Estimating uncertainties in raw data

Two simple rules

Digital devices

The uncertainty in a digital readout is given by the least significant digit. The example shown here is the time taken for a cart to pass between two photogates. The least significant digit in the display is .0002 so the uncertainty is ±0.0001s

Analogue devices

The uncertainty in a measurement made with an analogue device such as a ruler or an analogue voltmeter is 1/2 the smallest division of the scale. So for a typical meter rule with mm divisions the uncertainty would be ±0.5mm.

Applying these rules is perfectly acceptable but sometimes the value obtained is unreasonable since the uncertainty depends on the way the device is used not just the size of the scale. If, for example, a meter rule is used to measure the length of a piece of paper then the uncertainty could be less than 0.5mm, especially if the edges of the paper line up with the lines on the ruler. However if we use the same rule to measure the maximum height of a bouncing ball then the uncertainty is going to be much bigger. So the method will influence the uncertainty and that where judgment comes in.

Using Judgment

Using a ruler

Is the edge straight, curved or uneven?
Is the object to be measured stationary or moving?
Would it help to use a magnifying glass to view the scale?
Is there a parallax error?
If measuring the position of an image or the node in a string how well can you judge its position?
Is there an error at both ends of the ruler?

Using a voltmeter or ammeter

Does the reading fluctuate?
Will changing the range reduce the uncertainties?
What is the manufactures uncertainty of the instrument?
If holding the contacts by hand does the pressure applied change the reading?

Using a sensor connected to a datalogger (LabQuest)

Does the position of the sensor change the reading?
If reading a point from a graph, how well can you judge the point from the display?
If using the gradient of a line does the part of the line you choose change the gradient?
If reading from a digital display, how many decimal places is reasonable?

Why do measurements vary?

There are two reasons why a measurement might vary, one is because the instrument does not give the same reading every time and the other is because the quantity itself is varying.

Device

If we measure the mass of a steel ball on a top pan balance that measures to the nearest 0.1g then we may find that the reading varies between 52.3g and 52.4g, this could be because the actual value is somewhere between the two and the electronics in the balance is causing the value to flicker between one and the other. This is an instrument uncertainty.

Method

If we measure the time taken for a ball to drop 0.4m we might get measurements ranging from 0.2781s to 0.2828s. This is not due to some random fluctuation in the clock but it's because the ball does not drop the same way every time, this is an uncertainty in the method.

If we were to measure the width of a piece of an A4 paper with a ruler we would get a value of 21.0 ±0.5 cm (actually i'd say ±0.1cm since the edge of the paper lines up very closely to the line division on the ruler). if we repeat this measurement we get the same every time. This is because any change in the paper is so small that it is not detected by the instrument used to measure it (the ruler is not sensitive enough)

Repeating measurement to find uncertainty

One reason for repeating the measurement of a quantity is so we can take an average to reduce the uncertainty, but to reduce the uncertainty significantly would require a lot of measurement and we rarely have time for more than 5 repeats. it also helps the students to understand that measurements are not exact. A simple (and acceptable) way of finding the uncertainty is to take the half difference between the maximum and minimum values (½ the range) and use this as the uncertainty in the average. The problem is that this does not take into account the fact that taking an average actually reduces the error so students often get exaggerated error bars. Awareness of this problem is enough, detailed analysis is beyond the scope of the course.