Overview:

In this TI-Nspire™ CX lesson, students will build a digital thermometer and calibrate it to centigrade degrees using an analog temperature sensor. Calibration is done using the standards of boiling and freezing points of water. These two points are then used to find a slope-intercept linear equation to model the voltage output from the sensor as a function of temperature. The linear model is then programed into a TI-Basic program to display temperature from the TI-Innovator™ Hub's analog input reading of the sensor.

Goals:

1. Apply the skill of calibration from Skill Builder 5.
2. Design a digital thermometer using a TI Analog Temperature Sensor.
3. Synthesize a linear model of the form y=mx+b, to best fit of analog input vs. temperature data.
4. Author a program that reads analog input from sensor voltage and calculates and displays temperature in centigrade.
5. Evaluate the accuracy of the thermometer.

Background:

Temperature is a very familiar property of all objects and is a measure of the hotness or coldness of that object, but what is temperature? On the ultra-small scale or, microscopic scale, the temperature of an object is proportional to the motion of the particles that make up the matter within the object. Energy of motion is called kinetic energy and is possessed by all particles when they move through space, vibrate or spin in place.

All objects made from matter are made of these microscopic particles called atoms. Atoms are made up of moving subatomic particles called electrons, neutrons, and protons. Atoms also assemble into very large groups of atoms called molecules. All of these different kinds of particles are in motion. The protons, electrons, and neutrons vibrate and spin within the atoms. The atoms themselves can vibrate, spin, and move through space. Large molecules can contain millions of atoms and also move around, bend, vibrate, and spin.

All of these different types of kinetic energies, when combined, are responsible for what gives an object its temperature. When an object is hot, all the different particles within the object are spinning, vibrating, bending, and moving around very fast. When cold, all the object's particles are moving very slow. The sum total of all of the kinetic energies of all the particles within an object is what determines the object's temperature.

What if an object's particles don't have any motion of any kind? That is, no kinetic energy at all…, that special condition is known as "absolute zero" and that point was used to define the Kelvin temperature scale. On the Kelvin scale, our body's temperature is about 310K, so absolute zero (0K), is really cold. Actually, it's the coldest anything can ever be! That's Cool!

Anders Celsius (1701-1744) designed, built, and calibrated a thermometer made from a glass tube filled with liquid mercury metal. Mercury expands dramatically with temperature and remains liquid over a broad range of temperatures. He found after much experimenting, that the mercury in his thermometer reached a level that was always on the same mark when placed in water with melting ice. He also found that his thermometer, when placed in boiling water, always settled on the same mark.

Oddly, he decided to number the mark for the boiling point of water as zero (0) and the mark for the freezing point of water as one hundred (100)! He then divided the range between the two marks with one hundred equal divisions. Thus, the centigrade (100 mark) thermometer was invented. Shortly after his invention, a different scientist reversed the two points, which caught on, and this became the familiar Celsius temperature scale used today by much of the world.

The process of building a mercury thermometer is an example of calibration. First, a device is built that responds in a predictable way to some physical phenomenon, in this case, temperature. The device must then be adjusted so that the values the instrument reports are in agreement with all other similar instruments; this is called calibration. The process of adjusting the marks on the glass tube filled with mercury when placed in two known standard temperature baths is an example of calibration.

In this project, the digital thermometer will be calibrated using the same two standard points Celsius used, the freezing and boiling points of water. However, instead of making 100 equal divisions scratched into glass between the two, you will use the equation for a line that mathematically passes through those two points and then solve the equation in a TI-Basic program to calculate the temperature from an analog input connected to the temperature sensor.

Materials and Tools:

- TI-Nspire CX Technology
- TI-Innovator Hub with USB Cable
- TI-Innovator Breadboard Pack:
  - Breadboard
  - Male to Male jumper wires
  - Male to Female jumper wires
  - TI Analog Temperature Sensor
- Silicone sealant or hot glue
- Soda straw or other tube (optional 3-D design and print of housing)
- Ice water
- Boiling water
- Scissors
- Hot glue gun
- Tape
- Paper towels
- Hot plate
- Reference thermometer
- 3-D printer (optional)

Build the Hardware:

Assemble the circuit in the diagram on the right by completing the following steps:

1. Insert each leg of the TI Analog Temperature Sensor into three separate M/F jumper wires. Write down the color for each of the markings on the diagram on the right. Preferable wire colors:
   - V_s-Red
   - V_{out}-Yellow
   - GND-Black
2. Insert sensor and wires into a housing, and use a sealant or hot glue to mount the sensor water-tight in the housing.
3. Insert the Red-Vs wire into the 3.3V pin on the breadboard connector of the TI-Innovator Hub.
4. Insert the Yellow-V_{out} wire into the BB5 analog input of the TI-Innovator Hub.
5. Insert the Black-GND wire into any ground pin on the TI-Innovator Hub.
6. 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.

Write the Software for the TI-Nspire CX:

Example Code for the TI-Nspire CX:

Program 1:

```
Define pj5a()=
Prgm
Send "CONNECT ANALOG.IN 1 TO BB 5"
For n,1,50
Send "READ ANALOG.IN 1"
Get x
Disp "ANALOG IN = ",x
Wait 1
EndFor
EndPrgm
```

Program 1 Description:

1. Connect ANALOG.IN 1 to BB5 on TI-Innovator Hub.
2. Use a "For loop" to READ ANALOG.IN 1 fifty times.
3. Include a .5 second wait in the loop.
4. Display the ANALOG.IN value along with an appropriate message.

Task:

1. Place thermometer in an ice bath and allow cooling for about one minute. Run program 1 to measure the ANALOG.IN value. Record in table on the left.
2. Place thermometer in a boiling water bath and allow warming for one minute. Run program 1 to measure the ANALOG.IN value. Record in table.
3. Use the two ordered pairs in the data table to calculate the slope-intercept form of a linear equation.

Data:

Temperature ◦C	ANALOG.IN Value
0	
100	
Slope (m)	**Y-Intercept (b)**

<u>Sample Answer:</u> These values can vary by +/- 10%

Temperature ◦C	ANALOG.IN Value
0	<u>8560</u>
100	<u>3700</u>
Slope (m)	**Y-Intercept (b)**
<u>-.0206</u>	<u>176.13</u>

Teacher Tip: One way to find slope-intercept form of a line is to first find the slope using two points.

$$m = \frac{Y_2 - Y_1}{X_2 - X_1}$$

Then find the intercept using the calculated slope and one point.

$$b = Y_1 - mX_1$$

Write the Software for the TI-Nspire CX:

Example Code for the TI-Nspire CX:

Program 2

```
Define pj5()=
Prgm
Send "CONNECT ANALOG.IN 1 TO BB 5"
Request "M = ?",m
Request "B = ?",b
For n,1,200
Send "READ ANALOG.IN 1"
Get x
Disp "ANALOG IN = ",x
m*x+b→c
Disp "Temperature in C = ",c
Wait 1
EndFor
EndPrgm
```

Program 2 Description:

1. Connect ANALOG.IN 1 to BB5 on TI-Innovator Hub.
2. Prompt user to input both slope (M) and *y*-intercept (B) from the calculated equation based on the two calibration points in the table above.
3. Use a "For loop" to READ ANALOG.IN 1 two hundred times with a .5 second wait in the loop.
4. After each reading, apply the slope-intercept equation and the values of M and B to calculate temperature in Celsius degrees from the ANALOG.IN value.
   Temperature = (M*ANALOG.IN) + B
5. Display the calculated value of temperature with an appropriate message and unit.

Evaluate:

1. Use a standard thermometer to measure room temperature, and record this value as the accepted value.
2. Measure the room temperature with the project digital thermometer ,and record the value as the predicted value.
3. Calculate the percent error for your device.
4. Make an argument from evidence for the accuracy of your device.

$$\%Error = \frac{|Actual - \Pr edicted|}{Actual} \cdot 100$$

Actual Value	Predicted Value
Percent Error	

<u>Sample Answer:</u> |(23.5-24.3)/23.5|*100=3.40%

Extra for Experts:

Modify the program to prompt the user for the desired temperature unit and then display the current temperature in that unit of Celsius, Fahrenheit, or Kelvins.

<u>Sample Extra for Experts Program:</u>

```
Define pj5()=
Prgm
Send "CONNECT ANALOG.IN 1 TO BB 5"
Request "M = ?",m
Request "B = ?",b
For n,1,200
Send "READ ANALOG.IN 1"
Get x
Disp "ANALOG IN = ",x
m*x+b→c
Disp "Temperature in C = ",c
c+273→k
Disp "Temperature in K = ",k
((c*9)/(5))+32→f
Disp "Temperature in F = ",f
Wait 1
EndFor
EndPrgm
```