Overview

The spring simulation allows students to experiment with a virtual spring-mass system. They can change settings, run the simulation, and compare results. The default simulation behavior is equilibrium, as the spring is initially at rest. By changing the settings, a variety of oscillatory behaviors are generated. This model is intended as an introduction for this series of oscillatory models, although it also aligns with specific math and science curricular standards.

Learning Goals:

- Represent, interpret, and compare data on a graph.
- Explain concepts including oscillation, equilibrium, position, spring constant, mass, force, momentum, and resistance.
- Represent the system's loop structure, showing how position and momentum impact one another.
- Describe how and why springs oscillate.

Materials:

- One computer for every 2-3 students
- Simulation online at http://www.clexchange.org/curriculum/complexsystems/oscillation/Oscillation_SpringC.asp
- Handouts (See pages 4-13)

Curricular Connections:

- Science: ...use many models, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.
- Science: Laws of motion are used to calculate precisely the effects of forces on the motion of objects.
- Math: Vary assumptions, explore consequences, and compare predictions with data.*

*Common Core Standards

Key system dynamics concepts and insights:

- The structure of a spring system creates an oscillation.
- Oscillatory behavior can occur within physical systems, e.g., a spring and within social systems, e.g., relationships.

Student Challenge

Create a variety of springs that produce specific behavior. Be able to discuss what is causing the variations in oscillatory behavior.
Lesson Details

Preparation:
1. Create groups of two to three students each.
2. Check computers to make sure you can access the online simulation.
3. Copy handouts for each student. See the chart below to determine how many copies of each handout you'll need.

<table>
<thead>
<tr>
<th>#</th>
<th>Page</th>
<th>Handout</th>
<th>Description</th>
<th>Copies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4-7</td>
<td>Introduction</td>
<td>Students get started with the simulation using step-by-step directions.</td>
<td>Copy single-sided. 1 copy per student</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with Baseline Runs</td>
<td>They then set up and record the data from a baseline run for the spring.</td>
<td>Copy double-sided. 1 copy per student</td>
</tr>
<tr>
<td>2</td>
<td>8-9</td>
<td>Experimental Run</td>
<td>Students explore “What if?” questions, recording their data for each run. A minimum of three runs is recommended.</td>
<td>Copy double-sided. 3+ copies per student, depending on how many runs you’d like students to do.</td>
</tr>
<tr>
<td>3</td>
<td>10-12</td>
<td>Debrief</td>
<td>Students step through the debrief and write their reflections.</td>
<td>Copy double-sided. 1 copy per student</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>Assessment</td>
<td>Students summarize their learning.</td>
<td>Copy single-sided.</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>Assessment (Optional)</td>
<td>Students define spring concepts and describe interdependencies.</td>
<td>Copy single-sided.</td>
</tr>
</tbody>
</table>

4. Optional: You may want to read the background information about the underlying structure of the model. This can be useful as you guide students to understanding the model behavior, as it relates to real world behaviors, and the limitations of the model. See, “Spring-Mass Model Background Info,” available as a separate file for download.

Lesson Sequence:
1. If available, you can have students experiment with real springs, such as a Slinky®. By observing the behaviors of real springs, students can compare that experience to the theoretical output of the simulation.
2. Introduce students to any specific content knowledge related to springs. This may include concepts such as oscillation, equilibrium, position, spring constant, mass, force, momentum, and resistance. Discuss the difference between an initial position of a spring and the current position, once the spring is released.
3. Have students open the simulation and work through the simulation introduction, and experiments using the guided handouts. Note that the handouts guide students through the simulation in a step-by-step manner. If you’d like to leave the exploration more open, then you may wish to eliminate some of the handouts. Figure 2 shows the control panel screen.

2 • Lesson 1 – Level C • Springs Everywhere • ©2012 Creative Learning Exchange
Lesson Details

Debrief and Assessment:
1. Have students use the debrief handouts to reflect on the simulation experience. You can also debrief the simulation experience as a class, using ideas for bringing the lesson home. The assessments on pages 13 and 14 check for basic understanding of spring concepts embedded within the simulation.

2. General answers for the assessment on page 13.
   - Graph 1: Initial position = 0
   - Graph 2: Initial position = 5, low spring constant, low mass, no resistance.
   - Graph 3: Initial position = 5, high spring constant, low mass, no resistance.
   - Graph 4: Initial position = 5, low spring constant, low mass, high resistance.

3. Possible response for assessment on page 14: As the spring position rises toward 0 and eventually crosses to a positive position, the displacement goes down toward 0 and eventually crosses the 0 line to a negative displacement. As displacement falls, the impulse continues moving from a +1 to a -1, causing momentum to rise. As the momentum increases, velocity also increases, thus causing the position to rise. When the spring has reached its highest position, the system reverses itself with position now falling and displacement rising from a negative number to a positive number, and so on. Eventually, all the graphs reach equilibrium because of resistance.

Bringing the Lesson Home:

Discuss these and any other questions that have surfaced about model behaviors.
- What causes the spring to oscillate?
- What causes the spring to come to a resting point?
- What caused faster oscillations? Slower? Highest? Lowest?

Assessment Ideas:
- Have students use the debrief and assessment handouts.

The debrief takes students step-by-step through the debrief screens. The assessment checks whether students understand how the basic structure of the spring system generates particular behavior patterns.

Open web address: http://www.clexchange.org/curriculum/complexsystems/oscillation/

You’ll explore the sections (in bold) as indicated. Remember, you can always revisit a section anytime you like.

1. Click Introduction – Spring Dynamics
   a. List at least five examples of how springs are used.

   b. What does the phrase, “form ever follows function,” mean to you?

   c. What is at least one specific example of “form follows function?” You can give an example from architecture, mechanics, biology, or another context.

Click Menu. Click Experiment with the Model.
   d. Click on the “?” for each of the settings and then define these in your own words.

Change Position:

Mass:

Spring Constant:

Resistance:

You will use the following worksheets to predict and record your virtual experiments.
Run # 1: Baseline Runs for Spring

Click on the ? for each of the sliders and dials to see what each one does. Input the values shown below onto the simulation screen, but don’t run it yet.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Change Position</td>
<td>0</td>
</tr>
<tr>
<td>Mass</td>
<td>2</td>
</tr>
<tr>
<td>Spring Constant</td>
<td>0.1</td>
</tr>
<tr>
<td>Resistance</td>
<td>0</td>
</tr>
</tbody>
</table>

Predict: What do you think will happen to the spring’s position over time?

Draw a general prediction as a line on the graph. Note that the spring will start at a position of ‘0’ which is at the dot shown on the y-axis. Now click “Run.”

Analysis: What actually happened? Using two colors, create a key, show the scale on the y-axis, and draw the graphs for the spring’s position and momentum. Note that because this run shows equilibrium, the line for momentum overlaps the line for position, which also stays at ‘0’ for the entire run. You can see these individually by clicking the tab at the bottom left corner of the graph. You’ll also see graphs for velocity, impulse, and displacement. Don’t worry about these extra graphs.
Baseline Run (continued)

a. Explain your results. Why was the spring in equilibrium?

b. What one setting would you need to change from the current settings to get the spring moving?

c. Why would this work?

Make that one change and then run the simulation again. If you get the spring to go out of equilibrium, then record your results below in the table and on the graph as before. If not, then go back to ‘b’ and ‘c’ above and revise your answers.

<table>
<thead>
<tr>
<th>Change Position</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td></td>
</tr>
<tr>
<td>Spring Constant</td>
<td></td>
</tr>
<tr>
<td>Resistance</td>
<td></td>
</tr>
</tbody>
</table>

Don’t forget to make a key!
Baseline Run (continued)

d. Approximately how much time does it take for the spring to go through one cycle? (Hint: on the position graph, look at the time distance between two peaks. You can click and hold on the graph line to see the values.)

e. What do you think is impacting the speed of the oscillation cycle?

f. Why does the spring appear to oscillate forever?

g. Continue your exploration, asking “What if” questions. Ask one question at a time and then record what happens on a new run sheet.

Question 1: What might happen if the spring had a heavier mass?

Question 2: What might happen if the spring had a higher spring constant?

Question 3: What might happen if the spring was impacted by resistance?

Question 4: What might happen if the initial position of the spring was set differently?

Question 5: What are some other questions you could explore? Write one or more questions below and try them one at a time.
Experimental Run

**Run #:** __________  **Question:**

Make sure to change only the position (to a number other than 0) and one other setting from the baseline values that relate to your question.

<table>
<thead>
<tr>
<th>Change Position</th>
<th>Mass</th>
<th>Spring Constant</th>
<th>Resistance</th>
</tr>
</thead>
</table>

**Predict:** What do you think will happen to the spring’s position over time?

Draw a general prediction as a line on the graph. Note that the spring will start on the y-axis at whatever position you set above. Now click “Run.”

**Analysis:** What actually happened? Using two colors, create a key, show the scale on the y-axis, and draw the graphs for the spring’s position and momentum.
Experimental Run (continued)

a. Explain why you think the spring changed as they did.

b. Approximately how much time does it take for the spring to go through one cycle?

c. What do you think is impacting the speed of the oscillation cycle?

d. How does this run compare to the baseline run?

e. What’s similar?

f. What’s different?

g. What is causing the similarities and differences?
Debrief

Click Menu. Click 3. Debrief Central. You’ll go through each of these debrief sections to think about what you experienced in the simulation.

Click A. Behavior Patterns. Read and then click Continue.

a. What two elements must be at '0' for the spring to be at rest?

b. Why is that?

Click Continue.

c. What effect does resistance produce on a spring?

d. What is the difference between high and low resistance?

Click Continue. Click Next Section. Back at the Menu, click B. Explore the Model. Click and read through Tour the Model Structure and Tour the Loops. (Click on the arrow to go back to one from the other.)

a. Look at the map below and use it to answer the questions on the next page.
Debrief (continued)
b. Explain the elements, connections, and loops within the map; (see previous page). Hint: follow the cause-and-effect arrows around describing the connections along the way. The two loops are B1 (balancing loop 1) which causes the spring to oscillate up and down and B2 (balancing loop 2) which causes the spring to slow and stop.

c. How did setting the initial position higher or lower affect the spring?

d. How did changing the spring constant affect the spring?

e. How did changing the mass affect the spring?

Click Next Section. Back at the Menu, click C. Connections.
a. How are springs and bungee cords similar and different in terms of their structure and behavior?
Debrief (continued)

b. Why do springs oscillate?

c. What happens if you compress or stretch a spring?

d. In your own words, explain what was done to make the Millennium bridge safe to walk on.

e. What other systems oscillate in a similar way to a spring?

f. Why do they do this, specifically and in general?
Assessment: Springs Everywhere

a. What approximate settings would create the following graphs? You can fill in numerical values and/or qualifiers, such as high mass, low mass, no resistance, some resistance, etc.

![Graph 1]

<table>
<thead>
<tr>
<th>Change Position</th>
<th>Mass</th>
<th>Spring Constant</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

![Graph 2]

<table>
<thead>
<tr>
<th>Change Position</th>
<th>Mass</th>
<th>Spring Constant</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

![Graph 3]

<table>
<thead>
<tr>
<th>Change Position</th>
<th>Mass</th>
<th>Spring Constant</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

![Graph 4]

<table>
<thead>
<tr>
<th>Change Position</th>
<th>Mass</th>
<th>Spring Constant</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. How would you summarize your learning experience?
Lesson 1 - Handout 5

Final Run with Assessment of Graph Connections

Go back to Menu and to 2. Experiment with the Model.
Set up the simulation as follows and then run the simulation.

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change Position</td>
<td>-5</td>
</tr>
<tr>
<td>Mass</td>
<td>2</td>
</tr>
<tr>
<td>Spring Constant</td>
<td>0.1</td>
</tr>
<tr>
<td>Resistance</td>
<td>0.1</td>
</tr>
</tbody>
</table>

You should get the following graphs. Notice the arrows showing the basic connections among these elements in the simulation. On a separate paper, define each element and tell the “story” of why they are connected in this way. For example, you can start with, “As the position of the spring rises toward 0 (see the line going up), the displacement goes down toward 0....”
Lesson 1 - Level C
Springs Everywhere: Exploring Spring-Mass Dynamics
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This model is one in a series of models that explore the characteristics of complex systems.

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