Tremor Detector: Designing a Sensor

SLED
Science Learning through Engineering Design

Grade Level:	**Total Time Required:**
Grade 6	Two 50-minute class sessions

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Lesson Objectives:

Students will be able to:

1. Distinguish between potential and kinetic energy.
2. Describe how energy can lead to vibrations that can be detected.
3. Define a sensor as a device that receives a stimulus (vibrations) and responds to it in a distinctive manner.
4. Design a mechanical device that senses vibrations.

Indiana Standards:

6.PS.3 Describe how potential and kinetic energy can be transferred from one form to another.

6.PS.4 Investigate the properties of light, sound, and other energy waves and how they are reflected, absorbed, and transmitted through materials and space.

6-8.E.1 Identify the criteria and constraints of a design to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions

Next Generation Science Standards:

S-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ET1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Concepts and Vocabulary

Term	***Defined by a scientist or engineer***	***Defined by a student***
Energy	A thermodynamic quantity equivalent to the capacity of a physical system to do work.	the ability of something to do work
Potential energy	The mechanical energy that a body has by virtue of its position; stored energy.	energy that something has stored
Kinetic energy	The mechanical energy that a body has by virtue of its motion.	energy that something has due to its motion
Vibration	Oscillation; a regular periodic variation in value about a mean.	
Sensor	Device that receives a signal or stimulus and responds to it in a distinctive manner.	
Sensitivity	The ability to respond to physical stimuli or to register small physical amounts or differences.	
Device (sensor)	A tool, instrument, or mechanism to measure or detect change.	A machine to do something.

Equipment, Materials, and Tools

Materials		
Springs	Marbles	Poster board
Slinky junior	Rubber bands	Craft sticks
Wire (small and large gauge)	Modeling clay	Plastic straws
String	Glue	Pipe cleaners
Binder and paper clips (large and small)	Tape (masking, scotch, and/or duct)	Plastic wrap
Wooden blocks	Paper cups	

Tools		
Scissors	Ruler	

Synopsis of Engineering Design Activity

Synopsis of the Design Activity:

Problem:	Vibrations caused by natural occurrences (high winds, earthquakes) can damage bridges.
Goal:	Design a sensor that can be placed on a bridge and detect the occurrence and magnitude of vibrations.
Who is the client:	Indiana Department of Transportation
End-User:	Indiana Department of Transportation bridge engineer
What is the design:	Design a device to sense vibrations.
Criteria:	• Sensor can detect the occurrence of a vibration. • Sensor can distinguish between relatively small and large vibrations.
Constraints:	• Only the materials provided may be used. • Time. • Optional – sensor cost.

Lesson Plan #1: General Introduction / Inquiry

Guiding Question - How can we build something that detects vibrations?

Time: one 50-minute session

Procedure:

1. Begin by shaking a table. Next, drop a large textbook on the table.

   Ask: Why did the table shake or vibrate?
   Potential student response: Because you shook it or moved it.

   - Explain that the energy you transferred to the table by shaking it caused it to vibrate. Likewise, the energy of the falling book was transferred to the table and caused the table to vibrate.

   - Define energy as the ability of something to do work or move or shake. Explain that energy can be transferred between objects. Describe kinetic energy as the energy that something has due to its motion and potential energy as energy that something has stored.

   - If desired, can discuss how a textbook held 4 ft above the table's surface has greater potential energy than a textbook held 1 ft above the table's surface. If both textbooks were dropped from those heights, which would cause the table to vibrate the most?

2. Place a clear container of water on the table and bump the table.

   Ask: What happens to the water when the table vibrates?
   Potential student response: The water shakes. There are waves in the water.

   - Explain that energy is even transferred to other materials (the container of water) and can cause vibrations within the other material.

3. Next, stomp near the table.

   Ask: Did the table vibrate?
   Did it vibrate as much as when I shook it? Why not?
   Potential student response: Yes, but not as much because you did not shake it.

   - Explain that energy is being transferred and transformed all of the time. Sometimes we can sense it, other times we cannot.

4. *Ask: Why would we want to be able to detect and record vibrations, particularly those that we cannot easily see or feel?*
   Potential student responses (or teacher offered responses): sensing earthquakes, detecting the level of vibrations at various locations in a building, detecting people

moving in a secured area (in the halls without a hall pass), detecting movement of a patient in a hospital bed, etc.

Ask: *If we cannot see or feel them, how can we capture or sense them? How can we build something that detects vibrations?*

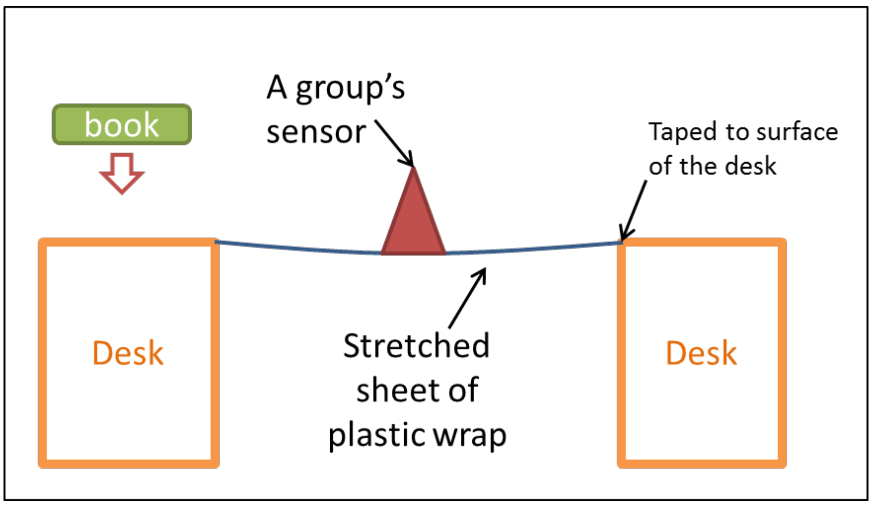
- Explain that a sensor can provide us with information about vibrations. Define a sensor as a device that receives a signal or stimulus and responds to it in a distinctive manner.

- If desired, can describe how sensors can be created from masses and spring (see Teacher's Resources on pg. 9)

Lesson Plan #2: Design Challenge

Time: one 50-minute session

Teacher Preparation: Prior to the design activity, the teacher should build a “vibration station” on which the students will place and test the vibration sensor that they create. Illustrated in the following schematic, one option for a vibration station is to stretch a piece of plastic wrap between two tables or desks to make a flexible bridge on which the sensor will be placed for testing. To create the small and large vibrations, the teacher could drop a heavy textbook on the desk from two different heights (e.g., 30 cm and 60 cm), taking advantage of the difference in potential energy of the book at the different heights in order to create the vibrations. The plastic wrap could be the clear commercial kind (e.g., Saran wrap) or could be fashioned from a trash bag.

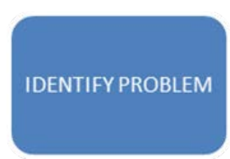


Schematic of the vibration station that will be used to test each group’s sensor.

Procedure:

1. Distribute, read aloud, and discuss the design brief (pg. 10). Ask the following:

   What is the problem?
   Who is the client?
   Who is the user?
   What are the criteria?
   What are the constraints?
   What materials and tools have been provided?



2. Have students respond to the above questions in their notebooks. Discuss responses with class.

3. Review with the students
   a. Show the students the materials that are available for the activity.
   b. Remind students to use the knowledge learned from the introduction / inquiry lesson plan to solve the problem.
   c. Review <u>simple spring-mass systems</u> and pendulums (see lesson extensions and resources).

4. Instruct students to individually brainstorm ideas and apply what they have learned about:
   a. Spring-mass systems and pendulums.
   b. The available resources (tools, materials, time), criteria, and constraints.
   c. Alternative methods to accomplish the design tasks.

5. Have students list or sketch their own ideas in their notebooks. Then have them choose their best idea to use as an individual design plan. Remind students that sketches should be large, neatly drawn, and clearly labeled showing dimensions and materials.

6. Students should then meet with their team and share plans, explaining how they expect their design to solve the problem. Each team should decide on a 'final' group design, which can be a combination of ideas or a specific design from an individual within the group. Have each team member sketch the final design. Each of the students' sketches should be detailed to allow anyone else to construct the design by looking at the drawing.

SHARE AND DEVELOP A PLAN

7. Student teams will construct their design and test the design when completed; taking notes about what is working well and what could be improved.

CREATE AND TEST

8. Each group presents their design to the whole class and then demonstrates their prototype for the class.

COMMUNICATE RESULTS

GATHER FEEDBACK

9. After all groups have presented, each student will answer the following questions in their notebook:

   How effective (good) was your design? How do you know?
   What would you change in your design? Why?

10. If time permits, encourage students to redesign based on test results. If time does not permit, instruct students to sketch a new design in notebook based on change mentioned above. Remind students to note any changes if design is modified from the original sketch.

IMPROVE AND RETEST

Assessment

The following are possible sources of formative and summative assessment:

Formative assessment:

- Review students' investigation sheet and students' entries in their design notebooks (design plans, results from testing)

Summative assessment:

- Assess students' investigation report sheet and final design plans.

Lesson Extensions and Resources

Web Resources:

Visualizing Mechanics: Spring-Mass System
http://www.youtube.com/watch?v=lZPtFDXYQRU

Inverted Pendulum example – Metronome
https://www.youtube.com/watch?v=gsJEMH_emBM

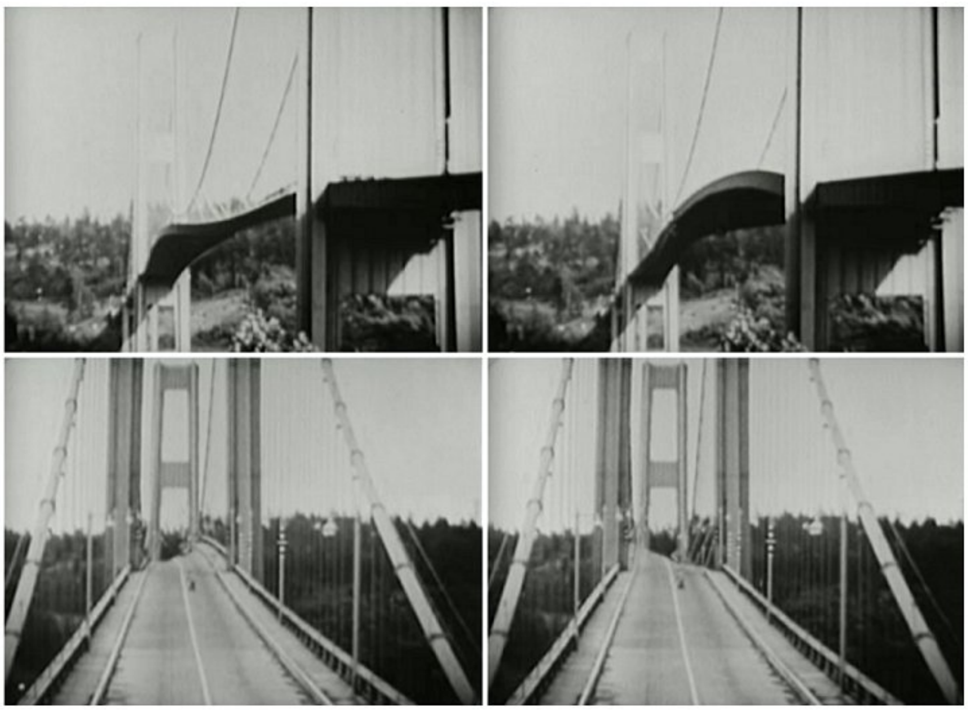
Pendulum with string
https://www.youtube.com/watch?v=02w9lSii_Hs

Vibrations on a string (helps with Tacoma Narrows bridge)
https://www.youtube.com/watch?v=jvsoDJSaq1Q

Real World Example: Tacoma Narrows Bridge

The original Tacoma Narrows Bridge was built to connect the city of Tacoma, Washington to the Kitsap Peninsula and spanned the Tacoma Narrows straight of Puget Sound. Construction of a new style of bridge design began in November 1938 and the bridge opened to the public on July 1, 1940. While the floor section was being installed towards the end of construction, sometimes the bridge began to vibrate strangely, making vertical wavelike motions in which the bridge moved ~ 1 1/3 ft above and below its resting position (see below images). Soon after its official opening, the bridge was nicknamed 'Galloping Gertie' due to this movement, which was somewhat similar to driving on a roller coaster. In mid-July 1940, Professor F.B. Farquharson, an engineering professor at the University of Washington, and colleagues began to study this problem to determine how to reduce the movement of the bridge. Over the next few months, they built and tested a scale model, and based on these tests, several modifications to the real bridge were recommended and made.

Unfortunately, these initial modifications did not work. Additional experiments suggested creating holes in the side girders would prevent the wind from pushing and pulling on the bridge and allow the wind to move through the bridge freely. Installation of wind deflectors was approved by the Washington Toll Bridge Authority in the beginning of Nov. 1940 and work was to start in the upcoming weeks. However, on Nov. 7, 1940 ~42 mph winds blew steadily down the Tacoma Narrows straight. At ~9:45 AM, the bridge began to vibrate in the familiar vertical wavelike motions and Professor Farquharson and colleagues came to collect information for the final wind deflector design and filmed the bridge. By ~10:15 AM, the bridge began to twist from side to side (laterally) in addition to making the vertical waves from the force of the wind, eventually causing the bridge to collapse at ~11 AM.



Four screen shots of a movie taken by an unknown photographer of the Tacoma Narrows Bridge. The time difference of the left and the right images is only a few seconds.

Footage of the Tacoma Narrows Bridge Collapse:

http://www.youtube.com/watch?v=lXyG68_caV4

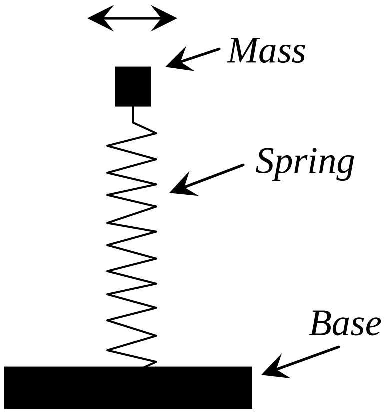
10 min historical documentary on the Tacoma Narrows Bridge:

http://www.youtube.com/watch?v=ASd0t3n8Bnc

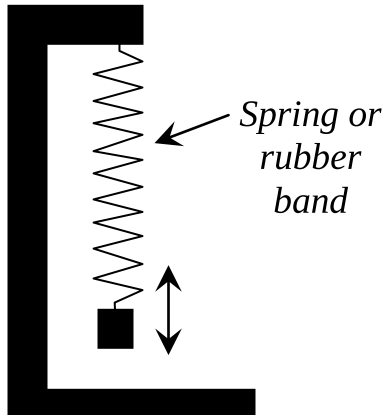
History of the Tacoma Narrows Bridge, University of Washington Libraries:

http://www.lib.washington.edu/specialcollections/collections/exhibits/tnb

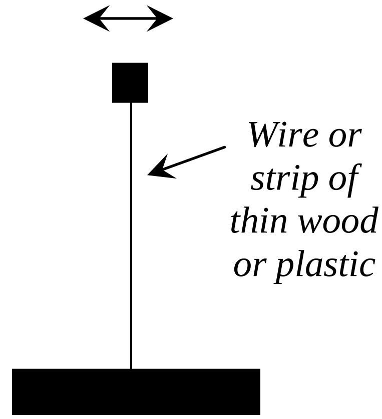
Teacher's Resource: Simple Vibration Sensor Designs
(Most designs can be made to detect vertical or horizontal vibrations)



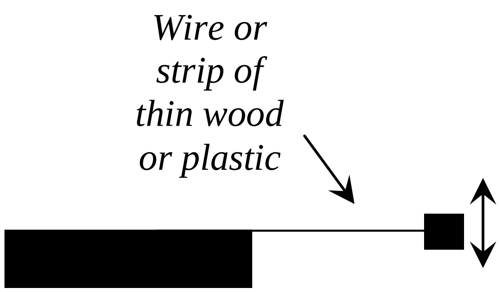
Inverted Pendulum



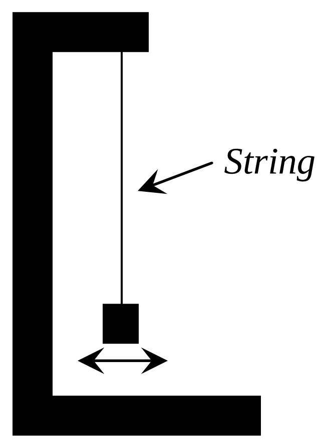
Vertical Spring



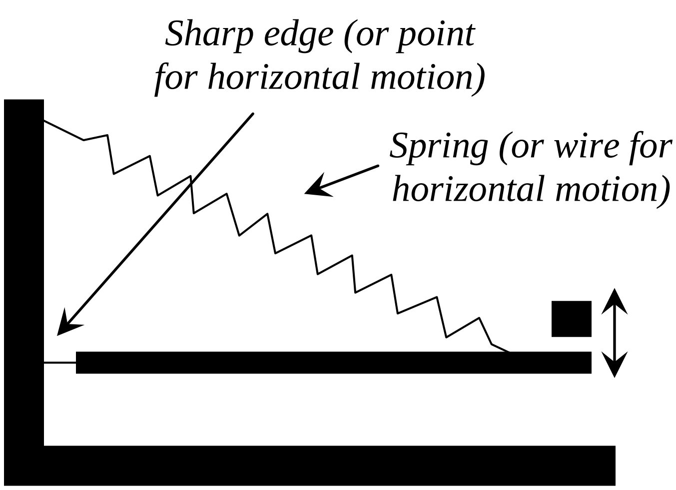
Inverted Pendulum



Vertical Motion Bending



Pendulum



Horizontal Pendulum

Design Activity

Student Resource

Image Obtained from: http://congeothia.com/wp/wp-content/uploads/2014/09/Bridge-Construction.jpg

Design Challenge: *"Can you build a device that senses vibrations?"*

The Indiana Department of Transportation (INDOT) has plans for constructing a new bridge in Tippecanoe County and has contracted the Lafayette Engineering Corporation (LEC) to design and install a device to sense vibrations in the bridge. INDOT bridge engineers need to be able to sense both the instance and magnitude of these occurrences in the event of a natural disaster (e.g., an earthquake or tornado) or a collision (such as a tractor-trailer striking the bridge from underneath).

As part of the Lafayette Engineering Corporation, you and your team have been delegated this design task. You will be provided with a variety of materials from which to construct your sensor, so choose wisely. You will need to first sketch your design, next select the proper materials, and then construct the sensor.

The sensor should be:

- Small enough to be attached to the bridge
- Able to both detect and distinguish between small and large vibrations
- Constructed from the materials provided