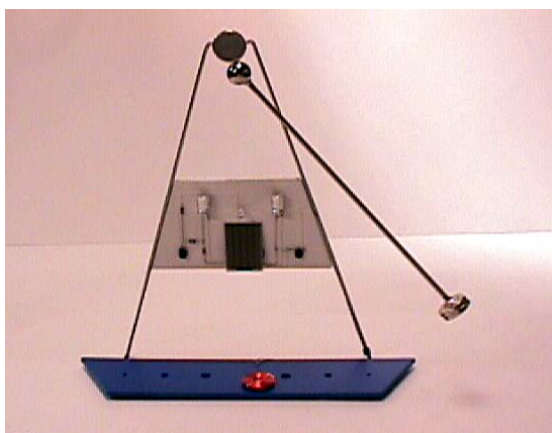


Area of study ENERGY AND CHANGE and WORKING SCIENTIFICALLY  
Target Level 6 or bright year 10 or 11 and 12 Physics and Maths students

# THE ONE SECOND PENDULUM



The **percent change** is one way to determine how large or small the effect weight, string length, or amplitude has on the period of the pendulum. The total change is equal to the difference between the largest and smallest value. The percent change is equal to 100% times this difference, divided by the smallest value. The sensitivity of one variable (like period) with respect to changes in another variable (like length) can be described by the ratio of the percent change in one, to the percent change in the other. This ratio is called the rate of change.

**These activities THE SIMPLE PENDULUM and the ONE SECOND PENDULUM are to be completed at school prior to your visit or just use them as assessment and levelling modules.**

You find pendulums all around you in clocks, swings, clothing as you move, electric power lines in the wind etc. They provide a great study tool for investigating the scientific method from a low to a very sophisticated level

This activity is targeted to the serious science students It allows the them to develop a high level of understanding of the Scientific Method through a rigorous investigation. This module can be followed by the **ONE SECOND PENDULUM** that enables the students to apply what they have discovered and to develop some understanding of statistical analysis.

This would be a great preparation of a visit to the GDC to use the large Foucault pendulum to prove that the earth is rotating as well as using it to find the mass of the earth.

You may do this experiment by constructing your pendulum or by downloading an interactive program where you can do the experiments from the program.

Go to <http://www.delphiforfun.org/Programs/pendulum.htm>

*This program explores three different types of pendulums. Each of the following pages allows the user to set parameters defining the pendulums and set them in motion to observe the effect. . Even if you are not into higher mathematics or programming, it's still fun to play with the parameters and observe results. The dual double pendulums and the forced damped pendulums make interesting viewing.*

**To be done after the simple pendulum unit**

These activities are designed for very able students in year10 or physics / maths students in year11 and year 12 to gain the most out of the exhibits at the Gravity Discovery Centre. The program is designed to offer a range of activities that are independent of each other and range in difficulty from the basics through to the sophisticated. The activities cover historical moments in science, cutting edge concepts and understanding of the scientific Process. For the program to work, Students and teachers need to have carried out preliminary research and experimentation at school and have developed a good understanding of the tasks they will carry out at the gravity centre. The activities have all been trialled with a group of talented year 10 students who really enjoyed the challenge of quickly being accelerated to a level of conceptual understanding well beyond where their classroom normally operates.

The tasks are at a **level 6** and in some cases the very able students are able to demonstrate a **level 7 *in the later pendulum units***. We suggest that you incorporate the preliminary work in the general course of the students and culminate that work with a visit to the Gravity Discovery Centre. What you expect the students the students to gain.

## ACTIVITIES BEING OFFERE

Activity	Preliminary work at school	Activity at the Gravity Discovery Centre
<b>Simple Pendulum</b> Making a time piece	Simple harmonic motion and the pendulum. Rate of change (the % method) The one second pendulum	Extrapolation of school data to predict and measure and compare the Gravity Discovery Centre pendulums period.
<b>The one second Pendulum</b>	This module allows students to use % variation to establish the influence of a variable on the behaviour of the simple pendulum in a mathematical analysis of data gained in the Simple Pendulum module.	Use this knowledge to help with your GDC investigations
<b>Conical Pendulum</b> Measuring the mass of the earth	Preliminary theory and trigonometry	Use the Gravity Discovery Centre pendulum to measure the mass of the earth
<b>Foucault Pendulum</b> Measuring the rotation rate of the earth	Study the history of the Foucault pendulum and learn how to calculate the rate of the earths movement under the pendulum at the Gravity Discovery Centre.	Test the prediction at the Gravity Discovery Centre
<b>Double Pendulum</b> Momentum cycles chaotic behaviour.	Gain an understanding of the energy transfers in the double pendulum and make calculations as to the period of the Gravity Discovery Centres double pendulum. Gain an understanding of what chaotic behaviour means.	Test the prediction at the Gravity Discovery Centre Observe the chaotic behaviour.

## Rate of Change *The One Second Pendulum*

### An analysis of the degree of change.

The **percent change** is one way to determine how large or small the effect weight, string length, or amplitude has on the period of the pendulum. The total change is equal to the difference between the largest and smallest value. The percent change is equal to 100% times this difference, divided by the smallest value.

$$\% \text{ change} = \frac{\text{largest} - \text{smallest}}{\text{smallest}} \times 100\%$$

The sensitivity of one variable (like period) with respect to changes in another variable (like length) can be described by the ratio of the percent change in one to the percent change in the other. This ratio is called the rate of change.

### Percent Change of Independent Variables

Largest Mass (kg)	Smallest Mass (kg)	Difference In Mass (kg)	% Change In Mass
Largest Amplitude (deg)	Smallest Amplitude (deg)	Difference In Amplitude (deg)	% Change In Amplitude
Longest String (m)	Shortest String (m)	Difference In String Length (m)	% Change In String Length

### Percent Change of Dependent Variable

Variable Changed	Largest Period (sec)	Smallest Period (sec)	Difference In Period (sec)	% Change In Period
Mass				
Amplitude				
String Length				

## Rate of Change of Dependent Variable With Respect to Independent Variables

Variable Changed	% Change	% Change in Period	Avg. Rate Of Change Of Period
Mass			
Amplitude			
String Length			

Use the results of your calculation to say which of the three things you changed had the largest effect.

Which had the smallest effect?

Which had no effect?

### **YOUR TASK IS TO DESIGN AND BUILD A 1 SECOND PENDULUM**

Construct a pendulum with a period of exactly one second. Use your graphs and your analysis of the percent change to determine how to set each of the three parameters.

Number Of Weights	Amplitude	String Length
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### **Test your Design**

Set up the Pendulum exactly as prescribed by your three choices and measure the period. Write your measurements down in the space below. (remember to let it oscillate a number of times)

Measured Period (sec)	Calculate the percentage difference between your measured period and your goal of one second.
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Do you think your Pendulum would make an accurate clock? Your answer should include an estimate of the drift of the period and the length of time that the pendulum would keep swinging.

How do you think you could improve your clock?

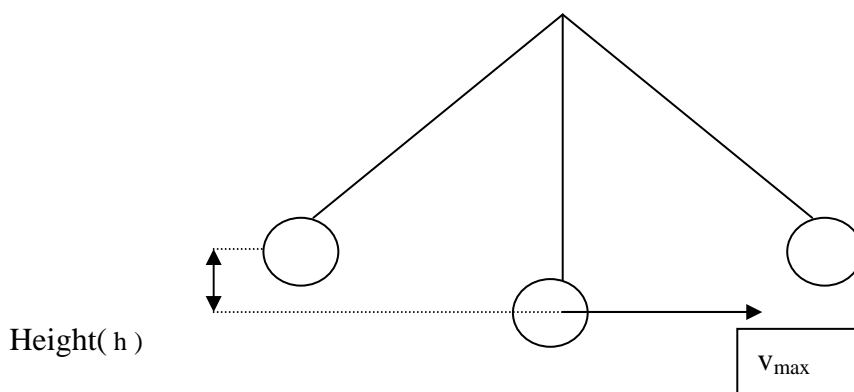
## MATHEMATICAL PREDICTIONS

Your results should have shown that the period of the Pendulum depends strongly on the length of the string and weakly on the amplitude (angle) and the mass has no effect. As with many models in science, there is no simple formula that predicts exactly how the period depends on the length or angle. **Your challenge** is to figure out how something like the Pendulum works without being able to get an exact answer. You need to, using knowledge of the law of energy conservation to work out a formula that will predict how the period (T) of the Pendulum depends on string length (l), mass (m), and angle ( $^{\circ}$ ) by using.

*In the case of the Pendulum (and in many others) the approximate solution will be enough to show virtually all of the interesting effects.*

### Method

1. Use energy conservation to get a formula for the maximum speed of the pendulum bob. The maximum speed occurs at the lowest height, which is when the pendulum passes through the equilibrium position.



Using the relationship that the energy potential at the top is equal to the energy potential at the bottom of the pendulum. This means that:

Use this relationship to derive the formula for the maximum velocity of the pendulum at the bottom of the swing.

$$E_p = E_k$$

$$mgh = 1/2mv^2$$

$$V_{(max)} =$$

**2. Estimate the total distance that the pendulum bob travels in one cycle.**

To do this you need the angle that you released the bob from and knowledge of the number of degrees in a circle. This together with the radius of the circle will give you enough information to calculate the total distance that the pendulum bob travels in one cycle. Work out this distance.

**Distance = .....**

**3. The speed of the pendulum bob is zero at the extremes of its motion, and equal to the maximum value in the middle. For simplicity, assume that the pendulum bob moves with a constant average speed equal to 1/2 of its maximum speed.**

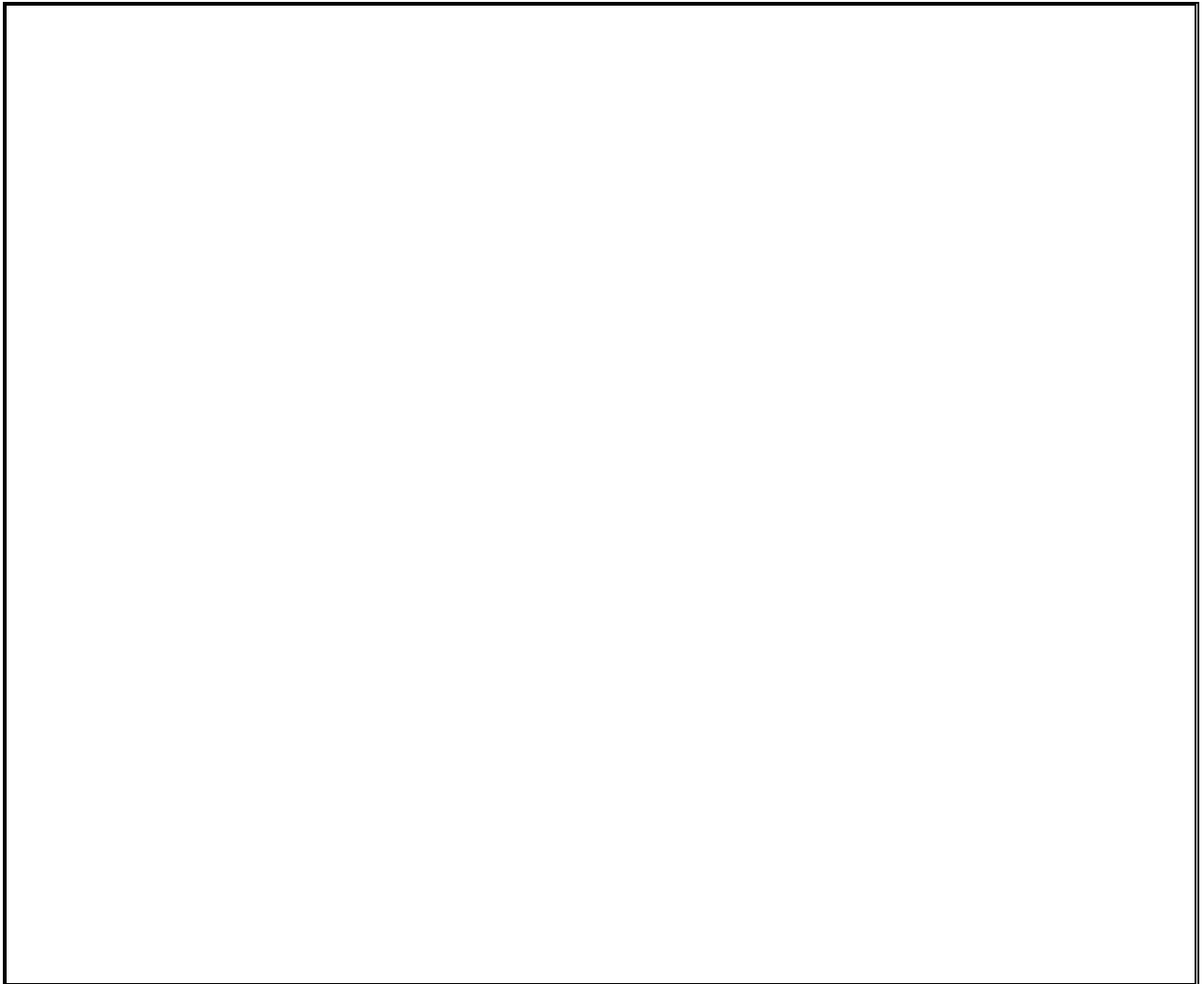
**1/2 of its maximum speed =.....**

**The period of the bob is the time taken for one complete cycle of the pendulum**

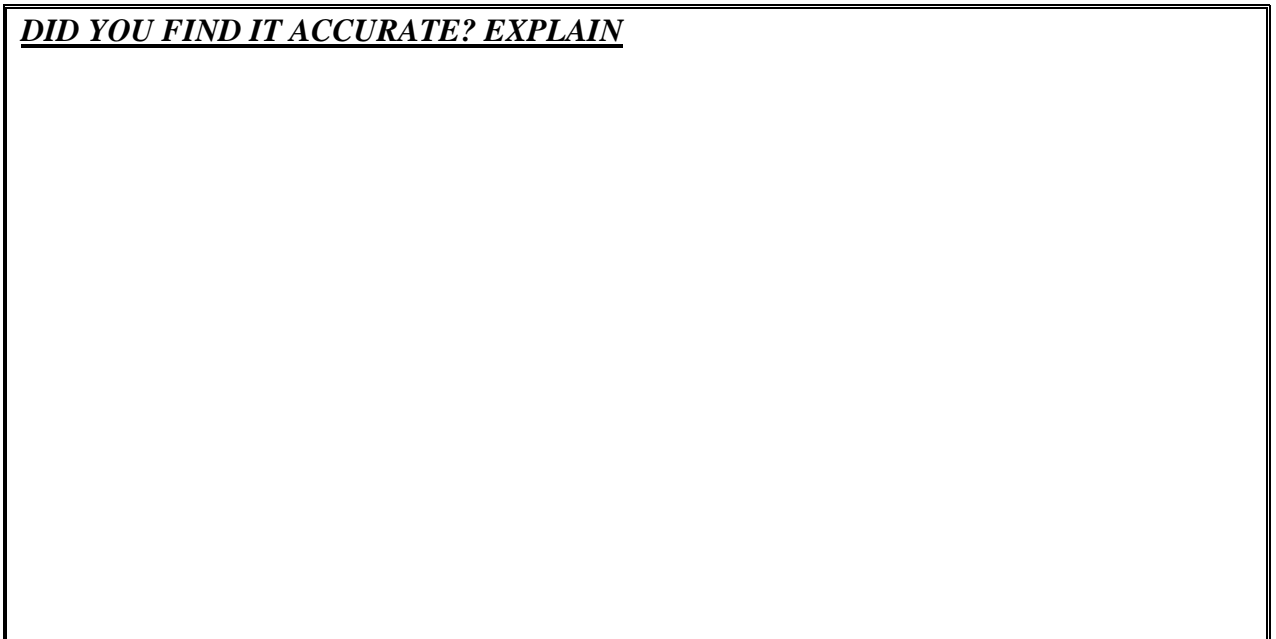
**4. Estimate the period by calculating the time it takes the pendulum bob to travel the distance in step 2 at the constant average speed from step 3. Remember the period T is the time taken for the bob to complete one cycle.**

**T =.....**

**TRY YOUR FORMULA OUT AT DIFFERENT LENGTHS AND ANGLES**



**DID YOU FIND IT ACCURATE? EXPLAIN**



**GDC TASK**

Find out the mass length and choose a release angle of the pendulum at the GDC and use your derived formula to calculate its period. *THEN TEST THE RESULT WITH THE PENDULUM*

Mass=

Length=

Release angle=

Calculate the period (t)

Experimental test results

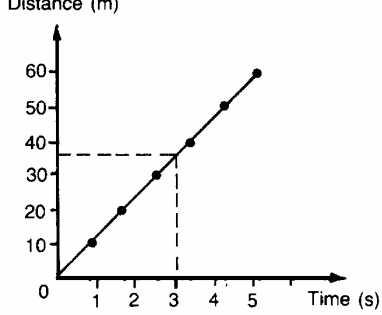
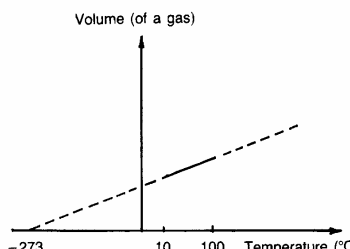


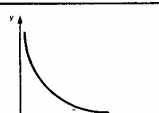


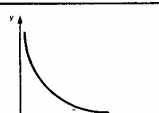


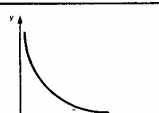
% error

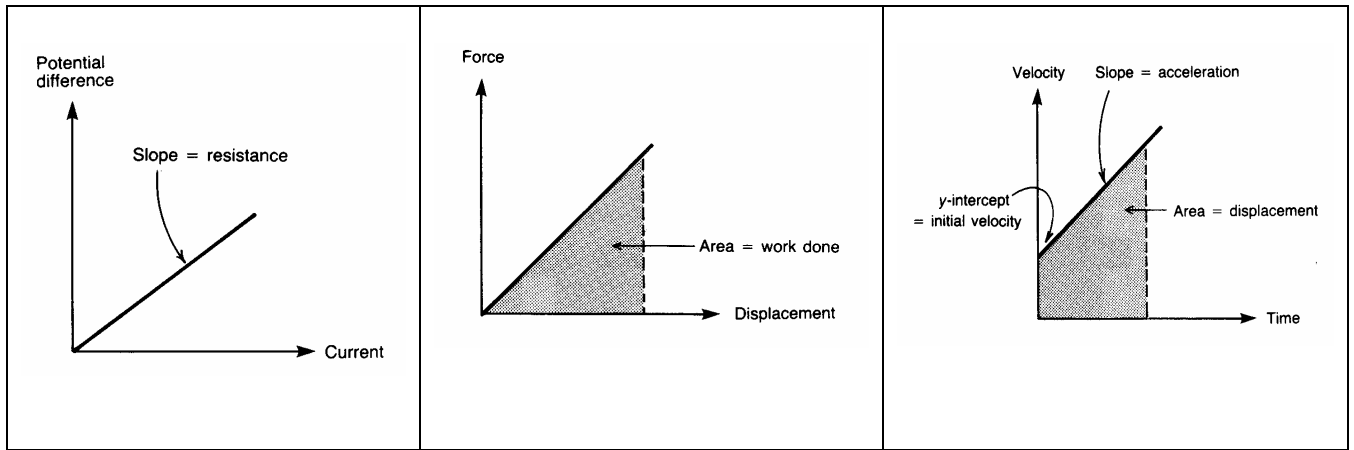
Comment on the accuracy of your result.

## Graphs in physics experiments

Not only do graphs provide a pictorial representation of data, which can be taken in at a glance, but also they are also convenient for showing trends or making comparisons. They may also permit interpolation (i.e. reading values in between those measured) or extrapolation (i.e. reading values beyond those measured). However one should always beware of extrapolation since a trend may not continue in definitely beyond the measured values.

More importantly in physics, a graph may permit us to determine a mathematical relationship between the quantities plotted. However, in order to be certain of the relationship, it is necessary to obtain a straight-line graph. A curved graph may suggest a relationship between the quantities involved. To confirm this suggested relationship we must plot a second graph (of the suggested quantities) that turns out to be a straight line. Some of the simpler relationships that you will deal with in this practical book are shown in the table below.

 <p>Interpolation shows 36m travelled in 3 seconds</p>	 <p>Extrapolation shows the volume of the gas is zero at <math>-273^{\circ}\text{C}</math></p> <p>Extrapolation</p>												
<h3><b>Mathematical interpretation of graphs</b></h3> <table border="1" data-bbox="252 1339 826 1796"> <thead> <tr> <th>Graph of <math>y</math> versus <math>x</math></th> <th>Suggested relationship between <math>y</math> and <math>x</math></th> <th>Graph plotted to confirm the suggested relationship</th> </tr> </thead> <tbody> <tr> <td></td> <td><math>y \propto x^2</math></td> <td><math>y</math> versus <math>x^2</math></td> </tr> <tr> <td></td> <td><math>y \propto \sqrt{x}</math></td> <td><math>y</math> versus <math>\sqrt{x}</math></td> </tr> <tr> <td></td> <td><math>y \propto \frac{1}{x}</math></td> <td><math>y</math> versus <math>\frac{1}{x}</math></td> </tr> </tbody> </table>	Graph of $y$ versus $x$	Suggested relationship between $y$ and $x$	Graph plotted to confirm the suggested relationship		$y \propto x^2$	$y$ versus $x^2$		$y \propto \sqrt{x}$	$y$ versus $\sqrt{x}$		$y \propto \frac{1}{x}$	$y$ versus $\frac{1}{x}$	<p>In the table, the relationship is confirmed if the graph from the third column is a straight line passing through the origin. If the straight line does not pass through the origin, we cannot claim that the quantity plotted on the vertical axis is directly proportional to the quantity plotted on the horizontal axis. Nevertheless, it is still possible to determine a relationship.</p> <p>It is of the form <math>y = mx + b</math> where <math>y</math> is the quantity plotted on the vertical axis <math>x</math> is the quantity plotted on the horizontal axis <math>m</math> is the slope (or gradient) of the line <math>b</math> is the point of interception with the vertical axis (y-intercept).</p>
Graph of $y$ versus $x$	Suggested relationship between $y$ and $x$	Graph plotted to confirm the suggested relationship											
	$y \propto x^2$	$y$ versus $x^2$											
	$y \propto \sqrt{x}$	$y$ versus $\sqrt{x}$											
	$y \propto \frac{1}{x}$	$y$ versus $\frac{1}{x}$											



Frequently, the slope of the graph and the x- and y-intercepts have some physical significance. The area between the graph and the horizontal axis may also have some applicable meaning. Three examples of graphs where the slope and/or area have some meaning are shown above.



These sheets are for teachers and students to help in the levelling of student work in this module.



## Overarching Major Learning Outcomes

There are opportunities to assess students in the following outcomes when taking part in this program.

**OLO 7:** Students understand and appreciate the physical, biological and technological world and have the knowledge and skills to make decisions in relation to it.

**OLO 5:** Students describe and reason about patterns, structures and relationships in order to understand, interpret, justify and make predictions.

**OLO 6:** Students visualise consequences, think laterally, recognise potential patterns and are prepared to test options.

## Science Major Learning Outcomes

### Working Scientifically

#### 1. Investigating skills

Students investigate and answer questions about the natural and technological world. They use the skills of scientific investigation, reflection and analysis to prepare a plan for their investigation; to collect, process and interpret data: to communicate their conclusions

#### 2. Communicating Scientifically

Students communicate scientific understandings to different audiences for a range of purposes.

#### 3. Applying Science in Daily Life

Students apply and evaluate scientific knowledge, skills and understanding across a range of contexts.

### Using Science in Society

Students understand that science is a human activity which influences all people as a part of their daily lives.

## **Understanding concepts**

### **1. Earth and Beyond**

Students understand the physical world around them and its impact on the way we live.

### **2. Energy and Change**

Students understand the scientific concept of energy and explain that energy is vital to our existence and quality of life.

## **Student Outcome Statements**

Students typically in years 8-10, will be performing at levels (3-6). The following examples demonstrate outcomes for levels 5 and 6

### **Investigating scientifically**

#### **Planning:**

1. Identifies the variables to be changed, the variable to be measured and at least one variable to be controlled. In a descriptive study plans are made for the necessary types of observations.
2. Analyses problems, formulates a question or hypothesis for testing and plans an experiment in which several variables are controlled.

#### **Conducting:**

1. Takes care with data collection so that data is accurate, uses repeated trials and uses independent variables that are usually continuous.
2. Uses equipment that is appropriate for the task and uses preliminary trials of the investigative procedure to improve the procedure or measurement techniques.

#### **Processing Data:**

1. Calculates averages from repeated trials, plots data as line graphs where appropriate and makes conclusions, which both summarise and explain the patterns in the data.
2. Makes conclusions, which are consistent with the data and explains the patterns in the data in terms of scientific knowledge.

#### **Evaluating:**

1. Makes specific suggestions for improving the data
2. Suggests a specific change that would improve the techniques used or the design of the investigation.

### **Energy and Change**

1. Understands that energy interacts differently with different substances and this can affect the use and transfer of energy.
2. Understand models and concepts used to explain the transfer of energy in an energy equation.

General notes on levelling

Level	Level Descriptors
2	<b>Describes</b> a number of features but does not <b>relate</b> them
3	Describes <b>patterns</b> and makes <b>generalisations</b> from <b>concrete</b> experience
4	Describes <b>non observable</b> properties or events
5	Explains in terms of a <b>concept</b> .
6	<b>Chooses applies</b> and <b>quantify</b> concepts and principals

**Appendix 2: Questions and associated levels**

Construct a pendulum with a period of exactly one second. Use your graphs and your analysis of the percent change to determine how to set each of the three parameters.

**To demonstrate level 6**

The students need to state clearly how close their construction was to 1 second and have measured it over an appropriate number of swings.

Their graphs should have shown that the length has a huge effect the angle of release a significant effect and the mass a probably not showing up.

They need to state have correctly calculated their pendulum formula.

**DID YOU FIND IT ACCURATE? EXPLAIN**

**To demonstrate a level 6**

The students need to comment on the influence of each of the variables in mathematical terms incorporating numerical data to backup their explanation.

Some web based resources that may be helpful to teachers and students in preparing for the visit.

**Web based resources**

<http://www.delphiforfun.org/Programs/pendulum.htm>

<http://online.cctt.org/physicslab/content/phyapb/lessonnotes/centripetal/lessonpendulums.asp>

[http://ephysics.physics.ucla.edu/ntnujava/Pendulum/esimple\\_pendulums.htm](http://ephysics.physics.ucla.edu/ntnujava/Pendulum/esimple_pendulums.htm)

**There are so many applets and good sites that you can get by using a good search engine. Give it a go.**