

Capturing Data: Modelling and Interpretation

STEM ACTIVITIES WITH TI-NSPIRE

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INTRODUCTION

Why use TI-Nspire?

The data handling features of TI-Nspire and the emphasis in the new secondary curriculum on real-life contexts, curriculum opportunities and cross-curricular dimensions all combine to give a strong rationale for introducing activities using TI-Nspire which use real data and link STEM subjects.

There is now a wealth of data available on the Internet in a variety of forms. TI-Nspire can make use of this data as it has the facility to copy and paste information from tables and spreadsheets into a Lists & Spreadsheet page. Data can also be captured using a variety of data logging probes linked to TI-Nspire handheld, such as temperature probes or motion sensors. It is then possible to manipulate, display and analyse this data in a variety of ways using facilities from 'Data and Statistics'. It is also possible to further analyse or attempt to model the data by inserting movable lines, plotting functions or fitting a variety of functions using different forms of regression.

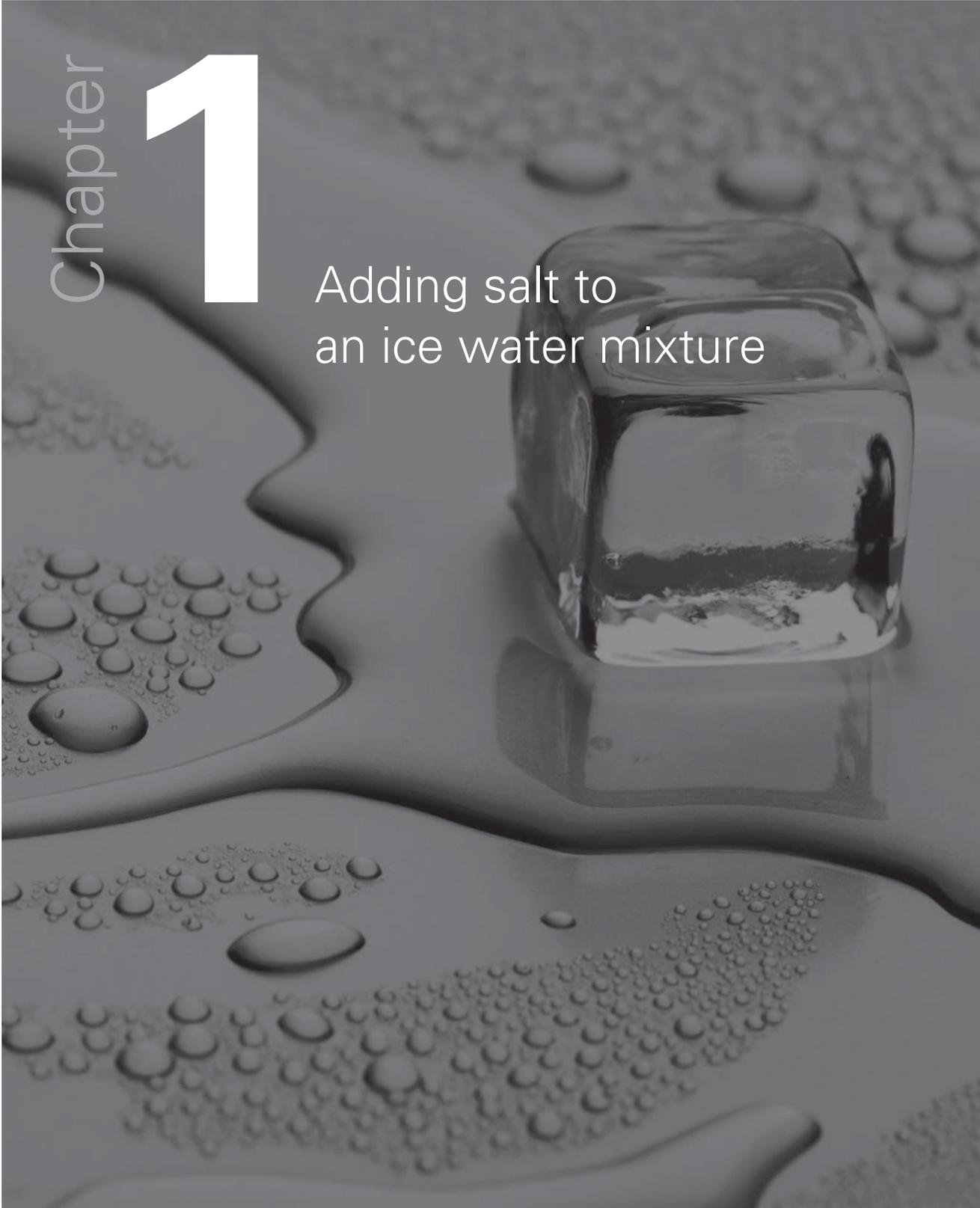
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Chapter

1

Adding salt to
an ice water mixture



Setting up TI-Nspire

Using a temperature probe, such as an EasyTemp probe, is probably the easiest way to begin logging data with TI-Nspire.

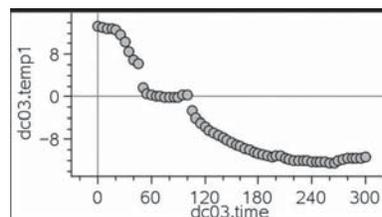
Switch the TI-Nspire handheld device on and open a new document. Plug the temperature probe in and a menu asking which application to use the temperature probe in will open. Choose Data & Statistics by pressing the *tab* button and selecting *OK*. Two windows will open, one with the control console, which is active by default and the other the Data & Statistics window. You will notice the start button is highlighted. Pressing the *enter* button will begin logging data. Pressing *tab* will toggle through each of the buttons in the control console. Pressing *ctrl* and *tab* will toggle between the two windows.

Notice that the temperature is displayed in the central window making the TI-Nspire handheld and temperature probe a rather expensive digital thermometer! If you begin logging data the default time period is 3 minutes or 180 seconds. For this brief investigation a longer time interval will be needed so press the *menu* button while in the control console window and a new menu with the top choice being *Experiment*. A new menu will open with the top choice being *Set Up Collection*. Select *Time Graph* and you will be able to adjust the time interval between samples collected and the length of the experiment. 5 second intervals and 320 seconds long should be sufficient - remember to scroll down or use the *tab* button to select *OK*.

Now toggle to the Data & Statistics window and press the *menu* button. Select *Window/zoom* and change the y-range to, for example, -15 and 25. Begin logging data by pressing *enter*.

The investigation

Place about 20ml of water into a beaker. Put the temperature probe into the water and begin logging data. Add about 6 ice cubes to the water. Stir and watch the temperature drop to zero. The temperature will reach zero and remain there, not dropping below zero. The ice will stop melting and the water will not turn to ice! Ice and water are in equilibrium at 0 C. After about two minutes add about 5ml of salt, stir and watch the temperature plummet.



fig_01

You will need

- An EasyTemp temperature probe
- A TI-Nspire handheld
- Ice
- Salt
- Beakers
- Stirring rods

The science

As soon as the salt dissolves in the water, heat will flow from the salt water to the ice and begin melting it. The temperature probe is recording the temperature of the salt water.

<http://antoine.frostburg.edu/chem/senese/101/solutions/faq/zero-fahrenheit.shtml>

<http://www.io.com/~bolie/Tech/FreezingPointDepression.html>

http://www.sci-experiments.com/ice_cream/saltwater.html

<http://www.newworldencyclopedia.org/entry/Fahrenheit>

The lowest temperature which can be reached in this way is -18°C and is the temperature at which salt water and ice are in equilibrium. Of course as the salt water temperature falls, so does the temperature of the remaining ice until both salt water and ice have reached -18°C . In some countries this is still the way to make ice cream.

You will notice that heat will attempt to flow in from the surroundings as the salt water temperature drops, causing ice to form on the outside of the beaker when moisture in the warm air condenses onto the beaker surface.

Throwing salt onto a road covered in ice at $-^{\circ}\text{C}$ will do nothing until the first vehicles crush the salt crystals into the ice, melting a little ice and so allowing the salt to dissolve in the water. If the road temperature is below -18°C , which it frequently is on the continent, using ice will have no effect at all. Hence the debate over the use of grit or salt.

The mathematics

We are dealing with temperature scales and the notion of negative quantities. Does zero Celsius really mean zero temperature? Of course not - and the minus sign in -18C has no meaning other than being on the number line with reference to the zero. Celsius is a relative scale, not an absolute one. Although Fahrenheit set out to produce an absolute scale, his is also a relative scale.

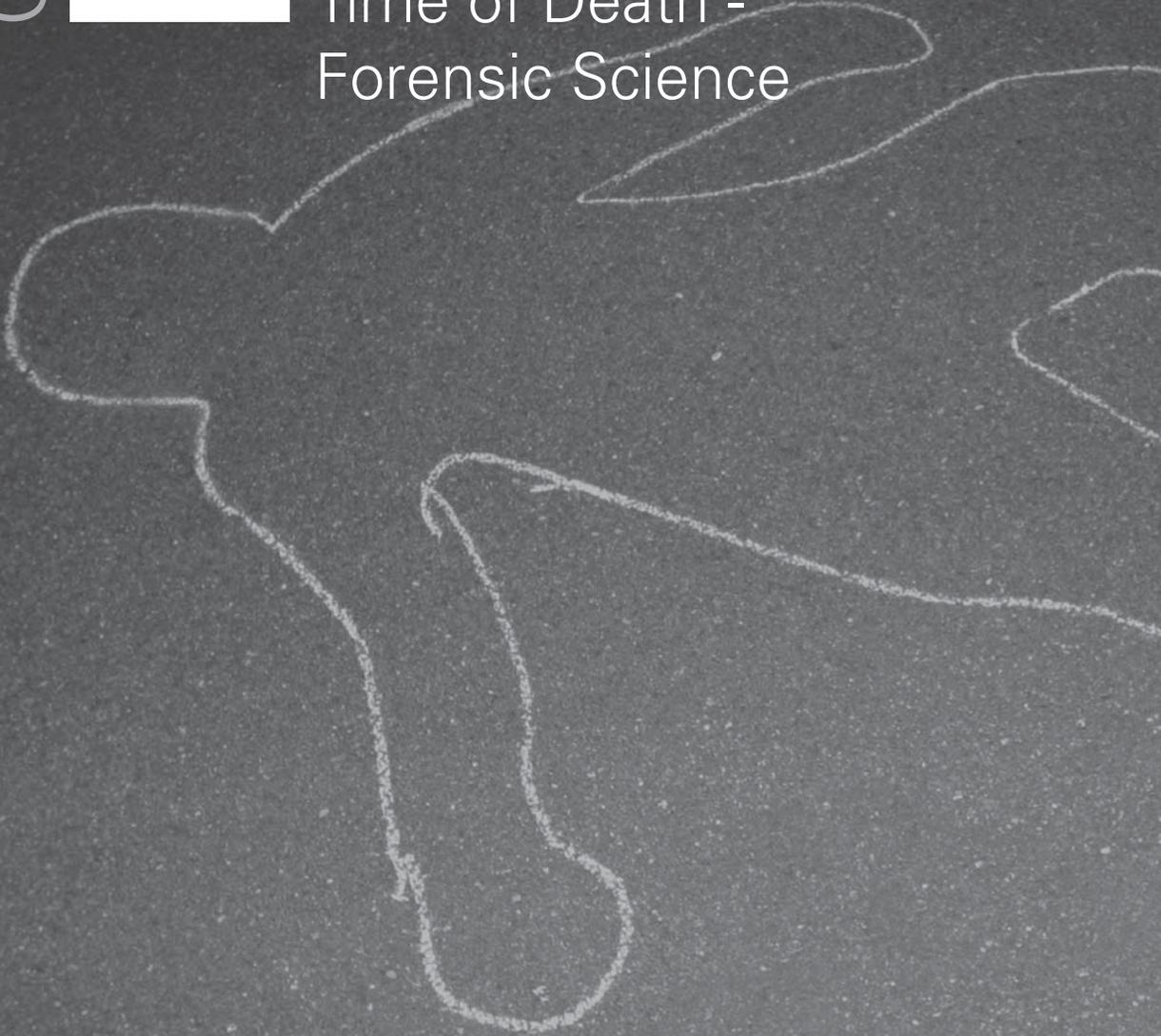
Historically the -18C is interesting as those maths teachers who have to cover the relation between Fahrenheit and Celsius will have noticed. Zero Fahrenheit corresponds to -18C and for Fahrenheit was the lowest temperature which could be reached. Therefore the Fahrenheit scale was an absolute one! It is worth pointing out that Fahrenheit's 100 point was the temperature of the human body which was in error at the time, but nevertheless the Fahrenheit scale was also intended to be a decimal scale, just like Celsius.

The number -18 is important for most homes as most meats contain salt water and so will not freeze until the temperature of -18C is reached - a real health and safety issue!

To download notes and the .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'Ice and salt'.

Chapter **2**

Time of Death -
Forensic Science



Establishing time of death at a crime scene is essential for helping the subsequent detective work. Crime Scene Investigators (CSIs) might attempt to use insects if the body has already cooled to the surrounding temperature. But if the body has been discovered in sufficient time then it is usually possible to establish time of death using Newton's Law of cooling. This simply states that objects cool at a rate which is proportional to the excess temperature over the surroundings. In other words a body's temperature will drop exponentially to the ambient temperature.

With modern technology it is not necessary for a student to have a good understanding of exponential functions in order to use them. Most children at the ages 11 to 14 have heard of quantities which change exponentially with time e.g. populations and bacteria. They know that an exponential increase means that the rate of increase of quantity increases with time even if they cannot express it. They might also surmise that an exponential decrease means that the rate of decreases itself decreases with time. This example shows how using technology will allow children to apply exponential functions to a problem they are likely to have seen on television, finding out the time of death.

The task

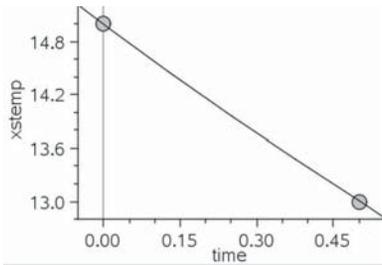
A simple challenge can be set to a class by setting up a beaker with warm water as the cooling body. You will need to know the time at which the beaker was at 37°C and then invite the class to determine that time by taking temperature measurements from the cooled beaker.

Simply taking one measurement of the temperature will not help as an infinite number of exponential curves can be drawn through one point! However only one exponential can be drawn through two points, so students should take a second temperature reading a few minutes after the first; half an hour in the example given.

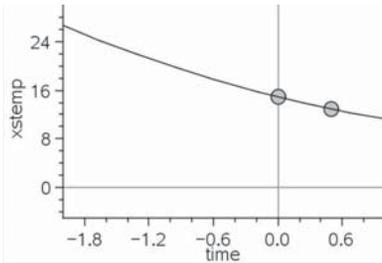
I find that it is easier to convert to hours, but that is just a preference.

The two temperatures are entered into a Lists & Spreadsheet page along with the two times at which the temperatures were taken, the initial time being zero. The temperature cannot fall below the ambient or room temperature, so this is subtracted from the two temperatures to give two adjusted temperatures. The students can then regress an exponential to the two adjusted temperatures in a Data & Statistics representation.

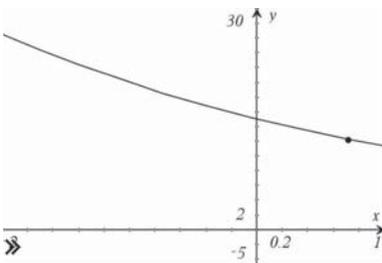
The equation of the regression can then be copied into the function line of a Graphs & Geometry page so that a moveable point can be placed on the curve. The point is simply moved backwards until the y-coordinate, temperature, reaches 37°C. The time which elapsed before the first reading was taken is given as the x-coordinate.



fig_02



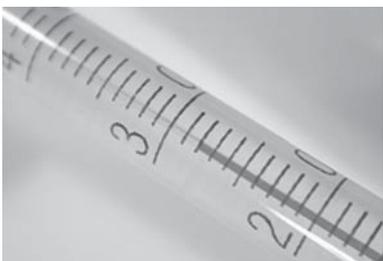
fig_03



fig_04



fig_05



fig_06

You will need...

- An EasyTemp temperature probe
- A TI-Nspire handheld
- A beaker of water about 10°C above room temperature
- Knowledge of when the beaker was at 37°C

The science

All physical quantities which change at a rate which is proportional to the size of the quantity itself will change exponentially. This is so ubiquitous in nature that it is surprising that it is not taught explicitly before Post-16 education. This example provides easy access to the idea of an exponential change.

The mathematics

In the English National Curriculum for mathematics, KS4 children (14-16 years old) are required to be able "to apply their knowledge, skills and understanding to relevant real-world situations" in the area of "proportional change and exponential growth".

The number of points needed to fit a function is of interest, only two points for a unique straight line or a defined monotonically increasing or decreasing function such as an exponential. How many points are needed for a unique parabola, cubic and so on?

To download notes and the .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'time of death'.

Chapter

3

Investigating
magnetic fields



Introduction

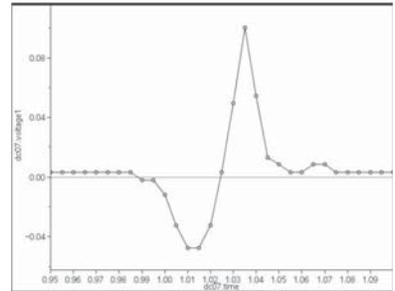
Using a voltage probe it is easy to investigate magnetic fields. The range of applications of magnetic fields is enormous, from swipe cards to nuclear magnetic imaging machines. Faraday discovered the laws of electromagnetic induction in 1831, without which there would be no electricity supply to-day. It is the voltage induced by moving a coil of wire in a magnetic field which is the focus of this investigation

The voltage probe has a sensitivity of $\frac{1}{100}$ of a volt and the TI-Nspire handheld itself has a large internal resistance making it particularly useful for this investigation. A potential difference (voltage) will move electric charges. This results in an electric current and all school children make electromagnets with electric currents. Conversely if electric charges within a conductor are moved across a magnetic field a voltage is induced across the ends of the conductor. This is the induced voltage.

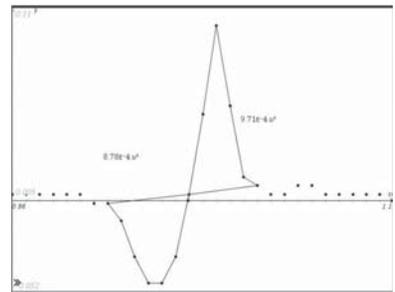
This induced voltage depends on the rate at which the magnetic field is cut, the size of the field and the amount of field which is cut. Try moving a swipe card slowly through the card reader and likely as not it will not be read. The induced voltages in the reader are greatest when the card is moving quickly.

Wrap a coil of insulated wire around a plastic tube such as a thermometer case. If a magnet is dropped down the tube the magnetic field will cut the coil. The more turns there are the more field is cut, so typically 30 turns will induce a readable voltage. Connect the ends of the voltage probe to the ends of the coil.

Students can investigate how the number of turns and the speed of the magnet will affect the induced voltage. The best wire to use is thin varnished copper wire for transformers. The coils are much narrower and more turns can be incorporated resulting in higher induced voltages. You will have to burn the varnish off the ends of the wire to make contact with the probe connectors.



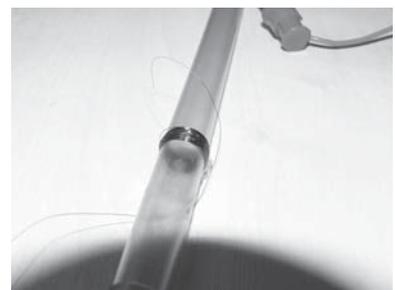
fig_07



fig_08



fig_09



fig_10

You will need

- A Vernier Voltage Probe
- A Vernier EasyLink adaptor
- A TI-Nspire handheld
- Transformer wire
- Some plastic tubing e.g. thermometer tubes

The magnets are easy to obtain from school suppliers e.g. cylinder alnico magnets 8mm by 25mm. Neodymium magnets provide larger fields and consequently greater induced voltages but cost more. Care should be taken to avoid pinching when using neodymium magnets. They are also more fragile and can shatter leaving sharp edges.

The science

When a wire cuts across a magnetic field a voltage is induced between the ends of the wire. This is because the electrons in the wire are forced to move one way, the effect being that of a current driven by a voltage. The wire can be in the form of a coil. This means that the voltages across all the wires (the individual coils) add up, so inducing a much bigger voltage between the ends of the wire or coil.

In general terms $V \propto$ Number of turns and rate of change of field.

Swipe cards have to be moved across a detector at some speed otherwise the induced voltage is insufficient to be read.

The mathematics

Interpretation of graphical data involves comparing maxima to see that the induced voltage is bigger the faster the magnet moves. However the larger voltage is induced for a shorter time

since $V = (N \times \text{change in field}) / (\text{time taken for the change})$

$$V \times \text{time taken for the change} = N \times \text{change in field.}$$

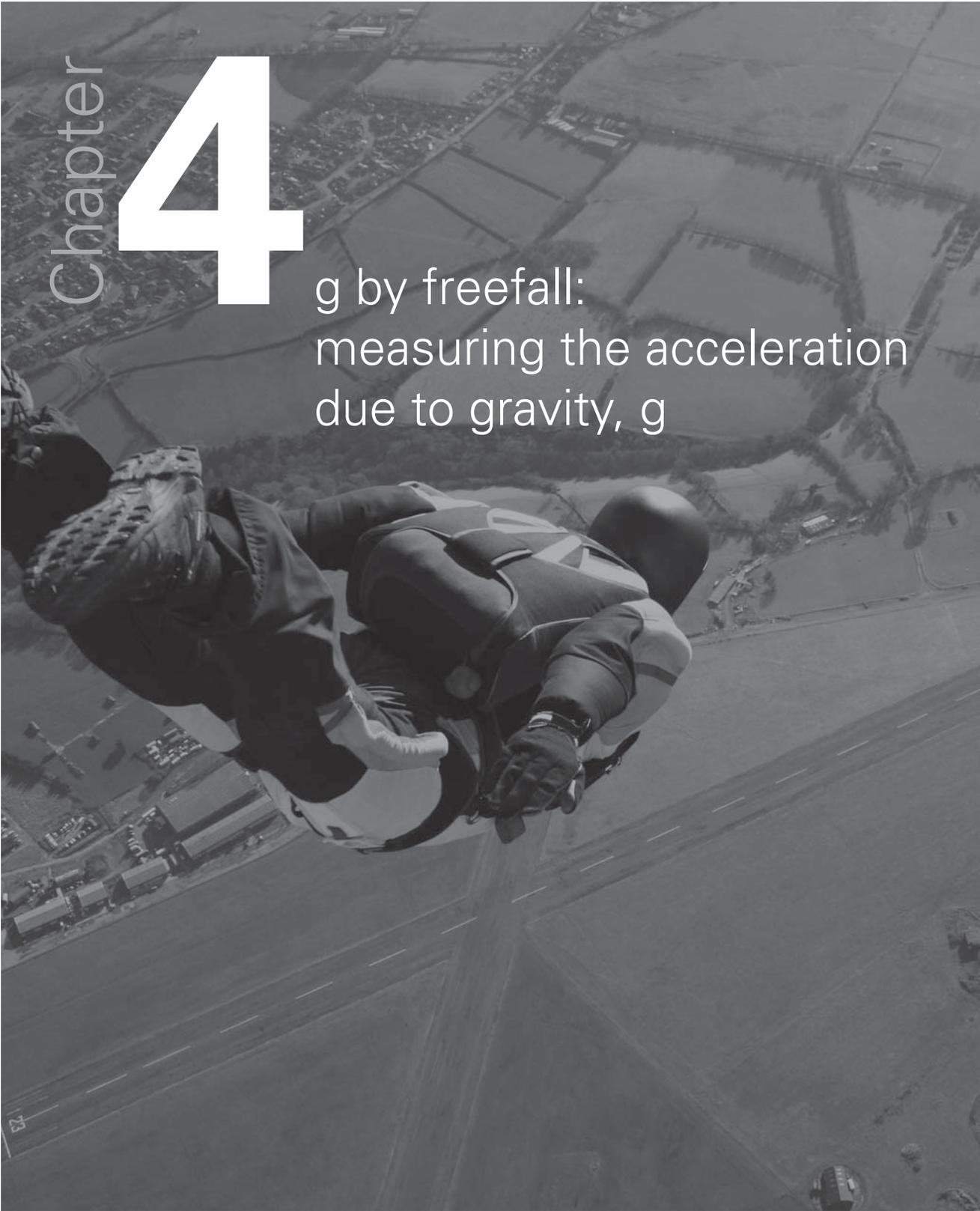
If we assume that the two poles of the magnet are similar in strength, the relation above means that the area between the two peaks and the time axis should be the same.

To download notes and the evaluated .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'em induction'.

Chapter

4

g by freefall:
measuring the acceleration
due to gravity, g



Introduction

Students will record motion data using a CBR 2 motion sensor and a football. The software automatically creates velocity and acceleration variables from the distance data. Students will use the straight line tool to make their measurement of g .

Using the CBR 2 provides a concrete link between the science and maths classrooms. Many maths teachers use the CBR 2 to walk the graph and science teachers would like a simple method of determining g , the acceleration of free fall. **Fig_11 / 12 / 13**

Freefall

Although g is not a physical constant in the same way that for example the density of copper is a constant there is an international standard value, 9.81 m/s^2 . The acceleration due to gravity varies over the surface of the earth, with latitude and with height above sea-level. For science teachers measuring g permits comparison of a measured result with a true value and so enables a meaningful discussion of accuracy to take place. The method is useful for both the maths and science teacher when discussing graphs of motion.

Bruce McCandless Fig_14

The first and only human satellite is in freefall high above the earth's surface. What is g up here?

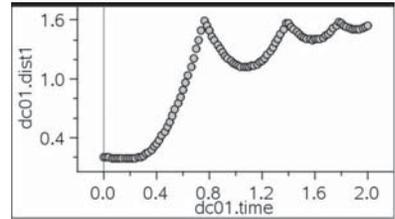
Galileo on the universe Fig_15

It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures. He developed our notions of the acceleration due to gravity and proposed that a falling body would fall with a uniform acceleration, as long as the resistance of the medium through which it was falling remained negligible.

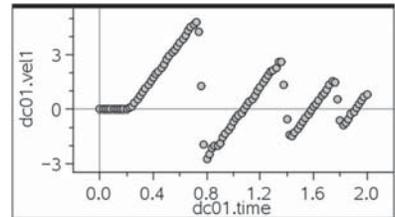
You will need

- A CBR 2 motion sensor
- A TI-Nspire handheld
- A Type B to Mini-A USB cable
- A small football, 25 to 30cm in diameter

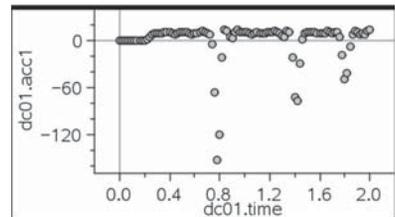
A tennis ball is too small as the reflected signal is lost after falling about a metre from the CBR 2. Sponge balls are no good as the reflected sound pulses are absorbed in the material and not reflected. Start about 30cm from the sensor as the emitted and reflected pulses are confused at shorter distances.



fig_11



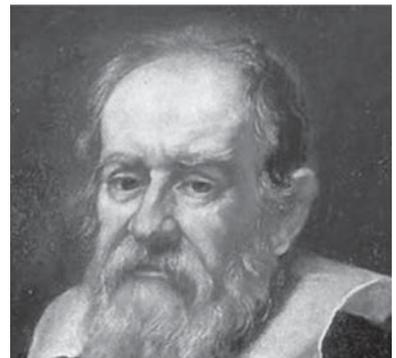
fig_12



fig_13



fig_14



fig_15

The activity

Clamp the motion sensor so that a ball can be dropped from underneath the sensor with about half a metre clear all round. Switch on the TI-Nspire handheld and open a new document or load the tns file 'g by freefall'. Plug in the CBR 2 and select Data & Statistics from the dialogue box.

Press the *menu* button and select *Experiment* then *Set Up Collection* and choose *Time Graph*. Set *Time Between Samples* to 0.02 seconds (the smallest interval possible with the CBR 2) and an *Experiment Length* of 2 seconds.

Hold the ball about 30cm underneath the CBR 2 and press *enter*. As soon as you hear rapid clicking sounds from the CBR 2, drop the ball.

On the TI-Nspire handheld, Add *Moveable Line* and check that each time the ball is in freefall the acceleration is the same. Measure its value as accurately as you can, both from the velocity time graph and the acceleration time graph.

The science

All objects in the absence of air resistance will fall to the earth from the same point with the same acceleration. Measuring g as accurately as possible helps geologists to work out what lies beneath the surface. Variations in g result in small changes to the motions of satellites in freefall. This is important for satellite navigation systems which rely on very precise timings of signals to locate objects on the earth's surface.

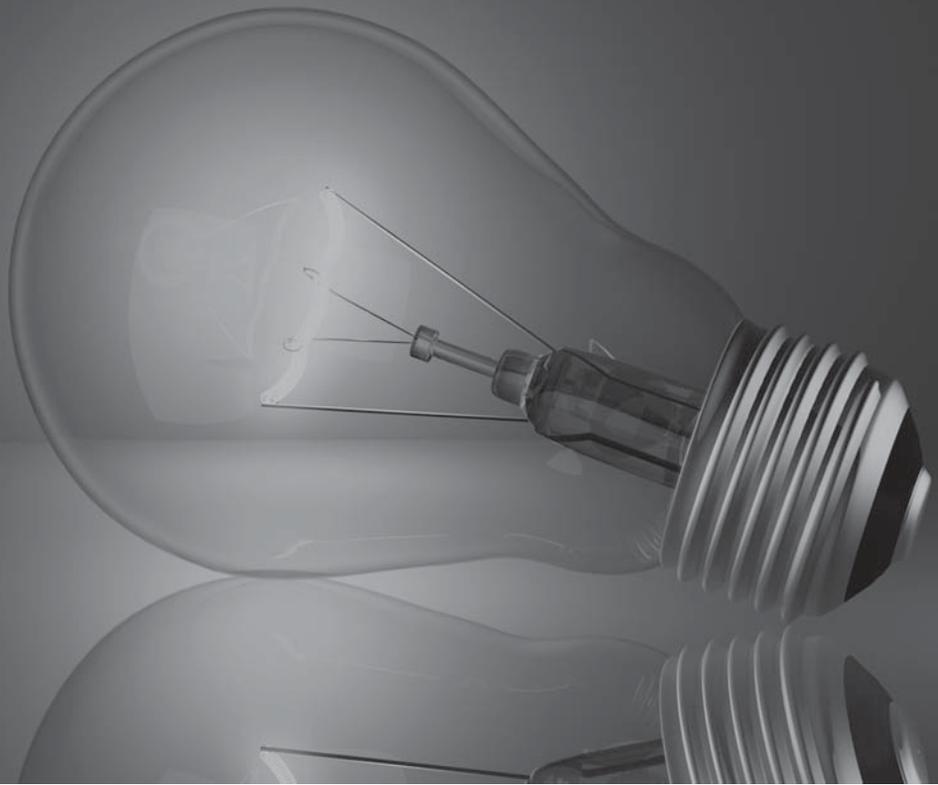
The mathematics

The gradient of the distance (displacement) time graph is the speed (velocity) and the gradient of the speed (strictly velocity) time graph is the acceleration. When using the movable line the gradient and y-intercept are automatically shown on the screen. The distance under the speed time graph can be compared to the distance time graph.

To download notes and the evaluated .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'g by freefall'.

Chapter 5

Light Law
or why is the
light so dim?



Introduction

When radiation streams out from a point source, the energy is shared over ever larger areas. This means that energy which passes through unit area at a distance of one unit will pass through 4 square units at double the distance. This idea applies equally to gravitation although no such gravitational radiation has been discovered. Light (from a point source), gravitation and electric field (again due to a point charge) all obey the inverse square law. This means that illumination of an object falls off rapidly with distance and putting a little distance between a gamma emitter and yourself quickly renders the radiation much less harmful.

You will need

- A Vernier light probe
- A Vernier EasyLink adaptor
- A TI-Nspire handheld
- A 5m tape measure
- A 60W tungsten filament lamp to serve as the light source
- A room which can be darkened (it does not have to be dark just shady will suffice) to reduce the effect of background light.

In this example data are collected as points with entry in the experiment set up menu.

Instead of collecting data with time you will need to set up the experiment to collect data with entries, the entry being the distance from the source. Data are automatically entered into a spreadsheet.

The science

Students are required quite early on to understand that gravity falls off with distance much more rapidly than being proportional to distance would allow. Most specifications cite distance as the way to reduce harmful effects from gamma radiation. Students may begin to appreciate

- how little of the Sun's energy we receive
- how little radiation from a sound source falls on the ear
- why the effect of gravity falls off so rapidly with distance
- Why the reading lamp needs to be so close for good illumination.

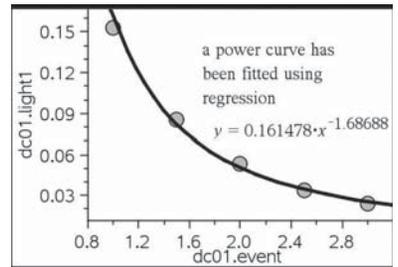
The mathematics

Fitting functions to real data and using the straight line as a test of goodness of fit rather than just relying on regression.

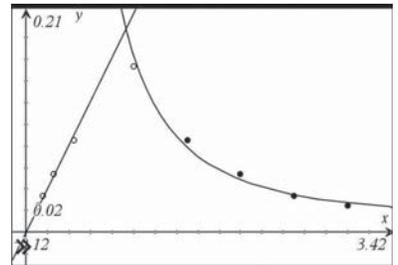
Inverse square variation is just one of a whole family of inverse variations. While Newton became famous for his inverse square law of gravity Coulomb independently developed an inverse square law for point electrical charges.

The area ratio of similar figures is the square of the length ratios, with the logical extension to volume ratios being the cube of the length ratios. Many biological systems are controlled by this mathematical relation.

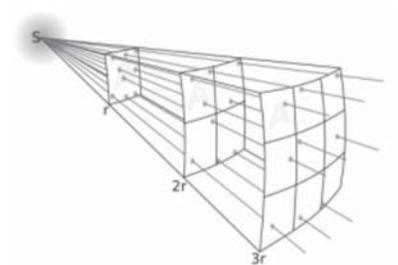
To download notes and the .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'Light Law'.



fig_16



fig_17



fig_18

Chapter 6

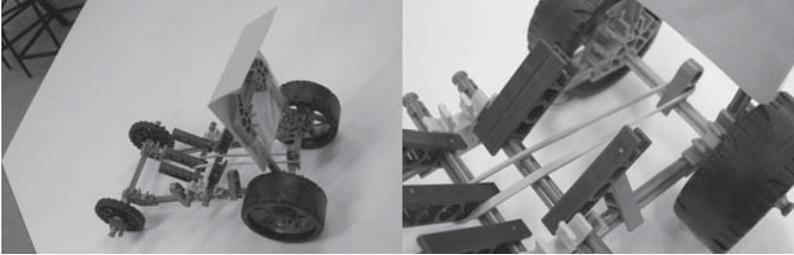
Car motion



Introduction

It is easy to build an elastic band driven car with K'nex.

The band itself can be wound different numbers of times or several bands can be used side by side to turn this activity into an investigation. A reflector made of card should be stuck on the back of the car. This will introduce some unavoidable air resistance!



fig_19

You will need

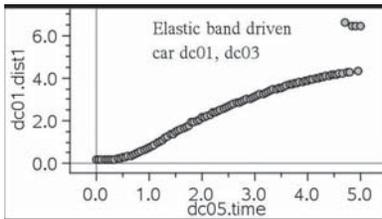
- A CBR 2 motion sensor
- A TI-Nspire handheld
- A Type B to Mini-A USB cable
- A K'nex car or any car which can be driven by elastic bands or friction motor.

The point about this exercise is that the motive power comes to an end fairly quickly.

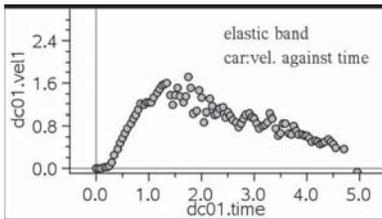
The activity

The activity simply requires students to collect distance time data for the car as it moves away from the CBR 2. Velocity and acceleration are calculated, but in this case the acceleration data are likely to be very scattered. It is worth comparing the distance time data for an elastic band driven car and a friction driven one. Students should identify the point at which motive power is lost and the vehicle begins to slow down.

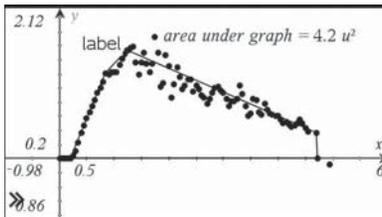
Estimates of the initial acceleration can be made and if the data are sufficiently good can be compared to the value supplied by TI-Nspire.



fig_20



fig_21



fig_22

The science

The CBR 2 itself uses ultra sound pulses and students should speculate on the reason for the CBR 2 losing sight of the car when it is far away. The audible clicks are generated for ease of use. Investigative work can be carried out comparing accelerations with cars of different mass or into the effect of more winds of the band or several bands side by side.

Students should identify the point where the elastic band is fully unwound. This is where there is no longer a push and the car begins to slow down and this is the point at which the forces are in balance. Students should think about whether the car will begin to slow down before the elastic band is unwound because of air resistance and friction.

It is extremely easy to collect the data with a handheld device.

The mathematics

The area under the velocity time graph should equal the distance covered. This is easy to check by re-plotting the points in a Graphs page and constructing a polygon around the points and the x-axis. The area is then simply measured with the area measuring tool and compared to the distance on the distance time graph. Grabbing any of the polygon points and moving them will change the area accordingly.

The exercise also involves graphical interpretation and allows the velocity time curve to be compared to the distance time curve using real data. Students will have to look very carefully at the distance time curve to identify what is happening when the car slows down. A function could be fitted and a moveable tangent attached to the curve would reveal what is happening.

To download notes and the .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'car motion'

Chapter

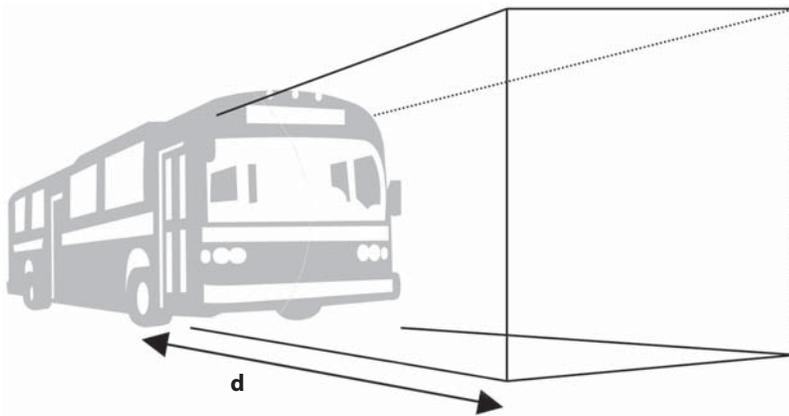
7

Air resistance



Introduction

Imagine a slab fronted vehicle like the bus shown below.



fig_23

Suppose its cross sectional area is A and it is pushing air ahead of itself for a distance d . At steady speed (velocity), v , the horizontal forces are balanced so that push, F , equals air resistance. But the push has to give the air in front kinetic energy. So the work done by the push is the work done on the air,

Work done = Energy transformed
 $F d = \frac{1}{2} A d \rho v^2$

where ρ is the density of the air.

The distance d cancels, and A and ρ are constants, so very approximately,

$$F \propto v^2,$$

i.e the air resistance should be proportional to the square of the speed (velocity).

What you need

- A CBR 2 motion sensor
- A TI-Nspire handheld
- A Type B to Mini-A USB cable
- The means to clamp the CBR 2 about 2m above the ground, say from a shelf or clamp stand mounted on a laboratory bench
- Paper to make cones at least 10cm in radius
- Plasticene and balance to make some 'weights' to add to the cone.



fig_24



fig_25

The science

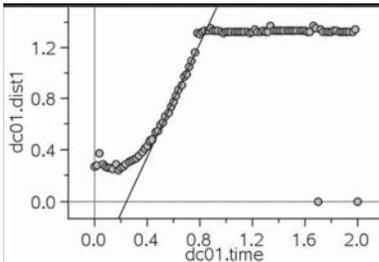
Terminal velocity features in science at age 11 to 14 (balanced forces) and at age 14 to 16 when students study meteorites and kinematics. Streamlining is studied as early as primary level, but it is not normally until post-16 that students bring all this work together to study air resistance.

The picture on the left **fig_24** shows the shuttle re-entering the earth's atmosphere while that below it **fig_25** shows a large meteor which has left a substantial trail. Both of course are the result of air resistance and friction with the air.

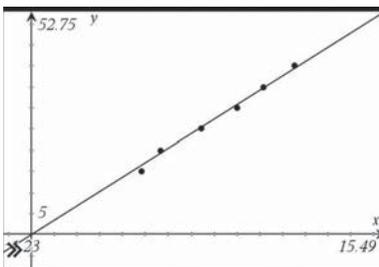
The mathematics

This activity involves finding a mathematical fit to the data. The fact that it is possible to provide a scientific explanation for the fit makes this an ideal STEM activity.

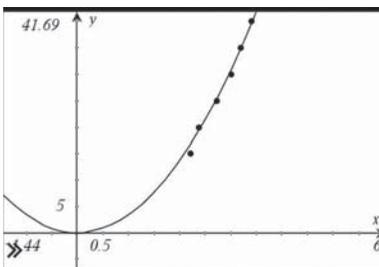
To download notes and the .tns file for this activity, go to www.nspiringlearning.org.uk/classroomresources and search for 'air resistance'



fig_26



fig_27



fig_28

STEM activities with TI-Nspire

The coming decade will see an increasing need for a flexible work force possessing a wide range of skills in Science, Technology, Engineering and Mathematics (STEM) in order to meet the needs of the new high level industries and to be able to produce technologically complex products. The booklets in this series were developed with this need in mind. They aim to provide stimulating activities which link aspects of STEM and at the same time encourage the use of technology and an awareness of its potential.

Why use TI-Nspire for STEM subjects?

TI-Nspire provides a learning platform which dynamically links a variety of ICT applications including documents, graphs, geometry, statistics, spreadsheets, data logging and a calculator. This dynamic linking assists students in making connections not only between different areas of mathematics but also with other areas of the curriculum and STEM subjects in particular.

There is now a wealth of data available on the Internet in a variety of forms which can be copied directly into TI-Nspire. Data can also be captured by linking to a variety of data logging devices such as motion sensors or by recording manually or using video analysis. It is then possible to manipulate, display and analyse this data in a variety of ways or to try to model the data using a variety of data handling and function plotting tools.

About the booklets

All the activities contain some background scientific or other information together with links to appropriate websites. Many of the activities are suitable for a range of ages and aptitudes with more challenging ideas being suggested as extension activities. Further information and TI-Nspire files for the activities can be found at www.nspiringlearning.org.uk.

There are five booklets in the series:

Introduction - contains a brief introduction and instructions for getting started using some of the features of TI-Nspire that are used frequently in the other booklets.

Capturing data: Modelling and Interpretation - contains activities which use a variety of data logging probes to collect real data and analyse it further.

Using real world data - contains activities which investigate and analyse data in a variety of ways from ready-made or easily generated data sets in a variety of contexts.

Mathematics in motion - contains investigations into modelling motion based on different forms of data collection: manual, video and data logging.

Computer graphics - brings together a number of different mathematical approaches which are used by computer programmers to create and manipulate images; techniques that have now found their way into "virtual reality". These activities make use of TI-Nspire applications especially Graphs and Geometry.

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