Good Vibrations: Music Resounds with Physics!

Overview

Description

In this activity, students are asked to experiment with systems in which standing waves are created in a string or spring via external vibrations. Students must determine what factors in each system determine the characteristic frequencies at which that system resonates—and they must try to identify the mathematical relationship each factor has to the resulting frequencies. This assignment assumes prior exposure to the basics of wave math and terminology, but it leaves much of the experimental design process to the students. The factors they investigate are not identified for them, nor are the mathematical relationships.

Final Product: As part of their small group, students will demonstrate to the class the resonant modes for their two experimental apparatuses. Each group member must participate in the presentation of the group's findings regarding the creation of these standing waves. In addition, each student will prepare an individual report of the activity detailing his or her research, experiments, diagrams, mathematical analyses, conclusions, and answers to all questions presented in the assignment.

Subject

Physics

Task Level

Grade 11

Objectives

Students will:

- Understand the differences between transverse and longitudinal waves.
- Understand the basic concepts of wave motion and wave terminology.
- Identify the designs of typical string and wind instruments.
- Acquire familiarity with apparatuses used in oscillatory motion (electronic vibrator/piston and string).
- Design simple experimental trials to identify and quantify the factors that affect resonance in transverse and longitudinal waves.
- Demonstrate familiarity with basic oscillatory motion.

- Use mathematical curve fitting to show the relationship between transverse string waves and the three factors (string length, tension, and linear density) identified during the Investigating section.
- Use mathematical curve fitting to show the relationship between longitudinal spring waves and the three factors (spring length, tension, and linear density) identified during the Investigating section.
- Express and present findings in report form.

Preparation

- Read Instructor Task information and Student Notes.
- Prepare student copies of Student Notes pages.
- Guide the students through an instructional unit on waves and oscillations, including basic formulas relating and describing wave/oscillatory motion.
- Make available equipment such as:
    - Electronic string vibrators
    - Strings
    - Springs
    - Scales
    - Weights and pulleys
    - Meter sticks
    - Various musical instruments. Recommended instruments: guitar, autoharp, flute, and slide whistle. Other valuable items: electronic keyboard, chart of standard musical pitches (frequencies), and various sizes of bottles partially filled with water.

Prior Knowledge

To be successful in this activity, the students should have a basic working knowledge of oscillation motion, waves, and the quantities that describe wave motion. Students will need experience measuring lengths and using known masses—both for weight and for inertia. Students should have basic knowledge of mathematics and skills consistent with high school algebra, including geometry. They will also need to know how to use a graphing calculator or a computer-based graphing program that will analyze data for "best-fit" functions.

Key Concepts and Terms

- Amplitude
- Antinode
- Force of tension

- Frequency
- Interference
- Linear density
- Node
- Oscillatory motion
- Period
- Resonant frequencies
- Speed of wave
- Standing wave
- Transverse and longitudinal wave
- Wavelength

Time Frame

This assignment will require approximately one hour of in-class time to introduce the concepts and perform demonstrations, and three hours for the actual activities. Most of the task can be done in class but may also require students to do some preparation, calculations, and written conclusions outside of class. Total estimated class time is four hours. This assignment can be modified to meet the needs of different classroom schedules and student ability levels.

Instructional Plan

Getting Started

Learning Objectives

Students will:

- Understand the differences between transverse and longitudinal waves.
- Understand the basic concepts of wave motion and wave terminology.

Procedure

1. Guide the students through an instructional unit on waves and oscillations.
2. Direct the students to read about and research musical instruments—both string and wind.
3. Distribute the Student Notes and discuss with the students the expectations of the task: To use the apparatus and materials provided to investigate the factors and mathematics behind resonant frequencies in transverse and longitudinal vibration systems.
4. Draw a sketch diagram of the experiment setup. Guide students to understand the components and how you would expect them to set up their own experiments.
5. Demonstrate wave motion using apparatuses available in the lab, and show students the Key Concepts and Terms section. Make reference to your diagram above. Help students see when the wave is resonant and how to identify nodes and antinodes. Disassemble the experimental setup, and let students do it by themselves.
6. Guide students on how to present experimental results in table and graphical forms.

Investigating

Learning Objectives

Students will:

- Identify the basic designs of typical string and wind instruments.
- Acquire basic familiarity with apparatuses used in oscillatory motion (electronic vibrator/piston and string).
- Design simple experimental trials to identify and quantify the factors that affect resonance in transverse and longitudinal waves.

Procedure

1. Distribute a clear, step-by-step procedure on how to assemble the experiment. This should contain sketch diagrams.
2. Distribute the necessary apparatus to students, and have them set it up and measure an initial mass and string length with a frequency suitable for producing a standing wave.
3. Put students in groups, and allow them time to collaborate and investigate methods for determining the patterns of transverse standing waves (resonance) in strings for various combinations of string length, tension, and mass (linear density). Students should count the number of loops (n).
4. Closely supervise each student group, formatively assessing their progress, and assist them when necessary to move them along in their investigations.

Drawing Conclusions

Learning Objectives

Students will:

- Demonstrate familiarity with basic oscillatory motion.
- Use mathematical curve fitting to show the relationship between transverse string waves and the three factors (string length, tension, and linear density) identified during the Investigating section.
- Use mathematical curve fitting to show the relationship between longitudinal spring waves and the three factors (spring length, tension, and linear density) identified during the Investigating section.
- Express and present findings in report form.

Procedure

1. Assign each student group to organize and communicate their results to their peers in an appropriate format. The presentation should include their mathematical conclusions, a demonstration of those conclusions to the class with both strings and springs, and a brief explanation of how those principles are applied to real musical instruments.
2. Assign each student to submit an individual report in your preferred format. The report should explain the results of the project, including: relevant data, tables, graphs, and equations used; mathematical results and conclusions reached; demonstrations used to support those conclusions; and examples of real string or wind instruments that use those principles.

Scaffolding/Instructional Support

The goal of scaffolding is to provide support to encourage student success, independence, and self-management. Instructors can use these suggestions, in part or all together, to meet diverse student needs. The more skilled the student, however, the less scaffolding that he or she will need. Some examples of scaffolding that could apply to this assignment include:

- Troubleshoot the apparatus to be sure that students have established reasonable tensions (weights), string/spring lengths and masses, and vibrator frequencies to allow for significant variations without exceeding the capacities of the equipment.
- If students are having difficulties finding the mathematical relationships between string length, loop count ("*n*"), and the corresponding standing wave frequency, encourage them to complete the table below and show their calculations. Ask them to try to describe that pattern in words to each other. This will help them form the verbal and mathematical explanation required in the concluding questions.
- Provide students with blank data tables as necessary. See examples below:

Tension, F (Newtons): __________ Mass of string, M (kg) ___________

Number of loops	Standing wave pattern	Length of string (m)	M/L (kg/m)	Frequency (f)
1				
2				
3				
4				
5				

Length of string, L (meters): ________ Mass of string, M (kg) ___________

Number of loops	Standing wave pattern	Tension, F (N)	Frequency (f)
1			
2			
3			
4			
5			

- If students are using a graphing program to establish the kind of function relating string tension (the mass hanging) to the corresponding standing wave frequency, their results may not be a clean square-root ($x^{1/2}$) relationship. It is probably sufficient for this activity that they see that the relationship is clearly not linear—that if they were to double the tension, this does not double the frequency. Help them see that they can put some kind of value (<1) on the exponent of the function.

- If some faster learning students inquire how soda bottles (or other systems fixed at one end but not at the other) resonate, ask first to see their results for the two-fixed-ends spring (which is like a tube open at both ends). If their conclusions and reasoning seem good, have them work on a third setup off to the side: a spring supported in a smooth channel on the top of a desk so that the end not attached to the vibrating piston rod is entirely free. Let the students watch how that one resonates, and challenge them to discover the math behind the length factor. Let them experiment with soda bottles and water, which might help them to form and test their hypotheses. Direct them also to online videos of Ruben's Tube and ask them to observe the locations of maximum and minimum gas pressure (positions with respect to the ends of the tube).

- To engage students in the activity, consider useful (and fun) references. For example, why does a person's voice suddenly go so much higher when talking via helium, which is a lighter gas? Warn students that most helium contains toxic impurities, and they shouldn't try this at home!

  Answer: Because sound travels faster in lighter gas. Because helium is lighter than nitrogen, oxygen and carbon dioxide, which are major components of the air we breathe, sound will travel faster in a throat filled with helium than it will in a throat filled with air. The faster speed of sound will allow more frequencies to resonate within a throat.

  As for temperature dependence, ask anyone in the room who plays a musical wind instrument why the pitch of their instrument changes if played on a really warm or cold day.

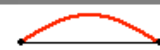
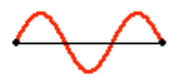
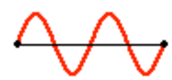
  Answer: This is because temperature affects the pitch of musical wind instruments. If played on a warm or cold day a different pitch is can be heard. Sound travels faster in warm air than cold air. Pitch (frequency) depends on the speed of the wave, which turns to depend on the temperature of the medium. This is because the faster moving air molecules in the warm air bump into each other more often than in cold air, and therefore can transmit the sound waves in less time.

  Encourage students who do not play instruments to talk to students who do, and encourage students who play one type of instrument to talk to students who play a different instrument. Challenge students to explain why covering different holes on a wind instrument cause different notes or why different strings, different frets, and different tensions on a string instrument cause different notes.

Solutions

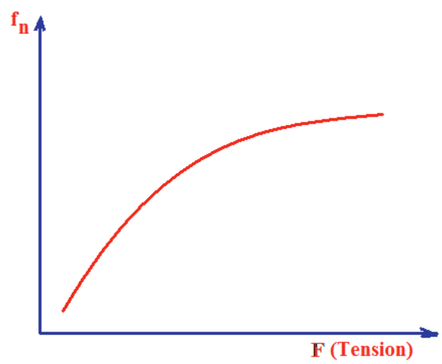
The information below is intended to help you assess students' final work products. It may not represent all possible strategies and ideas. The accompanying scoring guide provides specific examples of ways a student might demonstrate content understanding and mastery of cross-disciplinary skills.

In their reports, students should recognize that the pattern of a standing wave in a string depends on the string's free length, the amount of tension placed on the string, and the string's "size" (mass per cm). The table below summarizes the features of the standing wave patterns for the first four harmonics.

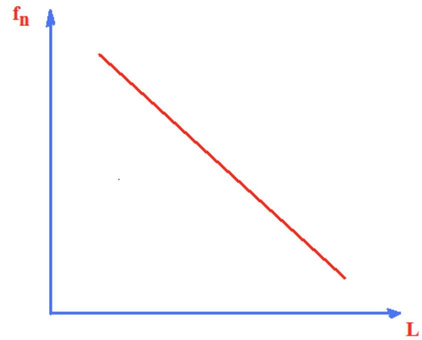
Harmonic	Number of Nodes	Number of Antinodes	Wave Pattern
1st	2	1	
2nd	3	2	
3rd	4	3	
4th	5	4	

Drawing Conclusions

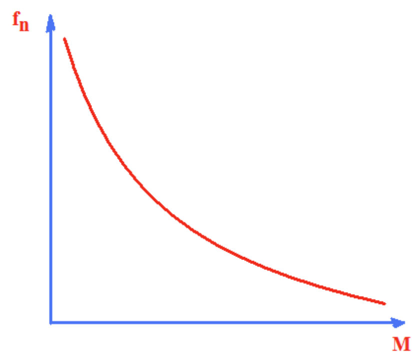
1. Resonant frequencies on a string are affected by tension, the length of the string, and the mass of the string. Students should have three tables. In each of the tables, only one factor will be allowed to vary. Students then record the corresponding resonant frequencies. With the aid of a graphing calculator or computer, students should quickly be able to get the graphs below.



Graph 1: For a fixed length, the resonant frequency will be directly proportional to the square root of the tension in the string. The resultant is a curved graph.

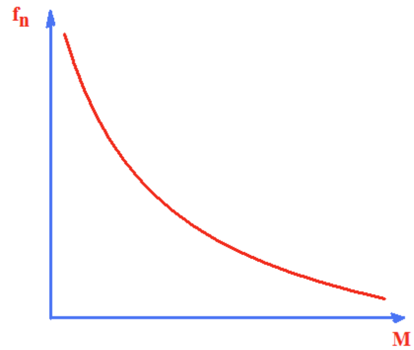


Graph 2: If the tension and linear density are fixed, the resonant frequency will be inversely proportional to the length of the string. In this case only the length is varied.

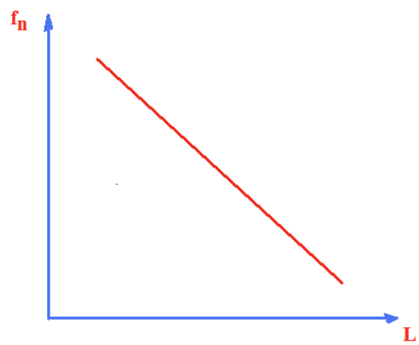


Graph 3: If the tension and length are fixed, and M is varied, the square of the resonant frequency will be inversely proportional to the square root of the mass of the string.

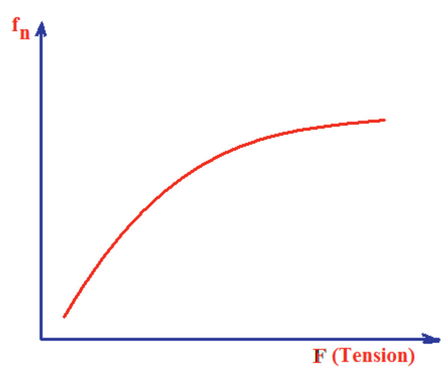
2. Resonant frequencies of a longitudinally vibrating spring are affected by the linear density of the spring, length of the spring, tension, and also by the elastic modulus of the spring. As the slinky is stretched to a longer length, the mass density (mass per unit length) decreases. This is because the total mass of the slinky remains the same, but the total mass is spread out over a longer length. The restoring force for a spring increases as the distance the spring is stretched increases. The bottom line is as the length of the slinky increases, the elastic modulus increases, and the mass density decreases. This means that the speed of mechanical waves increases as the length of the slinky increases. Graphs of each of these factors against the resulting resonant frequency are given below.



Graph 1: The relationship between the square of the resonant frequencies and mass density (linear density) when all other variables are held constant is an inverse curve. (That is: $f_n \alpha \frac{1}{\sqrt{M}}$)



Graph 2: The relationship between resonant frequencies and the length of the spring when all other variables are held constant is an inverse curve. That is, functions produce the best fits through the points is: $f_n \alpha \frac{1}{L}$



Graph 3: For a fixed length L, the resonant frequencies will be directly proportional to the square root of the tension in the spring. That is, functions produce the best fits through the points $f_n \alpha \sqrt{F}$

3. To get one octave above the lowest resonant frequency, students can halve the length, L, increase the tension by a factor of 4, or reduce the mass by a factor of 4.

   Two octaves can be obtained by either reducing the length, L, by a factor of 4, increasing the tension by a factor of 16, or reducing the mass by a factor of 16.

4. When a guitar string vibrates, the air that surrounds it also starts to vibrate. Each time that the guitar string travels upwards, it compresses the air molecules into a slight "thickening" of molecules called a "wave front." Vibration of air molecules will result in compressions and rarefactions, which are characteristic of longitudinal waves.

   The waves transport energy through collisions between air molecules and create a series of wave fronts traveling through the air, eventually hitting the human ear.

5. Like in most woodwind instruments, blowing into the mouthpiece causes the whole length of the instrument to vibrate. This vibration is transferred into sound waves as it bounces off the surface of the interior. Since the vibrations are parallel to the direction of the wave, it is a longitudinal wave.

6. Spring mass, length of spring, and tension affect the resonant frequencies of the spring.

   Tension linear density of the string and length can be most easily adjusted. Other properties of the air that affect the sound from musical instruments are the density of molecules in the medium and the motion of the molecules (which are affected by the temperature of the medium).

   Two properties of gas that can affect sound traveling through it are density of molecules and temperature of the gas.

7. In transversely and longitudinally vibrating springs, tension (e.g., guitar strings), linear density of the string, and length affect resonance.

   In longitudinally vibrating air, the density of molecules of the medium and temperature affect resonance.

TCCRS Cross-Disciplinary Standards Addressed

Performance Expectation	Getting Started	Investigating	Drawing Conclusions
I. Key Cognitive Skills			
A.1. Engage in scholarly inquiry and dialogue.	✓	✓	✓
A.2. Accept constructive criticism and revise personal views when valid evidence warrants.	✓	✓	✓
B.1. Consider arguments and conclusions of self and others.	✓	✓	✓
B.2. Construct well-reasoned arguments to explain phenomena, validate conjectures, or support positions.	✓		✓
B.3. Gather evidence to support arguments, findings, or lines of reasoning.	✓	✓	
B.4. Support or modify claims based on the result of an inquiry.		✓	✓
C.2. Develop and apply multiple strategies to solve a problem.		✓	
C.3. Collect evidence and data systematically and directly relate to solving a problem.	✓	✓	✓
D.1. Self-monitor learning needs and seek assistance when needed.	✓	✓	✓
D.2. Use study habits necessary to manage academic pursuits and requirements.	✓	✓	✓
D.3. Strive for accuracy and precision.	✓	✓	✓
D.4. Persevere to complete and master tasks.	✓	✓	✓
E.1. Work independently.			✓
E.2. Work collaboratively.	✓	✓	✓
F.3. Include the ideas of others and the complexities of the debate, issue, or problem.	✓		✓
II. Foundational Skills			
B.1. Write clearly and coherently using standard writing conventions.			✓
C.5. Synthesize and organize information effectively.		✓	✓
C.6. Design and present an effective product.			✓

C.8. Present final product.			✓
D.1. Identify patterns or departures from patterns among data.	✓	✓	✓
D.2. Use statistical and probabilistic skills necessary for planning an investigation and collecting, analyzing, and interpreting data.		✓	✓
D.3. Present analyzed data and communicate findings in a variety of formats.			✓
E.1. Use technology to gather information.	✓	✓	
E.2. Use technology to organize, manage, and analyze information.		✓	✓
E.3. Use technology to communicate and display findings in a clear and coherent manner.			✓
E.4. Use technology appropriately.	✓	✓	✓

TCCRS Science Standards Addressed

Performance Expectation	Getting Started	Investigating	Drawing Conclusions
I. Nature of Science: Scientific Ways of Learning and Thinking			
A.4. Rely on reproducible observations of empirical evidence when constructing, analyzing, and evaluating explanations of natural events and processes.	✓	✓	✓
B.1. Design and conduct scientific investigations in which hypotheses are formulated and tested.	✓	✓	
C.1. Collaborate on joint projects.	✓	✓	✓
C.3. Demonstrate skill in the safe use of a wide variety of apparatuses, equipment, techniques, and procedures.	✓	✓	
E.1. Use several modes of expression to describe or characterize natural patterns and phenomena. These modes of expression include narrative, numerical, graphical, pictorial, symbolic, and kinesthetic.	✓	✓	✓
E.2. Use essential vocabulary of the discipline being studied.	✓	✓	✓

II. Foundation Skills: Scientific Applications of Mathematics			
A.3. Understand ratios, proportions, percentages, and decimal fractions, and translate from any form to any other.	✓	✓	✓
A.4. Use proportional reasoning to solve problems.	✓	✓	✓
A.7. Use calculators, spreadsheets, computers, etc., in data analysis.		✓	✓
B.1. Carry out formal operations using standard algebraic symbols and formulae.			✓
B.2. Represent natural events, processes, and relationships with algebraic expressions and algorithms.			✓
D.1. Use dimensional analysis in problem solving.	✓	✓	✓
F.1. Select and use appropriate Standard International (SI) units and prefixes to express measurements for real-world problems.		✓	✓
F.2. Use appropriate significant digits.		✓	✓
III. Foundation Skills: Scientific Applications of Communication			
A.1. Use correct applications of writing practices in scientific communication.			✓
B.2. Set up apparatuses, carry out procedures, and collect specified data from a given set of appropriate instructions.	✓	✓	
B.3. Recognize scientific and technical vocabulary in the field of study and use this vocabulary to enhance clarity of communication.	✓	✓	✓
C.1. Prepare and present scientific/technical information in appropriate formats for various audiences.			✓
VIII. Physics			
G.1. Understand basic oscillatory motion and simple harmonic motion.	✓	✓	✓
G.2. Understand the difference between transverse and longitudinal waves.	✓	✓	✓
G.3. Understand wave terminology: wavelength, period, frequency, and amplitude.	✓	✓	✓

G.4. Understand the properties and behavior of sound waves.	✓	✓	✓

TEKS Standards Addressed

Good Vibrations - *Texas Essential Knowledge and Skills (TEKS): Physics*
112.39.c.2. Scientific processes. The student uses a systematic approach to answer scientific laboratory and field investigative questions. The student is expected to: 112.39.c.2.B. know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories. 112.39.c.2.C. know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but may be subject to change as new areas of science and new technologies are developed 112.39.c.2.D. distinguish between scientific hypotheses and scientific theories 112.39.c.2.E. design and implement investigative procedures, including making observations, asking well-defined questions, formulating testable hypotheses, identifying variables, selecting appropriate equipment and technology, and evaluating numerical answers for reasonableness.
112.39.c.3. Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to: 112.39.c.3.A. in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student. 112.39.c.3.F. express and interpret relationships symbolically in accordance with accepted theories to make predictions and solve problems mathematically, including problems requiring proportional reasoning and graphical vector addition.
112.39.c.7. Science concepts. The student knows the characteristics and behavior of waves. The student is expected to: 112.39.c.7.A. examine and describe oscillatory motion and wave propagation in various types of media. 112.39.c.7.B. investigate and analyze characteristics of waves, including velocity, frequency, amplitude, and wavelength, and calculate using the relationship between wavespeed, frequency, and wavelength. 112.39.c.7.C. compare characteristics and behaviors of transverse waves, including electromagnetic waves and the electromagnetic spectrum, and characteristics and behaviors of longitudinal waves, including sound waves. 112.39.c.7.D. investigate behaviors of waves, including reflection, refraction, diffraction, interference, resonance, and the Doppler effect.

Good Vibrations: Music Resounds with Physics!

Introduction

You may have heard the old joke: "Why does a hummingbird hum?" (Because he doesn't know the words.) But how does a hummingbird hum? For that matter how does anything hum? How does a string or a woodwind instrument (our two most common musical instruments) create such steady vibrations—not just any random noise, but specific tones and musical pitches?

You have already studied the math that describes waves. You have also studied concepts important to understanding waves – like oscillation, wave speed, wavelength, period, and frequency – and their relationships. And you know the difference between transverse and longitudinal waves.

Now consider what happens to a wave that "echoes back onto itself." Often that collision just makes a jumbled noise. But if it's tuned (timed) just right, the echoing wave coming back coincides with the next wave going forward, and they combine to make an extra loud sound. You might say that the forward wave is the sound, and the returning echo is the "re-sound," and, indeed, resound is another word for echo.

The extra loudness we hear in this case, with just the right timing (frequency), is called resonance. This is what a musical instrument achieves. The instrument is a device that's built to resonate at certain pitches.

But of course, we don't want to build a different instrument for every pitch. So, how do we get more than one resonant pitch from a single instrument? Take, for example, two of the simplest musical instruments: the string and the open tube. You will explore those instruments further in this assignment.

The Problem

You've heard guitars, violins, and pianos all produce various, steady pitches quite reliably. This is also true for flutes, pipe organs, and even pop bottles. How do they do this? What determines the pitches (frequencies) at which they resonate? You're going to experiment with strings and tubes to figure this out.

Directions

Getting Started

1. You will be assigned to work in a group. Meet with your group and start your brainstorming with some basic research on the design of wind and string

instruments. Browse the collection of instruments provided in your lab, or do some online research.

a. What vibrates in a string instrument? How can you tell? What vibrates in a wind instrument? How can you tell?

b. What traits are common among various members of each “family” of instruments (string, woodwind, etc.). What factors seem to control the pitch (frequency) at which a string instrument vibrates? How about a woodwind instrument?

2. Next, consider the equipment available in your lab. You have a variety of strings and springs, weights and pulleys, plus an electronic oscillator that vibrates a simple piston rod. The rod can vibrate the end of a string or spring at any angle (transverse or longitudinal) and any frequency you set.

3. Certain frequencies will result in strikingly large and steady vibrations of the string or spring. What do these vibrations look like?

   Try one setup where you stretch out a string and, using a constant amount of tension, vibrate the string transversely. For certain frequencies, you'll get patterns that look something like Figure 1 below:

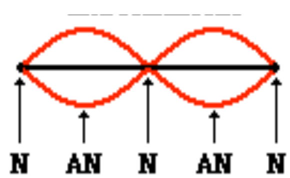


Figure 1

   The almost-motionless points are called nodes and the fastest-moving, farthest-traveling points are called antinodes. Check out these points by gently touching them.

Investigating

1. Now, pool your observations and ideas. Work with your group to design several experiments to measure how various factors actually affect the pitch(es) that resonate in a transversely vibrating string. (Hint: There are at least three such factors.) Be sure to vary each factor individually (and find several different resonant frequencies with each). Carefully record all your data, including all the settings on your string, factors you test, appearance of the string, and the resulting resonant frequencies.

2. What about a spring? Just like a string, it can vibrate transversely, but it can also vibrate longitudinally? Again, pool your observations and ideas, and design some experiments to measure how various factors affect the pitch(es) that resonate in a longitudinally vibrating spring. (Hint: There are at least

three such factors. Make note of the factors you find.) Be sure to vary each factor individually and find several different resonant frequencies with each. Again, carefully record all your data, including all the settings on your spring, factors you test, the appearance of the spring, and the resulting resonant frequencies. This may require a closer observation of the vibrations than in the case of a transversely resonating string.

Drawing Conclusions

1. What three factors did you observe that affected the resonant frequencies of a transversely vibrating string? Graph each of those factors against the resulting resonant frequency. What sorts of curve shapes do you get? Analyze the graphs with a graphing calculator or computer. What kinds of functions produce the best fits through the data points?
2. What three factors did you observe that affected the resonant frequencies of a longitudinally vibrating spring? Graph each of those factors against the resulting resonant frequency. What sorts of curve shapes do you get? Analyze the graphs with a graphing calculator or computer. What kinds of functions produce the best fits through the data points?
3. In music, a doubling of frequency (pitch) results in an increase in octave (a similar-sounding tone that is higher). According to your data above, how would you need to change each of the three factors you identified for transverse-wave resonance in order to produce a tone that is one octave above the lowest resonant frequency? How about two octaves above? Are there resonant pitches between one and two octaves?
4. According to your data above, how would you need to change each of the three factors you identified for longitudinal-wave resonance in order to produce a tone that is one octave above the lowest resonant frequency? How about two octaves above? Are there resonant pitches between one and two octaves?
5. What is actually vibrating when you hear a guitar string hum? What kind of wave does it produce? How does that wave's energy (its vibration) get to your ears?
6. What is actually vibrating when you hear a flute? What kind of wave does it produce?
7. The spring you observed resonating longitudinally can be used as a model for the longitudinal vibration of air that we call sound. What factors did you identify as affecting the resonant frequencies of the spring? Which of these are easily adjusted in the design of musical instruments? Which properties of the air itself (rather than the dimensions of the instrument) might affect the sound we hear? In other words, what properties of a gas can affect sound

travelling through it? Do some research here, and see if you can find two factors similar to the factors you identified for strings.

8. Work with your group to prepare a short but engaging presentation for your classmates that answers the following questions: What do your experiments, graphs, and calculations reveal are the quantitative factors (the measurements and the numbers) that affect resonance in transversely vibrating strings and longitudinally vibrating springs? What about longitudinally vibrating air?

   Demonstrate at least two predictable (computable) resonance cases with both the string and spring—*cases involving different values than the ones you used in your study*. Be sure to indicate also how these principles are applied to real musical instruments—either those available in the classroom or others encountered in your research.

9. Prepare an individual written report that describes your research, your experiments, and your mathematical analyses and conclusions. Explain how your conclusions are supported by your findings using the string and spring exercise. Discuss how the principles you studied are applied to various real musical instruments. Be sure to include all relevant data, graphs, and charts and address all questions asked throughout this assignment. Follow directions from your instructor to format the report.