Background Information on Simulation Created for

Lesson 1: Springs Everywhere: Exploring Spring-Mass Dynamics

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in collaboration with the Creative Learning Exchange

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Lesson 1: Springs Everywhere: Exploring Spring-Mass Dynamics

Note: This lesson is the entry point for the Oscillation curriculum created for the Complex Systems Project. Experimenting with a virtual spring will help students gain an intuitive understanding for why a spring oscillates. This knowledge will be reinforced in other lessons in this series.

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Introduction

What makes a spring a spring? It may be hard for students to articulate, but it's a fun topic for discussion. After all, we all know that jumping on a bed is more fun than jumping on the floor, and no one wants concrete blocks in their car suspension. Springs are a consequence of the material they're made of and the shape in which the material is formed. The material has to have both elasticity and rigidity. The shape can vary greatly. Most people think of coils, but a bow used to shoot an arrow is also a type of spring. The key is that energy is stored and released. Change the properties (structure) of the spring, and you'll change the energy that can be stored and released. In other words, the spring will oscillate differently. Engineers exploit the properties of various springs depending on the job at hand.

Overview of Model Behavior

Run the Model with the Default Settings

Initially, the spring is at rest. If you simulate the model without moving the slider for "Change Position" away from 0, the graph shown in Figure 1 is the result: the spring is not moving.

Note: if you are also demonstrating the movement of various springs in the classroom, it does not matter if the virtual spring is conceptualized as a vertical or horizontal spring.

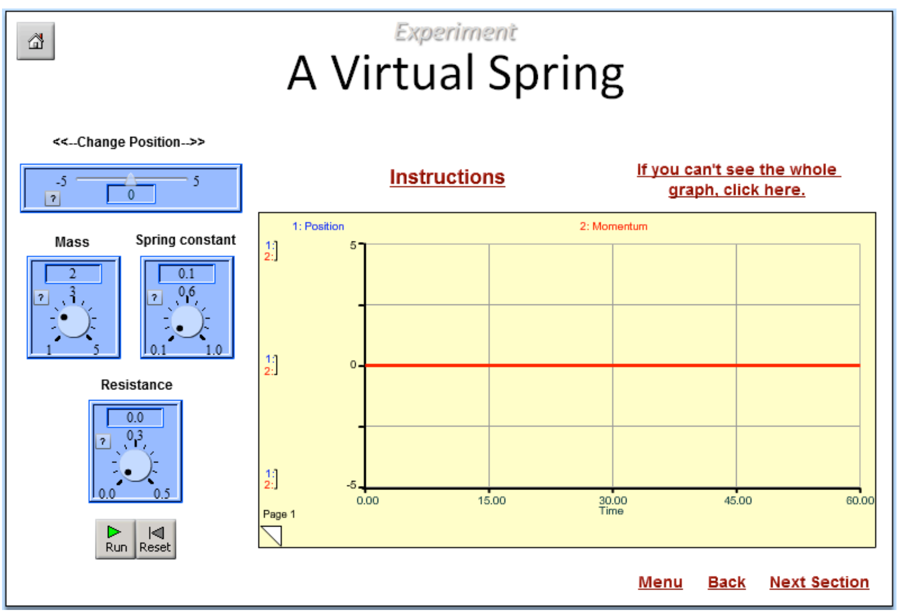

Figure 1: The Control Panel of the simulation, showing the spring "at rest."

To change the spring from its rest position, move the slider to the left or right. To create the run shown below, move the "Change Position" slider to 5 and click the "Run" button.

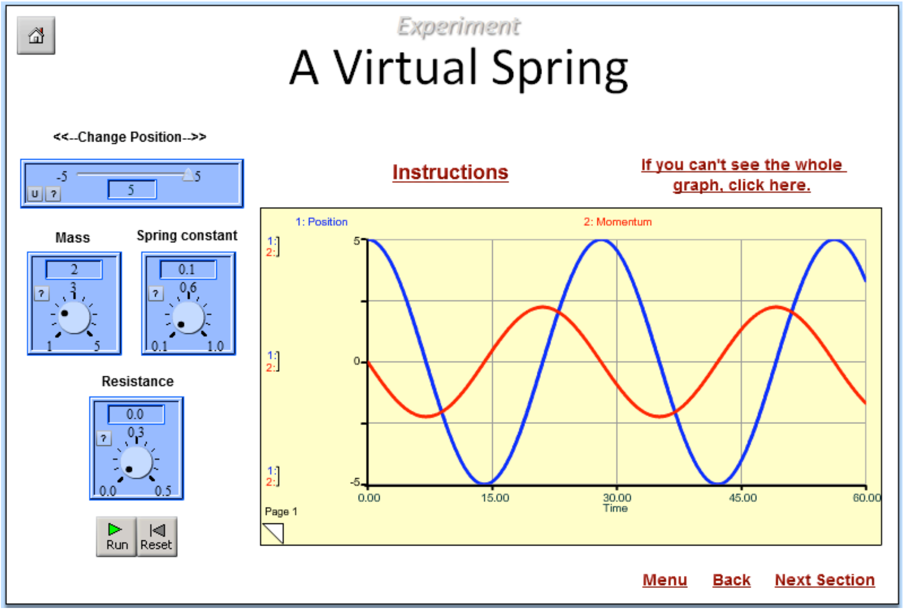

Figure 2: Without changing Mass, Spring constant or Resistance, move the "Change Position" slider to 5 and click "Run."

On your screen, click the white triangle in the lower left corner of the graph to page through the graphs of other variables. These graphs show the "default virtual spring," the behavior generated by running the simulation without making any changes to "Mass," "Spring constant" or "Resistance."

Notice that the simulation runs from 0 to 60, but the unit of time is not specified. The time unit would depend on the spring and the real-life situation. An appropriate unit of time for this model would be seconds, but students could be prompted to think of other applications where a longer or shorter time unit would be necessary.

How Does Changing the Mass Affect the Spring?

The heavier the mass, the slower the spring will oscillate. This makes logical sense, but it is also easy to test this statement by simulating the model with different values of "Mass." To create the runs shown in Figures 3 - 5, click the "Reset" button to clear all graph pages. Change "Position" to 5, click "Run," then change "Mass" to 5 and click "Run" again. The first page of the graph in the Control Panel shows position and momentum graphed together. Subsequent pages show comparative graphs. This means that each time you click the "Run" button a new graph line will be drawn and labeled with a sequential number. Click the "Reset" button each time you want to clear the graphs and start over.

Figure 3 shows position and momentum together. Compared to Figure 2, the behavior looks more "stretched out" with a higher value for mass. Figure 4 shows both runs for position. Run 1 is with a mass of 2 (the default value) and run 2 is with a mass of 5. The increase in mass means it takes more time for the spring to move from Position = 5 through one cycle and back to Position = 5. Velocity (Figure 5) is slightly lower for the second run because the momentum created by moving the spring from its resting position (even though there is more momentum) has to move a greater mass.

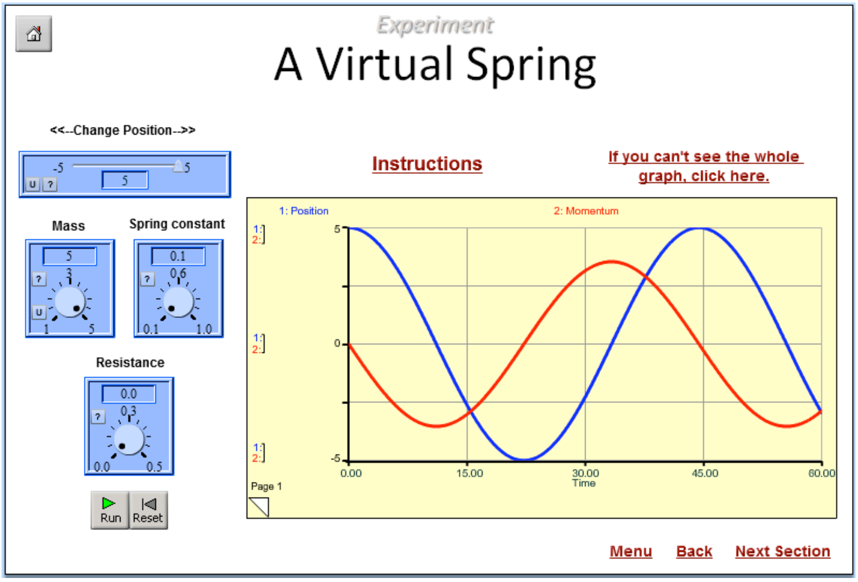

Figure 3: This graph is generated by changing "Mass" to 5 and moving the "Position" slider to 5.

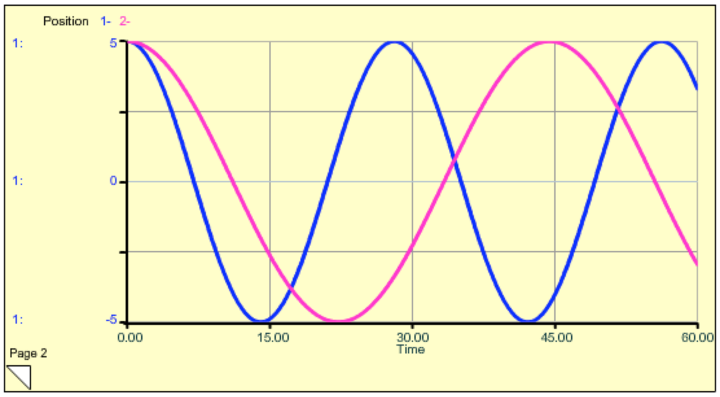

Figure 4: Graph of position with a higher mass in the second run.

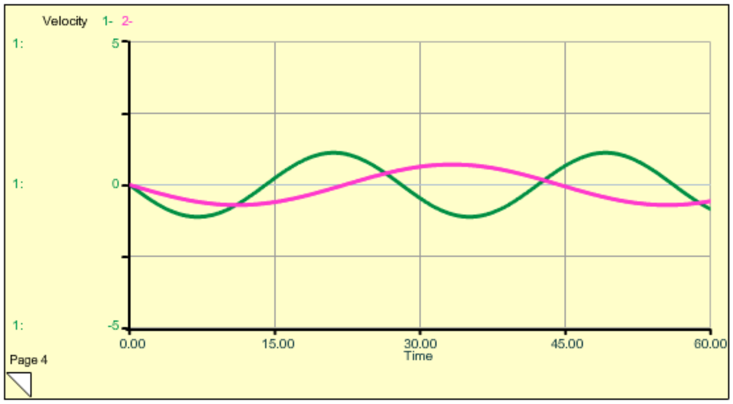

Figure 5: Graph of velocity with a higher mass in the second run.

How Does Changing the Spring Constant Affect the Spring?

The spring constant is actually a measure of the spring's properties. Different materials and shapes yield different spring constants. The higher the spring constant, the more energy is being stored by the spring. It "fights back" more, giving greater momentum and velocity, and yielding faster cycles. In the following graphs, Spring constant was set to 0.5. To recreate the comparative graphs, first click the "Reset" button, then move the "Position" slider to 5, simulate the model, then change "Spring constant" to 0.5 and simulate again.

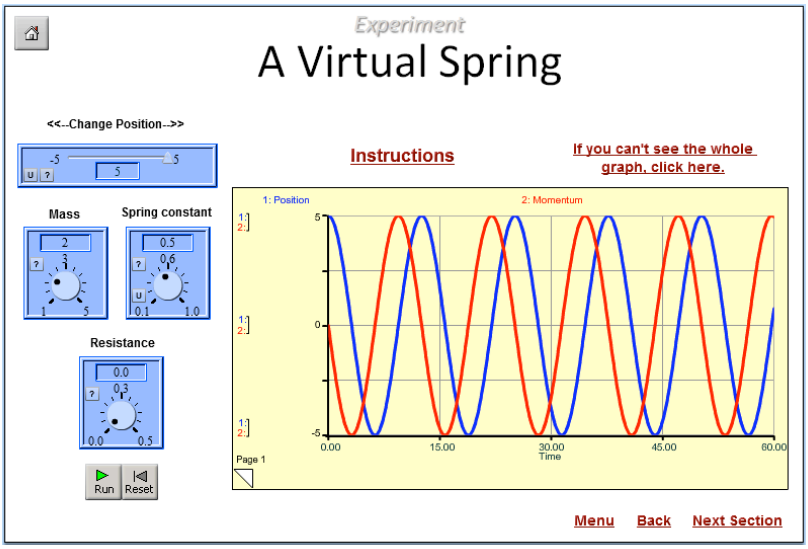

Figure 6: This graph is generated by changing "Spring constant" to 0.5 and moving the "Position" slider to 5.

This comparative graph of position (Figure 7) shows that the cycles are coming faster. The time from peak to peak (or trough to trough) is shorter.

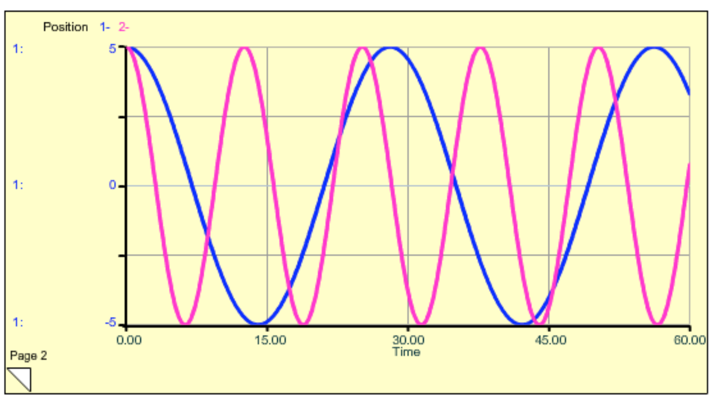

Figure 7: Graph of position, showing shorter cycles for a larger value of the Spring constant.

This graph of velocity (Figure 8) shows that the spring is given higher velocity when the Spring constant is larger, which causes the spring to oscillate faster.

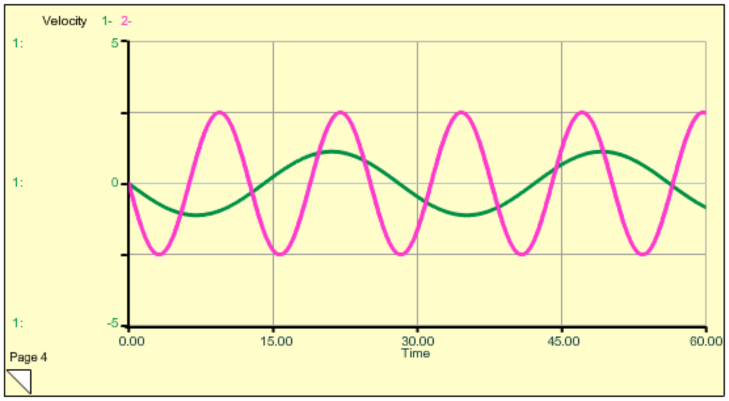

Figure 8: Graph of Velocity, showing higher Velocity for larger values of the Spring constant.

How Does Setting Position Higher or Lower Affect the Spring?

Students may recognize that changing values for mass and spring constant did not change the amplitude of the position graph. In other words, if position was set to 5, the spring oscillated between 5 and -5, either faster or slower depending on mass and spring constant settings, but never deviating from the number set using the "Position" slider. This is called harmonic oscillation; the oscillations just keep going with the same amplitude and never die. Setting the "Position" slider itself to a higher or lower value will cause the spring to oscillate at higher or lower amplitude.

In Figure 9, below, the "Position" slider was set to 0, 1, 2 and 3 in runs 1 – 4, respectively. The graph of position shows that the speed of the cycles was unaffected by how far the spring was pushed or pulled.

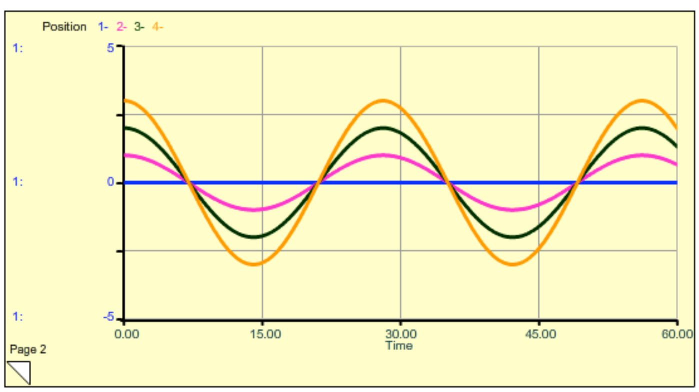

Figure 9: Graph of Position, showing differing amplitude based on how far the spring has been moved from rest.

This graph of Velocity (Figure 10, below) shows that the spring gains velocity depending on how far it is pushed or pulled. This enables the spring to cross the center line at the same time regardless of how far it's pushed or pulled to set it in motion.

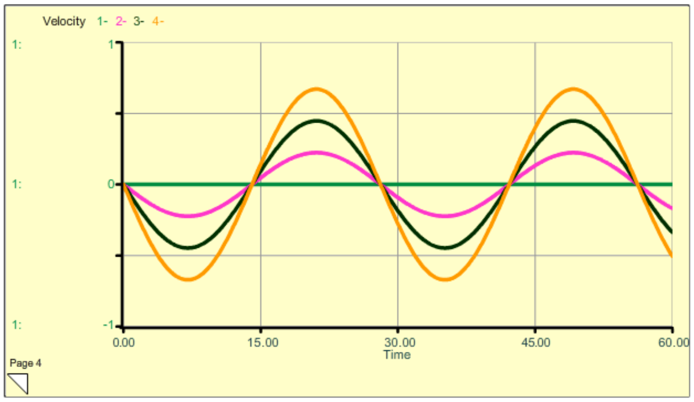

Figure 10: Graph of Velocity, showing how the speed of the cycles is maintained despite changes in the distance the spring has been pushed or pulled from rest.

How Does Resistance Affect the Spring?

In real life, springs don't keep oscillating forever. They slow and eventually stop moving (unless continuously propelled) due to effects such as gravity, surface friction, movement through a medium such as a liquid, and so on. This model uses the concept of "Resistance" as a generic and simplified representation of such forces. For each trip around the loop that connects position and momentum, resistance reduces the amount of impulse acting on the spring until finally the spring settles to rest.

In Figure 11, the "Position" slider is set to 5 for all runs; "Resistance" is set to 0, 0.2 and 0.5 in runs 1 – 3, respectively. Notice that the amplitude of the cycles does not reach the same constant height as before; just like a real spring, each successive cycle is dampened, or lower than before. The period of the oscillation, the time from peak to peak, stays the same. The spring is no longer a harmonic oscillator.

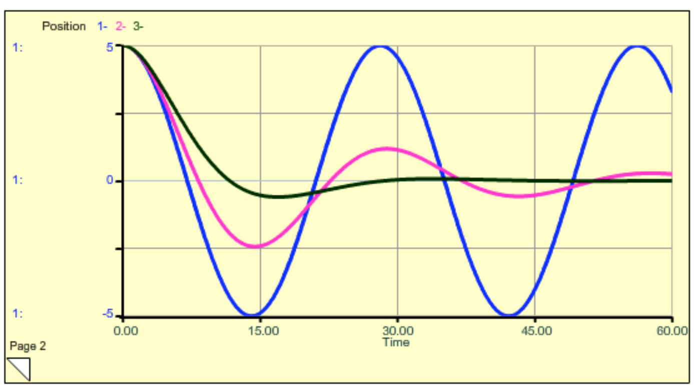

Figure 11: Graph of position, showing how resistance brings the spring back to its resting position.

Model Structure and Assumptions

The model structure is presented on the screen shown below (Figure 12). This screen is accessed via the menu by clicking the link "Explore the Model."

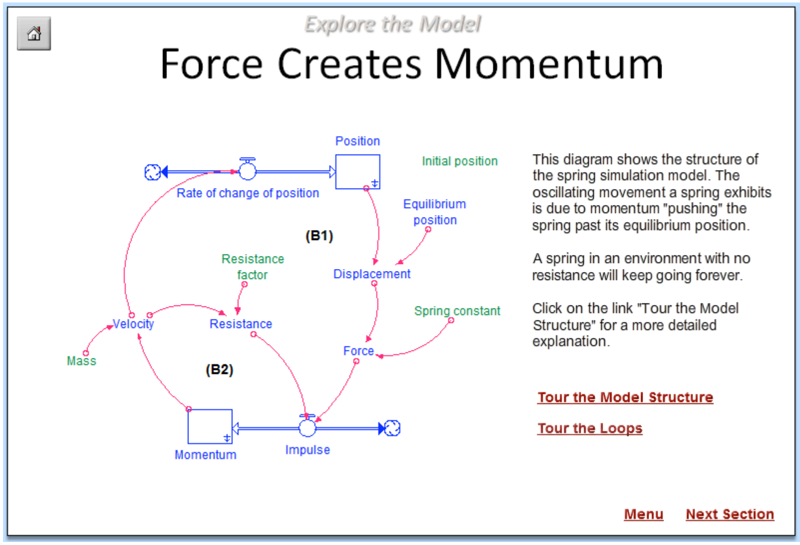

Figure 12: The structure of the model; green variables are changed in the Control Panel.

The links “Tour the Model Structure” and “Tour the Loops” give an overview of the model structure and the feedback loops governing its behavior. These loops are labeled “B1” and “B2” in the picture. Loop “B1” is the main balancing loop of the model – it is the loop that generates oscillation. Without the action of loop “B2” through Resistance, loop “B1” is responsible for the harmonic oscillation behavior pattern. This means that without any force to stop the spring from oscillating, it will continue oscillating forever with the same amplitude (height) and period (time from peak to peak).

The interplay of position and momentum keeps the spring oscillating (absent any resistance). Please see the screen shown below (Figure 13) in the Behavior Patterns debrief section for more explanation.

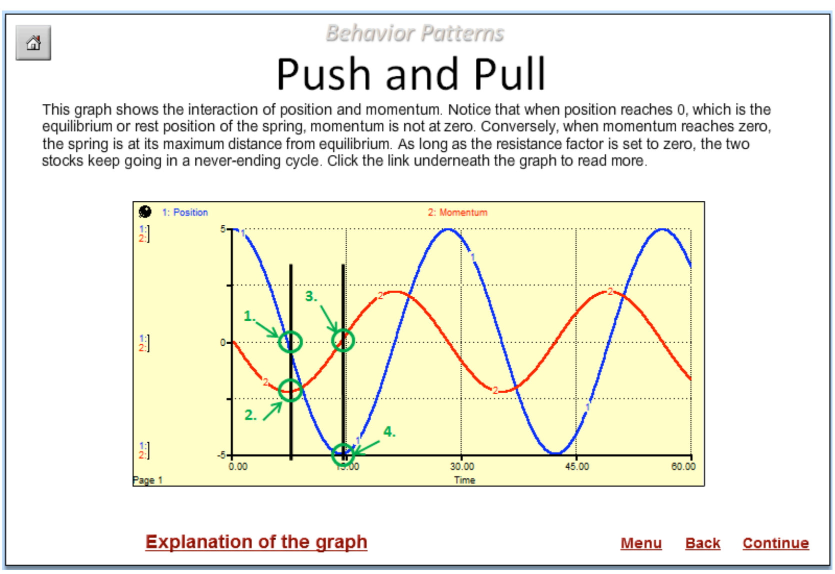

Figure 13: A Debrief screen explaining the push-and-pull relationship between position and momentum.

The model does not include any outside force that continually pushes or pulls the spring. The slider in the Control Panel labeled "Change Position" is connected to the variable "Initial position" in the model structure shown above. Moving "Initial position" away from zero sets the spring in motion; it is the equivalent of pushing or pulling a real spring and then letting go so the spring moves freely. A spring does not simply move back to its resting position and stop; momentum pushes it past the resting (equilibrium) position. At point 1 in Figure 13, position is back at its resting position, but momentum is at its maximum distance from rest. Then, when momentum reaches 0 (point 3), position is at its maximum distance from rest. This interplay continues as long as there is no resistance to slow the spring to a stop.

Limitations of the Model

The model is not intended to represent a particular physical spring. As mentioned, the concept of "Resistance" is a simplification of the forces that can be operating against the movement of a spring, such as surface friction and gravity. Despite these limitations, this model can be used to complement learning in a physics classroom. However, this is not the main learning goal of the lesson. Rather, the idea is to provide an intuitive understanding for why a system oscillates. Other lessons in this series will reinforce the concept of oscillation caused by a balancing feedback loop connecting two stocks.

Talking Points – Linking the Simulation to Real Life

Some useful questions for discussion with students include the following:

- What factors in a real spring must be considered in order to use a spring effectively? An engineer or mechanic who needs a spring for a particular task will need to consider how the spring fits into the overall design of the project. For example, what type of spring is called for – a compression spring, a torsion spring, or something else? He or she will also need to choose the type of material, its diameter, strength, shape, length and so on to do the job at hand.
- Do oscillating systems always oscillate? No, sometimes they are at rest. Systems that oscillate have the *potential to oscillate based on their structure*, but that doesn't mean that they are constantly in motion.
- Can control be exercised over an oscillating system *when it is oscillating*? Engineers used dampers to stabilize the Millennium Bridge. Skyscrapers and other large structures use similar constructs to stabilize – not necessarily eliminate – swaying and other unwanted movements. Balancing feedback loops, such as the one through Resistance in this model, can be used to add control and stability to many types of systems.
- If faced with a non-physical oscillating system (for example, a fluctuating love affair between two people), could there be factors that speed up the observed oscillation (similar to setting a higher spring constant)? Slow it down? Make the oscillations die? Check out other topics in the Oscillation curriculum to find out!

The Cause of the Problem is Within the System

The overall goal of the Oscillation curriculum is to teach a principle of complex systems: The cause of the problem is within the system. Socioeconomic systems that oscillate are often not recognized as oscillating due to their intrinsic structure. Explanations often point to outside influences that are themselves oscillating, or to a particular combination of outside factors believed to “drive” the oscillation. Yet by learning about a physical system such as a spring, we can clearly see that a spring oscillates because it is made to do so. It does not oscillate because a hand or other force continually pushes it in an up-and-down or back-and-forth motion. A spring gets set into motion with a push or a pull, and it oscillates due to its own structure.

Similarly, other familiar systems can oscillate due to their intrinsic structure. Two people (or even two countries) can experience that their feelings for each other wax and wane over time. This phenomenon is shown with a model structure that is very similar to the spring model structure. Predator-prey systems are well-known real-life examples and are included in this curriculum as a mini-series of lessons (showing logistic growth in a single population, cyclic interactions between predators and prey, and trophic interactions between predators, prey and biomass). Other lessons are also included to show that the dynamics that create oscillation arise due to system structure. Because the cause of a system’s behavior is due to its structure, the solution to changing the behavior also lies with the system’s structure (rather than eliminating an outside influence). For example, a spring stops oscillating due to damping forces such as surface friction and gravity. These lessons show that inherent oscillation can be tamed through the proper leverage. The cause of the problem, and the solution to the problem, is indeed within the system.