Lesson Plan
Control Mechanisms (9-12)

Estimated Time: 2–3 class periods.

Central Benchmark

11A Systems (9-12)#3

The successful operation of a designed system usually involves feedback. The feedback of output from some parts of a system to input of other parts can be used to encourage what is going on in a system, discourage it, or reduce its discrepancy from some desired value. The stability of a system can be greater when it includes appropriate feedback mechanisms.

Objective

Students will be able to explain how a feedback control system works.

Advance Preparation

Prepare the materials for the apparatus for controlling water level. Insert the small glass tube into the end of each rubber tube, and insert each glass tube into a rubber stopper. (The stopper/glass combination will provide a weight at the end of each rubber tube which will help prevent the tube from being pulled out of the cylinder.) Set up the apparatus as shown in the diagram: Apparatus for Controlling Water Level. Coil the end of the 2.5 m rubber tube around in the bottom of the bucket so that it does not come out of the bucket when the water is flowing.

Make the labels showing the roles each group member will play in modeling the control mechanism (see List of Materials).

Assemble the handouts and transparencies needed for this lesson (see Materials). Arrange these items in the order in which you will use them.

List of Materials

For the class:

- Mop(s)
- Thermostat (optional)

For each group (only two groups at a time will do a test):

- Watch or clock with second hand
- 1000 mL graduated cylinder
- 2.5 m rubber tube
- 1 m rubber tube
- 2 pieces of glass or plastic tubing, about 5 cm long
- 2 1-hole rubber stoppers
- Pinch clamp
- Faucet and sink
- Bucket
- Two chairs or stools

Box or books to put on a chair to raise the height of the bucket if necessary
Set of labels showing group members' roles:
Error detector
Feedback signaler
Input flow controller
Output flow regulator
Set point adjuster
Recorder

For each student:
Two sheets of graph paper

TRANSPARENCIES:
Apparatus for Controlling Water Level
How a Thermostat Works
Feedback Control System Diagram

HANDOUTS:
Apparatus for Controlling Water Level
Modeling a Mechanism for Controlling Water Level
How a Thermostat Works
Feedback Control System Diagram

Motivation

Attach one end of a 1 m rubber tube to a faucet. Place the other end of the rubber tube (this end weighted with a glass tube and rubber stopper) into a 1000 mL graduated cylinder.

Ask: *What will happen if you turn on the water?* (Answer: Water will go into the cylinder.)

Turn on the water. Allow the water to rise as near the top as possible without overflowing. (Students will probably call out that you should turn off the water.) Turn off the water.

Ask: *What would have happened if I hadn't turned off the water?* (Answer: It would have overflowed.)

Say: *Suppose there were some way we could take water out as we are putting water in. What would happen if we put in the same amount as we take out?* (Answer: The water would stay level in the cylinder.)

Comment: *The first thing we are going to do today is set up a mechanism that will control the amount of water in the cylinder. Our mechanism will not have mechanical parts, however, because* ***we*** *are going to be the parts. We are going to simulate the mechanism by acting out the different components of a control system. This kind of system is called a feedback control system because water level is measured and this measurement is fed back to a device that controls the water flow.*

Development

A. Modeling a Feedback Control Mechanism for Controlling Water Level

1. Explain how the apparatus will work.
Display the TRANSPARENCY: Apparatus for Controlling Water Level.

Distribute the HANDOUTS: Apparatus for Controlling Water Level and Modeling a Mechanism for Controlling Water Level and the equipment students will need for setting up the apparatus.

Say: *In a few minutes you will set up the equipment as shown in this drawing. Let's study the diagram first, as Step 1 on your instruction sheet suggests. Water flows from the tap into the cylinder and flows out through the siphon into a bucket. You will let water flow into the cylinder slowly. You will need to adjust the water flow rate until the rate is approximately 300 mL/min, that is, somewhere between 250 and 350 mL/min. How will you measure the rate at which the water is flowing?*

Help students conclude that they can measure the flow rate by seeing how far the water rises in the cylinder in a certain period of time. They will need to use a watch or clock with a second hand or a stop watch.

Say: *I suggest that you see how far the water rises in 15 seconds. Then multiply this amount by 4 to get the rate per minute. Then you can adjust the flow rate up or down until you get about 300 mL/minute.*

Ascertain student understanding by asking: *How would you make the rate go up?* (Answer: By opening the faucet so more water comes out.) *How will you make the rate go down?* (Answer: By turning the faucet so less water comes out.)

2. Have students assume specific roles in the model and learn what their jobs are.
Organize the class into groups of six. (Extra students may assist the recorder.) Tell students that each person is going to play the role of a mechanical part in this feedback-control system. Have groups read the list of roles in Step 2 of the student instruction sheet (Modeling a Mechanism for Controlling Water Level) and decide what role each person will play. Give each student the label for the role he or she has chosen.

Preferably, have only two groups at a time perform the test, with other groups observing. Assure the observing groups that they will conduct a test later.

Discuss the rules for the simulation and the procedures as they are listed on the student instruction sheet (Modeling a Mechanism for Controlling Water Level). Ascertain that the **Error Detector** understands his or her role by asking what mathematical operation he or she will be carrying out (subtraction). Make sure the **Output Flow Regulator** knows that the bucket may be placed only on the floor, the chair, or the table, and not at intermediate points. Also, make sure the **Output Flow Regulator** understands that the bucket must be lowered to increase flow and raised to decrease flow.

Have students rehearse their tasks, assuming the proper positions and doing a dry run of the activity. Assure them that, if the first test does not go well, they may try it again.

Show students where the mops and towels are, and remind them to clean up spills promptly so that no one falls by slipping on a wet surface.

3. Help students construct siphons.
Continue: *But before we can test the control mechanism shown in this diagram, we need to have each group make a siphon. This will allow the water to flow up the second tube over the edge of the cylinder and into the bucket.*

Demonstrate how to make a siphon. Assist groups as necessary, as indicated in Step 3 on the student instruction sheet.

4. Have students set up the apparatus.
Assist groups as necessary to complete Step 4 on the student instruction sheet (Modeling a Mechanism for Controlling Water Level). Explain that as groups do the experiment, the **Output Flow Regulator** will be moving the bucket among three places: the table top, the chair, and the floor. Have each **Output Flow Regulator** demonstrate how to move the bucket to each of these places. Have the buckets replaced on the chairs.

5. Help students adjust the water flow rate from the tap.

6. Help students conduct a test of the feedback control mechanism.
Make sure the Recorder has prepared to record the data where all can see it: on chart paper, the chalkboard, or an overhead transparency.

Make sure each group is performing the tasks described in the instructions. Make sure students have obtained the appropriate water flow rate from the tap and have established flow in the siphon. Make sure that tubes are immersed all the way to the bottom of the cylinder and the bucket to ensure water does not spill. Remind students to empty the bucket before it overflows, pinching off the siphon while doing so.

Circulate among the students as they work. Keep an eye on the buckets to make sure they do not overflow.

Continue the test for about eight minutes.

7. Have students graph their data.
Distribute graph paper. Tell students they should each construct a graph to show the results of the test their group conducted or observed. Tell students to show time on the X-axis and water level on the Y-axis. They should draw a horizontal line to indicate the set point. The amount by which each reading was above or below this set point should be shown in 30-second intervals. Students should draw a line connecting the points. If necessary, instruct students in the techniques for making a neat, clear graph: for example, selecting a suitable range for each variable, labeling axes properly, etc. You may wish to have students consult with partners as they develop their graphs.

8. Have students reflect on the meaning of the graph.
Student graphs should show a line alternating above and below the line representing the set point. Fluctuations may be greater at the beginning of the test and not as great as the test goes on.

Using the think-pair-share[1] strategy, have students tell their partners what the graph means. Have several report to the whole group. All students should understand that the graph shows that the water level alternated above and below the set point during the time the system was in operation.

Ask: *What were we trying to do in our simulation?* (Answer: Keep the water level in the cylinder at the set point.) *Were we successful, according to the graphs?*

Students will probably reply that the water level did not stay very close to the set point, but fluctuated considerably above and below the set point.

Ask: *Why did such fluctuations occur?* (Possible answers: Because the bucket is raised and lowered in increments of several feet; by the time the signal to change the bucket height is given, the water level has passed the set point.)

Ask: *Can you think of a way to maintain the level closer to the set point?*

Students may suggest several possibilities, such as these examples:

- Allow the bucket to be moved in smaller increments.
- Send signals more often, such as at 15-second intervals. This would allow the height of the bucket to be adjusted more frequently.
- Speed up the time it takes to transmit information to the **Output Flow Regulator.**
- Anticipate when the level is almost at the set point and send a signal before it gets there.

9. Have students vary the conditions and test the control mechanism again.
Have the groups that were observers during the first test conduct the second test. Vary the procedures in a way that students believe will result in maintaining the water level closer to the set point. The following changes could be made:

- Take readings every 15 seconds.
- Add an intermediate height for the bucket. This could be done by using a second chair with a box or books on the seat.
- Allow the **Feedback Signaler** to stand closer to the **Output Flow Regulator.**

[1] In the think-pair-share strategy, two partners first reflect on the response to a question individually and then share their responses with each other. Some pairs then share their responses with the whole group. This cooperative learning strategy serves to involve all participants in reflecting about and responding to a question.

Have students add the results of this test to their graphs.

10. Have students reflect on their new findings.
After students have completed their graphs, have each person write a brief summary of what the graph shows about the tests just conducted. Students should find that the line for the second test fluctuates less around the set point than did the line for the first test (though, again, fluctuations may be greater at the beginning of the test than they are as the test continues). Students should conclude that this indicates that increasing the number of levels at which the bucket may be placed, increasing the reporting intervals, or reducing the time it takes to send a signal helps maintain the water level nearer the set point.

Have students display their graphs and summary statements on a classroom wall. Invite the class to view all the graphs and question each other about any interesting ideas they see presented.

If time permits, you may wish to allow students to repeat one of their tests or try a new variation in the procedure.

11. Have students reflect on the meaning of the simulation.
Remind students that they were simulating the parts of a feedback control mechanism.

Ask: *Why was it necessary for us, as we acted out the parts of this mechanism, in some cases to keep our backs to the apparatus, or to give information to only one or two other people?* (Answer: Because we were simulating the action of mechanical devices, which can carry out only a single function at a time.)

Ask: *Could all six of the people be replaced by a mechanical device?* (Answer: No. A human would always have to decide what the set point will be. The other functions could be carried out by mechanical devices.)

Call attention to the graphs. Comment: *The fluctuations around the set point seem to be greater at the beginning of the test, then to flatten out. Do you suppose they will ever get entirely flat, indicating that the set point is being maintained exactly?* Students will probably conclude that, because there is always time between the reporting of the deviation from the set point and the adjustment of the bucket, the fluctuations will continue.

Ask: *Then why do the fluctuations decrease as the test goes on?* (Possible answers: Because the students are getting better at carrying out their observing and reporting functions more quickly, or the system starts out with a large difference between the actual level and the set point and it takes time for the fluctuations to settle down.)

Again using the graphs as references, point out how changing conditions allowed the set point to be more nearly maintained, with smaller fluctuations. Ask students if we continued to improve some condition, such as the reporting time or the number of levels at which the bucket could be placed, could the fluctuations be eliminated. Have students explain their reasoning. Most students will probably conclude that the causes for the fluctuations—and, therefore, the fluctuations themselves—cannot be eliminated entirely. For example, even if you could bring the reporting time down to one second, rather than 15 seconds, there would still be a slight delay. Explain to students that, even if you could work with computers so that the time lag were almost zero, some time lag would still exist, so that feedback could not be instantaneous and the set point could not be maintained with absolute accuracy.

12. Have students list other examples of feedback control mechanisms.
Comment: *Control mechanisms are used in manufacturing plants, cars, airplanes, and other places to control much more complicated processes than the one we just simulated. Electronic control systems and computers can do all of the things we suggested to improve control. Can you think of some things that are controlled by feedback control mechanisms?* (Among possible answers: thermostats in ovens or home heating systems, cruise control on cars, power control on microwave ovens, rocket guidance systems.)

Ask: *What about in living things?* (Among possible answers: body temperature, secretion of insulin depending on blood sugar level, other endocrine systems, cell metabolism.)

B. How a Thermostat Works

1. Describe the operation of a thermostat.
Display a thermostat.

Say: *A thermostat is a control mechanism that is used to control temperature. This one is used to maintain the temperature of a room*. Pass it around for students to see.

Display TRANSPARENCY: How a Thermostat Works.

Distribute HANDOUT: How a Thermostat Works.

Ask: *What happens to the length of a metal strip when it is heated?* (Answer: It gets longer.) *Some metals expand more than others when they are heated. You can use this property of metals to make a device that will measure temperature. If you attach strips made of two different metals, one strip will expand more than the other when heated, causing the attached strips to bend. This is illustrated at the top of the diagram. The metal on the left expands more than the metal on the right, so the combined bimetallic strip bends to the right.*

In a thermostat a bimetallic strip is wound into a spiral like the one shown on the diagram. A mercury switch is attached to the end of the spiral. This is a small sealed tube containing a blob of mercury. At one end of the tube there are electrodes. At a low temperature the tube is tilted so that the mercury flows to the right, making contact with the electrodes. This closes a circuit and an electric current flows in the wires. This sends a signal that starts up the furnace. After a while, when the furnace has heated the room, the bimetallic spiral unwinds a little, causing the mercury switch to tilt the other way. The mercury now flows to the left, breaking the electrical connection. The current stops flowing in the wires and the furnace shuts down.

When you change the set point on the thermostat, the tilt of the mercury switch is changed. If you set the temperature at 70^o, for example, the thermostat will signal the furnace to go on at about 68^o. When the room temperature reaches about 72^o the thermostat will signal the furnace to shut down.

Ask some students to describe the operation of a thermostat and correct any misconceptions.

If you were to draw a graph of the temperature of a room where the temperature is controlled by a thermostat, what would the graph look like?

Have students work in pairs to draw the graph. Have several pairs share their drawings with the class. The graph should look like a sine wave, with the temperature fluctuating above and below the set point.

2. Summary and Assessment.
Have students complete a journal entry in which they respond to the questions, “In what ways is the thermostat similar to the human control mechanism that we used to control water level? In what ways is it different?” Have students indicate how each part functions on the HANDOUT: Feedback Control System Diagram.