EXPLORATIONS

Activity 12

Murder in the First Degree — The Death of Mr. Spud

Objectives

- To model the process of cooling
- To use a cooling curve to simulate a forensic scenario to predict the time of death
- To use technology to find an exponential plot

Materials

- TI-73 graphing device
- CBL 2™ data collection device (optional)
- Small potato
- Pot with boiling water
- Containers of ice water
- Extra ice
- Celsius thermometer
- Terperature probe (optional)
- Stop watch

Introduction

In a murder investigation, a forensic expert may be called in to determine the time of death. Such determinations may involve examining the contents of the victim's stomach or inspecting decomposing insects on the body. One interesting approach is to examine the temperature of the body. Human body temperature is approximately 37 degrees Celsius. Immediately after a person dies, the body temperature begins to drop. By determining how far the temperature has dropped, you may be able to arrive at an accurate measure of the time of death. This information could play an important role in either the prosecution or defense of an alleged criminal.

Problem

A potato is placed in boiling water. After removing the potato from the boiling water, it begins to cool, just as a human body cools after death. By examining the temperature of a potato, determine the time of death (removal from the boiling water).

Collecting the data

Forensic experts measure the temperature drop in corpses in order to establish *standard curves* under controlled conditions. When a person is found dead and foul play is suspected, the forensic expert measures the temperature of the body. The forensic pathologist can approximate the time of death by determining where the temperature is on the standard curve.

You will simulate the drop in a person's body temperature at the time of death. Your teacher placed a potato in a pot of boiling water and allowed it to stand for 15 minutes. Removal of the potato from the boiling water will simulate the "death" of the potato. When the potato is removed from the pot, its temperature will drop toward the temperature of its surroundings, just as the temperature of a body drops following death. You will plot this data to establish a standard curve.

(Your teacher may ask you to collect data using a CBL 2™ data collection device with a temperature probe or may provide you with data for the standard curve.)

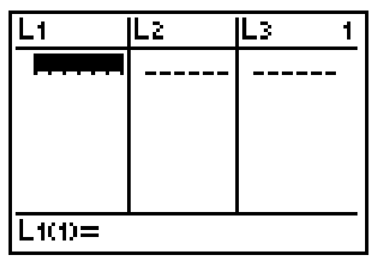
1. Get a potato with a thermometer from the teacher that has been in boiling water.
2. Immediately place the potato and thermometer into ice water.
3. Record the temperature and enter the reading as time 0 in the table on the **Data Collection and Analysis** page.
4. Record the temperature every five minutes for 30 minutes.

Setting up the TI-73

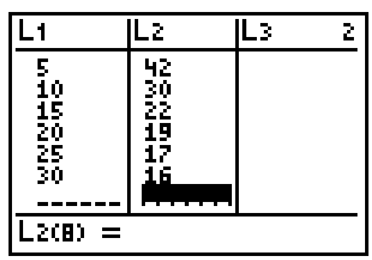
Before starting your data collection, make sure that the TI-73 has the STAT PLOTS turned OFF, Y= functions turned OFF or cleared, the MODE and FORMAT set to their defaults, and the lists cleared. See the Appendix for a detailed description of the general setup steps.

Entering the data in the TI-73

1. Press [LIST]. The data lists are displayed.

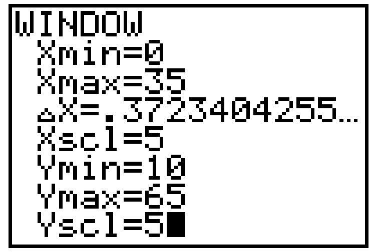


2. Enter the time in **L1**.
3. Enter the temperature in **L2**. (Make sure that the pairs of time and temperature match in each column.)



Setting up the window

1. Press [WINDOW] to set up the proper scale for the axes.
2. Set the **Xmin** value by identifying the minimum value in **L1**. Choose a number that is less than the minimum.

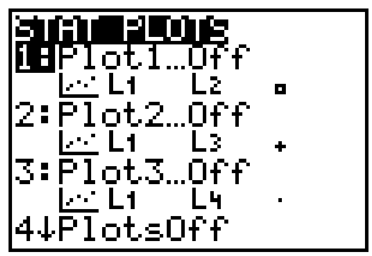


3. Set the **Xmax** value by identifying the maximum value in each list. Choose a number that is greater than the maximum. **Do Not Change ΔX Value.** Set the **Xscl** to **5**.
4. Set the **Ymin** value by identifying the minimum value in **L3**. Choose a number that is less than the minimum.
5. Set the **Ymax** value by identifying the maximum value in **L3**. Choose a number which is greater than the maximum. Set the **Yscl** to **5**.

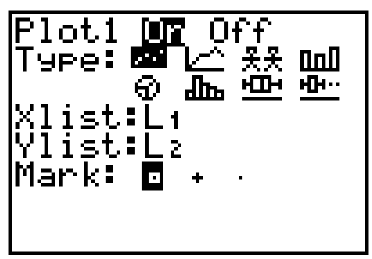
Graphing the data: Setting up a scatter plot

In order to analyze the data, you will need to set up a scatter plot and model the data using an exponential model. You will then use the exponential model as the standard curve to predict the time of death of the potato.

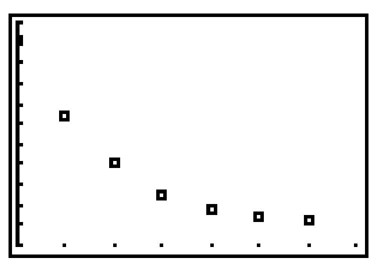
1. Press [2nd] [PLOT]. Select **1:Plot1** by pressing **1** or [ENTER].



2. Set up the plot as shown by pressing [ENTER] [▼] [ENTER] [▼] [2nd] [STAT] **1:L1** [▼] [2nd] [STAT] **2:L2** [▼] [ENTER].



3. Press [GRAPH] to see the plot.

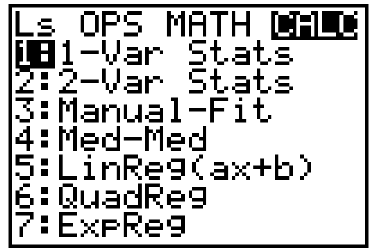


It is necessary to determine an appropriate regression model for this data. Does the plot appear to be linear? If not, how does the slope change?

Analyzing the data

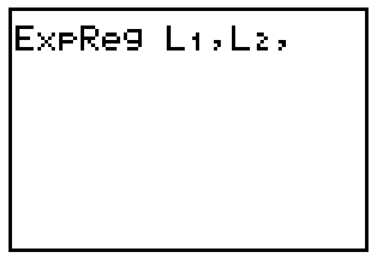
Finding an exponential regression

1. Press [2nd] [STAT] [◄] to move the cursor to the **CALC** menu.

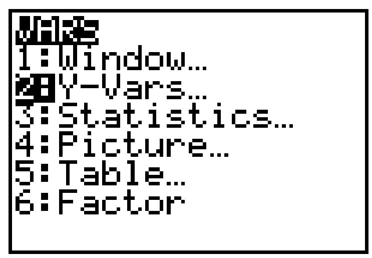


2. Select **7:ExpReg** by pressing **7**.

3. Press [2nd] [STAT] **1:**L_1 [,] [2nd] [STAT] **2:**L_2 [,].

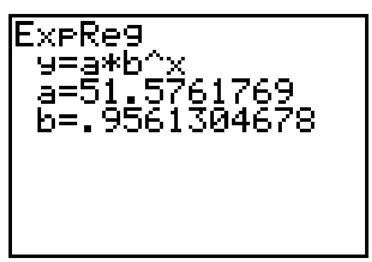


4. Press [2nd] [VARS]. Select **2:YVars** by pressing **2**.

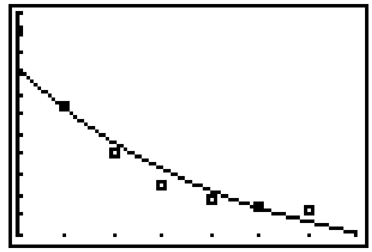


5. Select **1:**Y_1 by pressing **1** or [ENTER].

6. Press [ENTER] to calculate the exponential regression. The function is pasted in Y_1.



7. Press [GRAPH] to see the exponential model.



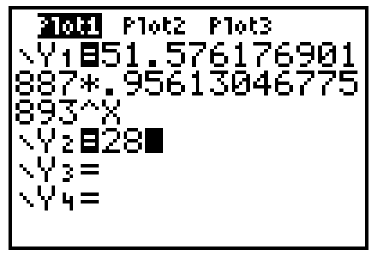
Determining the time of death

You will be given a potato whose time of death (removal from the boiling water) is unknown. This partially cooled potato will simulate a murder victim. Assume that the potato was murdered outdoors during the winter.

You will determine the time of death based on the temperature of the potato using the standard curve you developed.

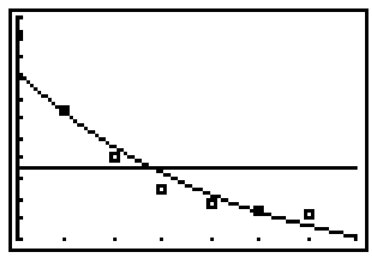
1. Your teacher will give you a second potato. Record the temperature on the **Data Collection and Analysis** page.

2. Press [Y=] and move the cursor to **Y2**. Enter the temperature of the potato. In this example, 28 degrees C was used.

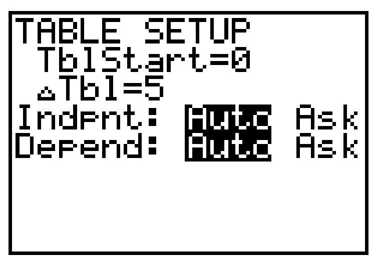


3. Press [GRAPH] to see the intersection of the two lines. The *x* value of the point where the two functions intersect is the time (in minutes) that the potato has been "dead."

   The **Table** function of the TI-73 will be used to determine the coordinates of the point of intersection.

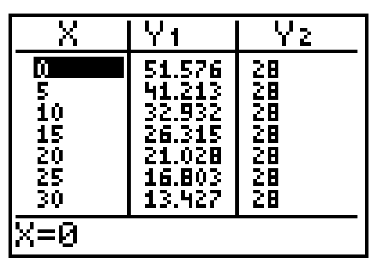


4. Press [2nd] [TBLSET]. Type in the lowest value in **L1** (0 in the example). Press [▼] **5** to set the **ΔTbl** value.



5. Press [2nd] [TABLE]. If necessary, use [▲] and [▼] to scroll the table.

   ***Note**: For this example, in the **Y1** column, 28 degrees Celsius falls between 32.932 and 26.315 which corresponds to 10 and 15 minutes. Based on that information, the table will be readjusted.*



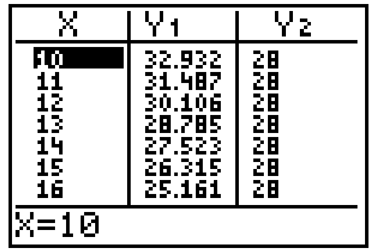
X	Y1	Y2
0	51.576	28
5	41.213	28
10	32.932	28
15	26.315	28
20	21.028	28
25	16.803	28
30	13.427	28

X=0

6. Press [2nd] [TBLSET]. Enter the results from Step 6. Press [▼] **1** to set the **ΔTbl** value.

7. Press [2nd] [TABLE]. If necessary, use [▲] and [▼] to scroll the table.

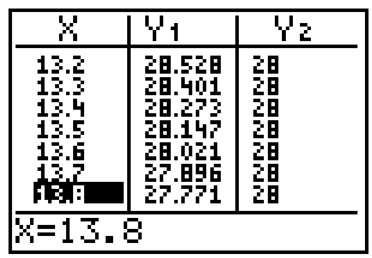
   Note: *For this example, in the* ***Y1*** *column****,*** *28 degrees Celsius falls between 28.785 and 27.523 which corresponds to 13 and 14 minutes. Based on that information, the table will be readjusted.*



8. Press [2nd] [TBLSET]. Enter the results from Step 8. Press [▼] **0.1** to set the **ΔTbl** value.

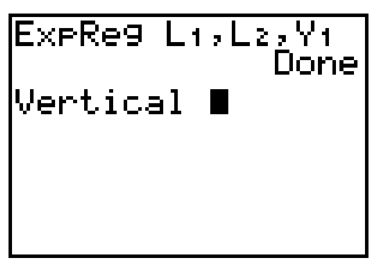
9. Press [2nd] [TABLE]. If necessary, use [▲] and [▼] to scroll the table.

   Note: *For this example, in the* ***Y1*** *column****,*** *28 degrees Celsius falls between 28.021 and 27.896 which corresponds to 13.6 and 13.7 minutes. Time measurements were made to the nearest minute. Therefore, we will report our result using the same level of precision. From the table, the time falls between 13.6 and 13.7. Rounding to the nearest minute, the coordinates of the point of interestion are (14, 28).*



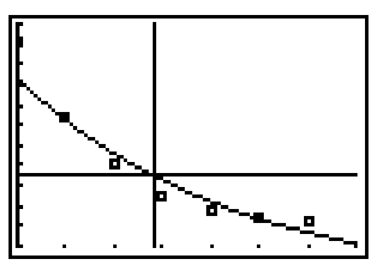
   To verify this graphically, we will use the **DRAW** function.

10. Press [DRAW]. Select **4:Vertical** by pressing **4**.



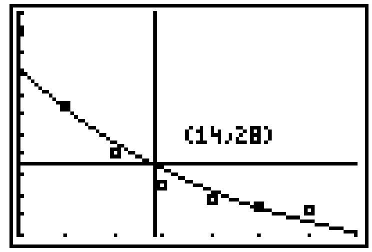
11. Type the results from Step 10, and press [ENTER].

   Note*: The coordinates of the point on the exponential model where all of the curves intersect is defined, for this example, by the vertical drawn at x=14 and the horizontal at y=28.*



12. The coordinates can be added onto the screen by pressing [DRAW] **7:Text**, moving the cursor near the intersect point, and typing your results.

Note: *Text appears to the below and to the right of the cursor.*



Record the point of intersection and answer questions 1 through 5 on the **Data Collection and Analysis** page.

Data Collection and Analysis

Name___________________________

Date ___________________________

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Collecting the data

Time (minutes)	0	5	10	15	20	25	30
Temperature (°C)							

Temperature of the potato: ____

Time of death of the potato: ____

Analyzing the data

1. Describe the shape of the temperature versus time plot.

____

____

2. What temperature does the plot appear to be approaching? What does that temperature correspond to in the situation being studied?

____

3. Explain why the plot is not linear. (**Hint:** If the plot was linear, it would mean that the temperature dropped at a constant rate. Why would such a drop not be expected?)

____

____

4. In what way(s) is this simulation not consistent with a real forensic study of the drop in body temperature following death?

____

____

5. Which model - exponential or linear - would be the better model to describe the following situations? Explain your answer in each case.

a. A car slowing down by 1/3 of the speed it was going the previous second.

____

____

b. A car slowing down 5 mph each second.

____

____

Extensions

1. In this activity, you determined the time of death by the drop in temperature. A similar problem that has a similar solution (conceptually) is to date the time of death when an organism died *thousands* of years ago. To solve this problem, scientists use a technique called *radioactive dating*. It is based on the decay of a substance called carbon-14 (C-14).

Most carbon in a living organism is called carbon-12 (C-12) and it does not decay. There is a small amount of C-14 in all living tissue. Once the organism dies, however, it no longer incorporates this substance in its body. The C-14 begins to decay. By examining how much C-14 is present (the ratio of C-12: C-14), you can determine the time since death. Carbon-14 has a half-life of about 5,600 years (actual half-life is 5,780 years). Instead of examining the drop in temperature of a corpse, radioactive dating is based on the decay of C-14 over thousands of years.

Consider the problem of dating an animal's remains. Assume that by analyzing the amount of carbon in its remains, you believe that it originally had 1000 grams of C-14, but now has only 100 grams.

Determine the amount of C-14 that remains after each 5,600-year interval, starting with 1000 grams of the substance.

Time (years)	5600	11200	16800	22400	28000	33600	39200
C-14 (Grams)	1000						

Amount of C-14 in Recovered Organism: 100 Grams

Years Since Organism Died: ____________________ yrs

2. Use two temperature probes interfaced to a CBL 2™ (Calculator Based Laboratory 2) to monitor the drop in water temperature of two "animals": one with insulating "fur" and the other, a "naked" animal. This situation can be simulated by using 2 glass or plastic beakers. Simulate fur by taping several layers of paper toweling around the beaker. For the "naked" animal, do not put any paper toweling around the beaker. Place equal volumes of water (approximately 75 degrees Celsius) into each of the beakers. Place the temperature probes into the beakers and take a reading every minute for 10 minutes.

Analyze and compare the drop in temperature of the two "animals". Model the temperature drop similarly to the temperature drop in the potatos.

Teacher Notes

Activity 12

Murder in the First Degree — The Death of Mr. Spud

Objectives

- To model the process of cooling
- To use a cooling curve to simulate a forensic scenario to predict the time of death
- To use technology to find an exponential plot

Materials

- TI-73 graphing device
- CBL 2™ data collection device (optional)
- Small potato
- Pot with boiling water
- Containers of ice water
- Extra ice
- Celsius thermometer
- Temperature probe (optional)
- Stop watch

Preparation

- The temperature of a corpse drops after death, assuming the environmental temperature is lower than the body temperature. When the body begins to putrefy, the temperature goes up a bit then gradually cools to match the surrounding temperature. If the body temperature has already reached that of the environment, other techniques must be used to pinpoint the time of death.
- Cooling curves do not exactly follow the simple exponential model built into the TI-73. Accurate models are more complex and their use would not be appropriate in an introductory Algebra class. A more accurate model would be:

  $T_t = C + (T_o - C) e^{-kt}$ where T_t is the temperature of the body at time t, T_0 is the initial temperature of the body, C is the environmental temperature, and k is the cooling rate constant. The assumption is that the environmental temperature remains constant, which is often not the case.
- Use small to medium size potatoes. Different size potatoes give different standard curves, so try to use potatoes that are of similar size and shape.
- Use the point of a pencil to make a hole in each potato prior to putting them into boiling water. Use the blunt end (eraser) of the pencil to enlarge each hole so that it can accommodate a thermometer. The tip of the thermometer should reach the middle of the potato.

- It is sometimes difficult to know how far to insert the thermometer in the potato. Hold the thermometer next to the potato to see how far to insert it. You could mark the thermometer with a strip of masking tape to identify the point where the thermometer was inserted.
- As the potato cools in the ice water, be sure the students add ice to the bath so that all the ice does not melt.
- It is understood that you may not want to spend class time collecting data for the standard curve unless this activity is being coordinated between a science and math teacher. You may want to provide the data for the standard curve (see the sample data below).
- Data for the cooling curve can be obtained using a CBL 2™ data collection device. Put the temperature probe into the potato so that the tip is in the center of the potato. Immerse the potato and probe in the boiling water bath for 15 minutes. Remove the potato and collect data for 30 minutes, collecting a data point every 60 seconds.
- Give the students potatoes that were removed from the boiling water at different time intervals. Be sure to put the potatoes immediately into the ice water bath to simulate, as much as possible, the conditions modeled by the cooling curve. Use a stopwatch for each potato so you know how long they have been "dead."
- For the first **Extension** activity, it may be easier for some students to use manipulatives to better visualize radioactive decay. Here are a few suggestions:

  a. Use small candies such as M&M's® to simulate radioactive decay. Students are told to spill about 50 M&M's from a cup and remove all of the samples with the letters facing up. Ask the students to count the number of remaining M&M's. Repeat the procedure, counting the number of M&M's left after each spill.

  b. Use coins to simulate radioactive decay.
- For the second **Extension** activity, use two graduated cylinders. Measure 100 mL of the same temperature water in each. Pour the water into the beakers at the same time. Place aluminum foil over each beaker and poke the temperature probes through the foil. The tip of the probe should sit in the same position in the middle of the water in each beaker; it should **not** rest against the side of one beaker. Start the experiment when the set-ups are correct.

Answers to Data Collection and Analysis

Collecting the data

Sample data:

Time (minutes)	0	5	10	15	20	25	30
Temperature. (°C)	61	42	30	22	19	17	16

Analyzing the data

1. Describe the shape of the temperature versus time plot.

The temperature drops sharply at first and then levels off.

2. What temperature does the plot appear to be approaching? What does that temperature correspond to in the situation being studied?

The plot approaches the environmental temperature, in this case, 0 degrees Celsius.

3. Explain why the plot is not linear. (**Hint:** If the plot was linear, it would mean that the temperature is dropping at a constant rate. Why would such a drop not be expected?)

A linear plot would mean that the rate at which the temperature drops is constant. The closer the potato gets to the environmental temperature, however, the less quickly it drops.

4. In what way(s) is this simulation not consistent with a real forensic study of the drop in body temperature following death?

Answers may vary, but one difference is the fact that the environmental temperature does not stay the same following death.

5. Which model — exponential or linear — would be the better model to describe the following situations? Explain your answer in each case.

a. A car slowing down by 1/3 of the speed it was going the previous second.

Exponential

b. A car slowing down 5 mph each second.

Linear