. Use a black jumper wire to connect the ground (blue) on the 3.3V bus to the ground (blue) on the 6.0V bus.
    - *The battery and TI-Innovator Hub must share a common ground.*
9. Double-check all connections for accuracy up to this point.
10. Lastly, connect the black wire (-) of the 4-AA battery pack to the 6.0V bus ground (blue) and the red wire (+) to the 6.0V power bus (red).
11. Touch the TTL Power MOSFET to check for heating. If the TTL Power MOSFET gets hot, IMMEDIATELY disconnect the battery and TI-Innovator Hub. Double-check all connections.
12. Plug the B end of the "unit to unit" USB cable into the TI-Innovator Hub and then the A end into the handheld device.



TTL Power MOSFET Diagram



G- gate, D- drain, S- sink

Tech Tip: It is important to demonstrate to students how to be methodical when checking for hardware and software errors. Show them how to trace the current through the circuit and the requirement for a complete circuit from source to ground. A common problem in this activity is the connections to the TTL Power MOSFET are wrong. If the TTL Power MOSFET heats up, quickly disconnect the battery

Write the Software for the TI-Nspire CX II:

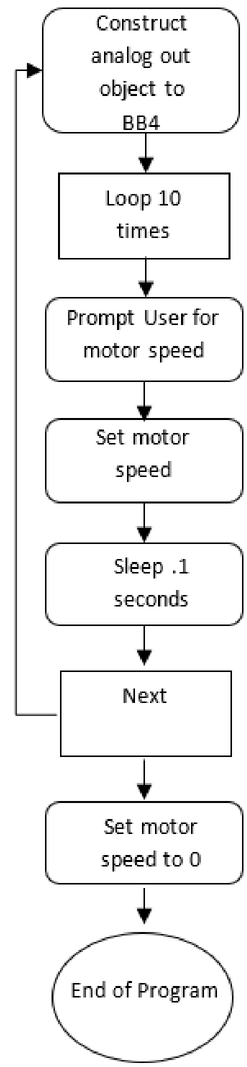
Task: Write a Python program on the handheld that will control the speed of a motor, where speed = 0-255.

Code for the TI-Nspire CX II:

```
from ti_hub import *

motor=analog_out("BB 4")
for n in range(10):
  speed=int(input("ENTER SPEED (0 to 255)"))
  motor.set(speed)
  sleep(5)
  motor.off()
```

Program Algorithm



Extra for Experts:

Have students modify their program so the motor does not instantly go to the speed that was entered by the user. Instead, slowly speed the motor up, using a “for” or a “while” loop, until it reaches the user entered set point. In other words, try to make the motor accelerate more smoothly. If this were an actual car motor, this modification would be part of the program running in the car’s chips, and it would produce a smoother acceleration and better driving experience.

Sample Extra for Experts Program:

```
from ti_hub import *

motor=analog_out("BB 4")
speed=int(input("ENTER OUTPUT VALUE "))
n=0
while n<speed:
  motor.set(n)
  print("analog out is set to",n)
  n+=1
  sleep(.1)
sleep(5)
```