Make Your Own DIGITAL Thermometer!

Using the 5E learning cycle to design and calibrate a scientific instrument

Timothy Sorey, Teri Willard, and Bom Kim

More and more, our world depends on digital measuring devices. They tell us whether we should wear a heavy or light jacket (digital thermometer), if we are running late (digital watch), and even at what speed we should pedal our bicycles to get to school on time (digital speedometer). Digital probeware has become commonplace in high school science laboratories. However, too often students use these devices without understanding how they work.

In the hands-on, guided-inquiry lesson presented in this article, high school students create, calibrate, and apply an affordable scientific-grade instrument (Lapp and Cyrus 2000). In just four class periods, they build a homemade integrated circuit (IC) digital thermometer, apply a math model to calibrate their instrument, and ask a researchable question that can be answered using the thermometer they create. This activity uses the 5E learning cycle—engage, explore, explain, elaborate, and evaluate—to help physical science students discover the many connections between math and science (Karplus 1979).

Period 1: Engage

The first class period begins as two glass beakers filled with 500 ml of water are passed around the classroom. (**Safety note**: Students and instructor must wear safety glasses or goggles for this demo.) Students handle beaker A, which has a water temperature of 5–10°C, and beaker B, which has a water temperature of 40–50°C. They then make qualitative observations to determine which beaker is hotter and which is cooler.

When asked to estimate the temperature of beaker B, students may disagree. A student will often suggest that we use a glass thermometer to determine its temperature. Instead, I offer them a store-bought digital thermometer.

As a class, we then discuss how instruments, such as thermometers, impact our lives and the various

Keywords: Temperature and regulation
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biological, chemical, and physical quantities they allow us to measure. We also investigate the many uses of digital thermometers—from personal health to cooking meat. After this engaging discussion, I suggest that we build our own digital thermometers.

Cost and materials

The thermometers in this activity are constructed from basic, commercially available materials, including

- 1 m of standard telephone cable,
- 8–12 cm of 0.5 cm inner-diameter glass tubing (fired on both ends for safety and smoothness),
- one piece of 7.5 × 1.0 cm shrink tubing,
- two pieces of 5 × 0.33 cm shrink tubing,
- a 9V battery lead,
- a 9V battery, and
- an LM35 sensor.

These materials can be purchased for just under $10. An LM35 sensor, which records temperature in volts, accounts for about $1.20 of the total. When completed, students have a device that ranges from -18°–150°C and is more durable than a typical lab glass thermometer. Detailed instructions for making the digital thermometer are available online (see "On the web").

Building digital thermometers

Initially, most students do not know that the LM35 sensor is a Celsius-based sensor, with an output of 0.01 volts (V) per 1°C, but they discover this later in the experiment. Figure 1 (p. 58) provides a circuit diagram displaying the orientation of the LM35 temperature sensor, the three colored wires, the battery poles (positive and negative), and the digital voltmeter (DVM).

Working in pairs, students trim the main plastic shielding of the telephone cable and remove 0.5 cm of the inner plastic insulation from three of the four colored wires. (**Safety note**: Use caution when dealing with pointed objects.) With the yellow, red, and green wires pushed through the glass tubing, each wire is carefully soldered to the LM35 sensor's power (V_s), output (V_{out}), and ground (GND) leads, respectively (Figure 1).

CAUTION

After shrink tubing is placed over the solder joints, wires are caulked with bathtub caulking and pulled back into the glass tube until the LM35 sensor is seated at its tip. The device should then be left to dry for 24 hours.

Period 2: Explore

The next class period, students complete the construction of their instruments by using 7.5 cm of 1 cm diameter shrink tubing to enclose and fortify the telephone cable–glass tube connection. They then solder the correct colored wires to the 9V battery connector.

Before receiving a 9V battery and DVM, each student pair predicts its instrument's output. To test their predictions, students plug in the 9V battery and use alligator clips to attach the red positive lead of the DVM to the LM35 sensor output, and the black DVM ground lead to the black 9V battery wire (Figure 2; Hill and Horowitz 1989; Skoog, Holler, and Nieman 1998).

Once the apparatus is completed and students begin to use their thermometers, many are surprised to find that their numbers do not match the values they have predicted. At this point, a historical discussion of thermometry—from Aristotle and Galileo to Daniel Fahrenheit and Anders Celsius—is introduced. Although I use a class discussion, students can also do library or internet research on the history of temperature measurement.

Students are then asked a guiding question: How did Daniel Fahrenheit and Anders Celsius convert the linear expansion of mercury in glass thermometers into degrees Fahrenheit and degrees Celsius? Students brainstorm and design calibration experiments to collect the data needed to answer this question. Some decide to calibrate with freezing or boiling water; others decide to measure water baths of various temperatures with both their digital thermometer and a glass thermometer (Figure 3). I encourage students to collect at least three ordered pairs of data (x = V, y = °C). Figure 4 shows six ordered data pairs.

Period 3: Explain

Many of my students have previously studied scatter plots and linear regressions in math class. These students

FIGURE 1

Circuit diagram.

This diagram shows the LM35 sensor, battery, digital voltmeter, and three (colored) telephone wires.

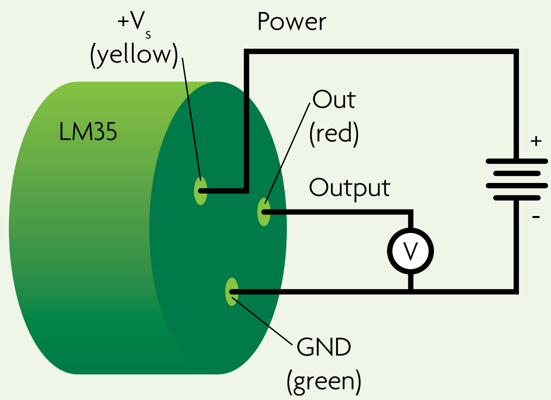
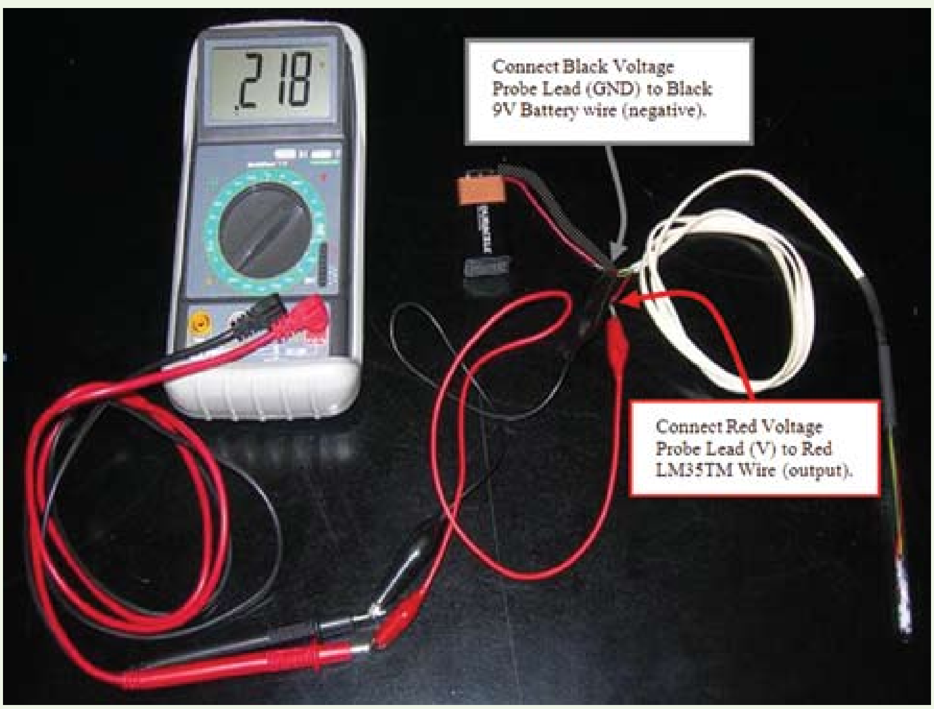


FIGURE 2

Digital thermometer with power supply (9V battery) and readout (digital voltmeter).



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typically see that it is logical to plot their data on graph paper, observe a trend, and draw a best-fit line between the points.

Most students choose two points on their best-fit line and write the equation that models related volts to degrees Celsius. They use graphing calculators and computer programs to graph their results, although the data can also be graphed using a pencil and paper. For the data in Figure 4, an equation, °C = 107.0V – 2.79, was determined using the graph in Figure 5 (p. 60).

Some students do not understand that, on the graph, *y* represents degrees Celsius and *x* represents voltage. Students are used to plotting *x* and *y* values, but often fail to recognize that these variables can represent physical quantities such as volts and degrees. At this point, students compare graphs and calibration equations. In my class, students recognized that everyone's data appeared to be linear but contained slightly different values for slope and *y*-intercept. Each group obtained an equation for the relationship between degrees Celsius and volts that was close to the expected value: °C = 100.0V – 0.

As a final check, students measure their body temperatures at the armpit using their digital thermometers and apply their calibration equations to convert from volts to degrees Celsius. (**Safety note**: Use caution in placing the glass tube under the armpit so as not to break the instrument.) In our class, students' body temperatures ranged from 0.34–0.38V, which corresponds to a range of 33.6–37.9°C. One student commented, "If I simply multipl[y] these voltage values by 100, that is about the same as the [degrees Celsius] values." This revelation was crucial for students in realizing that their digital thermometers did, in fact, work. Through the application of mathematics, they discovered that the LM35 sensor is a Celsius-based sensor.

The digital thermometer that students create contains almost all of the basic components found in an electronic sensor. Unlike a standard digital thermometer, this student-constructed version does not contain a "data processor" to convert volts to degrees Celsius. Instead, students apply mathematics to find a calibration equation they can use to convert data.

Period 4: Elaborate and evaluate

Equipped with their calibration equations, lab pairs then formulate an experiment that both answers a researchable question and validates the calibration of their digital thermometers. Some students need guidance in devising experiments. In a ninth-grade physical science class, typical research questions might range from "How fast does water cool down in a beaker compared to a foam cup?" to "When shaking different types of metal shot in an enclosed plastic bottle, does the type of metal affect the temperature increase?" In an advanced chemistry or physics class, student questions might include "What is the freezing point and boiling point of glacial acetic acid?" and "What is the equilibrium temperature of 100 ml of 20°C water mixed with 50 ml of 50°C water?" Guiding students toward a researchable question requires patience so that students can clearly identify manipulated and responding variables for their experiment.

FIGURE 3

Measuring water bath temperature.

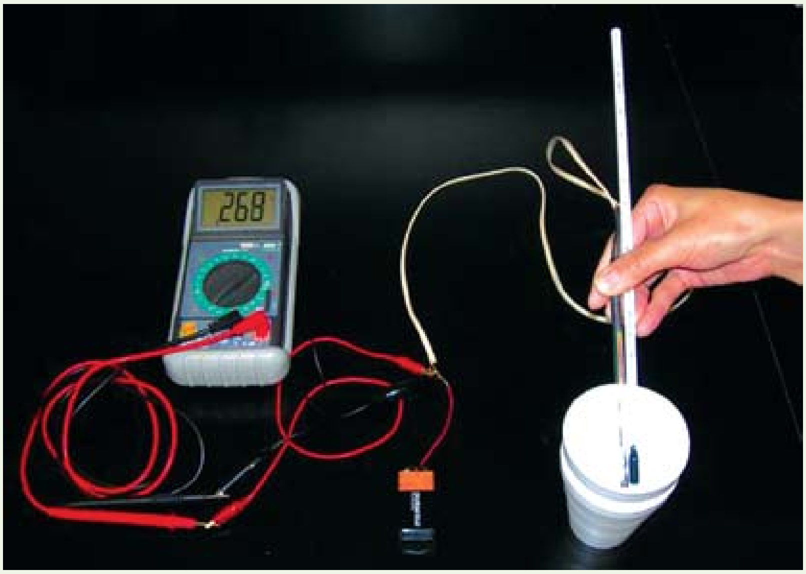


FIGURE 4

Temperature data obtained using LM35 sensor.

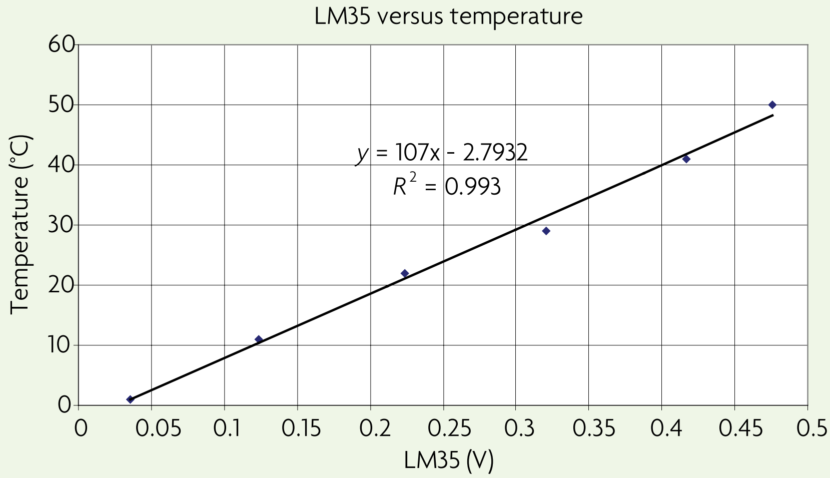
Water bath descriptions	Reading from LM35 sensor in volts (*x*)	Reading from thermometer in °C (*y*)
Ice–water slurry	0.035	1.0
Below room temperature	0.123	11.0
Room temperature	0.224	22.0
Slightly above room temperature	0.321	32.0
Above room temperature	0.417	41.0
Well above room temperature	0.476	50.0

Safety

Students must be trained for safety in the use of all manufacturing devices prior to creating this sensor and wear indirectly vented chemical-splash goggles at all times—especially during the cutting and firing of the glass tube and the soldering of electronic joints. Students should use the soldering station one at a time. Hazardous fumes from silicone caulking and soldering should be avoided by use of a fume hood or direct ventilating exhaust system. Make sure that students wash their hands with soap and water after using the solder—as it contains lead, a poisonous metal. An ABC-class, portable fire extinguisher must be located in close proximity so that it can be immediately available should the need arise. Floor areas under and within 11 m [35 ft.] of the soldering operation must be swept clean of combustible and flammable materials.

FIGURE 5

Relationship between voltage (V) and temperature (°C) in Figure 4 (p. 59).



Assessment

Over the course of four periods, students are assessed with a rubric (see "On the web"). For further evaluation, students can calibrate a new sensor using the same methods used to create their original sensor. The LM34 (Fahrenheit-based) and LM335 (Kelvin-based) sensors can be used as additional tools. Students can also be given data from these sensors and asked to find a new calibration equation.

Conclusion

The purpose of this hands-on activity is to have students learn the skills and knowledge needed to create a reliable scientific-grade instrument. Today, many educational, computer-based labs have been reduced to "plug-and-play" devices that acquire data, but are often implemented with little or no thought about calibration and precision.

This activity demonstrates a real-world connection to science—and encourages students to search for more connections between science and mathematics in the classroom and beyond. Together, science and math teachers must strive to provide students with hands-on, cross-curricular experiences that enhance their understanding and empower their explorations. As a result, students discover just how interconnected and inseparable the fields of science and mathematics truly are. ■

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Addressing the Standards.

The following National Science Education Standards (NRC 1996) are addressed in these activities:

- Science as Inquiry (p. 173)
  - Abilities necessary to do scientific inquiry
  - Understanding about scientific inquiry
- Science and Technology (p. 190)
  - Abilities of technological design
  - Understanding about science and technology

On the web

Digital thermometer creation instructions: *www.nsta.org/highschool/connections.aspx*

Rubric for guided-inquiry activities: *www.nsta.org/highschool/connections.aspx*

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