Imagine that you have traveled back to a time before modern clocks existed. A scientist named Galileo Galilei (1564–1642) has asked you to help him with an experiment he is conducting about falling objects. Galilei is planning to drop several objects from the top of a tall tower and needs to measure the exact number of seconds it takes for each object to hit the ground. You have been asked to design a pendulum clock for the experiment that can accurately measure time in fractions of a second.

A pendulum is any body that is free to swing under the influence of gravity. Galilei used a very simple pendulum—a mass suspended from the end of a string—as a timing device in many of his experiments. Galilei knew that the length of time it takes a pendulum to swing forward once and then back once (one cycle) is always the same as long as the pendulum stays the same. He also knew that if you change the pendulum in some way, the time it takes to complete one cycle, called a period, also changes.

In this lab, you will design a pendulum clock. To do so, you have to know what factors affect the period of a pendulum. A good place to start is to watch a pendulum while it is swinging. Based on your observations, you can make a hypothesis about how changing one variable might affect how fast the pendulum swings. Then you can design and carry out an experiment that tests your hypothesis. The results of your experiment will either support your hypothesis or not support it. You can then use your data to adjust the pendulum so that it accurately measures time in fractions of a second.

OBJECTIVES

Develop a hypothesis about how changing one variable on a pendulum will affect how the pendulum swings.

Conduct an experiment to test your hypothesis.

Evaluate the precision and accuracy of a pendulum for measuring time.

MATERIALS

- balance
- CBL system
- metric ruler
- motion sensor
- ring stand or table support
- several different hooked masses
- string
- TI graphing calculator
**Procedure**

**SETTING UP THE CBL SYSTEM**

1. Connect the motion sensor to the sonic port of the CBL unit. Connect the CBL unit to the graphing calculator with the black cable that plugs into the base of each one.

2. Turn on the CBL unit and the calculator. Start the PHYSICS program. Go to the MAIN MENU.

3. Select SET UP PROBES. Enter “1” as the number of probes. Select MOTION from the SELECT PROBE menu.

4. From the MAIN MENU, select COLLECT DATA. Select TIME GRAPH from the DATA COLLECTION menu.

5. Enter “0.1” as the time between samples in seconds. Enter “99” as the number of samples. Press ENTER, and then select USE TIME SETUP. Select NON-LIVE DISPLAY from the TIME GRAPH menu.

**SETTING UP THE PENDULUM AND OBSERVING ITS MOTION**

6. Put on your safety goggles. Tie one end of the string to a hooked mass and the other end to the support, as shown in **Figure 1**. You can use any mass and any length of string, as long as the pendulum is able to swing freely above the table surface.

**FIGURE 1 PENDULUM SETUP**

7. Set up the motion sensor so that it is directed towards the pendulum, as shown in **Figure 1**.

8. Pull the mass away from the motion sensor, and press ENTER on the calculator. Release the mass, and let the pendulum swing freely. Observe the pendulum as it swings.
9. When the CBL unit reads DONE, stop the pendulum from swinging. Press ENTER to view the SELECT GRAPH menu. Select DISTANCE to view the graph, which should look similar to the one shown in Figure 2. If your graph is not smooth, move the motion sensor, press ENTER, select NEXT, and then select YES to try again. You may have to do this several times to get a smooth graph.

**FIGURE 2 DISTANCE-TIME GRAPH FOR A PENDULUM**

10. When you have a smooth graph, use the arrow keys on the calculator to trace the x-values on the graph. Find the time difference between two consecutive peaks on your graph. This difference is equal to the period of the pendulum in seconds, as shown in Figure 2.

**FORMING A HYPOTHESIS**

11. Discuss with your lab group several factors, or variables, that you think might affect the pendulum’s period. On a separate sheet of paper, make a list of all of the variables you discuss.

12. Choose one variable from your list that you think will have the greatest effect on the period of the pendulum. Write a hypothesis that clearly states how you think changing this variable (the independent variable) will affect the period of the pendulum.

**PERFORMING THE EXPERIMENT**

13. Use an appropriate tool, such as a ruler or balance, to measure your independent variable.

14. Conduct your first trial. Pull back the mass, and press ENTER on the calculator. Then select NEXT and YES to collect data.
Designing a Pendulum Clock continued

15. Release the mass, and let the pendulum swing freely. Press ENTER on the calculator. When the CBL unit reads DONE, press ENTER to view the SELECT GRAPH menu. Select DISTANCE. Determine the period of the pendulum by tracing the \( x \)-values on the graph and finding the time difference between two adjacent peaks. Record the period in Table 1.

**TABLE 1 PENDULUM DATA**

<table>
<thead>
<tr>
<th>Independent variable (include units)</th>
<th>Period of the pendulum (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. Conduct two more trials without changing the pendulum by repeating steps 14 and 15 two more times. Record the period for each trial in Table 1.

17. Now change the independent variable, and measure it. Repeat steps 14 and 15 three more times. Be sure to treat the pendulum exactly the same in all three trials.

18. Change the independent variable once more, and measure it again. Repeat steps 14 and 15 three more times, treating the pendulum exactly the same in each trial.

19. When you have finished collecting data, dismantle the pendulum, and put your materials away.

**Analysis**

1. **Analyzing Data** Determine the average period of the pendulum for each set of trials by using the following equation. Record your answers in Table 1. Be sure your answers have the proper number of significant figures.

\[
\text{Average period} = \frac{\text{trial 1 period} + \text{trial 2 period} + \text{trial 3 period}}{3}
\]

2. **Constructing Graphs** Use your graphing calculator to plot your data from Table 1 in the form of a graph. Plot the independent variable on the \( x \)-axis, being sure to include the appropriate units. Plot the average period (dependent variable) on the \( y \)-axis. Include a sketch of this graph in Figure 3. If you do not have a graphing calculator, plot your data by hand in Figure 3. Connect the data points with the line or smooth curve that fits the points best.
Conclusions

1. **Evaluating Results**  Do your results support your hypothesis? Refer to your graph to explain why or why not.

2. **Analyzing Graphs**  Use your graph to determine how to adjust your pendulum clock so that its period is 1 second.
3. Evaluating Data  In this experiment, you measured the pendulum’s period three times for each change of the independent variable. What can you conclude about the precision of your data?

4. Evaluating Models  Do you think the pendulum clock you made could measure time accurately to the nearest one-hundredth (0.01) of a second? Explain why or why not.

5. Defending Conclusions  Suppose someone tells you that if your results are precise, then they must be accurate. Is this a true statement? Explain why or why not.

Extensions

1. Research and Communications  Research several different devices used to measure time, and compare their accuracy and precision.

2. Building Models  Design a pendulum clock that can accurately measure 1 minute. Compete with other members of your class to see who can develop the most accurate clock.
Imagine that you have traveled back to a time before modern clocks existed. A scientist named Galileo Galilei (1564–1642) has asked you to help him with an experiment he is conducting about falling objects. Galilei is planning to drop several objects from the top of a tall tower and needs to measure the exact number of seconds it takes for each object to hit the ground. You have been asked to design a pendulum clock for the experiment that can accurately measure time in fractions of a second.

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In this lab, you will design a pendulum clock. To do so, you have to know what factors affect the period of a pendulum. A good place to start is to watch a pendulum while it is swinging. Based on your observations, you can make a hypothesis about how changing one variable might affect how fast the pendulum swings. Then you can design and carry out an experiment that tests your hypothesis. The results of your experiment will either support your hypothesis or not support it. You can then use your data to adjust the pendulum so that it accurately measures time in fractions of a second.

**OBJECTIVES**

*Develop* a hypothesis about how changing one variable on a pendulum will affect how the pendulum swings.

*Conduct* an experiment to test your hypothesis.

*Evaluate* the precision and accuracy of a pendulum for measuring time.

**MATERIALS**

- balance
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Designing a Pendulum Clock continued

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FORMING A HYPOTHESIS

11. Discuss with your lab group several factors, or variables, that you think might affect the pendulum's period. On a separate sheet of paper, make a list of all of the variables you discuss.

12. Choose one variable from your list that you think will have the greatest effect on the period of the pendulum. Write a hypothesis that clearly states how you think changing this variable (the independent variable) will affect the period of the pendulum.

Answers will vary, but the hypothesis must be testable. Sample hypothesis:

Increasing the length of the string will increase the period of the pendulum.

PERFORMING THE EXPERIMENT

13. Use an appropriate tool, such as a ruler or balance, to measure your independent variable.

14. Conduct your first trial. Pull back the mass, and press ENTER on the calculator. Then select NEXT and YES to collect data.
15. Release the mass, and let the pendulum swing freely. Press ENTER on the calculator. When the CBL unit reads DONE, press ENTER to view the SELECT GRAPH menu. Select DISTANCE. Determine the period of the pendulum by tracing the x-values on the graph and finding the time difference between two adjacent peaks. Record the period in Table 1.

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</tr>
</thead>
<tbody>
<tr>
<td>(include units)</td>
<td>Trial 1</td>
</tr>
<tr>
<td>30 cm string</td>
<td>1.3</td>
</tr>
<tr>
<td>20 cm string</td>
<td>1.2</td>
</tr>
<tr>
<td>10 cm string</td>
<td>0.7</td>
</tr>
</tbody>
</table>

This sample data was collected to test the following hypothesis: Increasing the length of the string will increase the period of the pendulum. (See step 12.)

16. Conduct two more trials without changing the pendulum by repeating steps 14 and 15 two more times. Record the period for each trial in Table 1.

17. Now change the independent variable, and measure it. Repeat steps 14 and 15 three more times. Be sure to treat the pendulum exactly the same in all three trials.

18. Change the independent variable once more, and measure it again. Repeat steps 14 and 15 three more times, treating the pendulum exactly the same in each trial.

19. When you have finished collecting data, dismantle the pendulum, and put your materials away.

**Analysis**

1. **Analyzing Data** Determine the average period of the pendulum for each set of trials by using the following equation. Record your answers in Table 1. Be sure your answers have the proper number of significant figures.

   
   \[
   \text{Average period} = \frac{\text{trial 1 period} + \text{trial 2 period} + \text{trial 3 period}}{3}
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2. **Constructing Graphs** Use your graphing calculator to plot your data from Table 1 in the form of a graph. Plot the independent variable on the x-axis, being sure to include the appropriate units. Plot the average period (dependent variable) on the y-axis. Include a sketch of this graph in Figure 3. If you do not have a graphing calculator, plot your data by hand in Figure 3. Connect the data points with the line or smooth curve that fits the points best.
Designing a Pendulum Clock continued

**FIGURE 3 RELATING THE INDEPENDENT VARIABLE TO THE PERIOD OF THE PENDULUM**

![Graph](image)

Answers will depend on each group’s data. For the sample data provided in Table 1, the graph would look similar to the one shown.

**Conclusions**

1. **Evaluating Results** Do your results support your hypothesis? Refer to your graph to explain why or why not.

   Conclusions will vary for each group of students. Some data will support some students’ hypotheses, and other students will find that their hypotheses are unsupported. The sample data provided clearly show that the longer the string, the greater the period of the pendulum.

2. **Analyzing Graphs** Use your graph to determine how to adjust your pendulum clock so that its period is 1 second.

   For the sample data, students’ graphs should indicate that the shorter the string, the shorter the period of the pendulum. Answers will vary according to whether students need to adjust to a greater period or a shorter period.
Designing a Pendulum Clock continued

3. Evaluating Data In this experiment, you measured the pendulum’s period three times for each change of the independent variable. What can you conclude about the precision of your data?

Students should conclude that the precision of their data is greater if the results of each swing per trial are similar. Students should also conclude that a greater number of trials contributes to greater precision of data.

4. Evaluating Models Do you think the pendulum clock you made could measure time accurately to the nearest one-hundredth (0.01) of a second? Explain why or why not.

Students’ pendulum clocks cannot measure time to the nearest 0.01 of a second because they are limited by how precisely students can measure the materials the clocks are made of. For example, there is too much uncertainty in the exact length of the string and the mass of the object attached to it to measure time that precisely.

5. Defending Conclusions Suppose someone tells you that if your results are precise, then they must be accurate. Is this a true statement? Explain why or why not.

This is not always a true statement. Results may be precise without being accurate. For example, if the motion detector was not working properly, it may make similar measurements for each trial, but these measurements may not reflect what is really happening.

Extensions

1. Research and Communications Research several different devices used to measure time, and compare their accuracy and precision.

2. Building Models Design a pendulum clock that can accurately measure 1 minute. Compete with other members of your class to see who can develop the most accurate clock.