Measurement and Uncertainty
Objectives

The objectives of this lab are to:

✔ Learn how to perform simple measurements.
✔ Learn how to find experimental uncertainties in your measurements.
✔ Learn how to correctly write down your measurements with their uncertainties.
✔ Learn how to obtain the uncertainty in a calculated value (for example a perimeter or an average).
✔ Learn the difference between precision and accuracy.
Measure the length and the width of the palm of your hand with the ruler provided. Record your results in Table 1 in your lab book. Make sure that you include units.
The measurements you just recorded in *Table 1* have uncertainties associated with them. Their values are largely determined by the precision of the measuring device, i.e. the ruler in this case.

**QUESTION 1**: What is the precision of the ruler you used to measure your hand?

*Hint*: For a device with a scale its precision can be determined by figuring out what is the smallest division on the scale.
In general, the precision of an instrument is a very good choice for the uncertainty of a single measurement performed with it. However, certain qualities of the object being measured can also influence the uncertainty, usually making it bigger.

Remember that the uncertainty is a reflection of your confidence that the measurement is inside a certain range of values.
Are the edges of your object (i.e. a hand for this experiment) sharp and well defined or are they not clearly defined?

Ask yourself how reliable is your measurement: are you confident to 0.2 mm, 0.5 mm, 1 mm, 2 mm, or more? Whatever you decide will be your uncertainty.

**Question 2:** Write down the estimated uncertainties in your length and width measurements based on the considerations discussed above.
QUESTION 3: Write down the length and width of your hand together with your estimated uncertainty in the form $x \pm \delta x$. Be sure to include units. Your uncertainty should have only one significant figure and your measurement value should have the same number of decimal places as your uncertainty.

Notice that your length measurement is larger than your width measurement. To determine which of those measurements is more precise you have to calculate their corresponding relative uncertainties. The smaller the relative uncertainty the more precise the measurement is.

QUESTION 4: Calculate the relative uncertainties for the length and width of your hand. Which relative uncertainty is larger?
Relative Uncertainty

QUESTION 5: According to your answer to Question 4 which measurement is more precise?

Have your instructor check your measurements and your relative uncertainties and sign your Laboratory Worksheet.
Combining Quantities and Comparing Results

You will now calculate the perimeter and area of your hand treating it as a rectangle of length $L$ and width $W$ (see Table 1). The perimeter is defined as the distance around a two dimensional shape.

**QUESTION 6:** Calculate the perimeter $P$ of your hand. Be sure to include units. Show your workings.

In order for you to find out the absolute uncertainty of the perimeter you will have to use the addition/subtraction rule stated in the Introduction section to this lab.

**QUESTION 7:** Calculate the absolute uncertainty in the perimeter of your hand.
QUESTION 8: Write down the perimeter of your hand in the form \( x \pm \delta x \) following the rules outlined in section 4 on p. vii of your laboratory workbook.

QUESTION 9: Is the absolute uncertainty in perimeter smaller or larger than the absolute uncertainties in length and width? Is this an expected result? Comment.

Treating your hand as a rectangle wasn’t the most accurate method of finding out its perimeter. You will now use a piece of string to find a more accurate value of that quantity.
You will now measure the perimeter of your hand. Use a string to make an outline of your hand, keeping it as close as possible to the outside of your hand. Be sure to close the loop across your wrist!

When done, use a meter stick measure the length of string corresponding to the perimeter of your hand.

Record this length of the string in Table 2 of your Laboratory Workbook.

Estimate the uncertainty of this measurement and record the value in Table 2.
Comparing Results

One of the most important things about experimental uncertainties is how we use them to see if two or more quantities can be considered equal.

If you have two values for a quantity $x$ say $x_1 \pm \delta x_1$ and $x_2 \pm \delta x_2$ then these two numbers **agree within experimental uncertainty** if the range $x_1 - \delta x_1$ to $x_1 + \delta x_1$ overlaps with the range $x_2 - \delta x_2$ to $x_2 + \delta x_2$.

For example if two people measured a length of an object and the first person got $L_1 = 10.6 \pm 0.4 \text{ cm}$ and the other person got $L_2 = 11.1 \pm 0.2 \text{ cm}$ as their results do their results agree with each other?

The first person says that the length he measured is in a range:

$10.2 \text{ cm} < L_1 < 11.0 \text{ cm}$

The second person says that the length he measured is in a range:

$10.9 \text{ cm} < L_2 < 11.3 \text{ cm}$

Since the two ranges overlap we can say that the two measurements do agree with each other within experimental uncertainty.
Comparing Results

QUESTION 10: Does the perimeter you measured with the string agree with the perimeter you calculated earlier? Refer back to Question 8. In answering this question, write the range of both quantities as in the example above. Comment on any disagreement between the two.
You will now calculate the area of your hand and its uncertainty

**QUESTION 11:** Treating your hand as a rectangle, calculate the area $A$ of your hand. Be sure to include units.

**QUESTION 12:** Using the multiplication/division rule (see Introduction section to this lab) and your answer to Question 4 calculate the relative uncertainty in the area of your hand.

**QUESTION 13:** Is the relative uncertainty in area smaller or larger than the relative uncertainties in length and width? Is this an expected result? Comment.

**QUESTION 14:** Calculate the absolute uncertainty of the area of your hand and write down your result in the form $A \pm \delta A$ following proper rules for significant figures.
You will now measure the area of your hand with graph paper. Laying your hand on top of the graph paper in your Laboratory Workbook (keep your fingers together), carefully trace the outline of your hand. Each partner should trace their own hand.

Determine the area of your traced hand by counting the squares (1 cm\(^2\) each) inside the outline. Do your best to estimate the area in the squares which are only partially inside the outline of your hand.

Record this area in Table 3 of your workbook.

Estimate the uncertainty in the area and record this value in Table 3. In estimating this uncertainty, ask yourself how many squares you could be off by.
Combining Quantities and Comparing Results

QUESTION 15: Briefly explain your method for estimating the uncertainty in the area from the graph paper method.

QUESTION 16: Does the area you measured with the graph paper agree with the area you calculated in Question 11? In your answer to this question, be sure to write the range of both quantities. Comment on any differences.
In this part of the lab, you will gather some data from your lab mates, to find out the average (mean) width and length of a first year physics student’s hand and its uncertainty.

First rewrite your measurements from Table 1 into the first row of Table 4 (no need to rewrite their uncertainty).

Visit other, nearby students in the lab and ask them for their measurements of length and width from their Table 1. Write them down in the remaining rows of Table 4. You should record 10 values each of length and width in Table 4.
Your goal now is to find the average length $L$ and the average width $W$ as well as their absolute uncertainties (i.e. standard errors). You will use a software called Graphical Analysis to do that.

Enter your length values in the table.
Click **Analyze** then **Statistics**.

Record the mean ($L$), standard deviation ($\sigma_L$), and point count ($N$) in **Table 4**.

Calculate the standard error and record your result in **Table 4**.

Repeat the steps outlined above for your measurements of the width and record the results in **Table 4**.

**STANDARD ERROR** is the absolute uncertainty of the average value.
QUESTION 17: Write the average hand length in the form \( L \pm \delta L \) using results from Table 4. Find the relative uncertainty in length.

QUESTION 18: Write the average hand width in the form \( W \pm \delta W \) using results from Table 4. Find the relative uncertainty in width.

QUESTION 19: Does your own hand’s length and width agree with the average value in Table 4? (calculate ranges and see if they overlap).
QUESTION 20: Identify one source of random uncertainty and one source of systematic uncertainty in your experiment.

- Place your lab workbook in your assigned shelf.
- Tidy your workbench.
- Sign out (at the centre desk by the door) before you leave.