

SIMPLE EXPERIMENTS FOR HIGH SCHOOL USING A DISPLAY INTERFACE AND A SYSTEM OF COUPLED PENDULUMS

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Abstract. This paper presents an experimental approach using a system of coupled pendulums by a thin rod. The interest of students and their active participation in performing experiments can be increased. Some experiments can be simplified by using modern technology equipment. For this, we used a projector for viewing the process on big screen: experimental data collection using a motion sensor, graphical representation and analysis of the results in real time, using the SPARKVue interface on an iPad. One of the themes of the experiment was to investigate how the time of energy / motion transfer between the two bobs varies as a function of the height of the coupling rod. For this, during experiments, students were asked to use timers of their smartphone to measure time, for different positions of the coupling rod, and record the data in the table on the worksheet. From the graph, we deduce the g value and confirm the distance from the bob to the support. Also, using the SPARKVue display interface for the motion of one bob from this coupled pendulums model, easily generated the fascinating Lissajous figures. They involve two perpendicular harmonic motions, one of the components involves time-varying amplitude, a feature that not present in the production of most Lissajous patterns.

Key words: coupled pendulums, connecting rod, small oscillations, beat period, beat frequency, display interface, PASCO Scientific, motion sensor, AirLink, iPad, SPARKVue App.

1. INTRODUCTION

Scientific research literature findings show that the oscillatory motion can be studied experimentally by classical method [1, 2], virtual method [3, 4] and the method of acquisition of signals generated by various sensors during its oscillation [5, 6].

Experimental approach applied to this study uses acquisition of signals generated by a motion sensor and interactive lecture demonstrations method, useful for students and helps to understand new material. Using application of interactive

lecture demonstrations, students are motivated to be not only passive observers, but also active participants of education process. The data are displayed in graphical form in real time, so that students get immediate feedback and see the data in an understandable form that can be discussed. Students, who were studying in application of interactive lecture demonstrations group, positively valued employment of interactive demonstrations in learning of physics. They acknowledged that their effectiveness and interest in subject has increased [7].

The experimental approach uses a pair of coupled pendulums by a rod of negligible mass, what offer an interesting study of coupled oscillatory motion. The SPARKVue display interface installed on iPad with one Motion Sensor connected by AirLink device, via Bluetooth, to the iPad, created very powerful system for collection, analysis and display of demonstration data. The associated software is easy to use and allows the experimental data to be displayed as graphs and tables. It provided to integrate modern science tools into physics teaching and made it possible to prepare and carry out interactive demonstration with a maximum of technical comfort. Also, all these devices are increasingly demanded by digital generation of students. They greatly encourage the study and it is perceived as a significant increase in students' motivation to engage in scientific issues [8].

The objective of this approach: understanding and teaching the concepts of coupled oscillation motion chapter by science class of high school students.

In order to transform the student in an active person which, guided by teachers, discovers and scrutinizes new knowledge territories, there are new teaching strategies in agreement with student's learning manners:

- the lesson has as a starting point certain student's experiences, and embraces questions and activities that involve the student;
- as part of the lesson, one uses a combination of activities that tackle different learning manners that the student prefers: visual, auditory, practical;
- the lesson involves an active participation of the student in the learning process, through accomplishing experiments, simulations and problems by means of a computer [3].

Differentiated instruction according to the student's readiness and learning profile can lead to a significant increase of the efficiency in learning Physics and implicitly to an increase of the interest in and motivation for the study of this subject.

Quantitative experiments play a special role for relevant teaching and learning, because they can serve to support the construction of new concepts and new relations between concepts (laws) on the basis of concepts already known ones [9]. In such experiments, a new concept or law is always constructed sequentially, starting from those that already exist and which also provide the basis for an experiment's design and interpretation [10].

2. EXPERIMENTAL SETUP

The experimental device consists of two identical simple pendulums, horizontally coupled with rigid thin rod (Fig. 1). The strings of pendulums have same length L and are coupled by a thin horizontal rod at distance h from the bobs (Fig. 2). The distance h can be easily varied.

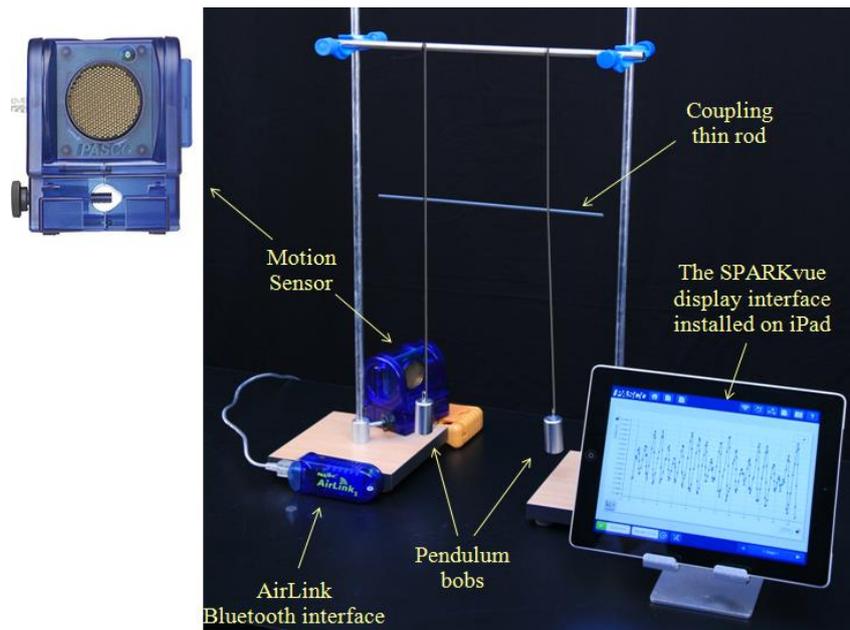


Fig. 1 – The experimental setup and equipment: coupled pendulum system with thin rod, AirLink Bluetooth interface between motion sensor and iPad and SPARKvue app display interface. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

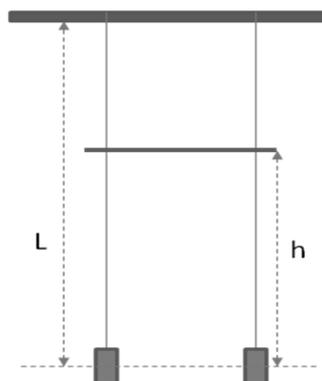


Fig. 2 – A coupled pendulum setup: same length L of both pendulums coupled by a thin horizontal rod at distance h .

3. NORMAL MODES IN-AND OPPOSITE-PHASE OSCILLATION THEORY

The pendulums may oscillate in any directions, but the coupling is strongest when the bobs move in a plane defined by the equilibrium of the strings. We focus on the small oscillations along x -axis. Two types of stable synchronous motion have been identified (Fig. 3). In normal mode, the pendulums oscillate in phase or in out of phase. For first case, the frequency is that a simple pendulum of L length (Fig. 3a). For second case, the frequency is that a simple pendulum of h length (Fig. 3b).

Considering a simple pendulum of length h and analyzing the force of gravity and the force of the string acting on the bob, also considering small amplitudes, the equation of the motion can be written [11]:

$$\ddot{x} = -\frac{g}{h}x,$$

where x is the displacement of the bob from the fixed end and $\ddot{x} = \frac{d^2x}{dt^2}$.

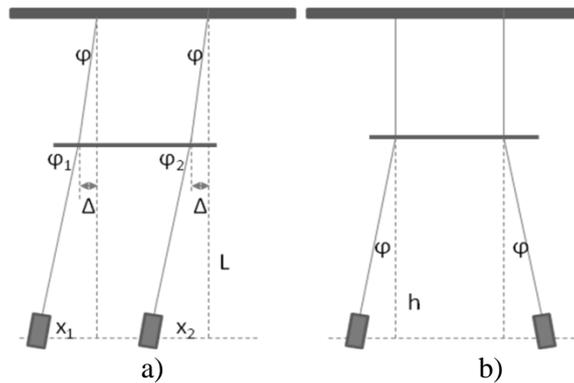


Fig. 3 – In normal mode: a) the pendulums oscillate in phase, the frequency is that a simple pendulum of length L ; b) the pendulums oscillate in out of phase, the frequency is that a simple pendulum of length h .

The forces on a bob of the coupled pendulums are also due to gravity and the string. Analyzing the force in the same way as a simple pendulum, we can write:

$$\begin{aligned} \ddot{x}_1 &= -\frac{g}{h}(x_1 - \Delta) & \ddot{x}_2 &= -\frac{g}{h}(x_2 - \Delta) \\ \ddot{x}_1 - \ddot{x}_2 &= -\frac{g}{h}(x_1 - x_2). \end{aligned} \quad (1)$$

This equation describes the normal mode for which $x_1 = -x_2$ and the radian frequency is

$$\omega_1 = \sqrt{\frac{g}{h}}.$$

Adding the equations for normal mode, we have:

$$\ddot{x}_1 - \ddot{x}_2 = -\frac{g}{h}(x_1 - \Delta + x_2 - \Delta). \quad (2)$$

To the extent that $\varphi_1 \approx \varphi_2$ then $\frac{x_1}{L} \approx \frac{x_2}{L} \approx \frac{\Delta}{L-h}$ and $\frac{x-\Delta}{h} = \frac{x}{L}$.

Equation (2) becomes

$$\ddot{x}_1 + \ddot{x}_2 = -\frac{g}{L}(x_1 + x_2). \quad (3)$$

This equation describes the normal mode for which $x_1 = x_2$ and the radian frequency is $\omega_2 = \sqrt{\frac{g}{L}}$.

If we initially displace only one of the pendulums, $x_1 = A_0$; $x_2 = 0$; $\dot{x}_1 = 0$; $\dot{x}_2 = 0$ at $t = 0$, the solutions of the coupled equations are:

$$x_1 = A_0 \cos\left(\frac{\omega_1 - \omega_2}{2} t\right) \cos\left(\frac{\omega_1 + \omega_2}{2} t\right), \quad (4)$$

$$x_2 = A_0 \sin\left(\frac{\omega_1 - \omega_2}{2} t\right) \sin\left(\frac{\omega_1 + \omega_2}{2} t\right). \quad (5)$$

The frequency (f) and the period (T) of the beats are given by

$$f = \frac{\omega_1 - \omega_2}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{g}{h}} - \frac{1}{2\pi} \sqrt{\frac{g}{L}}, \quad (6)$$

$$T = \frac{1}{f}. \quad (7)$$

In both configurations, the students should observe that, if the pendulums oscillate in these two normal modes, there is no energy transfer from one pendulum to the other [11].

4. RECORDS AND DATA PROCESSING

The experimental approach sets in motion a single bob of the two oscillating pendulums and measure the time interval between two rest positions of the another

one pendulum. The rest position for one of the two oscillating pendulums corresponds to the maximum amplitude or displacement from its equilibrium position, of the other, and vice versa [2].

For this, during experiment, students were asked to use timers of their smartphone to measure the beat period, for different positions of the coupling rod, and record the data in the table on the worksheet (Table 1). Measuring the time interval it was set to 5 full oscillations and then, in order to have a mean time, the measured values are divided to 5. It was important to use a sufficiently long time interval in order to reduce experimental error.

Equation (6) for the beat frequency can be written

$$f = \frac{\sqrt{g}}{2\pi} h^{-1/2} - \frac{1}{2\pi} \sqrt{\frac{g}{L}},$$

where L is known and h can be varied to measurable values with estimated error of 0.1 cm.

Table 1

Associated beat frequency of the position h of the rod

h [cm]	T [s]	$h^{-1/2}$ [cm ^{-1/2}]	f [Hz]
18 ± 0.1	20 ± 0.1	0.235	0.05
16 ± 0.1	10 ± 0.1	0.250	0.10
15 ± 0.1	7 ± 0.1	0.258	0.14
13 ± 0.1	5 ± 0.1	0.277	0.20
12 ± 0.1	4 ± 0.1	0.288	0.25
10 ± 0.1	3 ± 0.1	0.316	0.33
9 ± 0.1	2 ± 0.1	0.333	0.50
8 ± 0.1	2 ± 0.1	0.353	0.50

Plotting f against $h^{-1/2}$ (Fig. 4) yields a straight line of slope $\sqrt{g}/2\pi$ and intercept $\sqrt{g/L}/2\pi$.

Thus, from the slope of the line we determined, in a very good approximation, the acceleration due to gravity. Considering the theory, we used the formula, $g = 4\pi^2 h/T^2$ for errors calculation. The error measurement of length is 0.1 cm and for period of oscillation, our measurements have an accuracy of 0.1 s.

Our results were $g = 9.786 \text{ m/s}^2$, $\Delta g/g = 0.105$ and $\Delta g = 1.033$. Since the error value, we can write $g = 9.89 \pm 1.0 \text{ m/s}^2$. The relative error is quite large, 10 %, but the accuracy of the experiment can be increased, measuring a time interval greater, for a larger number of oscillations.

Also, from the intercept, we find the distance $L = 22.4 \pm 0.1 \text{ cm}$, confirmed by measurements.

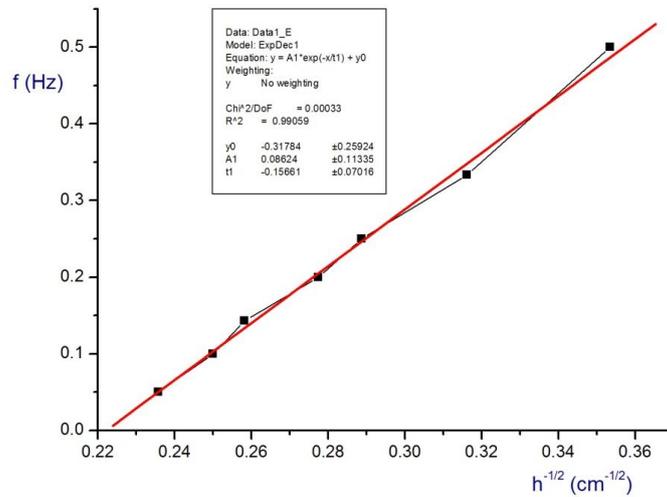


Fig. 4 – From the slope of the line and intercept we can determine the acceleration due to gravity and the length L of the pendulums. The colored versions can be accessed at <http://www.infim.ro/rrp/>.

Another theme of the experiment was to investigate how the time T of energy/motion transfer between the two bobs varies as a function of the height h of the coupling rod. (Fig. 5) In this case, initially one bob was at rest and the other one was displaced from his equilibrium position and allowed to oscillate.

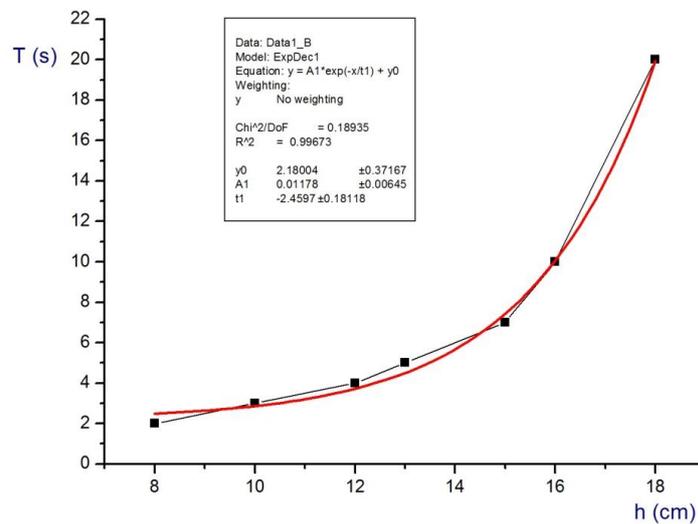


Fig. 5 – The dependence of the time T necessary to transfer movement energy from one bob to another, to the height h of the coupling rod. The colored versions can be accessed at <http://www.infim.ro/rrp/>.

5. CAPTURE, RECORD AND DATA PROCESSING WITH MOTION SENSOR AND IPAD

Collected data by the motion sensor are transmitted via Bluetooth to SPARKvue app interface on iPad, for capture, record and processing data, plot and analyze the results.

Measurements were made for one bob, maintained initially at rest and started to oscillate after energy transfer from another one.

First of all, students received information about all devices used as we brought together the experimental setup.

Motion sensor was oriented to the bob that received oscillation energy transfer. The AirLink device was attached to the motion sensor and turned ON. Then, we turned ON the Bluetooth on the iPad and have been set the connection to the AirLink.

The iPad was connected to a video projector, to see the enlarged screen display. Then, SPARKvue application was launched, were set measurements and graphic representation of the position, and measured in cm and the time, in seconds. If the second bob began to move, the motion sensor started to make a noise and we gave Play for data capture in the application.

In Fig. 6 is showing the sinusoidal oscillation motion. Students were excited about the graphic representation in real time, seen on the big screen projection.

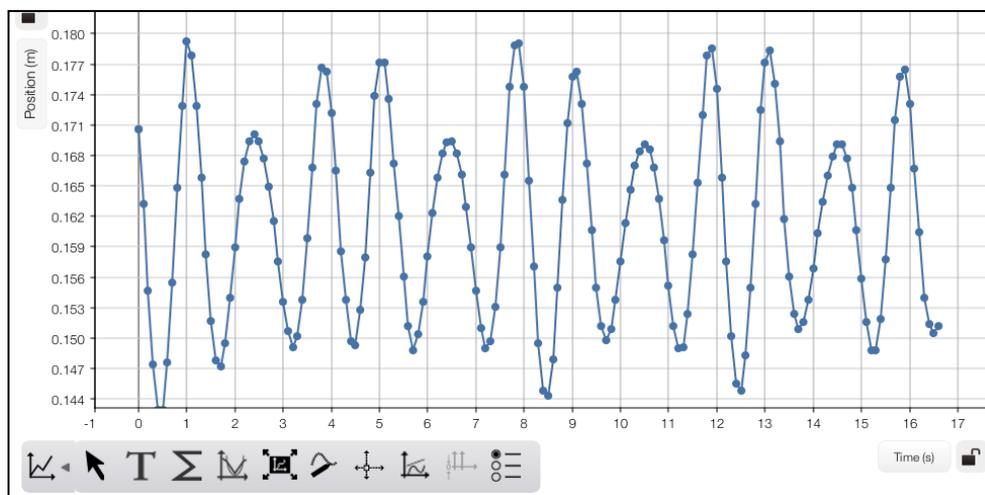


Fig. 6 – The graphical display of resulting motion of one bob, maintained initially at rest and started to oscillate after energy transfer from another one. The colored versions can be accessed at <http://www.infim.ro/rrp/>.

After a longer time, the students can see the harmonic motion (Fig. 7). They can measure the oscillation period and the transfer of energy to the other bob.

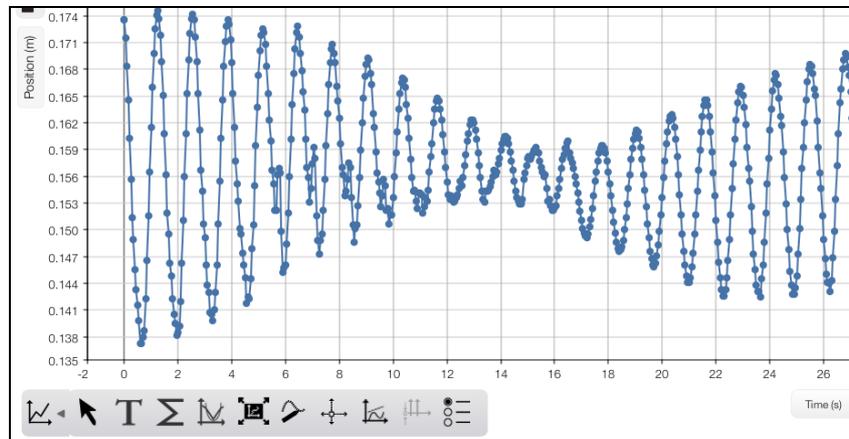


Fig. 7 – The time interval between two consecutive maximum of amplitude in the graph can be compared with the measured time interval between two rest positions of another pendulum. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

The most attractive and interesting part of the experiment is while maintaining data capture from motion sensor. On the screen we observed the generation of some lines of dots, arranged in the shape of superb Lissajous figures. It can be seen forming in real time and how tighten to fit on the screen (Fig. 8).

The formation of these is due to the system of coupled pendulums. Although at first, we do one of the pendulums oscillate only in one direction, as the movement is transmitted by strong coupling, the other one in equilibrium, his motion will have two components, on perpendicular directions. Also, it can be seen that the oscillation amplitude decreases when is changing the direction of energy transfer between the two pendulums by coupling rod.

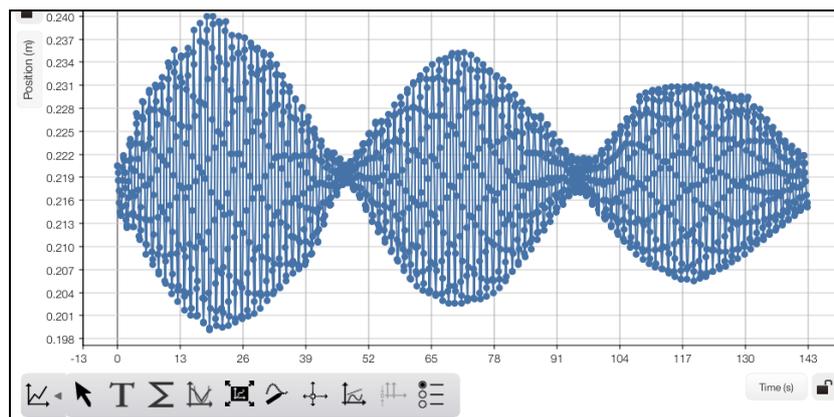


Fig. 8 – The formation of Lissajous figures is due to the system of coupled pendulums. The colored versions can be accessed at <http://www.infim.ro/rfp/>.

First, it varies only in terms of the equilibrium position, having only one component and developing beats as it moves. Then, energy is transferred through the coupling rod, the amplitude varies with time, traces out a Lissajous figure as it oscillate. While the formation of this Lissajous figure involves two perpendicular simple harmonic motions, one of the components involves time-varying amplitude, a feature not present in the production of most Lissajous patterns [11].

Data are reported to the students in the form of graphs that evolve as the experiment progresses. The student can predict results in terms of graphs, and if there is a discrepancy between the graphs of the observations and the predictions, students must be aware of this and make the required adjustments in either the experiment or the prediction on the basis of this graphic information.

The use of graphs as a central means of communications raises some important cognitive and educational questions. There is plentiful evidence that students even at the college level can have the ability to produce graphs from ordered pairs, while being very deficient in their ability to interpret graphs [12].

6. CONCLUSIONS

Mechanical skills are important almost in every field of activity and the physics of coupled oscillators have a large number of applications, in science, engineering, design and even in medicine. Learning and knowledge of the laws of motion of single or coupled pendulums, the concepts of frequency and period of the oscillatory motion can be enhanced through an experiment as complex as it is generous and attractive.

The goal of this approach was to make students to understand how is obtained a graphical representation of the oscillation motion; as occurs the transfer of energy/motion between the two pendulums and how it depends on the position of the coupling rod. The success of this approach was demonstrated by increased interest of students who have adapted naturally with the iPad app for acquisition of signals generated by the motion sensors during the experiment. Also were excited that they used their smartphone for measurements.

We must be aware of the possibilities offered by technology, but also the ease with which it is used by the younger generation. Their attention was fully captured by the display screen projection, in real time, making connection between movement of pendulums and representation and processing of the graphs.

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