Name: ______________________________________ Date: ________________________

Guided Learning: Resonance (Part 2)

Swings…A closer look
The best time to push Jean is when she reaches the top of her swing. Pushing before then is inefficient because some of your effort is wasted slowing her down. For part of the time you are fighting against Jean's motion rather than increasing it. Pushing afterward is not inefficient in this way—all the energy you input into the system goes toward increasing Jean's speed. But her speed still increases less simply because (assuming you stay in one place), there is less time to push her before she is out of arm's reach.

Many systems involve cycles of one type or another. In the case of Jean's swinging, a cycle would include one full trip in each direction. In this lesson you will mostly be considering cycles of back-and-forth motion, but other cycles are possible. For example, each orbit Earth makes around the Sun is a cycle. The time required for each cycle is called the **period** of the system. The period for one of Earth's cycles around the Sun is one year.

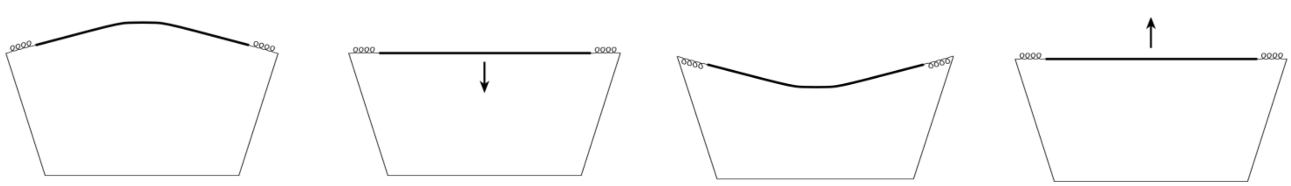
Jean and the swing form a system with a **natural frequency**. If Jean swinging by herself would complete a cycle every 2 seconds, it would correspond to a frequency of $\frac{\text{1 cycle}}{\text{2 seconds}}$ = 0.5 cycles per second, or 0.5 **hertz**. A period of 5 seconds corresponds to a frequency of 0.2 hertz, abbreviated 0.2 Hz.

Quick Check: A swing takes 10 seconds to complete a cycle; what is its frequency? ________

Many systems have natural frequencies. The simplest examples are vibrating objects. A tuning fork is a piece of metal constructed to vibrate with a particular natural frequency. For most modern music scales, middle A (the musical note A lying above middle C) has a frequency of 440 Hz. A tuning fork set to vibrate at this frequency can be used to help tune other instruments.

Springs, pendulums, trampolines, tapped drinking glasses, swaying bridges, and many other items represent systems involving periodic motion. They all have natural frequencies.

Samuel is jumping on a trampoline. The pictures below show the trampoline at different times.



1:14:23 PM   1:14:24 PM   1:14:25 PM   1:14:26 PM

1. What is the natural frequency of the Samuel-trampoline system? ____________________

2. A classmate says the natural frequency is $\frac{1\text{ cycle}}{3\text{ seconds}} = 0.\overline{3}\text{ Hz}$ What error has he made?

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Driving forces and resonance

When you push Jean at regular intervals, you are supplying a **driving force** to the Jean-swing system. Earlier, you found that the effect of a driving force depends on its frequency. This phenomenon is known as **resonance**. Frequencies that are particularly effective at increasing the system's energy are called resonance frequencies. The previous activity showed an example where the natural frequency is a resonance frequency. In fact, a stronger claim is true:

> A driving force generally causes the greatest increase in a system's energy when it matches the system's natural frequency.

If you push Jean each time she reaches her highest point, your pushes match the system's natural frequency. Because of this, the system is not disturbed very much. Your pushes cause Jean to rise higher than if she were swinging without any help, but they have little effect on the frequency of her swings. The time it takes her to complete one cycle is approximately the same whether she swings by herself or if you push her at the swing's natural frequency.

But what happens if you regularly push her before she reaches the top?

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1. You begin regularly pushing Jean before she reaches the top of her swing. How does this affect the period of her swing? Explain your answer. (Hint: consider the effect of *opposite* action. Think about how pushing Jean *upwards* right before she reaches the top of her swing will affect the time it takes for her to complete a cycle.)

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2. The natural frequency of a swing is 0.30 Hz and you push Jean before she reaches the top.

   A. After you have been regularly beginning your push prior to the top of her swing, which of the following could be the frequency of the Jean-swing system? (circle one)

   0.28 Hz   0.30 Hz   0.32 Hz

   B. How frequently will *you* be pushing her at this time? Explain.

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3. **Challenge**: If the natural frequency of the swing is 0.50 Hz, one resonance frequency is the natural frequency, corresponding to pushing her once every two seconds. Figure out another resonance frequency, and explain your reasoning. (Assume you always push the same way. You cannot push her one direction sometimes and the other direction at other times.)