Teaching ideas for Topic 1: Measurement and uncertainties

It is envisaged that this topic will be taught at the start of the course. It is an ideal beginning, because:

- knowledge and experience of measuring is required throughout the practical aspects of the course; experimental experience will be examined in one or more of the required experiments, as given in the 'Applications and skills' section of the IB Physics guide
- an appreciation of the uncertainty of a measurement is fundamental to the nature of science and is linked well with aspects of theory of knowledge (TOK) and with the need for international-mindedness
- familiarity with prefixes, units and the use of standard form in calculations allows students access to more detailed and complex arithmetic operations
- the use of vectors in physics is crucial for higher-level learning and problem-solving.

Ideas for teaching the topic

- Making a measurement of something and accepting the limits to the accuracy of that measurement is fundamental to good physics. Teachers might like to begin this topic using a variety of measuring instruments to allow students to measure a range of different things – see the practical activities below. It is worth pointing out that the uncertainties in their measurements give the students information about how **reliable** the measurement is. This can be reinforced by getting the students to make repeated measurements and finding the average. This links directly with aim 4 in the group 4 aims in the IB Physics guide.
- It may be prudent at this early stage to make sure that students understand the difference between a measurement that is **accurate** and one that is **precise**. Many different ways of showing this are possible. Here is one way: imagine a footballer who is going to practise taking penalty kicks at the goal. If the footballer kicks every ball 1m wide of the goal, he has kicked the ball with great precision, but poor accuracy. If he kicks every ball into the goal but some enter the goal at the bottom left, some at the bottom right and some in the middle of the goal, he has kicked the ball accurately but not precisely. If every kick he takes makes the ball enter the goal in the same place, then his kicks have been accurate and precise.
- When measurements are combined to produce some other quantity, an idea of how reliable this is can be obtained by propagating the uncertainties in the original measurements. This is a vital skill for students to acquire. So the next step for teachers might be to get students to measure various quantities that can be combined to produce another value. An example of this is for students to measure the mass and volume of an object and use their measurements to find the density of the object, propagating the uncertainties in mass and volume to get an uncertainty in the density. This links directly with aim 9 in the group 4 aims in the IB Physics guide.
- The ability to add, subtract and find components of vectors is another vital mathematical skill for students to have. This provides a strong foundation for later work in Topic **2**: Mechanics and in the additional HL Topic **10**: Fields. This section of the topic can be delivered practically (see below) or analytically, but a combination of both may be the best way for students to pick up these important ideas quickly. Familiarity with trigonometric functions will be beneficial for later topics, too. This links directly with aims 2 and 3 in the group 4 aims in the IB Physics guide.

Practical activities

- Students might begin this topic by measuring a range of different things with a variety of different instruments – perhaps in a circus, for example: width, height and thickness of a sheet of paper (with rulers and a micrometer); diameter of a ball (this might provide interesting discussion about the appropriate instrument if a range of different balls is available); mass of the piece of paper (electronic scales or other weighing instrument); tension force in a spring (with a newton meter or equivalent); weight of a student (bathroom scales); temperature of some water in a beaker (thermometer or equivalent temperature probe); pressure of air in an inflated balloon (Bourdon pressure gauge or equivalent); or any other simple measurements to make within the laboratory. A good variety – and some good imagination – will provide students with interesting tasks, and this will promote sensible questioning from them.
- For each measurement, the absolute uncertainty should be considered and the fractional (or percentage) uncertainty introduced. This then allows measurements to be combined; for example, if the length of a piece of paper is $l \pm \Delta l$, how long will n pieces of paper be and what will be the absolute and fractional uncertainty?
- The use of SI units is sensibly introduced here. This allows familiarity with prefixes, such as 'milli' and 'micro'. It will also support students in their growing confidence of using standard form in calculations. This is ideal for one or two set tasks as homework to consolidate learning.
- After a lesson and some practice with this, more demanding tasks can be assigned; for example, find the density of paper or the pressure a student exerts on the floor. Although the practical activity per se is not hugely demanding, it is useful in guiding students into good practical method and the propagation of uncertainty in their calculations is exactly what students need to be able to do.
- This is also a good time to introduce graphing results. Using error bars to find best-fit lines (either by hand or with a suitable software program such as Graphical Analysis or Excel) is a good exercise for students and this will lead on to finding gradients and the uncertainty in them. (It is worthwhile at this point to stress that the word 'line' can mean a straight line or a curve.)
- With some simple such as with a mass hung from two strings, or held between fixed points by springs, with newton meters to measure forces and protractors to measure angles, students can check their calculations involving addition and components of vectors.

ICT

- This topic is ideal for introducing the effectiveness of spreadsheets for tabulating, analysing and graphing data. As this is such an important skill for students to acquire, early exposure to using spreadsheets is advised. One idea is to introduce the statistical uncertainty in a set of repeated measurements – done in the IB way by using half the range – this is easily accomplished with a spreadsheet.
- It is also a good time to introduce the use of suitable data-logging hardware/software to make measurements such as voltage, position, speed and temperature. As this is a required aspect of the practical scheme of work (PSOW4), students' early familiarity with this will pay dividends later on.

Common problems

- Students can often misinterpret prefixes – this is particularly true in calculations involving powers. For example, the prefix 'M' for Mega (meaning $\times 10^6$) is often confused with the prefix 'k' for kilo (meaning $\times 10^3$), and 'm' for milli (meaning $\times 10^{-3}$) is confused with μ for micro (meaning $\times10^{-6}$). Good discipline in setting out solutions to questions (and some good learning) is helpful here and can eliminate these difficulties quickly.

- Converting fractional and percentage uncertainties into absolute uncertainties. As this is often the last step in a sequence of calculations, students frequently omit this. Plenty of practice with this should help – another good exercise for homework.
- Mathematics! Trigonometric functions such as sine and cosine are often confused, and this results in poor analysis with vectors and their components. There is lots of room for practice questions in this part of the topic.

Theory of knowledge (TOK)

- Empiricism, as a way of knowing, is seen by some as the only true way of knowing. Making an observation (i.e. a measurement) on something is the first step to this. This introduces excellent lines of questioning such as: How do I know that what I am observing/measuring is the same as what someone else is observing/measuring? Or: What sources of bias might there be in the observation/measurement I make? Or: What effect does my observation/measurement have on what I am observing/measuring? Questions like these link to the nature of science itself and also lead to how scientists can collaborate by agreeing a set of protocols that all will follow.

International-mindedness

- The very use of an agreed set of units (the SI system) is a clear example of the international-mindedness of scientists. The nature of science requires collaboration and agreement, along with rigorous testing and checking; this can only be done is there is one set of ‘rules’ that all will follow.
- It has been said that physicists communicate with each other by the language of mathematics. Students might like to discuss how important it is, therefore, that mathematics provides a nationality, language and culture-free way of communicating.