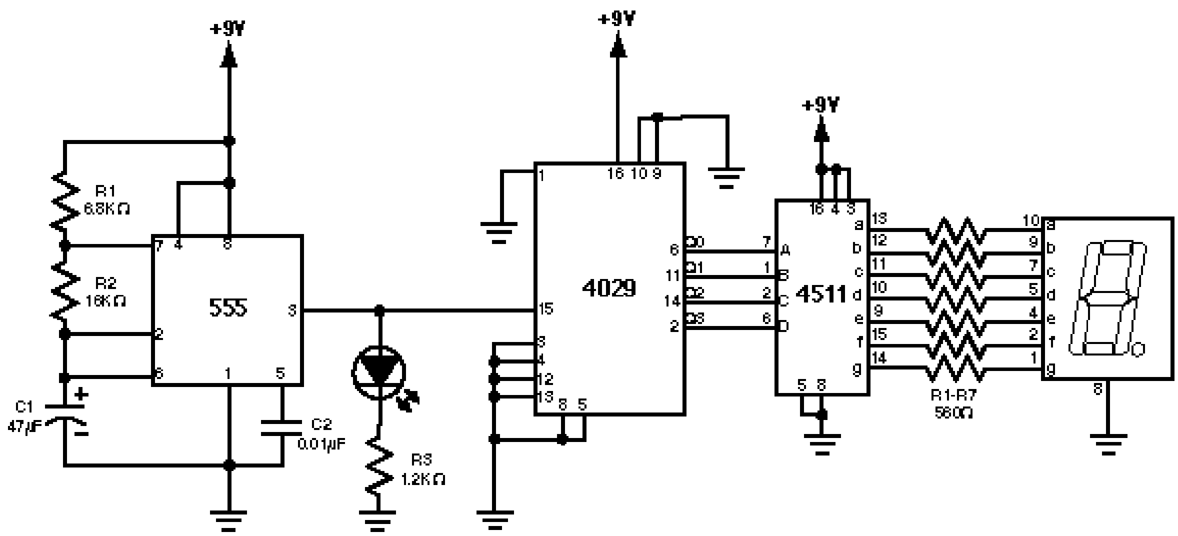
STUDENT SUPPORT MATERIAL

IB PHYSICS
INTERNAL ASSESSMENT



Circuit diagram of a digital counter from www.hobbytron.com

DESIGN

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Defining the problem and selecting variables	Controlling variables	Developing a method for collection of data
Complete/2	Formulates a focused problem/research question and identifies the relevant variables.	Designs a method for the effective control of the variables.	Develops a method that allows for the collection of sufficient relevant data.
Partial/1	Formulates a problem/ research question that is incomplete or identifies only some relevant variables.	Designs a method that makes some attempt to control the variables.	Develops a method that allows for the collection of insufficient relevant data.
Not at all/0	Does not identify a problem/research question and does not identify any relevant variables.	Designs a method that does not control the variables.	Develops a method that does not allow for any relevant data to be collected.

Clarification Comments

Aspect 1: defining the problem and selecting variables

Your teacher may give an open-ended problem for you to investigate. There may be several independent variables from which you could choose one that provides a suitable basis for the investigation.

Although the general aim of the investigation may be given by the teacher, you must identify a focused problem or specific research question. Commonly, students will do this by modifying the general aim provided and indicating the variable(s) chosen for investigation.

The teacher may suggest the general research question only. Asking students to investigate some physical property of a bouncing ball, where no variables are given, would be an acceptable teacher prompt. This could be focused by the student as follows: "I will investigate the relationship between the rebound height and the drop height of a bouncing ball."

Alternatively, the teacher may suggest the general research question and specify the dependent variable. An example of such a teacher prompt would be to ask the student to investigate the deflection of a cantilever. This could then be focused by the student as follows: "I propose to investigate how the deflection of a cantilever is affected by the load attached to one end." It is not sufficient for the student merely to restate the research question provided by the teacher.

Variables are factors that can be measured and/or controlled. Independent variables are those that are manipulated, and the result of this manipulation leads to the measurement of the

dependent variable. A controlled variable is one that should be held constant so as not to obscure the effect of the independent variable on the dependent variable.

The variables need to be explicitly identified by the student as the dependent (measured), independent (manipulated) and controlled variables (constants). Relevant variables are those that can reasonably be expected to affect the outcome. For example, in the investigation of the bouncing ball, the drop height would be the independent variable and the rebound height would be the dependent variable. Controlled variables would include using the same ball and the same surface for all measurements.

Students will **not** be:

- given a focused research question
- told the outcome of the investigation
- told which independent variable to select
- told which variables to hold constant.

Aspect 2: controlling variables

"Control of variables" refers to the manipulation of the independent variable and the attempt to maintain the controlled variables at a constant value. The method should include explicit reference to how the control of variables is achieved. If the control of variables is not practically possible, some effort should be made to monitor the variable(s).

Students will **not** be told:

- which apparatus to select
- the experimental method.

Aspect 3: developing a method for collection of data

The planned investigation should anticipate the collection of sufficient data so that the aim or research question can be suitably addressed and an evaluation of the reliability of the data can be made.

The collection of sufficient relevant data usually implies repeating measurements. For example, to find the period of a pendulum, the time for a number of oscillations is measured in order to find the time for one oscillation. Measuring the time for just one oscillation for a given pendulum length would not earn a "complete". Or, for example, measuring the time for a ball to roll a given distance down an inclined plane can be repeated a number of times and then an average time can be determined.

The data range and the amount of data in that range are also important. For example, in the pendulum experiment, a length range of 10 cm to 100 cm might be used, but measuring the period for only three points within that range would not be appropriate. Similarly, measuring the period for 10 data points in a range from 80 cm to 90 cm would also be inappropriate.

Students will **not** be told:

- how to collect the data
- how much data to collect.

Research Questions in the Design Criterion in Physics Internal Assessment

Aspect 1 of the Design criterion requires students to formulate a focused problem or research question and to identify independent and dependent variables, and relevant controlled variables. It is essential that the teacher give the student an open-ended prompt. The topic must allow for a variety of different approaches.

There are two types of appropriate teacher prompts. First, where the **dependent variable is given** and the student must select the independent variable as well as appreciate the controlled variables. An example here is when the teacher tells the student to investigate one factor that affects the deflection of a cantilever. The second type of prompt is where the **neither the dependent nor independent variables are given.** An example of an openended teacher prompt would be "Investigate a leaking can of water." The student must identify and select the variables. Some variables in this example include the liquid depth or temperature or viscosity, the hold size or shape or location, the time to drain the can, the distance the water squirts, the air pressure above the liquid level and so on.

A student's research question is appropriate when it asks for a **relationship or function** between two quantities, e.g., "How does the length of a pendulum relate to the period?"

Inappropriate research questions often look for a specific value, e.g. "What is the value of gravity?" or "What is the specific heat capacity of an unknown liquid?" Teacher prompts that ask for the verification of a known law or theory are also inappropriate, e.g. "Confirm Newton's second law of motion" or "Verify the equation $PV = nRT$". Teacher prompts that give both the dependent and dependent variables are also inappropriate, e.g. "Investigate the relationship between the period of a pendulum and the length of the pendulum."

Here is a list of appropriate teacher prompts for Design criterion, Aspect 1, and a possible student research question response. Student must carefully define the variables and appreciate the controlled variables.

1. **Batteries and Lemons.** Electrical cells can be produced using lemons or potatoes, along with electrolytes and electrodes of different metals. Investigate factors affecting the voltage produced by such a cell. The dependent variable is given. A student might ask "How does the spacing between electrodes affect the voltage?"

2. **Bicycle Stopping.** Investigate one factor that affects the stopping distance of a moving bicycle. The dependent variable is given. A student might ask: "How does the total weight of the bike relate to the stopping distance?"

3. **Big Splash.** Investigate the splash of water when a ball falls into a bucket of water. The dependent variable is given but only in a vague way; the student must define what as splash is. A student might ask: "How does the drop height of a ball *affect* the range (as measured from the center of the bucket) to the water splashing out?"

4. **Bouncing Ball.** Investigate some physical property of a bouncing ball. Students must decide on the dependent and independent variables here. A student might ask: "Is there a constant relationship between the drop height and the rebound height over a reasonable range of drop heights?"

5. **Bungee Jumps.** Bungee jumping can be simulated in the laboratory in different ways. Investigate one factor that affects the bungee jump. Students must not only decide on the dependent and independent variables but also define clearly what the variables are. A student might ask: "How does the maximum rebound height of a bungee jump depend on the length of the elastic string?"

6. **Cantilever Deflection.** Investigate one factor that affects the declination of a cantilever. The dependent variable is given. A student might ask: "How does the hanging mass at the end of a cantilever affect the declination?"

7. **Cantilever Oscillation.** Using a hacksaw blade investigate one factor that affects the oscillation of the blade. The dependent variable is given. A student might ask: "How does the period of oscillation depend on the length of the blade?"

8. **Catapult.** Investigate one variable affecting the range of a toy catapult. The dependent variable Is given. A student might ask: "How is the range of a catapult's projectile affected by the mass of the projectile object?"

9. **Coffee and Milk.** Investigate the effects of mixing cold milk with hot coffee. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between the cooling rate of coffee and the amount of milk added?"

10. **Conductive** Paper. Investigate some electrical property of conducting paper. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between the effective resistance of a square of conducting paper and the paper's total surface area?"

11. **Craters.** Investigate the formation of craters in the laboratory. A ball can be dropped into a box of sand or modeling clay. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between the depth of a crater and the drop height of a ball?"

12. **Dominoes.** Investigate the domino effect with a set of dominoes. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between spacing of consecutive dominoes and the effective speed of the domino effect?"

13. **Drinking Fountain.** Investigate one factor affecting the distance traveled by the water from a rubber tube connected to a tap. The dependent variable is given. A student might ask: "What is the relationship between the water range and the water pressure?"

14. **Electric Motor.** Investigate one factor that affects the efficiency of a small electric motor. The dependent variable is given. A student might ask: "What is the relationship between the load on an electric motor and its efficiency?"

15. **Electrical Play-dough.** Investigate an electrical property of a chunk of play-dough. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between the diameter of a cylinder of play-dough and its resistance?"

16. **Electromagnetic Strength.** Build an electromagnetic and investigate one factor affecting its strength. The dependent variable is given. A student might ask: "What is the relationship between the current in the electromagnet and the number of paperclips that the electromagnet can hold?"

17. **Evaporation.** Investigate factors affecting the rate of evaporation. The dependent variable is given. A student might ask: "What is the relationship between the surface area of a container of water and the rate of evaporation?"

18. **Fluid Resistance.** Fluid resistance can be studied in a laboratory with different fluids and small balls falling through them. Investigate one factor affecting the

terminal speed of balls falling through a liquid. The dependent variable is given. A student might ask: "What is the relationship between terminal speed and the temperature of a given fluid?"

19. **Margarine Tub.** Investigate one factor affecting the distance traveled by a weighted margarine tube when it is propelled alone a runway. The dependent variable is given. A student might ask: "What is the relationship between the mass of the tube and the distance traveled?"

20. **Paper Helicopter.** Construct a paper helicopter using paper cut into a "T" shape and fold over in opposite ways the hat of the "T". Add a paper clip is needed. Investigate some property of the toy helicopter. Students must define all the variables and look for a relationship. A student might ask: "What is the relationship between the helicopter blade area and the time it takes to drop a given height?"

21. **Pool Depth.** Submerge balls of various sizes to the bottom of a swimming pool. Investigate any relationship between some physical property of the ball and the time it takes to rise back to the surface. The dependent variable is given. A student might ask: "What is the relationship between the size of a ball and the time it takes to rise up tot he surface?"

22. **Slinky.** Investigate the oscillation of a toy slinky. The dependent variable is given. A student might ask: "How does the period of oscillation relate to the number of slinky turns?

Example of a Design Experiment

The teacher prompt is: "Investigate the domino *effect."*

The teacher shows the students the domino *effect* by lining up a number of dominos and then lightly pushing the first one and so producing the domino chain reaction. Students have studied mechanics and waves. This is an open-ended investigation where the student must decide on both the dependent and independent variables.

A student would satisfy **Aspect 1** of Design (defining the problem and selecting the variables) if they:

- state a clear research question e.g. "how does the separation between a fixed number of dominoes affect the time it takes for all the dominoes to fall" .

- identify the relevant variables correctly e.g. the dependant as the pulse speed/time to fall, the independent as the separation of dominoes, and the control variables as the number of dominoes and surface upon which the dominoes rest.

Under **Aspect 2** of Design (defining a method for the control of variables) the student would earn a complete is they addressed the following:

- The method of starting the domino motion. For example, the student might use a small inclined plane of fixed length and roll a ball down the incline in order to hit the first domino with the same impulse for the various trials of the experiment.

- A method for timing. For example, the student might use two photo-gate timers, one at the start and one at the end of the domino chain, which would be activated by a falling domino. The timer would start when the first domino moves and stop when the

last domino moves. They could also just use a stopwatch.

- Standardization. The student would explain how they would keep the domino chain in a straight line.

- Details of controlling the independent variable. There should be discussion as to how the distance between the dominoes is altered and how the distance between consecutive dominos is made the same for each trial. This would involve stating the two points from which the separation is measured.

- A list of materials. This would include a box of dominos, photo-gate timers or stopwatch, a ramp and small ball for the incline, a metre stick to keep the domino chain at a constant 2.00 m length, and a 30 cm rule for measuring domino separation.

Under **Aspect 3** of Design (developing a method for the collection of data) the student would earn a complete is they addressed the following:

- Repeated measurements. The student would realize that repeated measurements for the same domino separation are required. An average time would then be calculated.

- Scope and limit. The student would realize that the minimum separation of the dominos is when they are touching, face to face, i.e. zero. The student should also realize that there is a maximum separation that is more or less equal to the height of a domino. The student should ensure that a suitable range of values is chosen between these limits.

- Changing the number of dominos one at a time allows for ample data within the allowed range.

DATA COLLECTION AND PROCESSING

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Recording raw data	Processing raw data	Presenting processed data
Complete/2	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Processes the quantitative raw data correctly.	Presents processed data appropriately and, where relevant, includes errors and uncertainties.
Partial/1	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Processes quantitative raw data, but with some mistakes and/or omissions.	Presents processed data appropriately, but with some mistakes and/or omissions.
Not at all/0	Does not record any appropriate quantitative raw data or raw data is incomprehensible.	No processing of quantitative raw data is carried out or major mistakes are made in processing.	Presents processed data inappropriately or incomprehensibly.

Clarification Comments

Ideally, students should work on their own when collecting data.

When data collection is carried out in groups, the actual recording and processing of data should be independently undertaken if this criterion is to be assessed.

Aspect 1: recording raw data

Raw data is the actual data measured. This may include associated qualitative data. It is permissible to convert handwritten raw data into word-processed form. The term “quantitative data” refers to numerical measurements of the variables associated with the investigation. Associated qualitative data are considered to be those observations that would enhance the interpretation of results.

Uncertainties are associated with all raw data and an attempt should always be made to quantify uncertainties. For example, when students say there is an uncertainty in a stopwatch measurement because of reaction time, they must estimate the magnitude of the uncertainty. Within tables of quantitative data, columns should be clearly annotated with a heading, units and an indication of the uncertainty of measurement. The uncertainty need not be the same as the manufacturer’s stated precision of the measuring device used. Significant digits in the data and the uncertainty in the data must be consistent. This applies to all measuring devices, for example, digital meters, stopwatches, and so on. The number of significant digits should reflect the precision of the measurement.

There should be no variation in the precision of raw data. For example, the same number of decimal places should be used. For data derived from processing raw data (for example, means), the level of precision should be consistent with that of the raw data.

Students should **not** be told how to record the raw data. For example, they should not be given a preformatted table with any columns, headings, units or uncertainties.

Aspect 2: processing raw data

Data processing involves, for example, combining and manipulating raw data to determine the value of a physical quantity (such as adding, subtracting, squaring, dividing), and taking the average of several measurements and transforming data into a form suitable for graphical representation. It might be that the data is already in a form suitable for graphical presentation, for example, light absorbance readings plotted against time readings. If the raw data is represented in this way and a best-fit line graph is drawn and the gradient determined, then the raw data has been processed. Plotting raw data (without a graph line) does not constitute processing data.

The recording and processing of data may be shown in one table provided they are clearly distinguishable.

Most processed data will result in the drawing of a graph showing the relationship between the independent and dependent variables.

Students will **not** be told:

- how to process the data
- what quantities to graph/plot.

Aspect 3: presenting processed data

When data is processed, the uncertainties associated with the data must also be considered. If the data is combined and manipulated to determine the value of a physical quantity (for example, specific heat capacity), then the uncertainties in the data must be propagated (see sub-topic 1.2). Calculating the percentage difference between the measured value and the literature value does not constitute error analysis. The uncertainties associated with the raw data must be taken into account.

Graphs need to have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scatter graph with data-point to data-point connecting lines).

In order to fulfil aspect 3 completely, students should include a treatment of uncertainties and errors with their processed data.

The complete fulfilment of aspect 3 requires the students to:

- include uncertainty bars where significant
- explain where uncertainties are not significant
- draw lines of minimum and maximum gradients
- determine the uncertainty in the best straight-line gradient.

Detail on Errors and Uncertainties

The treatment of errors and uncertainties is relevant in the internal assessment criteria of:

- Data Collection and Processing, Aspects 1, 2 and 3 (recording raw data, processing raw data, and presenting processed data).
- Conclusion and Evaluation, Aspects 1 and 2 (a reasonable interpretation, with justification, may include the appreciation of errors and uncertainties, and evaluation of procedures may, if relevant, include the appreciation of errors and uncertainties).

The **core** physics syllabus covers errors and uncertainties in the following section of the *Physics* guide (2007):

- Measurement and Uncertainties (topic 1.2)

Both standard and higher students are to be assessed by the same syllabus content and the same assessment criteria.

Expectations at Standard Level and Higher Level

All physics candidates are expected to deal with uncertainties throughout their investigations. Students can make statements about the minimum uncertainty in raw data based on the least significant figure in a measurement. They can calculate the uncertainty using the range of data in a repeated measurement, and they can make statements about the manufacturer's claim of accuracy. Students can estimate uncertainties in compound measurements, and can make educated guesses about uncertainties in the method of measurement. If uncertainties are small enough to be ignored, the candidate should note this fact.

Students may express uncertainties as absolute, fractional, or as percentages. They should be able to propagate uncertainties through a calculation-addition and subtraction, multiplication and division, as well as squaring and trigonometric functions.

All Students are expected to construct, where relevant, uncertainty bars on graphs. In many cases, only one of the two axes will require such uncertainty bars. In other cases, uncertainties for both quantities may be too small to construct uncertainty bars. A brief comment by the candidate on why the uncertainty bars are not included is then expected. If there is a large amount of data, the candidate need only draw uncertainty bars for the smallest value datum point, the largest value datum point, and several data points between these extremes. Uncertainty bars can be expressed as absolute values or percentages.

Arbitrary or made-up uncertainty bars will not earn the candidate credit. Candidates should be able to use the uncertainty bars to discuss, qualitatively, whether or not the plot is linear, and whether or not the two plotted quantities are in direct proportion. In respect of the latter, they should also be able to recognize if a systematic error is present. Using the uncertainty bars in a graph, students should be able to find the minimum and maximum slopes, and then use these to express the overall uncertainty range in an experiment.

Qualitative and quantitative comments about errors and uncertainties may be relevant in the Data Collection and Processing criterion, Aspect 1. Qualitative comments might include parallax problems in reading a scale, reaction time in starting and stopping a timer, random fluctuation in the read-out, or difficulties in knowing just when a moving ball passes a given point. Candidates should do their best to quantify these observations. For example, one candidate measured a voltage from an unstable power supply, and wrote the following

qualitative and quantitative comments:

> The voltage varied slightly over time; it went up and down by several hundredths of a volt. Therefore, the values recorded have an uncertainty greater than the least significant digit of each measurement. The uncertainty was estimated to be more like ± 0.04 V.

Interpreting the Relevant Assessment Criteria

Data Collection and Processing, Aspect 1 (recording raw data)

For a **complete,** students need to present raw data in a clear and comprehensible way, including the name of the quantities, the symbols and units, and an estimated raw uncertainty for each raw data quantity. Uncertainties are always relevant in raw data, even if they are small enough to ignore.

Voltage *V*/V $\Delta V \approx 0$V	Current *I*/mA $\Delta I = \pm 0.3 mA$
1.00	0.9
2.00	2.1
3.00	2.8
4.00	4.1
5.00	5.0
6.00	5.9
7.00	7.1
8.00	8.0
9.00	8.9
10.0	9.9

For a **partial,** students need to present raw data in an appropriate manner but there may be some mistakes or omissions. In the next example, awarded a partial. The student again records raw data appropriately in a table but the symbols are not given, there are no estimated uncertainties and the raw data is recorded with an inconsistent number of significant figures.

Voltage *I*	Current/
1	0.9
2	2.1
3	2.8
4	4.1
5	5
6	5.9
7	7.1
8	8
9	8.9
10	9.9

A student may earn a **not-at-all** if they forget to record any raw data or if the presentation and details are incomprehensible or if essential information is missing such as units.

Raw Data: Voltage and Current
1 @ 0.9, 2 @2.1, 3 @ 2.8, 4 @4.1, 5 @ 5, 6 @ 5.9, 7 @ 7.1,8 @ 8,9 @ 8.9,10 @ 9.9

Data Collection and Processing, Aspect 2 (processing raw data)

Data processing is usually understood as combining and manipulating raw data to determine the value of a physical quantity. Often raw data is multiplied or divided, added or subtracted from other values or constants. When this is done errors and uncertainties should be propagated. However, there are cases where the raw data is appropriate for graphing and for establishing a conclusion. For example, in an Ohm's law experiment voltages and currents may be recorded and graphed. In such cases processing will be understood as transferring the data to an appropriate graph, constructing a best-fit line and determining the slope. Students will not be penalized under aspect 2 if their investigation is of this type. The processing of uncertainty consists in correctly constructing the relevant uncertainty bars on the graph and correctly calculating the slope of the graph.

When students process data by product or quotient, sum or difference or some other mathematical function, such as averaging, then how well the student processes the raw data determines assessment under aspect 2.

In this example the student finds the average of three trial measurements of the time it takes for a ball to roll down a 1.00 m inclined plane. She clearly and correctly calculates the average time and the uncertainty thus earning a **complete.**

Distance s / m $\Delta s \approx \pm 0.00$m	Time t / s $\Delta t = \pm 0.01$s	Average Time t_{ave} / s $\Delta t_{ave} = \pm 0.06$s
1.00	6.28	6.33
	6.39	
	6.31	

$$t_{ave} = \frac{t_1 + t_2 + t_3}{3} = \frac{(6.28 + 6.39 + 6.31)\text{s}}{3} \approx 6.33\text{s}$$

$$\Delta t_{ave} = \frac{\text{Range}}{2} = \frac{t_{max} - t_{min}}{2} = \frac{(6.39 - 6.28)\text{s}}{2} \approx 0.06\text{s}$$

$$t_{ave} \pm \Delta t_{ave} = (6.33 \pm 0.06)\text{s}$$

In this next example the student calculates the square of the average time for three trial runs as shown above and also determines the uncertainty. Again, the student earns a **complete.**

The average time and uncertainty is $t_{ave} \pm \Delta t_{ave} = (6.33 \pm 0.06)\,\text{s}$.

The uncertainty in average time as a percentage: $\Delta t_{ave}\% = \dfrac{0.06}{6.33} \times 100 \approx 1\%$

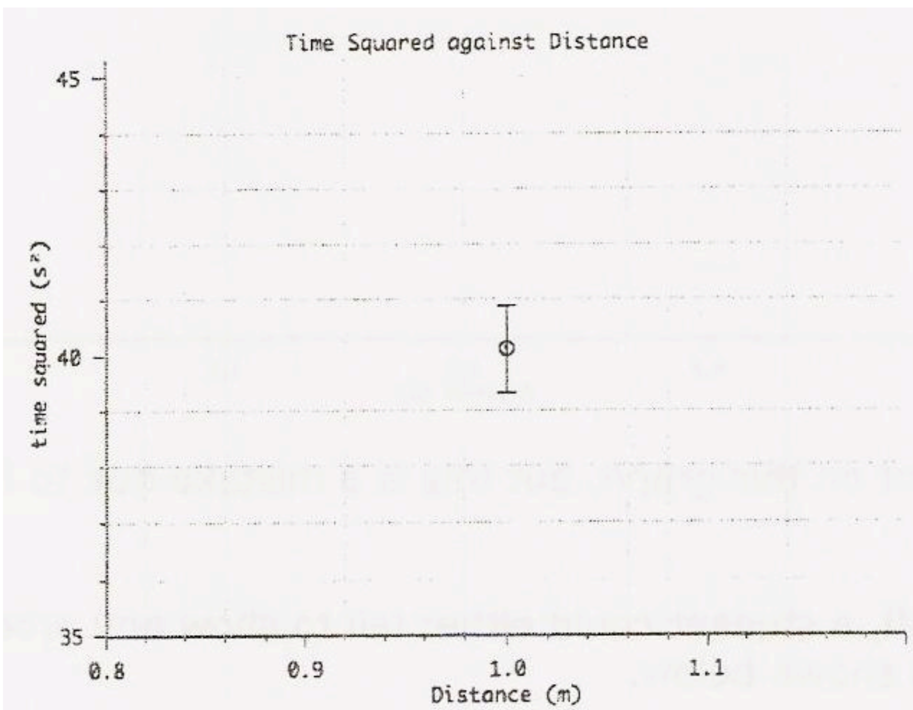
The average time squared is $t_{ave}^2 = (6.33\text{s})^2 \approx 40.1\,\text{s}^2$

The uncertainty in time squared is $\Delta t_{ave}^2\% = 2 \times 1\% = 2\%$

The average time squared and its uncertainty is thus:

$$\therefore t_{ave}^2 \pm \Delta t_{ave}^2\% = 40.1\,\text{s}^2 \pm 2\% = (40.1 \pm 0.8)\,\text{s}^2$$

The datum and its uncertainty are now correctly processed as an uncertainty bar on a graph (see aspect 3) of time squared against distance.



In the next example the student again finds the average of three trial measurements of the time it takes for a ball to roll down a 1.00 m inclined plane but expresses the average with too many significant figures and does not appreciate the propagation of uncertainty. This earns a **partial.**

Distance s / m	Time t / s $\Delta t = \pm 0.01\text{s}$	Average Time t_{ave} / s $\Delta t_{\text{ave}} = \pm 0.01\text{s}$
1.00	6.28	6.3266
	6.39	
	6.31	

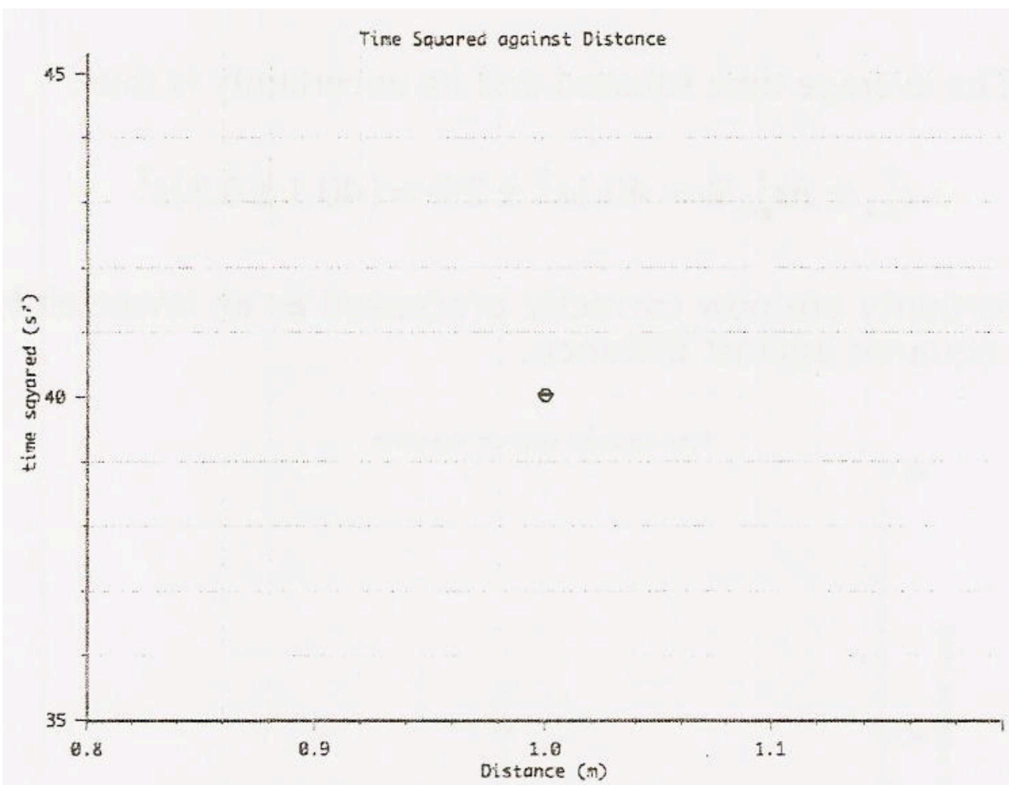
The average time and its uncertainty is $t_{\text{ave}} \pm \Delta t_{\text{ave}} = (6.3266 \pm 0.01)\text{s}$

Next the student calculates the square of the average time.

The average time squared is $t_{\text{ave}}^2 = (6.3266\text{s})^2 = 40.02586\,\text{s}^2 \approx 40.03\,\text{s}^2$

Then the student simply carries forward the raw data uncertainty, which is incorrect.

$$\therefore t_{\text{ave}}^2 \pm \Delta t_{\text{ave}}^2 \% = (40.03 \pm 0.01)\text{s}^2$$



The error bar is insignificant on this graph, but this is a mistake due to incorrect data processing.

Finally, earning **a not at** all, a student could either fail to show any processing of data or

processes it incorrectly, as shown below.

Distance s / m	Time t / s	Average Time t_{ave} / s
1.00	6.28	6.32666
	6.39	
	6.31	

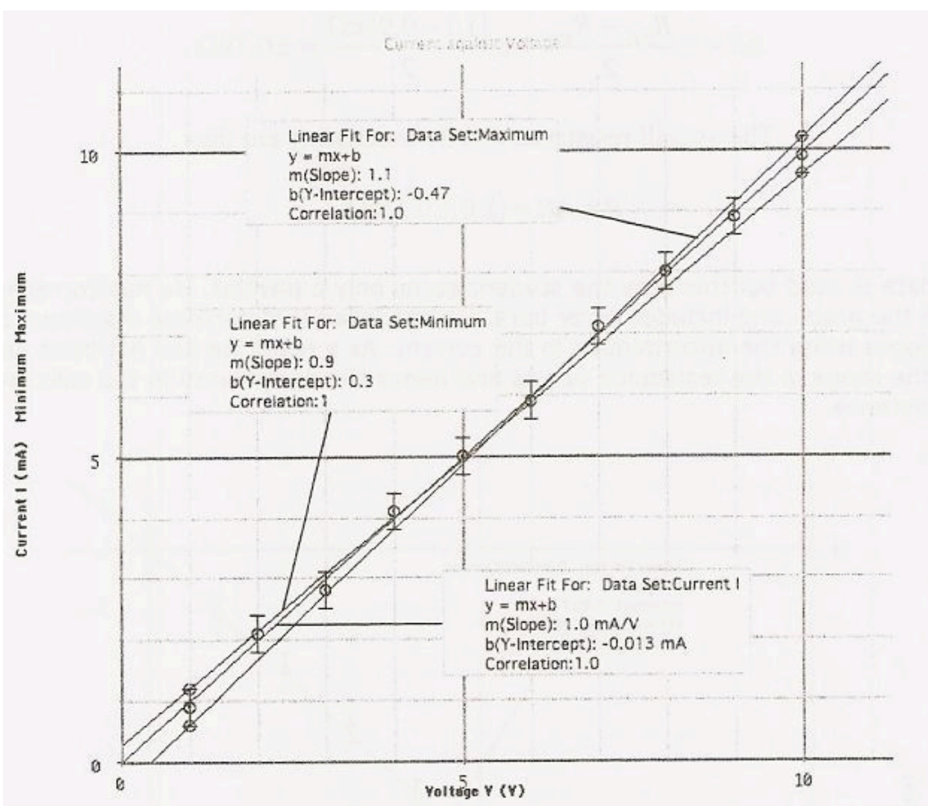
Next the student calculates (but incorrectly records) the square of the average time.

$$\text{The average time squared is } t_{ave}^2 = (6.32666\text{s})^2 = 38.9439\,\text{s}$$

There is a major error in the square of the average time. No uncertainties are appreciated here and the data is transferred to the graph as a data point.

Data Collection and Processing, Aspect 3 (presenting processed data)

A student constructs a graph of current against voltage in an Ohm's law experiment. He uses the slope of the graph and the uncertainties in the current to establish the resistance and its uncertainty. The information has been correctly processed and presented. This example earns a **complete.**



The resistance is then calculated with this value.

$$R = \frac{V}{I} = \frac{\Delta V}{\Delta I} = \frac{1}{\frac{\Delta I}{\Delta V}} = \frac{1}{m} = \frac{1}{1.0 \times 10^{-3}\,\mathrm{AV}^{-1}} = 1.0 \times 10^{3}\,\Omega = 1.0\,\mathrm{k}\Omega$$

The minimum and maximum experimental values of resistance are calculated based on the uncertainty bars for current using the first and last data points.

$$R_{\max} = \frac{1}{m_{\min}} = \frac{1}{0.9 \times 10^{-3}\,\mathrm{AV}^{-1}} = 1.1\,\mathrm{k}\Omega$$

$$R_{\min} = \frac{1}{m_{\max}} = \frac{1}{1.1 \times 10^{-3}\,\mathrm{AV}^{-1}} = 0.9\,\mathrm{k}\Omega$$

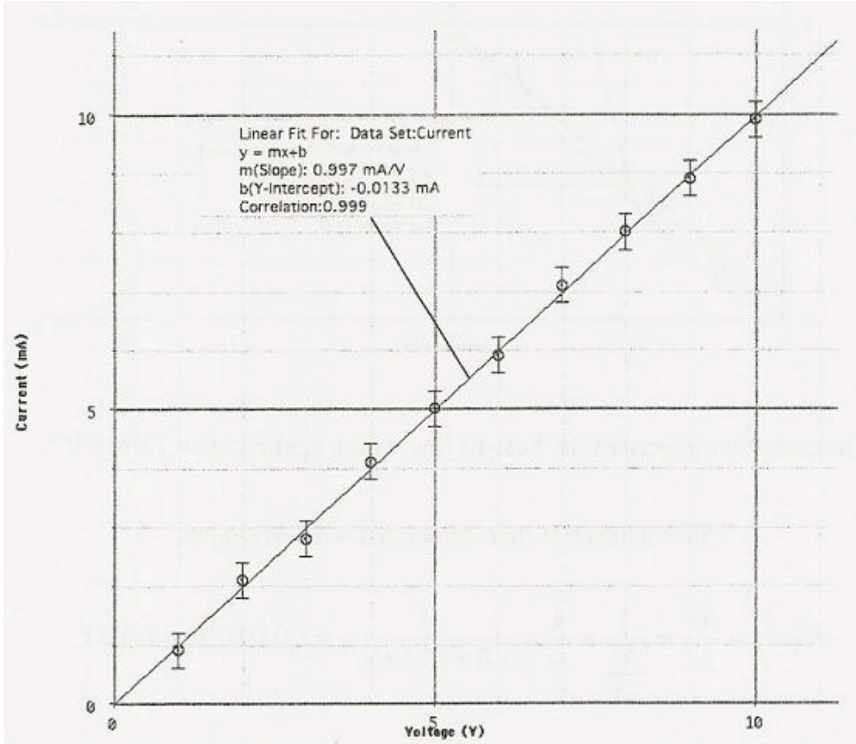
The resistance uncertainty is then

$$\Delta R = \pm \frac{R_{\max} - R_{\min}}{2} = \pm \frac{(1.1 - 0.9)\,\mathrm{k}\Omega}{2} = \pm 0.1\,\mathrm{k}\Omega\,.$$

The overall resistance and its uncertainty are thus

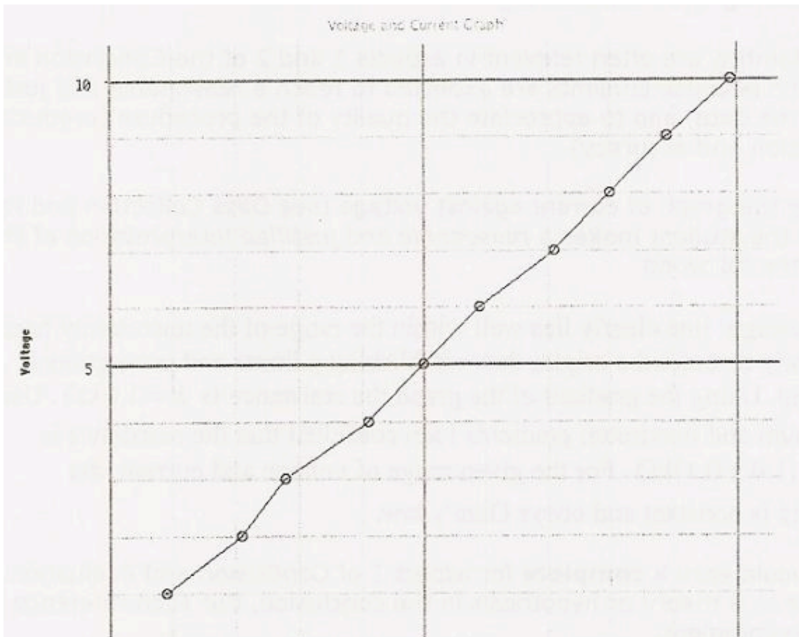
$$R \pm \Delta R = (1.0 \pm 0.1)\,\mathrm{k}\Omega\,.$$

The same data is used but this time the student earns only a **partial.** He has correctly constructed the graph and included error bars. He has failed to determine maximum and minimum slopes using the uncertainties in the current. As a result he has not been able to determine the range in the resistance values and hence the uncertainty in the calculated value of resistance.



The resistance is $R = \dfrac{V}{I} = \dfrac{\Delta V}{\Delta I} = \dfrac{1}{\text{slope}} = \dfrac{1}{0.99\,\text{mAV}^{-1}} \approx 1.0\text{k}\Omega$

Next, the student draws an inappropriate graph with major errors, thus earning a **not at all.**



$$\text{Resistance} = R = \frac{V}{I} = \frac{10}{10} = 1\Omega$$

Conclusion and evaluation

Levels/marks	Aspect 1	Aspect 2	Aspect 3
	Concluding	Evaluating procedure(s)	Improving the investigation
Complete/2	States a conclusion, with justification, based on a reasonable interpretation of the data.	Evaluates weaknesses and limitations.	Suggests realistic improvements in respect of identified weaknesses and limitations.
Partial/1	States a conclusion based on a reasonable interpretation of the data.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Suggests only superficial improvements.
Not at all/0	States no conclusion **or** the conclusion is based on an unreasonable interpretation of the data.	Identifies irrelevant weaknesses and limitations.	Suggests unrealistic improvements.

Clarification Comments

Aspect 1: concluding

Conclusions that are supported by the data are acceptable even if they appear to contradict accepted theories. However, the conclusion must take into account any systematic or random errors and uncertainties. A percentage error should be compared with the total estimated random error as derived from the propagation of uncertainties.

In justifying their conclusion, students should discuss whether systematic error or further random errors were encountered. The direction of any systematic errors should be appreciated. Analysis may include comparisons of different graphs or descriptions of trends shown in graphs. The explanation should contain observations, trends or patterns revealed by the data.

When measuring an already known and accepted value of a physical quantity, students should draw a conclusion as to their confidence in their result by comparing the experimental value with the textbook or literature value. The literature consulted should be fully referenced.

Aspect 2: evaluating procedure(s)

The design and method of the investigation must be commented upon as well as the quality of the data. The student must not only list the weaknesses but must also appreciate how significant the weaknesses are. Comments about the precision and accuracy of the measurements are relevant here. When evaluating the procedure used, the student should specifically look at the processes, use of equipment and management of time.

Aspect 3: improving the investigation

Suggestions for improvement should be based on the weaknesses and limitations identified in aspect 2. Modifications to the experimental techniques and the data range can be addressed here. The modifications should address issues of precision, accuracy and reproducibility of the results. Students should suggest how to reduce random error, remove systematic error and/or obtain greater control of variables. The modifications proposed should be realistic and clearly specified. It is not sufficient to state generally that more precise equipment should be used.

Detail on Errors and Uncertainties

Errors and uncertainties are often relevant in aspects 1 and 2 of the Conclusion and Evaluation criterion because students are expected to reach a reasonable and justified interpretation of the data, and to appreciate the quality of the procedure (producing a measure of precision and accuracy).

After constructing the graph of current against voltage (see Data Collection and Processing, Aspect 3, above) the student makes a *reasonable* and *justified* interpretation of the data when they state the following.

> The best straight line clearly lies well within the range of the uncertainty bars and passes nearly through the origin, thus establishing a linear and proportional relationship. Using the gradient of the graph the resistance is $R = 1.0\ \text{k}\Omega$. Using the minimum and maximum gradients I am confident that the resistance is $R \pm \Delta R = (1.0 \pm 0.1)\ \text{k}\Omega$. For the given range of voltage and current, the relationship is constant and obeys Ohm's law.

This conclusion would earn a **complete** for aspect 1 of Conclusion and Evaluation. The student may refer to a theory or hypothesis in the conclusion, but such reference is not required to earn a complete.

For a **partial** in the Conclusion and Evaluation, Aspect 1, consider the current against voltage graph as shown in Data Collection and Processing, Aspect 3, which earned a partial. Although the graph shows uncertainty bars they are not used to establish a conclusion. Only the gradient of the graph is used, and no comment is given about the quality of the data. The student wrote the following:

> The graph is a straight line through the origin so for this given resistor we find the resistance as 1000 ohms. This is a good result.

If there is no justification of the limits of the data then the conclusion earns a partial. A reasonable interpretation is really an incomplete interpretation.

A student whose graph is shown above under Data Collection and Processing, Aspect 3, which earned a not at all, has no appreciation of errors or uncertainties and does not construct a best straight line. Moreover, the student incorrectly calculates the resistance as 1 ohm. The following Conclusion and Evaluation, Aspect 1, earns a **not at all.**

> The graph is good; it gives me a resistance of exactly 1 ohm. The experiment was a success.

When attempting to measure an already known and accepted value of a physical quantity, such as the charge of an electron or the wavelength of a laser light, candidates need to appreciate whether or not the accepted value lies within the experimental value range.

Perhaps a candidate conducts the Young's double slit experiment and determines that the laser light wavelength is 610 nm. With experimental uncertainty, the student decides that $\lambda_{exp} \pm \Delta\lambda_{exp} = (6.1 \pm 0.2) \times 10^2$ nm. The manufacture's literature that came with the laser gives a wavelength of A = 632.8 nm. The student might write the following:

> The accepted value is 6.328×10^3 run while my experimental value is $(6.1 \pm 0.2) \times 10^2$ run. The accepted value lies just outside the experimental range, which is from 5.9×10^2 run to 6.3×10^2 run. My estimation of errors and uncertainties need to be reexamined. Nonetheless, my results are close the accepted value, about 4% too low.

In addition to the above comment, candidates may also comment on errors in the assumptions of any theory being tested, and errors in the method and equipment being used. For example:

1. Perhaps a graph of voltage against current does not form a linear and proportional line. It may be that the load resistance is changing as the current changes, so an ohmic relationship does not hold.

2. Measuring the magnetic field alongside a current-carrying wire may confirm the inverse relationship, but for the smallest distances and the largest distances the data does not line up. The induction coil has a finite size, and the centre of it is assumed to be zero. This may not be the case. At large distances, the radius is similar in magnitude to the length of the wire, and the inverse law for the magnetic field assumed an infinite wire length.

3. When using the sonic detector, the software was not calibrated with the speed of sound first, and so the measured distances were inaccurate. This error was due to an unexamined assumption, but it was appreciated when the experimental results were evaluated.

4. The experiment was done to determine the effiCiency of an electric motor. As the investigation was carried out, the battery may have lost power. This would have affected the results.

Overall, candidates can critically appreciate limitations in their experimental results due to assumptions in the theory, in the experimental techniques, and in the equipment used. Qualitative comments, based on a careful reading of graphed results, will guide the candidate's criticism.

MANIPULATIVE SKILLS

Manipulative skills are assessed summatively. This means that one overall mark will be given. The skills assessed should cover most of the two-year course, and the mark given should reflect the student's general ability near the end of the course. The mark is not an average nor does it relate to a given investigation. The overall skill level demonstrated on a number of occasions is given. The examples below are suggestions to aid assessment of manipulative skills and are not considered to be a prescribed list.

Note: No supporting evidence is required for moderation of manipulative skills.

Aspect 1: Following instructions

The candidate:

- reads/listens to instructions before asking for help
- only starts the investigation after having read/listened to all the instructions
- is able to follow a sequence of several written or verbal instructions with little assistance.

Aspect 2: Carrying out techniques

1. Measuring length

The candidate:

- chooses an instrument appropriate to the length to be measured
- uses the instrument correctly
- records the zero reading
- reads a vernier scale correctly

2. Cathode-ray oscilloscope (CRO) investigation

Candidates investigate the operation and use of a CRO.

The candidate:

- uses a CRO to work in an unfamiliar environment
- learns skills of adjustment and measurement
- should explore the various controls
- should ask for help only after a good attempt has been made to use the eRO for the assigned tasks

3. Building an Electric Motor

Candidates construct a small DC motor from a kit. Most good educational suppliers sell DC motor kits, complete with instructions. The candidate will not be able to construct the motor unless the instructions are followed closely.

The candidate:

- assembles the motor correctly
- adjusts the number of loops of wire to ensure successful rotation
- adjusts the contact position to give continuous rotation
- ensures that overheating does not occur when the motor is in use

4. Electrical measurement investigation

Candidates investigate the behaviours of different batteries made from lemons or potatoes (of varying shapes and sizes) and electrodes of two different metals.

The candidate:

- assembles a basic electric circuit
- chooses the correct instrument scale
- reads the scale to the correct precision

5. Bunsen burner investigation

Candidates determine the temperature of a Bunsen burner flame. It is suggested that heating a small metallic object and then introducing it to water can be a successful method of determining the temperature of the burner.

The candidate:

- handles the burner correctly
- uses tongs and goggles
- transfers the object to the calorimeter quickly and safely
- stirs the liquid to obtain an even temperature
- reads the thermometer scale to the correct precision

6. Projectiles investigation

Consider an object projected onto a horizontal plane at an angle to the horizontal other than 90°. Design and carry out an experiment to investigate the relationship of its range, and its maximum height, with the angle "A".

This experiment involves the construction of a shooting device that will project the object with a constant velocity at fixed angles "A", as well as clearly recording the path of the object.

The candidate:

- assembles the equipment correctly
- measures the angle to the correct precision
- measures range and height using appropriate techniques and to the correct precision

Aspect 3: Working Safely

The candidate:

- always wears safety clothing appropriate to the task such as eye protection, lab coats and gloves when told to do so
- pays proper attention to written or verbal safety instructions and hazard symbols
- keeps the workspace clear of unnecessary materials
- leaves bags and coats in a safe position
- lights and uses a Bunsen burner safely
- leaves glassware on solid surfaces and ensures that they cannot be knocked or roll off the surface
- reports when equipment has been broken
- clears broken glassware immediately
- washes and tidies up the equipment after use
- avoids using electrical apparatus near a water supply
- makes sure that there are no trailing electrical leads
- uses electrical apparatus within its current limitations to avoid overheating

PERSONAL SKILLS (PS) will be evaluated only once and only during the Group 4 Project. No other IA criteria can be assessed in the Group 4 Project. PS will not be moderated.

ICT Requirement. Students are expected to experience information and communications technology during the practical scheme of work in the following ways: (a) data-logging, (b) the use of a spreadsheet for data processing, (c) software for graph plotting, (d) a database, and (e) computer modelling or simulation. The use of ICT will not be assessed (although data-logging may be appropriate for DCP assessment if used in the way described in the course guide).