Cooling Rates – ID: 8546

By Lars Jakobsson

Time required
45 minutes

Activity Overview

In this activity, students will collect data on the temperature of a cooling metal sensor. They will then fit a model to their collected data and attempt to find numerical values for the variables in the modeled equation. Finally, they will use the derivative to investigate the rate of temperature change as a function of the difference in temperature between the probe and the environment.

Concepts

- *Heat transfer by convection*
- *Mathematical models of physical phenomena*

Materials

To complete this activity, each student will require the following:

- *TI-Nspire™ CAS technology*
- *50 mL to 100 mL water in an insulated container*
- *copy of the student worksheet*
- *pen or pencil*
- *paper towels*
- *Vernier EasyTemp™ or Go!™Temp temperature sensor*
- *safety goggles*
- *blank sheet of paper*

TI-Nspire Applications

Calculator, Graphs & Geometry, Lists & Spreadsheet

Teacher Preparation

Students should be familiar with the idea of heat transfer and with the fact that it does not occur at the same rate in all situations. Exponential cooling, which is explored in this activity, applies to heat transfer by convection only. Furthermore, it applies only to situations in which the ambient temperature remains effectively constant.

- *As a point of interest, you may wish to explain that forensic scientists sometimes use exponential cooling models to estimate time of death. You could also have students brainstorm situations in which these models do or do not apply.*
- *The screenshots on pages 2–6 demonstrate expected student results. Refer to the screenshots on page 7 for a preview of the student TI-Nspire document (.tns file).*
- ***To download the .tns file and student worksheet, go to education.ti.com/exchange and enter "8546" in the search box.***

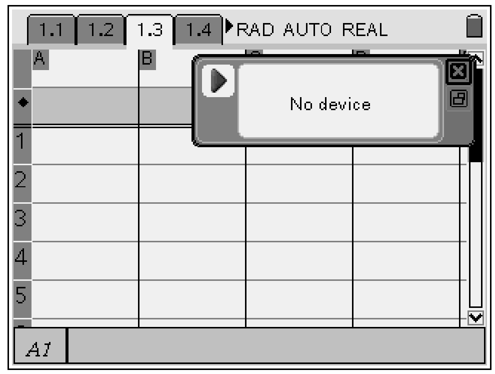
Classroom Management

- *This activity is designed to be* ***student-centered****, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students should record their answers to the questions on a separate sheet of paper.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:

- How does the temperature of a hot object change when it is placed in a cool environment?
- How can we make a mathematical model of such a temperature change?
- How is the rate of temperature change related to the difference in temperature between the object and the environment?

Part 1: Collecting temperature data

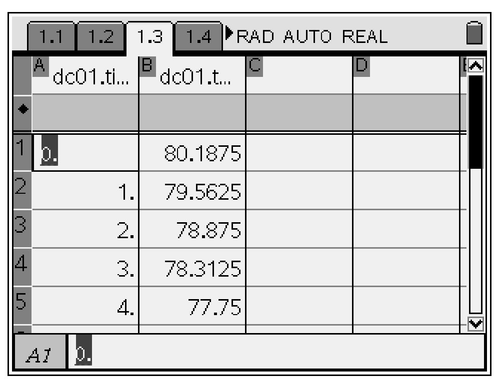


Step 1: Students will use a Vernier EasyTemp™ or Go!™Temp temperature sensor to collect temperature data. Students should open the file **PhyAct01_cooling_EN.tns** and read the first two pages. When students reach page 1.3, they should connect the temperature sensors to their handhelds or computers. This should activate the temperature sensor, and a temperature display should appear in the data collection box.

Q1. What is the ambient temperature?

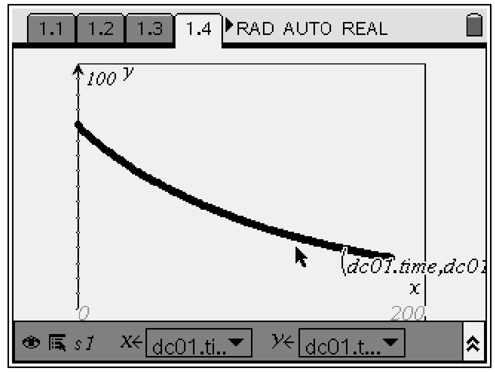
A. *The ambient temperature will vary. Make sure students' values are reasonable.*

Step 2: After making sure all students are wearing safety goggles, give each student approximately 100 mL of boiling water in an insulated container. Students should place the metal ends of their temperature sensors into the water and wait for the temperature reading to stabilize. Then, they should remove the sensor from the water and wipe it off.



Step 3: Immediately after removing the sensor from the water, students will begin data collection. Data collection will run for three minutes. When it is complete and students close the data collection box, their screens should look like the one shown. At this point, students can disconnect the temperature sensors. Collect the containers of water from the students and dispose of them properly. After you have taken all the containers of water away, students may remove their safety goggles.

Step 4: Next, students will advance to page 1.4 and make a scatter plot of the temperature and time data.

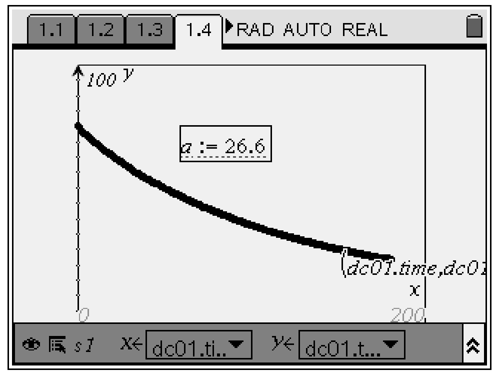


Q2. Describe the shape of the graph.

A. *The data curve downward, indicating that temperature decreased over time at a nonuniform rate. The curve should be approximately exponential, as shown.*

Part 2: Fitting a curve to the data

Step 1: Next, students will attempt to fit an exponential curve of the form $y = a + b \bullet c^x$ to their data.



Q3. Should *c* be greater than, less than, or equal to 1? Explain your answer and give your prediction for the value of *c*.

A. *The variable* c *should be less than 1 because temperature decreases as time increases. Students may struggle with this reasoning. You may wish to give them several simple examples (e.g.,* $\left(\frac{1}{2}\right)^x$ *vs.* 2^x*) to illustrate why a decreasing curve implies a base that is less than 1. Their predictions about the value of* c *will vary.*

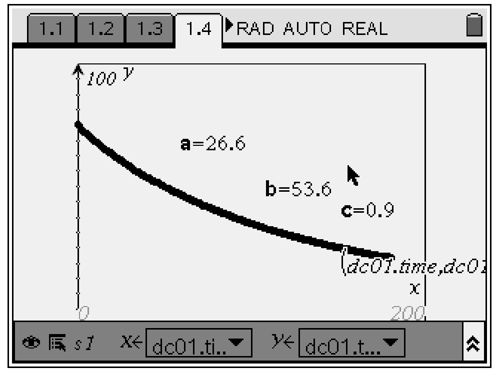
Q4. What value should *a* have? (Hint: What will happen to the temperature of the sensor as time approaches infinity?)

A. *The variable* a *should be equal to the ambient temperature. You can help students understand why this is so by reminding them that the temperature of the sensor will eventually (i.e., as time approaches infinity) equal the ambient temperature and showing them how the equation requires that* y *approach* a *as* x *approaches infinity.*

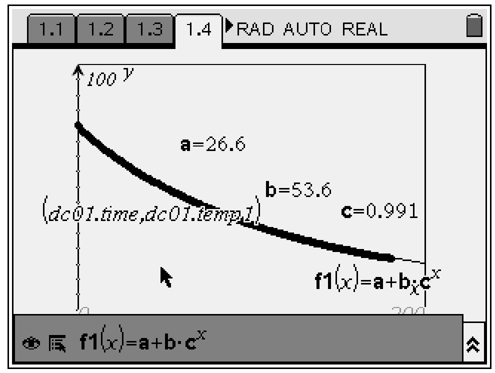
Q5. What value should *b* have?

A. *The variable* b *should equal the initial temperature of the sensor minus the ambient temperature.*

Step 2: Next, students define the variables **a**, **b**, and **c** using the text box tool, the sto→var button, and the **Store Var** command.



Step 3: Next, students set the function **f1(x)** equal to **a** + **b** · **c**^{x}. They change the graph to a **Function** graph and enter the expression in the function line. They should then vary the value of **c** to obtain the best possible fit to their data set.

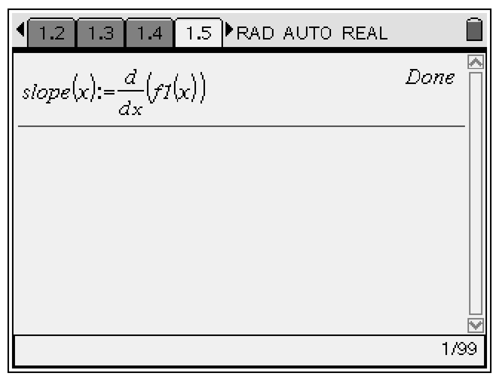


Q6. What value of *c* gave you the best fit to your data?

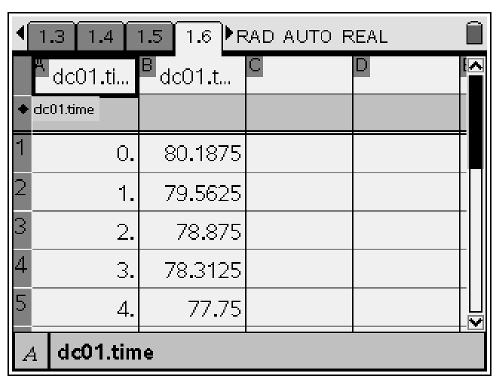
A. *The value of* c *will vary from student to student, but it should be very close to 1.*

Part 3: Exploring the relationship between cooling rate and temperature difference

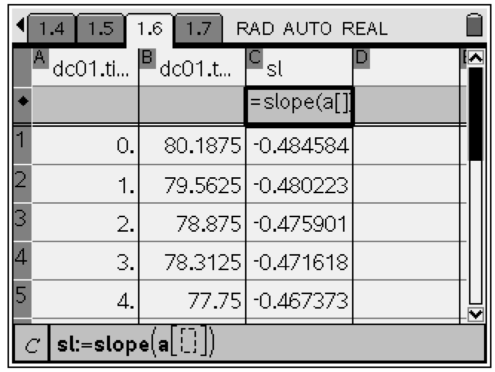
Step 1: Students will now define the function **slope(x)** as the derivative of **f1(x)**. Students may have a hard time understanding the concept of the derivative. You may wish to discuss the idea of infinitesimally small intervals with them, or show a few simple examples. Note: Make sure that students use the **:=** notation (not just **=**) when defining the slope function. The **=** notation will cause the handheld to calculate and display the actual equation for **slope(x)**.



Step 2: Next, students set up a *Lists & Spreadsheet* application to store slope and temperature-difference data before plotting them. They set Column A equal to the time data collected in part 1 and Column B equal to the temperature data collected in part 1.



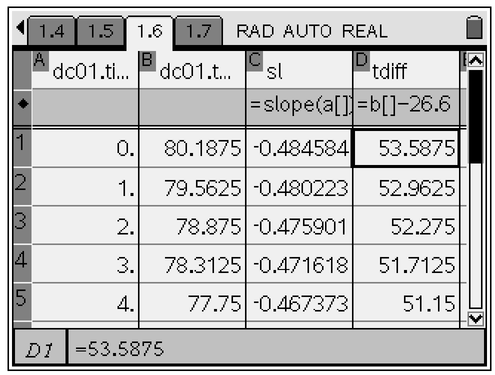
Step 3: Next, students use the **slope** function to fill Column C with slope data. They name the slope series **sl**. Remind students that they can resize the columns to make the formulae easier to read. Note: The handheld will run slowly after the first function is entered. Students should be patient and wait until the clock icon disappears before entering new commands.



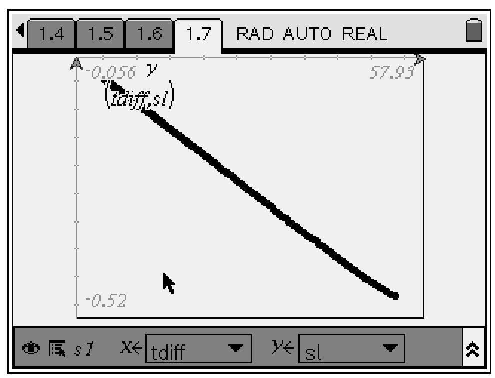
Q7. Why is the variable for the **slope** function in Column C time, not temperature? (That is, why do you have to type **a[]** and not **b[]** into the function?)

A. *The data in column A are passed into the* ***slope*** *function because* ***slope*** *is a function of time (x), not temperature.*

Step 4: Next, students use a function to fill Column D with temperature-difference data. They name the series **tdiff**. Note: Make sure students use their ambient measured temperatures in the **tdiff** formula (i.e., that they do not just copy the formula shown in the worksheet).



Step 5: Next, students make a scatter plot of slope versus temperature difference.



Q8. Describe the shape of the graph.

A. *The data lie on a nearly straight line.*

Q9. What does the shape of the graph tell you about the relationship between cooling rate and temperature difference?

A. *The shape of the graph implies that cooling rate decreases linearly as temperature difference decreases.*

Q10. If the graph were extended, what would its x- and y-intercepts be? What does this tell you about the relationship between cooling rate and temperature difference?

A. *The graph appears to pass through the origin. This implies that, when the temperature difference is 0, the cooling rate is also 0—exactly what would be expected. If students have a hard time with this concept, remind them that an object will never cool to below the ambient temperature.*

Q11. Which would you expect to cool more quickly, a 90ºC sensor in a 10ºC room, or a 50ºC sensor in a 20ºC room? Explain your answer.

A. *A 90ºC sensor in a 10ºC room will cool more quickly than a 50ºC sensor in a 20ºC room because the temperature difference is greater in the first example.*

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(Student)TI-Nspire File: *PhyAct01_cooling_EN.tns*