IT'S COOL

An Experiment and Modeling Lesson

Prepared
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The Creative Learning Exchange
1 Keefe Road
Acton, MA 01720
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INTRODUCTION

In this lesson, fifth grade students measure, record, and graph the changing temperature of a cooling cup of boiling water. Students then build a simple STELLA model of the system and run further experiments on the model. This lesson introduces students to the concept of feedback in a system dynamics model. It is also appropriate for middle school students.

OBJECTIVES FOR STUDENTS

- Students will conduct a scientific experiment and accurately record their data.
- Students will make predictions and test their hypotheses in the experiment and on the model.
- Students will draw a behavior over time graph in their experiment. They will read and interpret the behavior over time graphs produced by the model.
- Students will build a simple model of the cooling system as a class. They will discuss feedback: As the water temperature approaches room temperature, the rate of cooling slows.
- Students will build the same model on their own and try other experiments on it.
- Students will work together in teams.

BACKGROUND: Teaching Students to Build System Dynamics Models

Rob Quaden and Alan Ticotsky are Waters Grant systems mentors at the Carlisle Public Schools in Carlisle, Massachusetts. Working with classroom teachers, they have been trying to determine at what ages students can learn basic system dynamics modeling skills. As the curriculum evolves, primary grade students seem able to learn preliminary graphing skills, and third graders can use a simple feedback model as a class.

Recently, Al and Rob, along with four fifth grade classroom teachers, taught students to build their own simple models in a series of three consecutive lessons.

- First students played the In and Out Game to learn about stocks and flows, behavior over time graphing, and basic STELLA mechanics. (The "In and Out Game" by Ticotsky, Quaden, and Lyneis is available on-line form the Creative Learning Exchange at http://sysdyn.mit.edu/cle/. It is adapted for K-8 use.)
- Next, students built linear STELLA models on their own to solve math word problems. ("Linear Models: Using STELLA to Solve Word Problems" by Quaden, Ticotsky and Lyneis is also available on-line from the Creative Learning Exchange. It can also be used in middle school and as part of Algebra I.)
- Finally, students learned about feedback as they conducted the hot water experiment and built this STELLA model of it as a class.

The cooling lesson is adapted from a lesson developed by Sara Bysshe, Dessa Dancy, and Rob Quaden, at a 1998 CCSTADUS system dynamics summer training session in Portland, Oregon. Carlisle 7^{th} graders have also done the cooling lesson as an introduction to feedback modeling.

PREPARING FOR THE LESSON

Time Requirements

This lesson takes two class periods: one for the experiment and one for the modeling.

Materials

For the experiment you will need:

- An electric tea kettle or another way to boil water in the classroom.
- A paper cup and a thermometer for each team of students.
- A copy of the enclosed data collection sheet and graph for each student. Pencils.
- A stopwatch or clock/watch with a minute hand or timer.

For the modeling, students need computers loaded with STELLA system dynamics software.

- STELLA is available from High Performance Systems, Inc., 45 Lyme Rd., Suite 200, Hanover, NH 03755. Tel. 603-643-9502. http://www.hps-inc.com
- The model accompanying this paper is in STELLA 5.0, but these simple models can be built on earlier versions as well.
- One computer for every two students is ideal, but use what you have.
- It is very helpful to have a projection device or large monitor for classroom demonstrations.

Helping Hands

When students are at the computers building models, it is very helpful to have the support of other "STELLA literate" adults or older students. Model building is a learner-centered activity, but students need help with modeling glitches and guidance to "ask better questions." Recruit other teachers, aides, parents or anyone else who can help.

CONDUCTING THE EXPERIMENT

1. Explain to students that they will be conducting a “real” scientific experiment. Present the procedure: They will be measuring the temperature of very hot water as it cools and they will record and graph their data.

2. Review the details:
   - Boiling water is very hot and dangerous, so they must be very careful with it.
   - They must record their data very accurately because they will need them later for model building. Students will work in teams.

3. Distribute the following behavior over time worksheets and ask students to sketch their predictions for how the temperature of the water will change. For now, this is just their best guess. It does not matter if it is wrong or right; it will help them think about what is happening in the experiment when they see how closely the data matches their prediction.

   Help students prepare their predictions by explaining the graph. The horizontal axis is time from 0 to 30 minutes. The vertical axis represents the temperature of the water from freezing to boiling, 0 to 100 degrees Celsius. On the vertical scale, help students identify and locate “room temperature” (25 degrees Celsius). Ask students to show, by drawing in the air, how they would graph room temperature over the next 30 minutes. If it is 25 degrees now, what will it be in the next minute, and so on. Ask students to graph both room temperature and their prediction for the hot water temperature on their behavior over time graphs.

4. Group students into teams. Give each team one cup and fill it with boiling water. Ask students to measure the initial temperature immediately and record it on the worksheet. (Note that their initial temperature is less than 100 degrees because the heat source has been removed.) Using the stopwatch, announce each subsequent minute with a ten second warning and tell the students to “measure and record” their water temperature.

5. After about five minutes, when all teams are on track, introduce the following behavior over time graph. Plot the first few points together, insuring that students put the initial temperature on the vertical axis and a dot on each subsequent minute line. (This can be confusing if they are not careful. Suggest that students use a straightedge to accurately follow each minute line up from the bottom to where it intersects the current temperature line.)

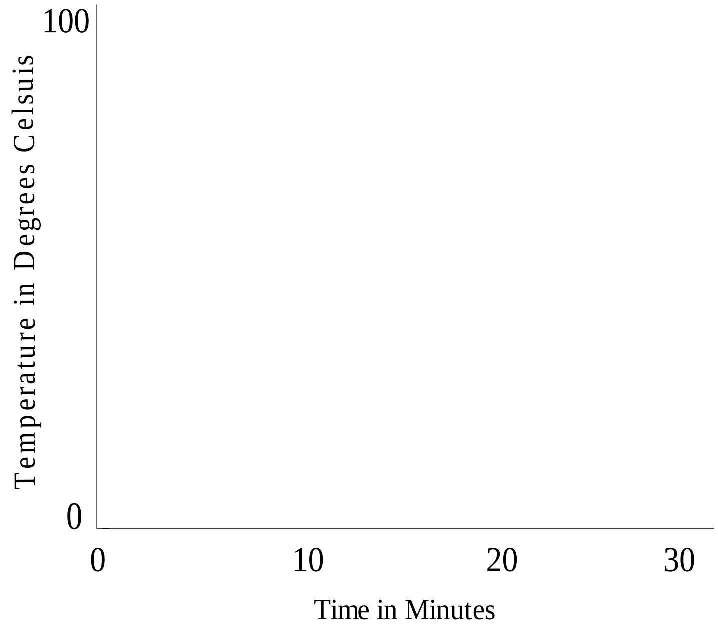
6. Meanwhile, continue to announce the minutes with instructions to “measure and record.” Continue graphing as time allows. Twenty minutes gives a good picture.

7. To wrap up the lab, ask students to compare their lab graphs with their predictions. Any surprises? What does the lab graph say about the cooling rate? What do they predict would happen if they could run the experiment longer?

Name:

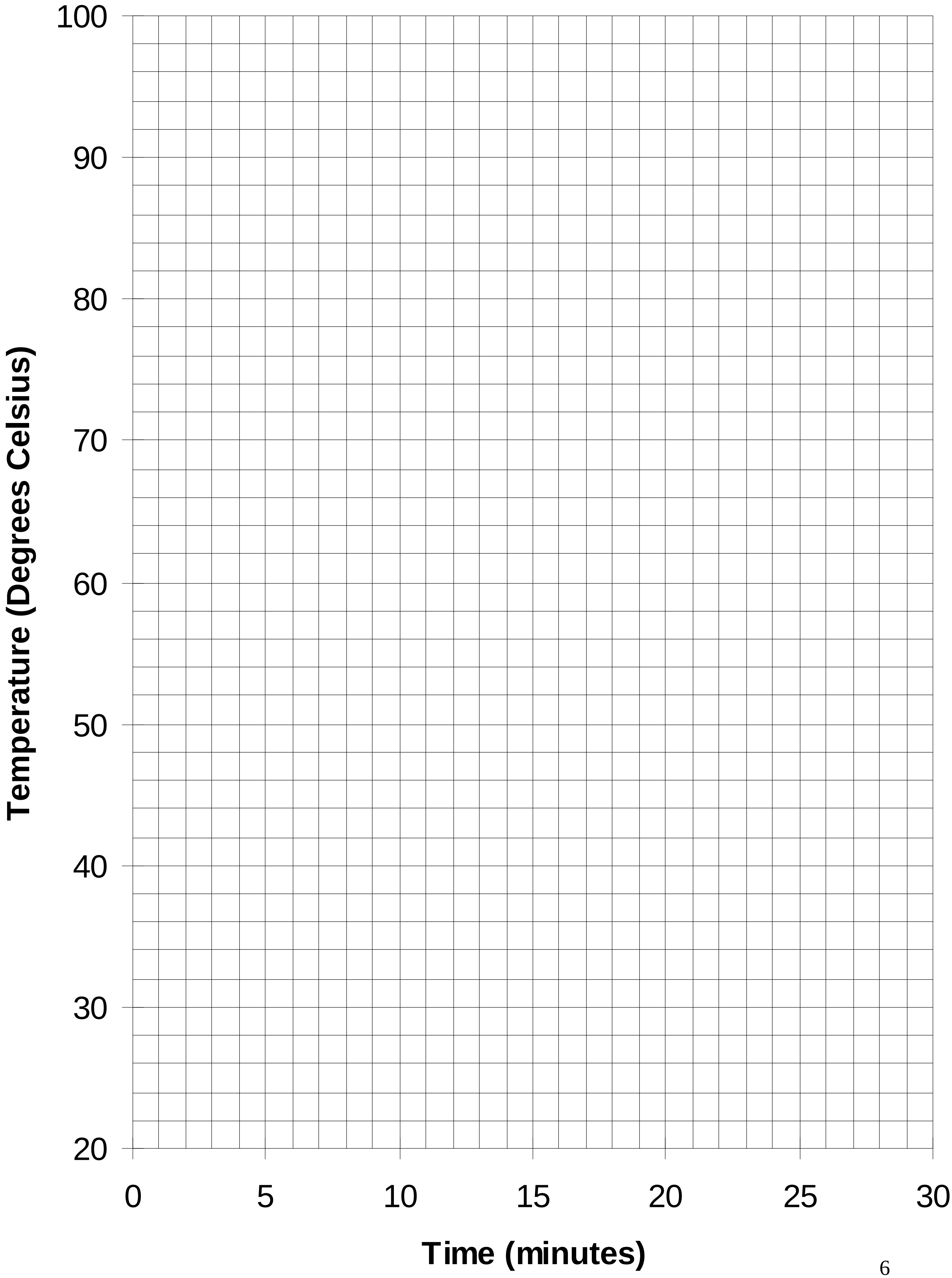
COOLING EXPERIMENT

Your prediction:



Your data:

Time (minutes)	Temperature	Time(minutes)	Temperature
Initial		16	
1		17	
2		18	
3		19	
4		20	
5		21	
6		22	
7		23	
8		24	
9		25	
10		26	
11		27	
12		28	
13		29	
14		30	
15			

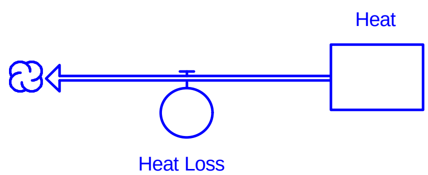

100
90
80
70
60
50
40
30
20
Temperature (Degrees Celsius)
0
5
10
15
20
25
30
Time (minutes)

BUILDING THE MODEL

Students will build a STELLA model of the cooling system step-by-step as a class. Then they will build the same model at their own computers and vary the cooling factor until their model replicates the cooling behavior they observed in their experiment.

1. Introduce the modeling by briefly reviewing the cooling experiment and earlier linear modeling. This time the class will be building a complicated model together. Students need to take careful notes so that they can build the same model on their own in a few minutes.

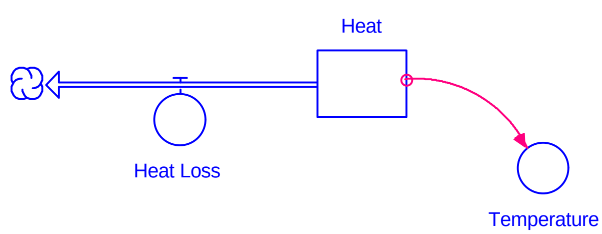
2. Start with the stock and flow. Review these concepts and ask students to identify what was increasing or decreasing over time in their experiment. Drag down a stock and label it "Heat." Drag down an out-flow and label it "Heat Loss." (The arrow must flow *out*.)



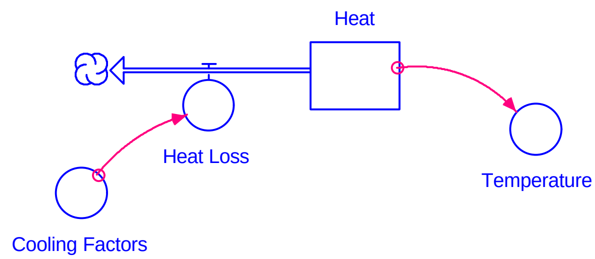
3. Briefly discuss the difference between heat and temperature. Heat is a form of energy which makes the molecules in the water move around very rapidly. When the water is heated in the kettle, it gains more heat energy. When the water cools, that energy flows out of the water and into the air. Temperature is one *measure* of how much heat energy an object has and it is measured on a thermometer in degrees. Heat is the amount of energy needed to get the water to a certain temperature. (Two objects can have the same temperature but different amounts of heat if they are of different sizes or made of different materials. Think of different items baked in an oven together.) Heat energy is measured in calories or BTUs. The amount of stored heat energy in the water can accumulate in a stock. Technically, degrees cannot.

   Scientists would use complicated formulas in their model to compute how much heat energy is in the water, but a simplified version suffices here. For this model with constant cups of water, one "unit" of heat will equal one degree. This simplified version avoids calculating calorie conversions while still correctly distinguishing between heat and temperature at a level appropriate for fifth graders. For now, that is all they need to know.

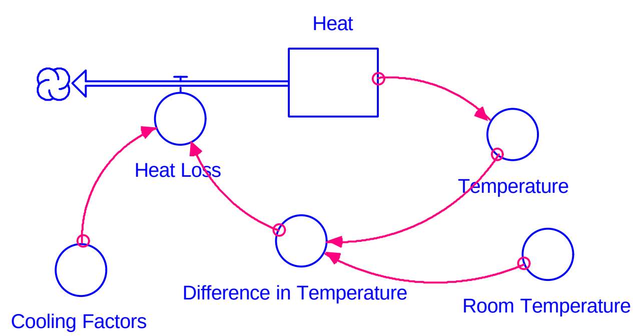
4. Drag down a "converter." This is a new STELLA tool; it holds information that will help the model compute the flows. In this case, the converter will convert the "Heat" units to "Temperature" in degrees. In our simplified version, Heat = Temperature. Demonstrate how to connect them using the red arrow. (The arrow must flow in this direction.)



5. Referring back to the experiment, ask students what variables could influence how quickly the heat leaves the water. Expected suggestions: size of cup, insulation of cup, stirring the water, amount of water, room temperature, breezes, etc. To make it simple, combine all those variables that have to do with characteristics of the water and the cup and call them "Cooling Factors." Make this a converter and connect it..

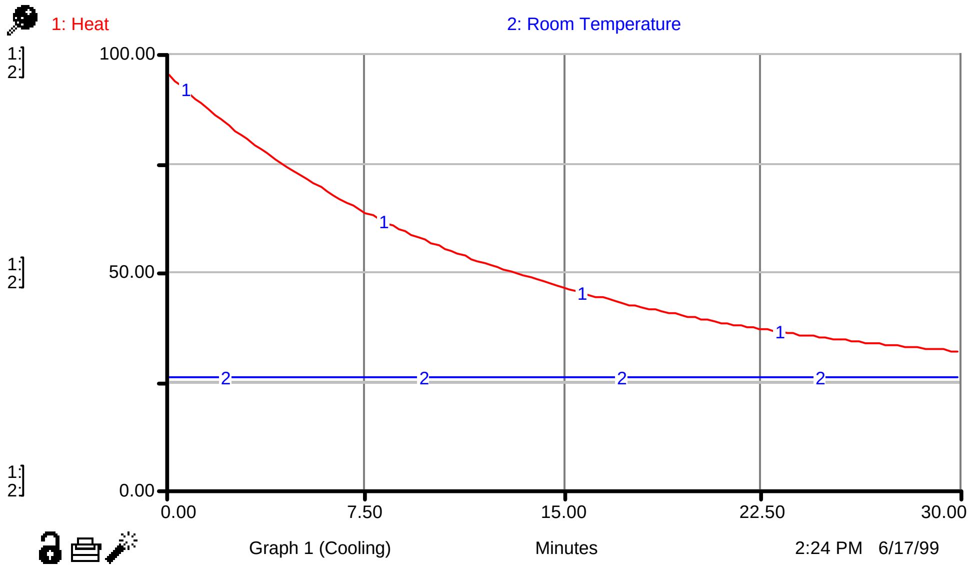


6. What effect does room temperature have on the cooling rate? What happens if you have very hot water in a very cold room? What happens if you have water that is just a little warmer than room temperature? Do they lose heat as rapidly? Help students to see that if the difference between the water temperature and the room temperature is greater, then the heat loss is greater. As the water temperature approaches room temperature, heat is transferred more slowly. The "Difference in Temperature," not just the actual temperature, affects the rate of heat loss. As the arrows form a loop, the stock of heat affects the heat loss. As the heat decreases, the rate of heat loss decreases. This is called *feedback*.



7. Click on the globe icon and enter the equations together:
   - Initial Heat = 95 (This is their initial water temperature in degrees Celsius.)
   - Temperature = Heat (Explained above.)
   - Room Temperature = 25 (In degrees Celsius.)
   - Difference in Temperature = Temperature – Room Temperature ("Difference" means subtract. The order *does* matter. Heat flows out, so the difference must be positive.)
   - Cooling Factor = .08 (Estimate what percentage of the heat would leave each minute. Some fifth graders will need help converting a percentage to a decimal. This value is just a best guess for now. Later students will adjust this to replicate their experiment.)
   - Heat Loss = Difference in Temperature x Cooling Factor (The greater the difference, the greater the loss.)
   - Time Specs: Run the simulation for 30 minutes. Leave the DT at .25. Time: Minutes.
   - Graph: Double click on the graph and select "Heat" and "Room Temperature" to display. Highlight both selections and click on the arrows to the right to set the scales. Set both scales for 0 to 100, and click "set."

8. Run the model.



Notice that this run *does not* match the students' data. Check the model again together. The difference must be in the "Cooling Factor."

9. Let students go to their computers in teams, build this model themselves, and experiment with other values for the cooling factors until their models replicate their experiment.

10. More challenging questions:
    - When does the water reach room temperature? (Extend the "length of simulation to see.)
    - When does it go to 10 degrees? (Never, but let them try. The goal of this negative loop is room temperature. The water temperature cannot dip below that.)
    - What difference does changing the initial temperature of the water make?
    - What about changing the room temperature to very hot or very cold?

Trouble Shooting

- Insist that students label all the parts of their models accurately, so that they can be very clear about what they are modeling.
- Be sure that the flows are properly connected to the stocks. If a cloud appears where they should connect, erase the flow with the dynamite icon and start again.
- Be sure that the flow arrows flow in the right direction, in this case *out* of the stock of heat. They are computed in the direction in which they are drawn regardless of how they are labeled. Make corrections by erasing the flow with the dynamite icon.
- The red connector arrows must also flow in the right direction.
- *Insist* that students read the *graphs* rather than relying on the tables. Accept *no* tables unless students can explain their graphs first. *This is an essential skill to develop.*

YOUR FEEDBACK

We welcome your comments and suggestions on this lesson. Please send them to us through the Creative Learning Exchange. Thanks.