Bringing Nobel Prize Physics in the Classroom

The Pendulum and Gravitational-Wave Detector

Μυρτώ Αποστόλου, Barbara Finato, Eva Paňková, Wilson Canelo Peňa, Moulay-Badr Attaiaa

Paris Centre for Cosmological Physics
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Background information for teachers

Overview of this lesson pack:

Name of the activity	Vibration isolation with a pendulum suspension.
Topics introduced	pendulum, interference, vibration isolation
Curriculum Connection	COLOMBIA: The aim of this activity is to inspire students to study physics by a lab practice related to Gravitational waves & pendular motion introducing and introducing some of the STEAM approach. Also, it encourages students to work collaboratively and to promote critical thinking. GREECE:The connection can be made with the modules : Force and interaction . Gravity ,Oscillations-Mechanical waves . The activity can be taught in secondary school and the aim is to make students approach modern physics in a hands-on way and get pleasure and fun from the activities. SLOVAKIA: This activity can be taught to middle school students when covering light module, force and motion module, energy and work module. The activity supports the idea of learning by doing connected with inquiry based learning while students interact with content by simulations and their own crafting and gathering data. Students develop graphing and investigation skills ITALY: This activity can be taught to middle school students learning force and space module. Students learn about graphs, dependent and independent variables /hands-on and simulation Students develop critical thinking and interdisciplinarity , they make investigation using IBSE method
Reference Demonstrator	The Pendulum: From Cooking Spaghetti to a Gravitational Wave Detector
Age of students	>12
Duration	90 -120 min

Overview of this lesson pack:

Type of activity	Practical hands on activity Investigation using simulation
Description of activity	Teacher activities: The teacher will engage the students the teacher will present the main topic using videos the teacher will guide the students during investigation Student activities: the students will follow the tutor ´s instruction, investigate through manipulation with simulation, real models the students will gather and analyse the data the students will discuss ideas within the groups, based on results they will make conclusions
Equipment requirements	PC, internet connection, thin wires, balls, smartphone, Lego kit (bricks and We-Do2 kit)
Prior knowledge for students	graph, force, energy concept.

Background and overview of “The pendulum: from cooking spaghetti to a gravitational-wave detector“ demonstrator:

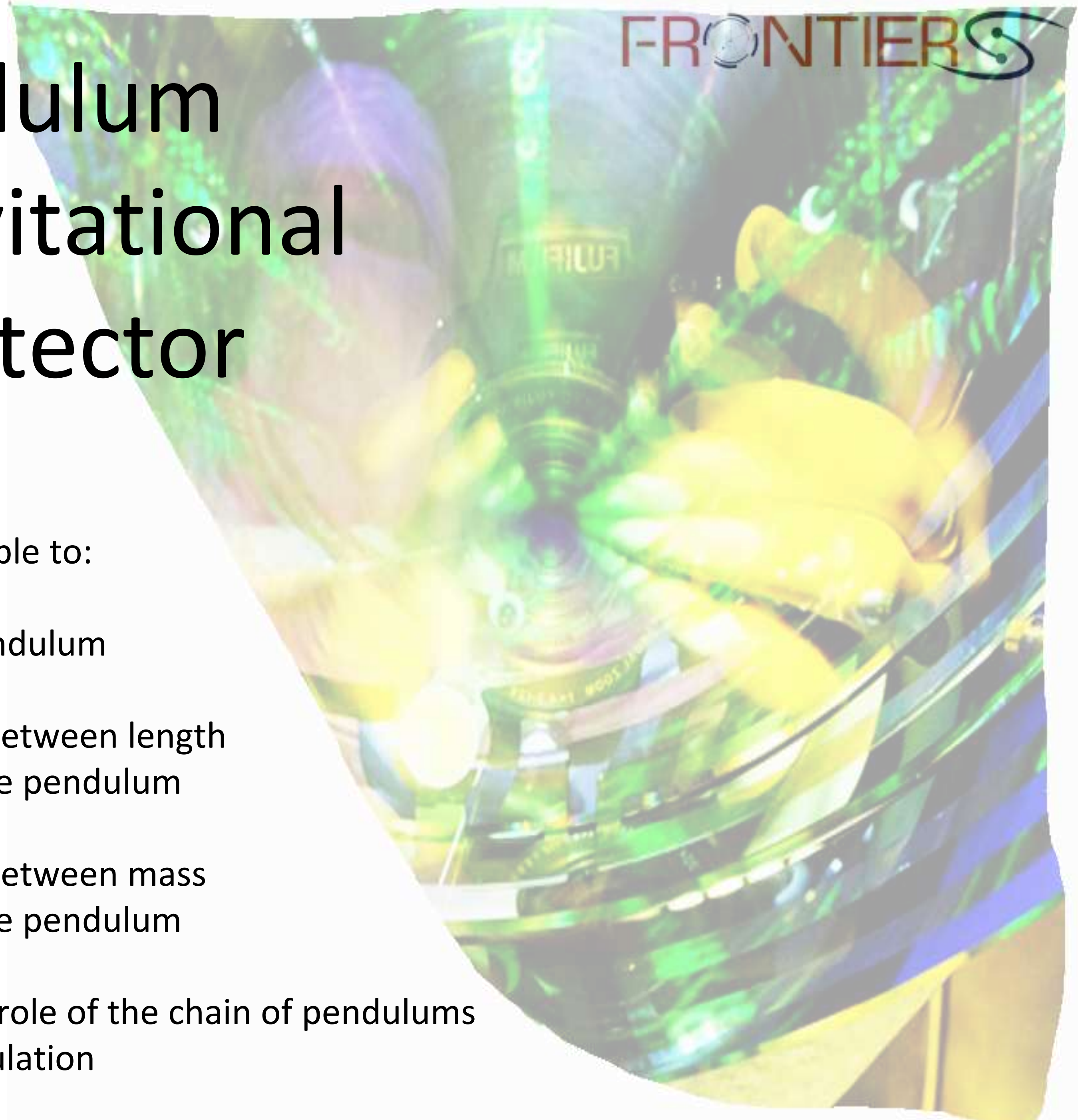
This demonstrator introduces the concept of the pendulum, a very simple mechanical system, but a powerful tool to give deep insights in physics phenomena such as oscillations, gravitation, vibrations transmission, the concepts of speed, acceleration, energy, resonance.

In LIGO and Virgo the pendula are used to reduce the transmission of ground vibrations to the instrument to a level compatible with the extreme sensitivity required by these detectors: a displacement of a billionth of a billionth of a meter over 4 km.

Presentation for students

Teacher guidelines can be found in the notes attached to each slide

The pendulum and gravitational wave detector

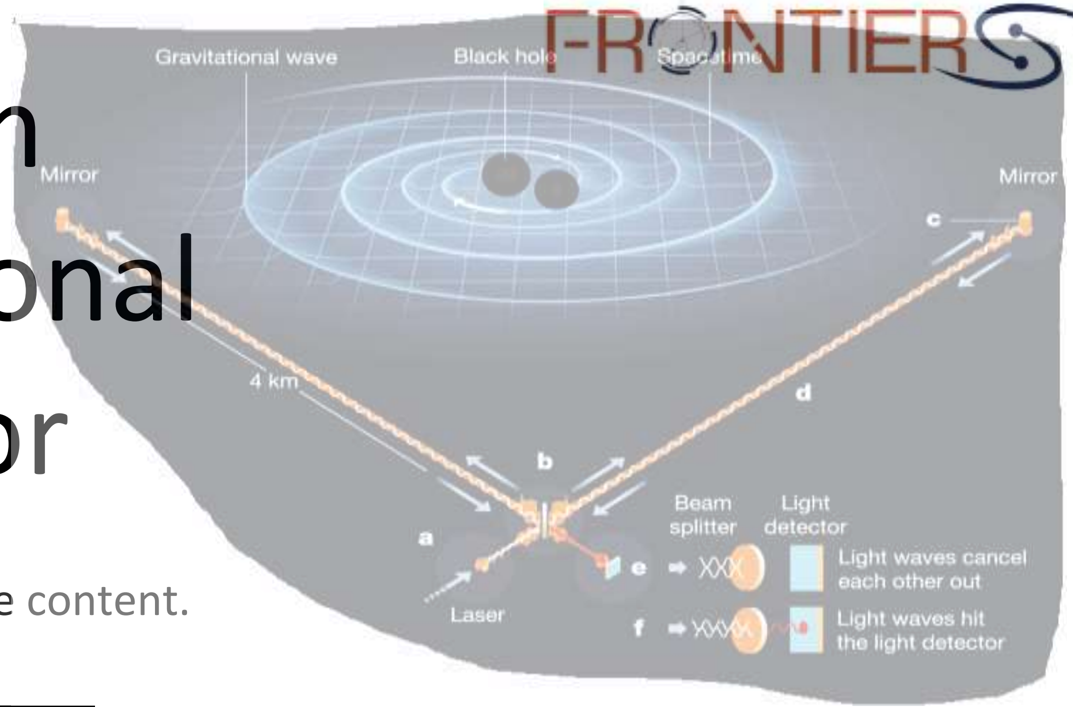


Learning intentions:

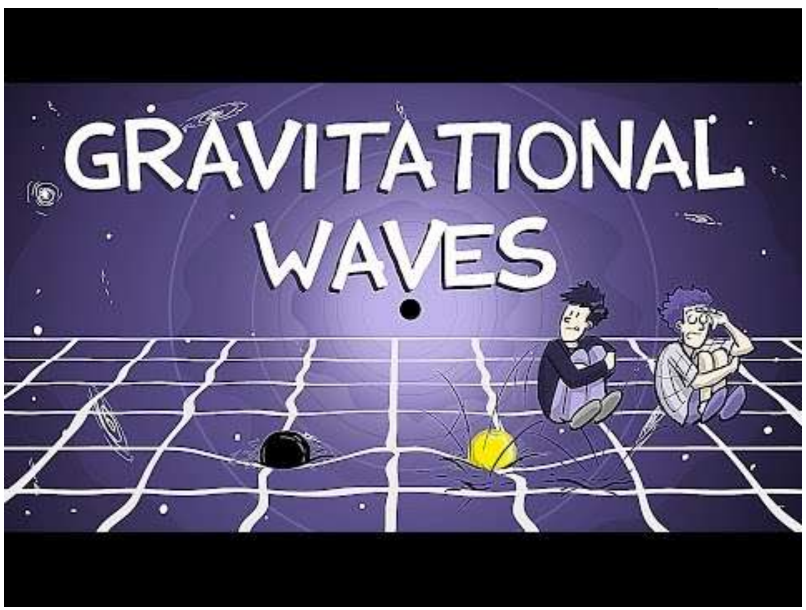
Students should be able to:

- Describe the pendulum
- Clarify relation between length and period of the pendulum
- Clarify relation between mass and period of the pendulum
- Understand the role of the chain of pendulums in vibration simulation

The pendulum and gravitational wave detector



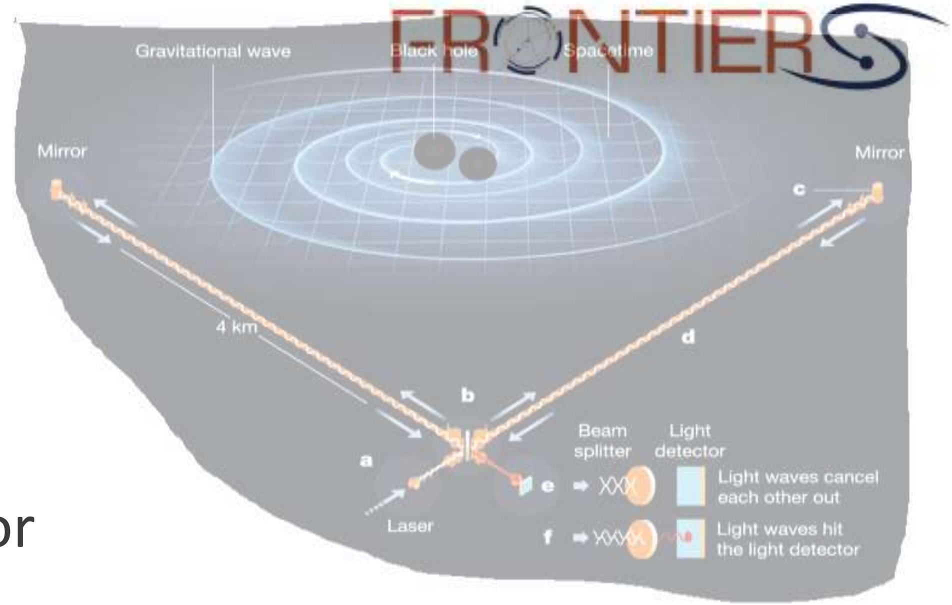
Orienting: Provide contact with the content.

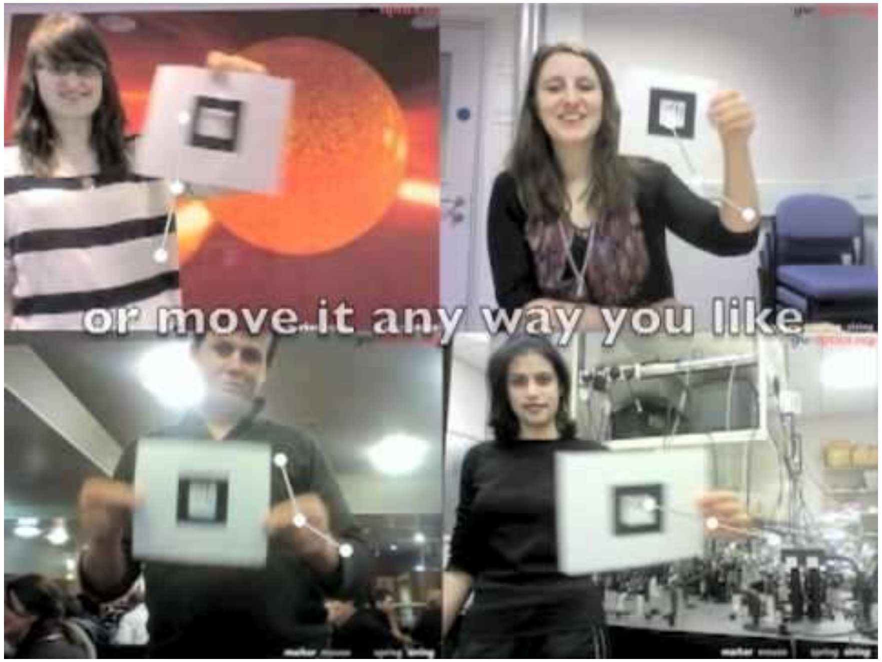


The mirror as a pendulum.

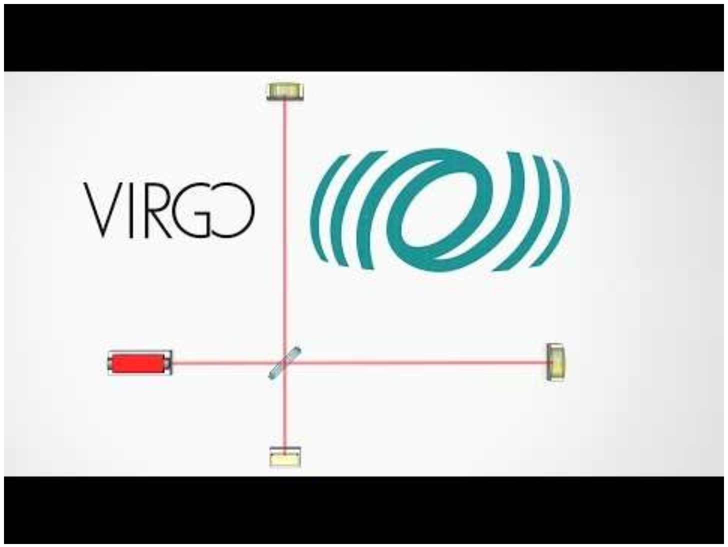
The main idea of the vibration isolation is to suspend the mirror as a pendulum.
Ground vibration are faster than the natural period of oscillation of the pendulum (called "resonance").
Suspending the mirror as a pendulum makes the **mirror much quieter** than the ground.

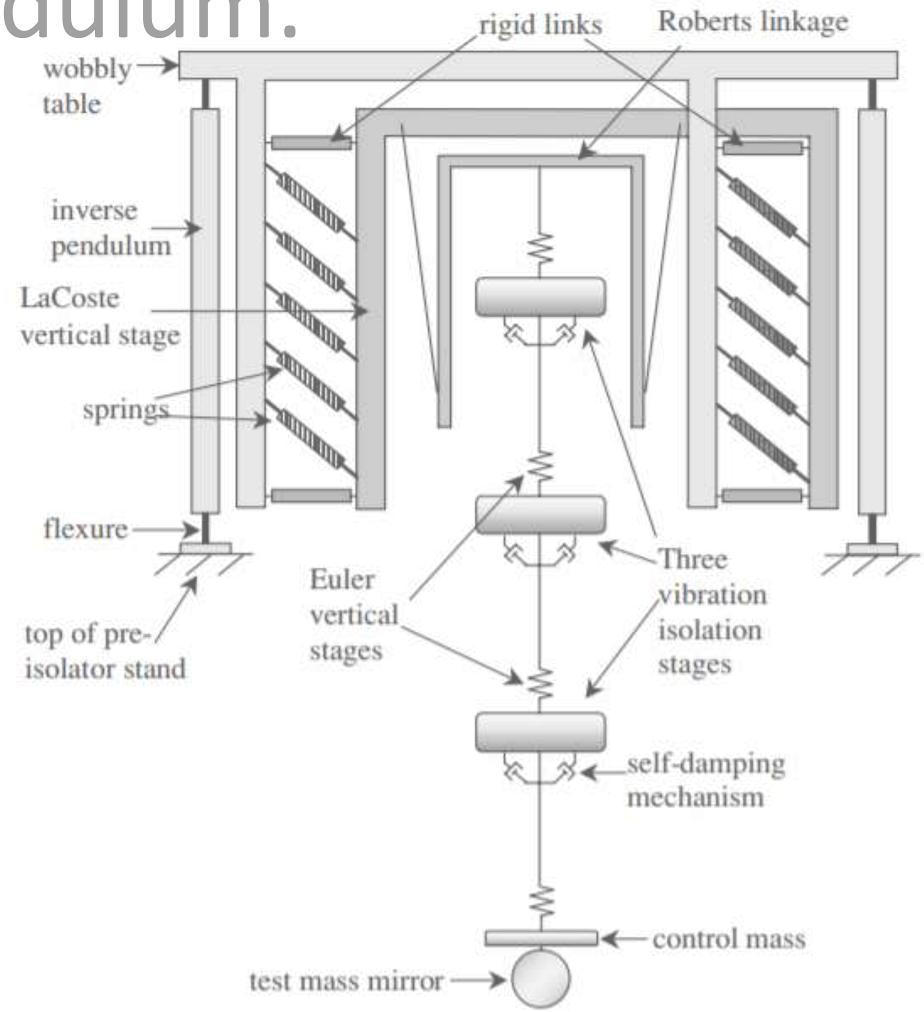
[Augmented Reality Pendulum]





The mirror as a pendulum.





[Article page 6, part 2.6. Vibration isolation and control]

Virgo & LIGO: Joint Detection of Gravitational Waves

LIGO (Laser Interferometer Gravitational-wave Observatory) and **Virgo**, giant laser interferometers announced their **joint detection** of a gravitational wave signal from the coalescence of two black holes in September **2017**.

Virgo has been designed and built by a **collaboration** between the French Centre National de la Recherche Scientifique (**CNRS**) and the Italian Istituto Nazionale di Fisica Nucleare (**INFN**).

Virgo is now operated and improved in **Cascina**, a small town near Pisa on the site of the European Gravitational Observatory (**EGO**), by an **international collaboration** of scientists from France, Italy, Belgium, The Netherlands, Poland, Spain, Germany and Hungary.

What is the relation between simple pendulum and LIGO?

Hypothesis generation:

Do two pendula of the same mass have the same period?

Do two pendula of the same length have the same period?

How more pendulums relate to reduction the vibration noise transmission?

How to *isolate* LIGO from Seismic Vibrations while keeping it sensitive to measuring Gravitational Waves?

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In one minute, an animation can explain something, which usually requires very many words.

Instruction:

The students will be asked to draw the consecutive positions of an object of their choice (e.g apple),

to take pictures of their drawings to make the oscillation appear.

After that, they will open a video editing program (e.g windows movie maker),

they will insert a title, their photos and a sound.

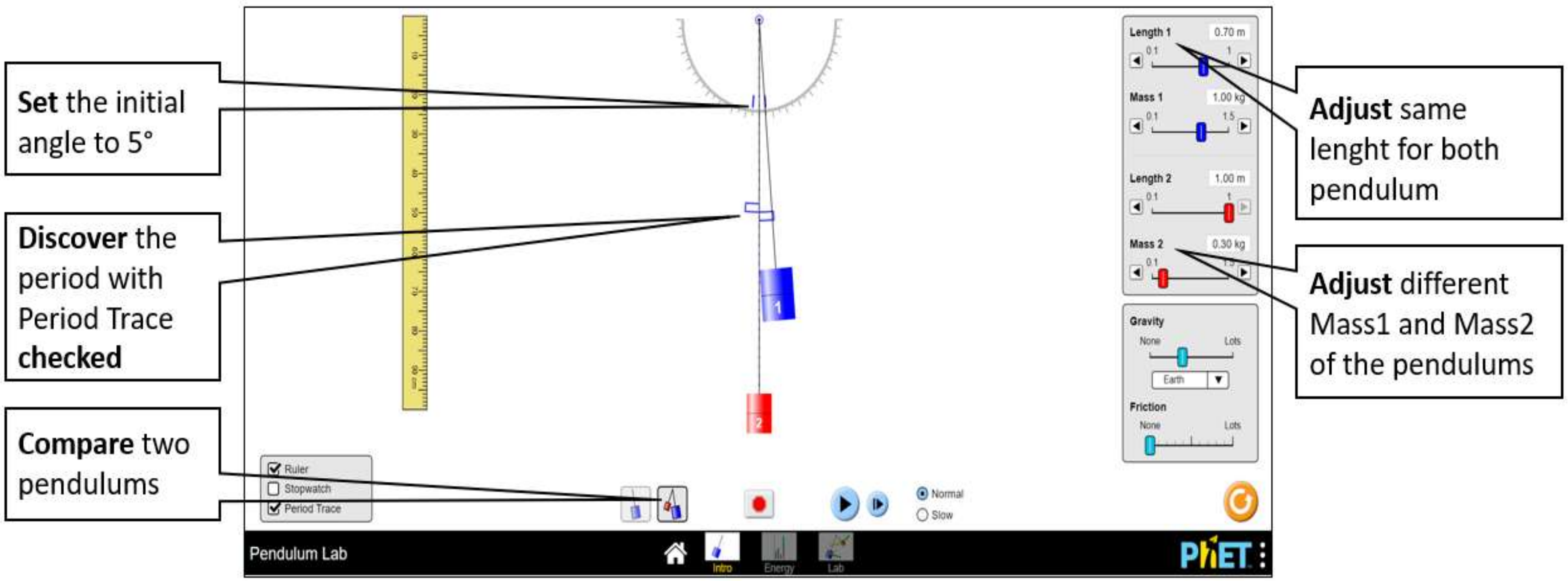
The properties of a simple pendulum

Perform investigation:

Question 1:

Do two pendula of the same **mass** have the same period?

Investigate and **fill** the table on the next slide.



Investigation:

Relation between mass of pendulum vs. period of oscillation

Instruction:

Complete data table according your observation.

Angle °	Length (m)	Mass (kg)	Period (s)
5	0.8	0.1	
5	0.8		
5	0.8		
5	0.8		
5	0.8		
5	0.8	1.5	

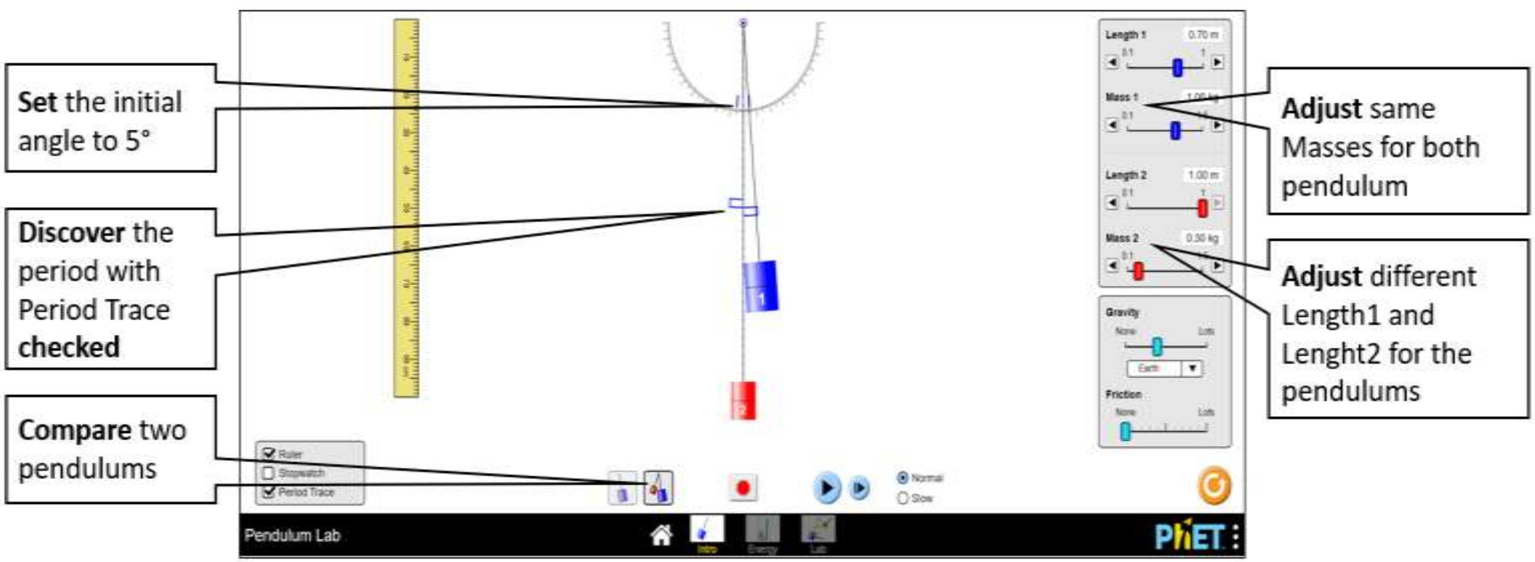
The properties of a simple pendulum

Perform investigation:

Question 2:

Do two pendula of the same **length** have the same period?

Investigate and **fill** the table on the next slide.



Investigation:

Relation between length of pendulum vs. period of oscillation

Instruction:

Complete data table according your observation.

Angle °	Mass (kg)	Length (m)	Period (s)
5	1.0	0.3	
5	1.0		
5	1.0		
5	1.0		
5	1.0		
5	1.0	1.0	

Hands on activity
Complete data table for each part suggested.

Part 3: Relation between angle vs period (a length & and a mass must be chosen to be constant)

Angle °	Period T (s)
3	
6	
9	
12	

The idea of using data from the data tables is that students observe results and identify what variables have a direct or indirect relation. Also, it can be asked students to make a plot for each data table so they can asses their observations.
Note: for each trial, it is asked students to calculate period by measuring time for a certain number of "oscillations". For example, they can estimate period for ten "oscillations"; if ten oscillation last 10 seconds, then period = one second. It's just an example!

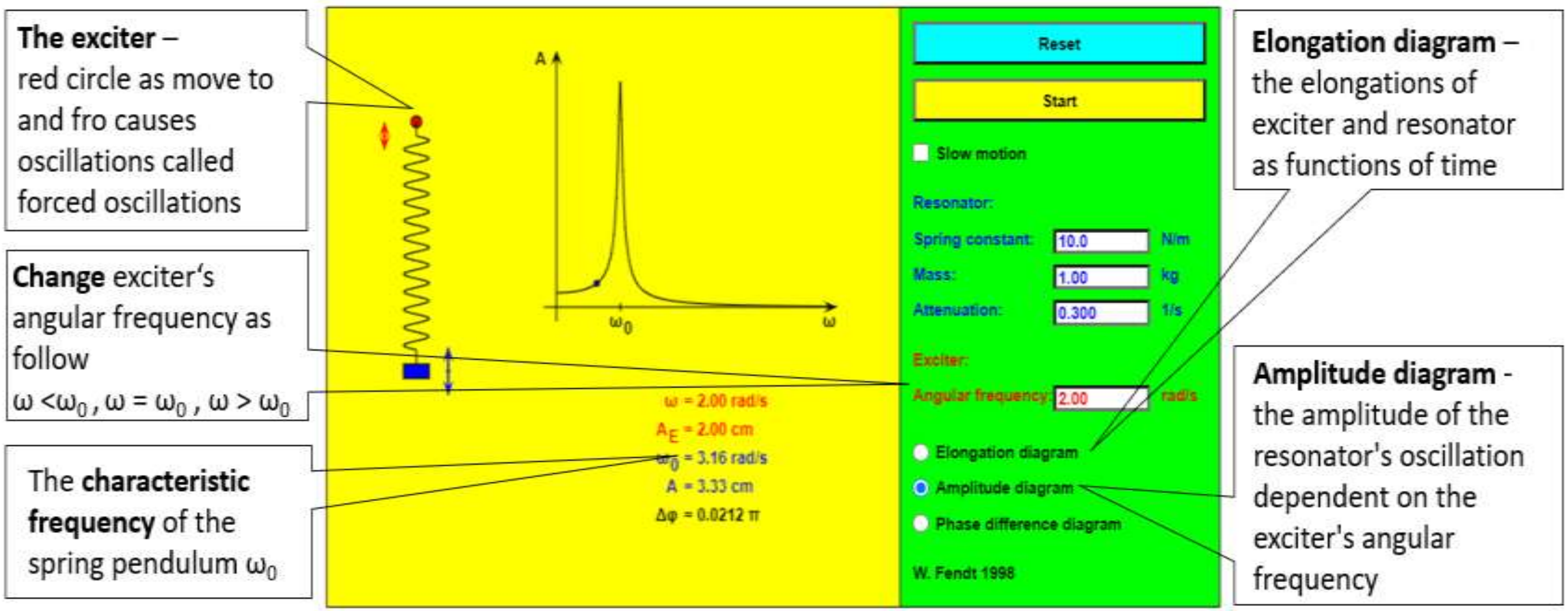
The properties of the series of the pendulums

Perform investigation:

Question 3:

How more pendulums relate to reduction the vibration noise transmission?

We will investigate the amplitude of the resonator's oscillation dependent on the exciter's angular frequency ω.



Quadrupole pendulum inspired by Ligo and Virgo

Material:
a table, Lego Bricks, string, 2 caps, water

Instruction:
-build a pendulum as shown in the picture
-observe what happens when you knock on the table

Compare your observations with pendulum behaviour at video

https://www.youtube.com/watch?v=hc7Wf-DozZ4

Let’s build a cascades of pendulum

Material:

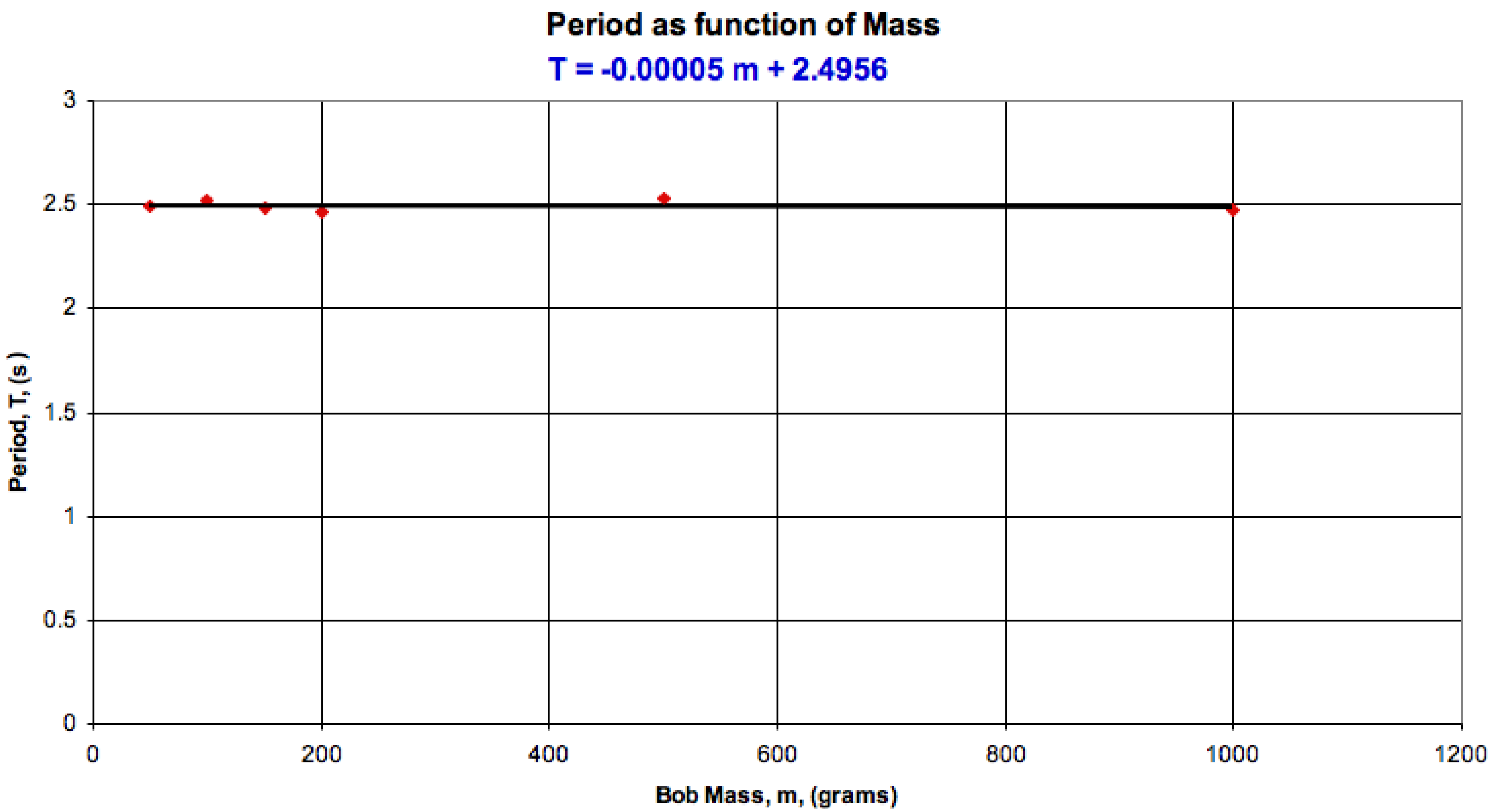
a support (floor lamp, a shelf)
a piece of string
washers (pendulum),
accelerometer sensors (micro:bit, arduino, smartphone app)

Instruction:

- the masses (washers, pendulums) are attached every 20 cm by piece of string
- attach sensors (smartphones) to washers
- measure horizontal acceleration

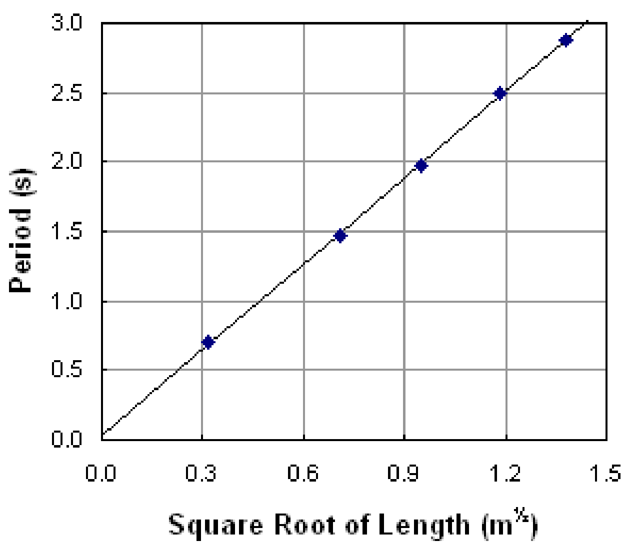
Analysis and interpretation

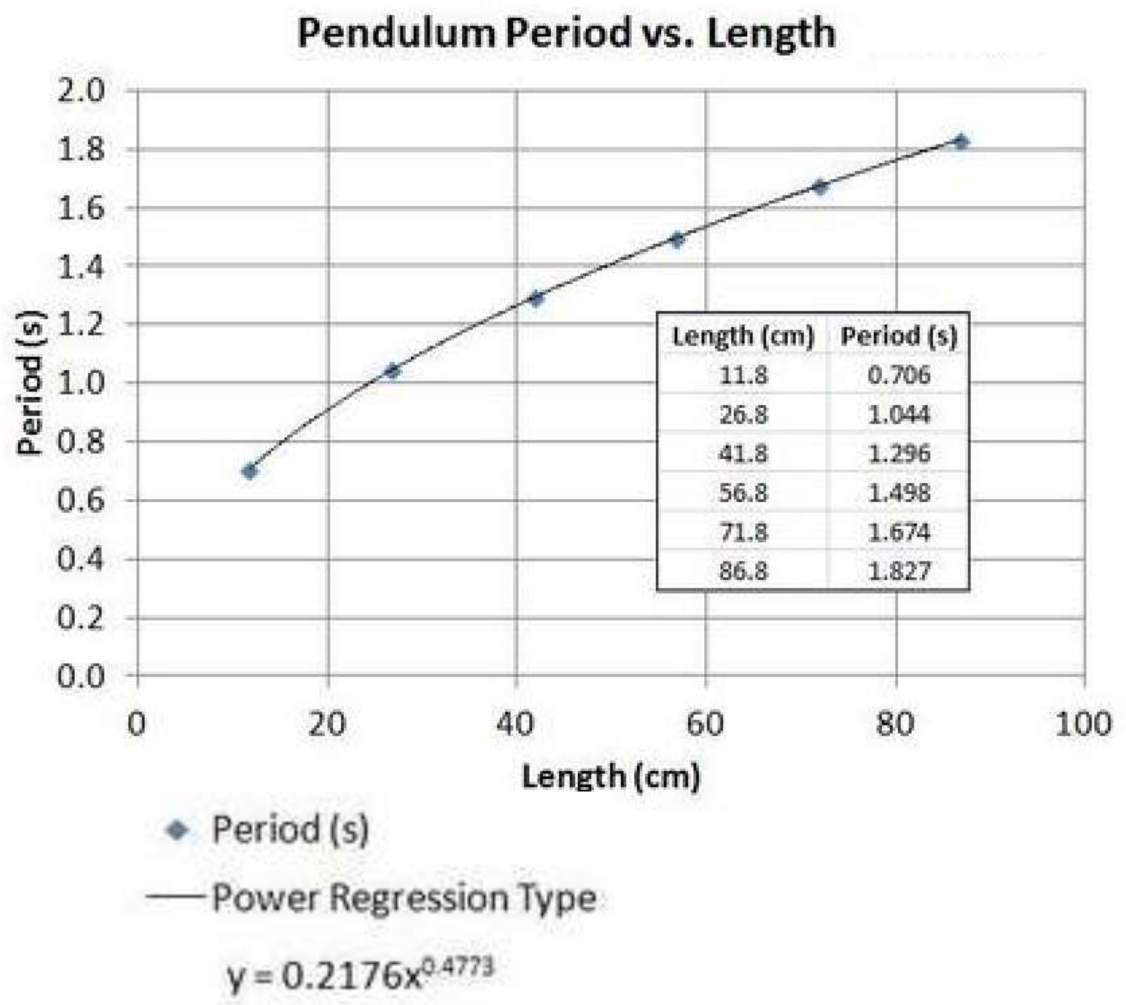
Do two pendula of the same **mass** have the same period?



Analysis and interpretation

Do two pendula of the same **length** have the same period?

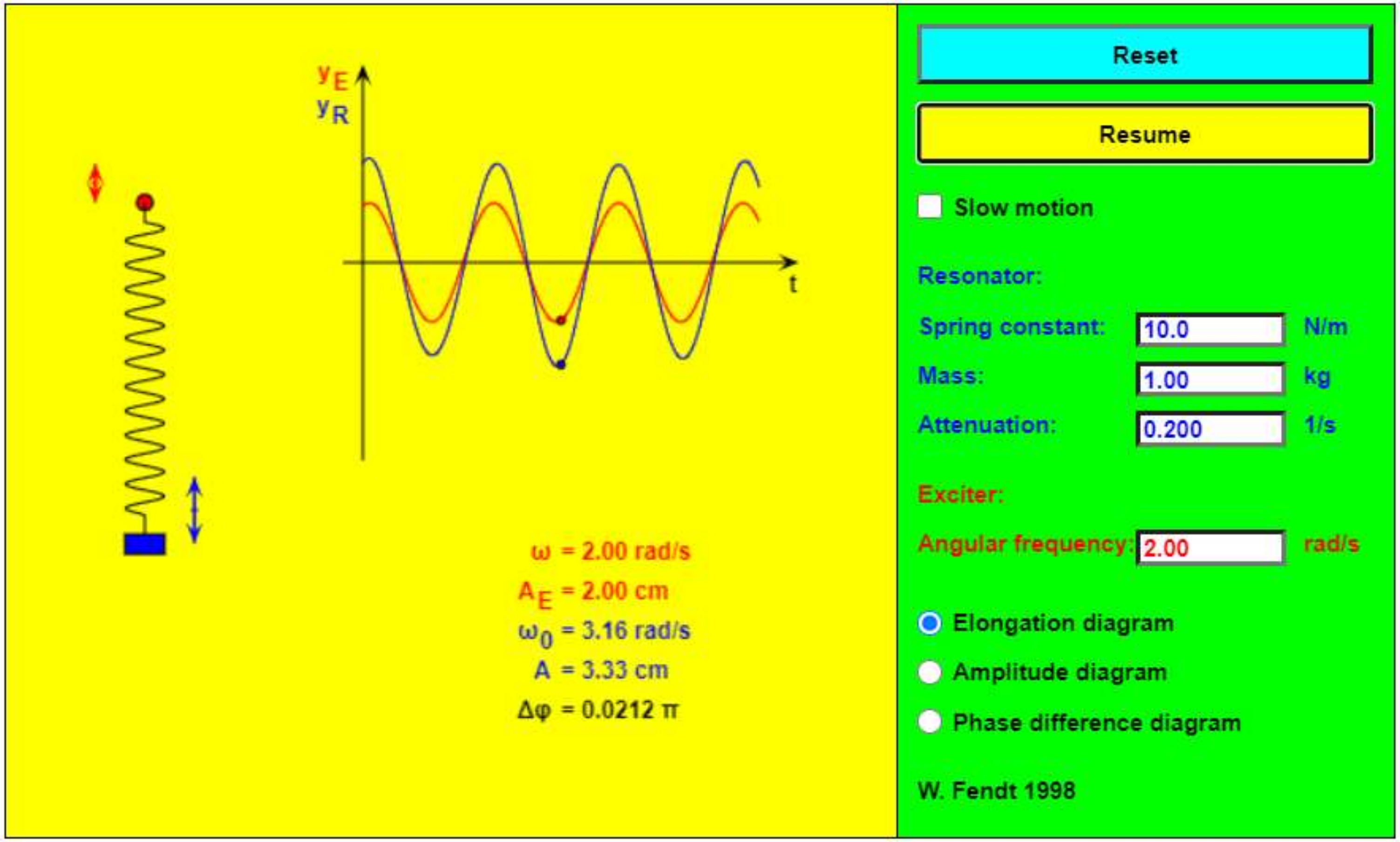




Length (cm)	Period (s)
11.8	0.706
26.8	1.044
41.8	1.296
56.8	1.498
71.8	1.674
86.8	1.827

Analysis and interpretation

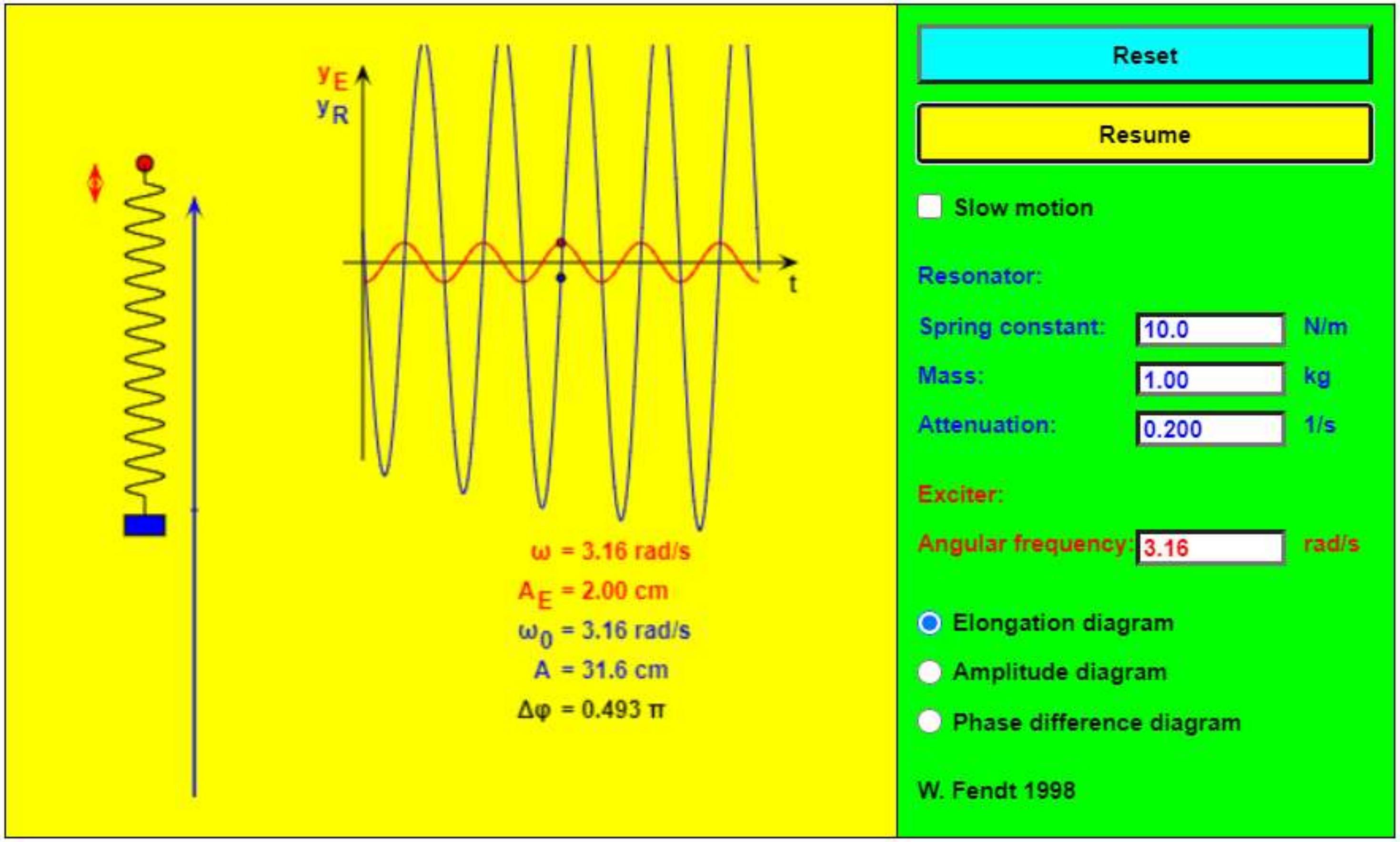
How more pendulums relate to **reduction** the vibration noise transmission?



Exciter angular frequency is **less than** characteristic frequency of the pendulum $\boldsymbol{\omega < \omega_0}$

Analysis and interpretation

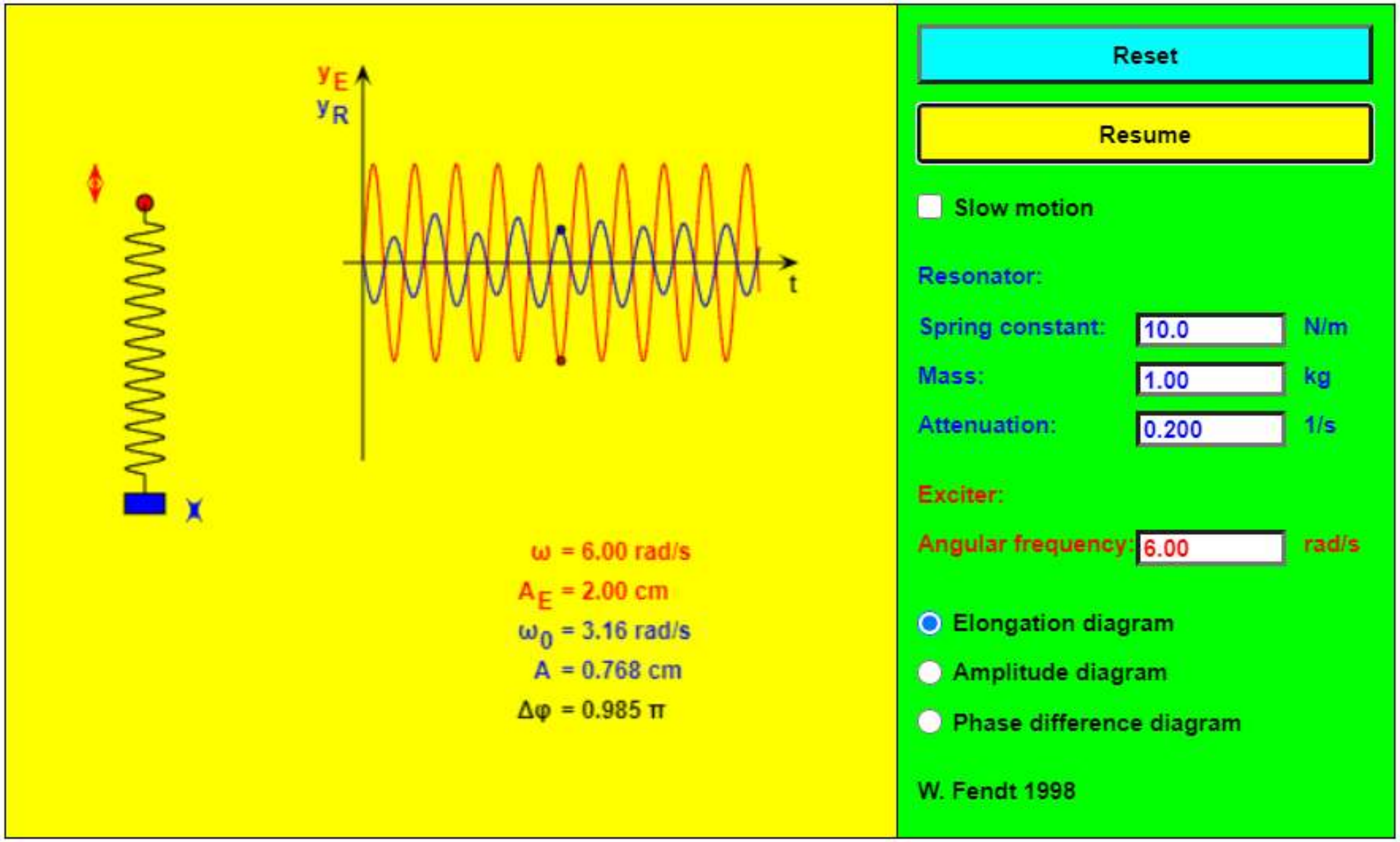
How more pendulums relate to **reduction** the vibration noise transmission?



Exciter angular frequency **is equal to** characteristic frequency of the pendulum $\boldsymbol{\omega = \omega_0}$

Analysis and interpretation

How more pendulums relate to **reduction** the vibration noise transmission?



Exciter angular frequency **is higher than** characteristic frequency of the pendulum $\boldsymbol{\omega > \omega_0}$

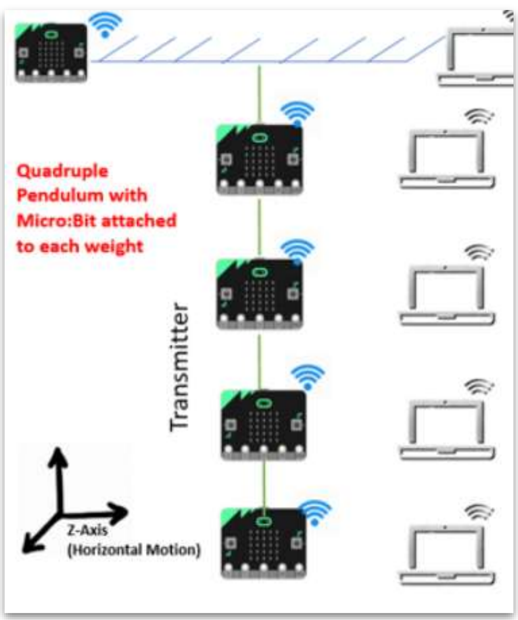
Analysis and interpretation

An explanation:

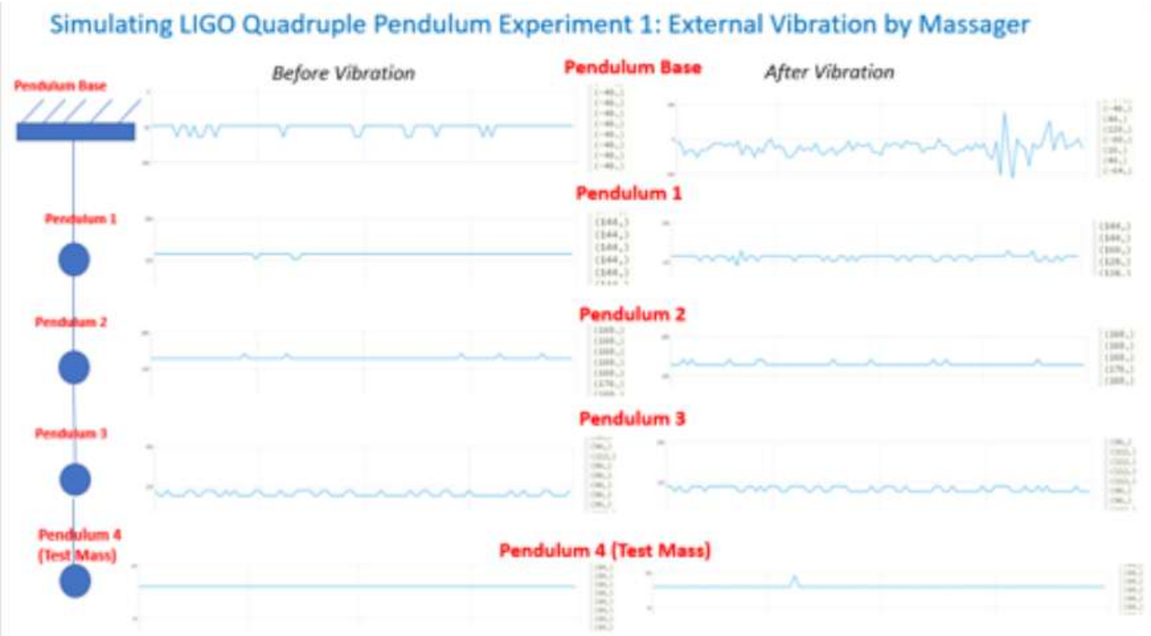
The most top micro:bit measures induced vibrations

The subsequent four micro:bits measure the acceleration of each pendulum

The bottom most pendulum (Pendulum 4) measuring acceleration of the test mass.



sensors set up, operate WIFI



a graph showing the vibrations

Which apps can you use to measure and elaborate data?

Science Journal https://sciencejournal.withgoogle.com/,
Science Journal transforms your device into a pocket-size science tool that encourages students to explore their world.
You can use your smatphone as a device to measure these changes in motion—an accelerometer.
https://sciencejournal.withgoogle.com/experiments/getting-started-with-motion/

Geogebra https://www.geogebra.org/

Desmos https://teacher.desmos.com/?lang=it

They are a free program that can be used as a graphing calculator, dynamic geometry package

Graphs

pendulum’s period / pendulum’s length: why do you linearize it ?

When you draw a graph, you plot the independent variable – the variable that the experimenter controls – on the x-axis, and the dependent variable – the variable that responds when the independent variable is changed – on the y-axis

The dependent variable would be the pendulum’s period, and the independent variable would be the pendulum’s length. Controlled variables would include the pendulum’s mass and the angle at which the pendulum was launched

You could have some problems graphing the collected data, so you will have to linearize the graph

Linearizing a graph means modify the independent and/or the dependent variables so a straight line appears

In your case you plot a graph in which the square of the periodo is on the y-axis and the length of the pendulum is on the x-axis

https://www.wtps.org/cms/lib8/NJ01912980/Centricity/Domain/887/AP1Summerpart2GraphMeth.pdf

Glossary

Graph: is a way to present data from an experiment.
Constant : a quantity whose value remains the same.
Variable : is a changing quantity that the experimenter controls.
Independent variable: is the quantity that emerges from the control variable in an experiment.
Period: The period (**T**) of a wave is the time for a bob's pendulum on a medium to make one complete vibrational cycle. It has the second (s) as its unit of measurement.
Frequency: In the inverse of period. $\boldsymbol{f} = 1 / \mathbf{T}$. Hertz (Hz) is its unit of measurement.
Amplitude: The maximum displacement or distance moved by a bob's pendulum measured from its equilibrium position.

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Thank you for your attention!