Module 2, Lesson 1 – Connecting a thermistor to the NXT computer

Teacher

30 minutes

Overview of module 2

The *Sensor deployment and data gathering* module will require students to integrate their sensors with microprocessors (LEGO NXT), and write simple programs to enable gathering and analysis of sensed environmental data. Students will then deploy their sensor system and use it to make measurements of their local environment which they will then plot and analyze. The deployment and data gathering module will require students to use mathematics skills (systems of equations, simple statistics, manipulation of formulae), science skills (hydrology, electrical circuits), pre-engineering skills (design, testing and problem solving, tool use), technology skills (programming and interfacing a microprocessor) and general skills (teamwork, communication).

Purpose of this lesson

- Connect a thermistor to an NXT computer.
- Compare the circuitry inside the NXT which allows it to measure voltages.
- Use circuit equations to predict how NXT measurements will vary with temperature.

Materials

Copy of the lesson
1 NXT
1 NXT connector cable
1 Thermistor
Hook up wire
1 Soldering iron
Solder
Graph paper (or Excel)

Procedure

Connecting a thermistor to the NXT computer

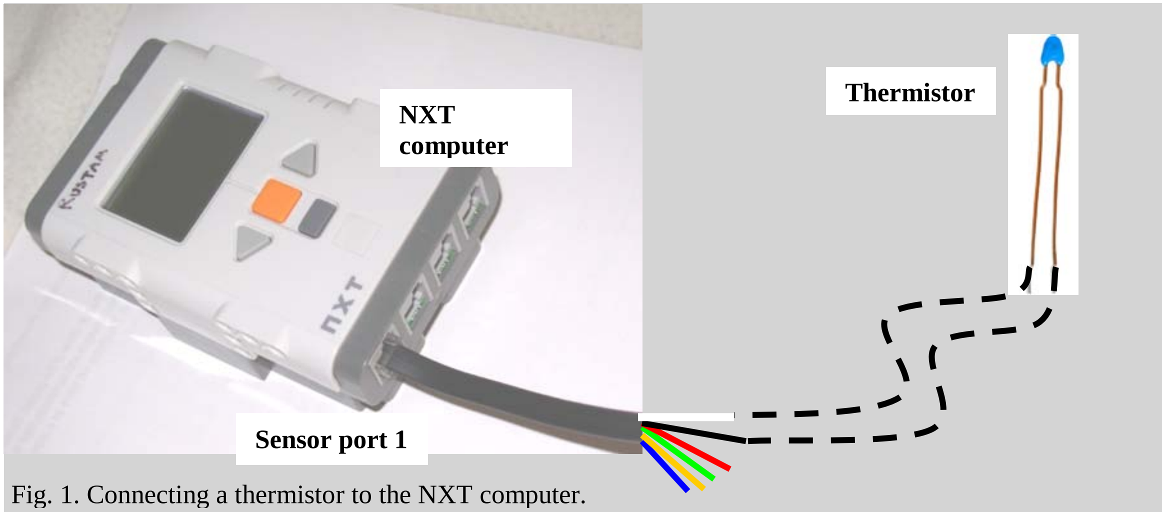


Fig. 1. Connecting a thermistor to the NXT computer.

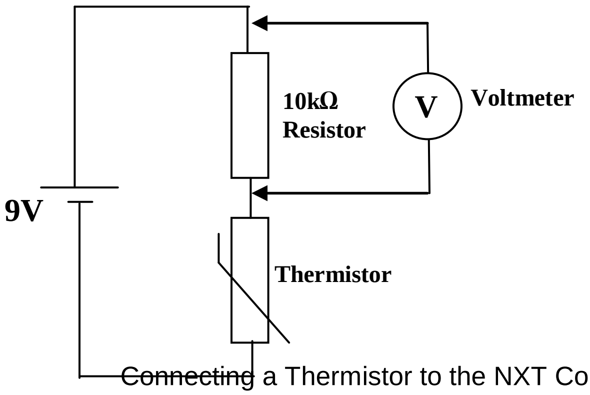
1) Cut an NXT connector cable in half (or obtain a half cable from your teacher).
2) Find the black and white wires, strip them carefully and solder them to the wires leading to your thermistor.
3) *Once you have completed the soldering*, you can then plug the connector cable into sensor port 1 on the NXT (see fig. 1). ***Do not solder the wire while it is still connected to the NXT – the internal circuits could be damaged by heat.***

How does an NXT measure voltage?

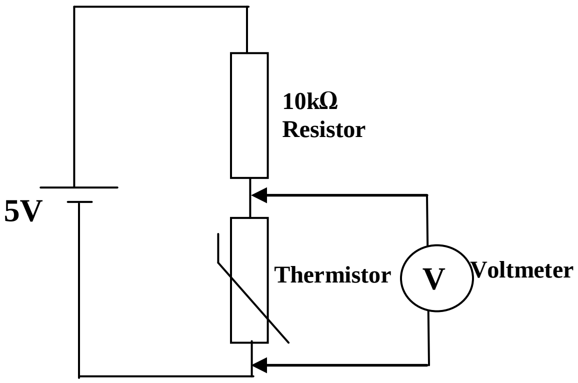
When you connect a thermistor across the terminals of the NXT computer, you are forming almost the same circuit previously built with the resistor and the multimeter (see module 1, lessons 3, 4 and 5). The differences are:

- Previously you used a 9V battery, but inside the NXT there is the equivalent of a 5V battery.
- Previously you put multimeter across the resistor in the potential divider circuit, but inside the NXT there is a voltmeter that will be measuring the voltage across your thermistor.

Your previous circuit looked like this:



NXT circuit is like this:



The NXT circuit doesn't *look* like the diagram because the 5V battery, the 10kΩ resistor and the voltmeter are all hidden inside the NXT, see fig. 3.

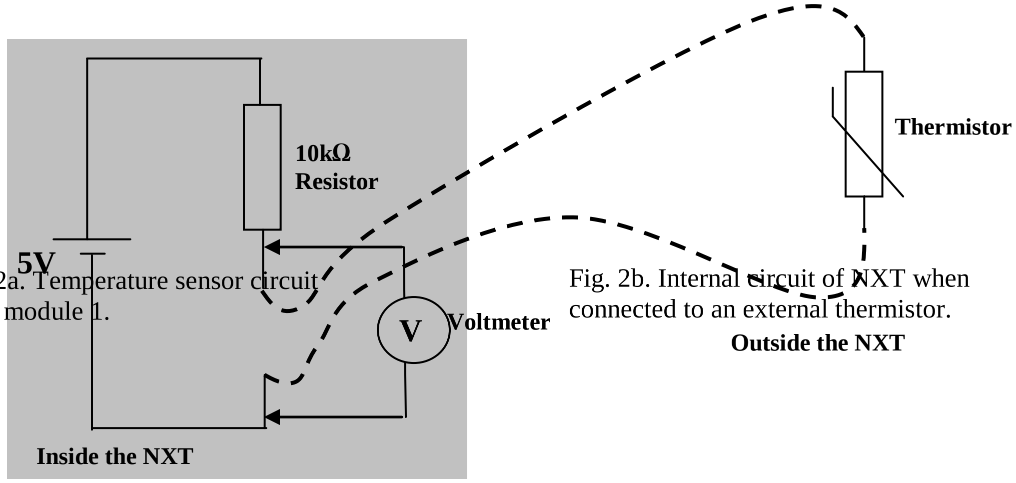


Fig. 3. Internal circuitry of the NXT (shown in grey box), connected to an external thermistor. *Note that this is EXACTLY the same circuit as fig. 2b. If you don't understand this, ask your teacher.*

The voltmeter inside the NXT can pass a number, which represents the voltage, to a program which is running on the NXT. **You will write this program yourself in the next lesson!** The voltage measured by the NXT is given by the potential divider equation:

$$V_{NXT} = \frac{R_T}{(10000\Omega + R_T)} \times 5 \qquad \textbf{equation 1}$$

(see module 1, lessons 4 and 5), where R_T is the resistance of the thermistor.

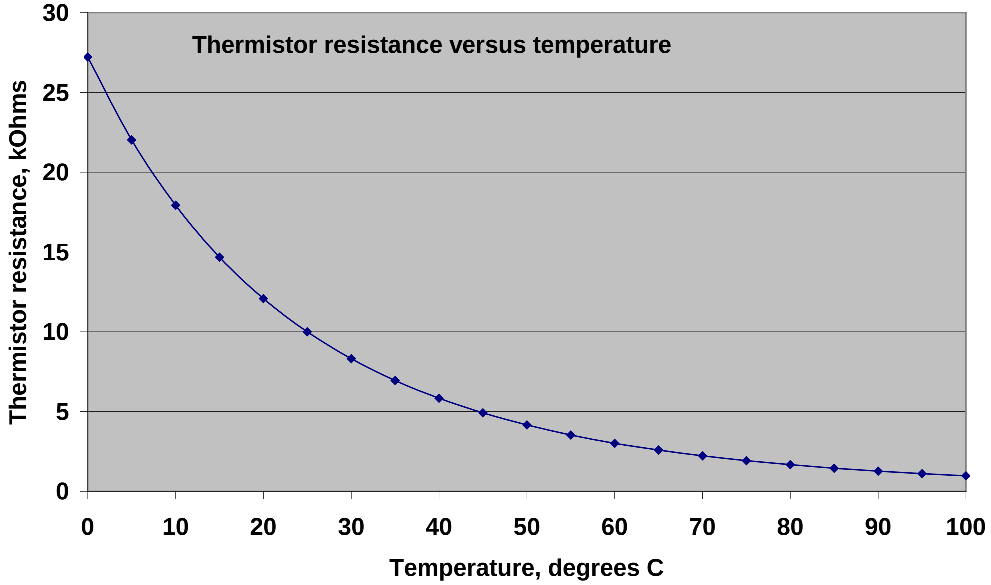
<u>Assessment 1</u>

Use equation 1 and your graph for temperature versus resistance for the thermistor (i.e. temperature versus R_T, (expressed in Ω) ***which you created in module 1, lesson 3***), to plot a graph which predicts what voltages will be measured by the NXT at different temperatures (i.e. V_{NXT} versus temperature).

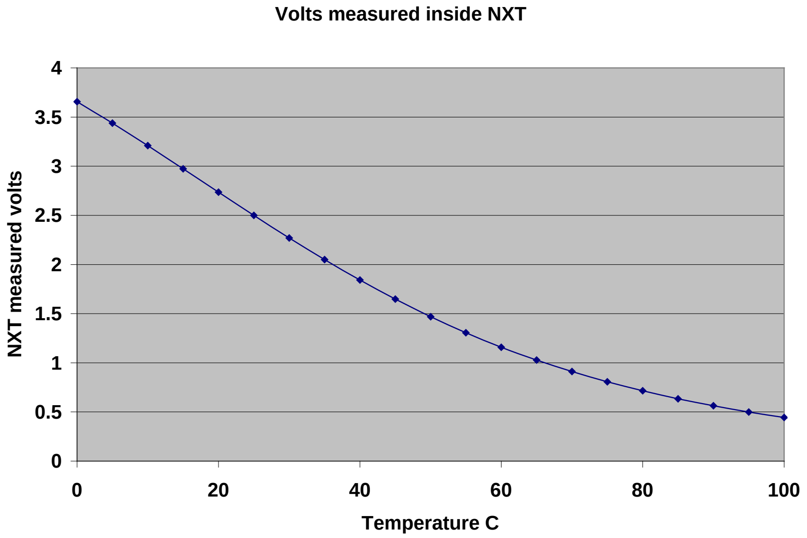
*Answer – table should look something like this (as discussed in module 1, lesson 3, the actual temperatures used don't need to match the chart below precisely). If students have lost their data from module 1, then you can give them the resistance values shown in the chart below to use; these should be approximately correct for the 10 k*Ω thermistors.

Temperature °C	0	10	20	30	40	50	60	70	80
Copy resistance values from Module 1, Lesson 3									
Resistance (kΩ)	27.2	17.9	12.1	8.3	5.8	4.2	3.0	2.2	1.7
Convert kΩ to Ω by multiplying by 1000									
Resistance (Ω)	27200	17900	12100	8300	5800	4200	3000	2200	1700
V_{NXT} (V)	3.66	3.21	2.74	2.27	1.84	1.48	1.15	0.90	0.73

Note: if students have lost their graphs from module 1, then the following can be used:



Answer: graph should look something like this.

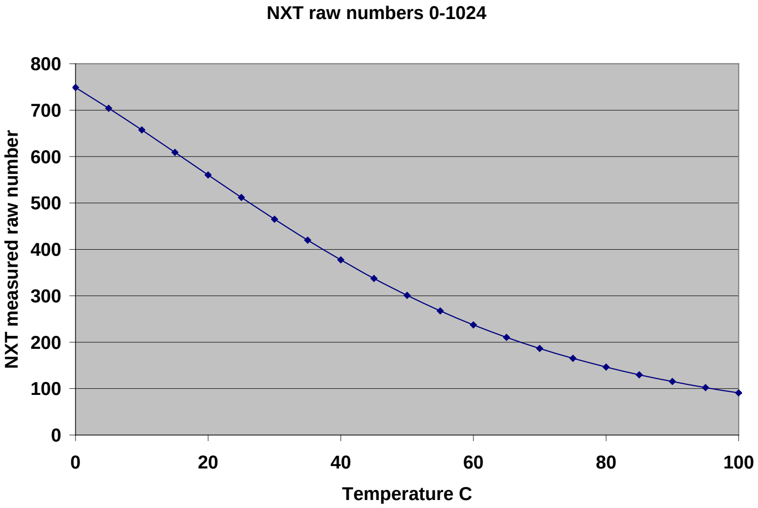


Assessment 2 - Units of measurement

Note to teacher: The NXT measures voltage as a 10 bit number. If you want to mention binary numbers with your students, you can talk about how 10 bits or binary digits enables numbers to be represented from zero up to 2^{10}*, i.e 0 to 1024. Otherwise, simply consider that the voltmeter inside the NXT outputs "raw" numbers from 0 to 1024, to represent voltages from 0 to 5V.*

a) The voltmeter inside the NXT outputs "raw" numbers from 0 to 1024, to represent voltages from 0 to 5V. Hence, for every one volt on the above graph, the NXT will read 1024/5 = about 205 units. Using this information, now plot another graph to predict what the "raw numbers" will be, from 0-1024, as measured by the NXT voltmeter, versus temperature.

Answer:



b) Approximately, what is the range of "raw" NXT numbers that spans the range of temperatures that you expect to measure in the environment (say from 0 - 40°C).

Answer: 0-40°C corresponds to NXT raw values from about 750 down to 380.

c) The NXT can only handle *integers*, i.e. it can only handle distinct whole numbers without any fractions or decimals. How many such distinct intervals can be output by the NXT over the temperature range of 0 - 40°C? Hence, what is the best *resolution* that can be attainable by a temperature measuring system that is built using your thermistor and an NXT? Remember, that by *resolution* of a sensor, we mean the smallest difference between two temperatures that can be distinguished or measured by the sensor.

Answer: 750 – 380 comprises 370 distinct measurable intervals. This corresponds to a range of 40°C. Hence the finest possible difference in temperatures that could theoretically be resolved *by such a sensor is approximately 40 ÷ 370 = around ± 0.1* °C. *Note that this is not necessarily the same as the eventual accuracy of the sensor (see definitions of resolution, accuracy, repeatability etc. discussed in module 1), but it does place a theoretical upper bound on the possible accuracy of the sensor.*