Teaching ideas for Topic 2: Mechanics

This topic follows on sensibly from Topic **1**: Measurements and uncertainties and builds on the experience and practical ability that students have already developed. It also includes the first of the required experiments (see the 'Applications and skills' section of the IB Physics guide): determining the acceleration of free-fall experimentally. As this topic features strongly in examinations, it is an important topic for students to engage with.

Some useful points to consider are:

- This topic is really an exploration of Newton's laws of motion. A thorough understanding of these will take students a long way towards being a good physicist. Extending students' knowledge of forces by a simple link, such as 'work done = force × distance moved (in direction of force)' allows a smooth move from Subtopic **2.2**: Forces to Subtopic **2.3**: Work, energy and power.
- There is a wide range of possible experimental tasks that students can undertake – and they are not dependent on sophisticated equipment. A simple stopclock and a tape measure, for example, may be all that is required to measure the acceleration of free-fall.
- It is a fruitful topic, from which good investigations and ideas for extended essays and internal assessment (IA) work come. Kinematics, a little mathematical analysis and some careful experimentation can produce surprisingly good results.

Ideas for teaching the topic

- It may be a good start to this topic to revise/learn (where appropriate) ideas of motion graphs. This is an excellent way to start the topic and will enable students to cover the importance of: the difference between vector and scalar quantities and how they are displayed graphically; speed (the gradient of a graph of distance against time); velocity (the gradient of a graph of displacement against time); acceleration as the rate of change of velocity (gradient of graph of velocity against time); and the use of areas of graphs and what those areas represent physically, for example displacement as area of velocity against time graph and change of velocity as area of acceleration against time graph. If students are able enough at this stage, the area of a graph of force against time gives impulse or change of momentum, which will be useful later.
- Some careful work with equations of motion involving a constant acceleration (SUVAT) is vital. Examination problems do not require students to consider quantitatively the effect of air resistance, although they should understand the qualitative effects and how air resistance leads to terminal velocity. Note that this also applies in the newly introduced section about fluid resistance and terminal speed. Perhaps this is best done first in one dimension and then in two, where the ability to deal with two independent, perpendicular vectors can be developed and projectile motion can be analysed. Higher Level students might like to extend this to three dimensions, although this will not be examined. This links directly with aim 2 in the group 4 Aims in the IB Physics guide.
- Newton's laws of motion form the foundation of much of the classical mechanics in any physics course. Students will need to understand the concepts of equilibrium (both as a balance of forces and as a balance of rotational moments), of how pairs of force act and of friction. The use of free-body force diagrams and the vector work covered in Topic **1** will allow students to work through this section of the topic effectively.
- There is good scope for teacher worksheets that cover energy considerations. Calculation questions will develop familiarity with the equations required and improve the discipline of students in setting out their answers correctly. This section also links directly with the concept of efficiency and its importance in fuel conservation in Topic **8**: Energy production.

- Momentum and its link to Newton's second law in the form $F = \Delta p/\Delta t$ is a strong idea that is used in a wide range of physical interactions, from colliding cars to atomic motion. Through the analysis of simple collisions (these could be done experimentally with an air track or similar device) the important idea of the conservation of momentum can be developed and extended to interactions that are elastic (such as billiard balls colliding), inelastic (such as a squash ball bouncing on the floor) or superelastic (such as fireworks exploding). This links directly with aims 3 and 6 in the group 4 aims in the IB Physics guide.

Practical activities

- A good starting task here might be to begin with the first of the required experiments: determining the acceleration of free-fall. Once the kinematics of constant accelerated motion are understood, students can drop objects from a variety of heights, time their fall and by appropriate graphing (i.e. plotting height fallen against time taken squared) can use the gradient of the graph to find g. This is a good investigation to start with, because it will bring out important experimental details such as variables, control, range of independent variable and sources of uncertainty in measurement. It also provides the opportunity for students to compare what they measure with what they would expect analytically. This will prompt excellent discussions about use of assumptions in physics and what it is that affects the amount of air friction on an object – and also lead to possible investigations for IA.
- Making the assumption that air friction is negligible is something that students can find difficult. Perhaps this is to be expected, as we all live in an environment filled with air and our experiences of things moving through the air make this assumption difficult to accept. So, a good follow-up to this is to demonstrate a feather and a coin dropping at the same time: a sealed clear plastic tube about a metre long with a coin and a feather inside can be used for this. If a vacuum pump is used to suck out the air from inside the tube, the feather and coin will fall with the same speed, unhindered by air friction, and hit the bottom of the tube at the same time. Allowing air back inside the tube and repeating the demonstration will show the effect of the air friction.
- A good investigation for students to do is to make some paper cones and drop them. Students can find a good variety of variables to investigate, such as how the time taken to fall depends on the mass or the diameter of the cone. This will help to strengthen ideas about forces and the effect of air friction. With a mobile phone app such as SloPro students can video their cones falling and see if the cones fall with terminal velocity by playing back their videos in slow motion.
- This is a good part of the syllabus for using any data-logging equipment, such as Pasco or Logger Pro. Position sensors and motion sensors are ideal for producing motion graphs that students can then analyse. This will also fulfil the requirements of the practical scheme of work (PSOW4) for the use of IT.
- An important experiment for students to do is to verify Newton's second law in the form $F = ma$. With a friction-compensated ramp (this is a good experiment in itself; use a small trolley or a toy car and find out how much you must raise one end of a ramp so that the trolley/car moves down the ramp at constant speed when given a small push) and a pulley attached to the end of a desk, pull the trolley/car down the ramp by attaching a string to it and put a mass on the other end of the string. Keep the total mass of the trolley/car and the mass doing the pulling constant. The weight of the mass on the end of the string is the accelerating force. Measure the acceleration of the trolley/car using a ticker-tape timer or motion sensor. The accelerating force can then be varied by moving mass between the mass on the trolley/car and the mass on the end of the string. Students will appreciate seeing the agreement of what they observe with what they expect from analysis. This links directly with aim 6 in the group 4 aims in the IB Physics guide.
- Investigations involving the link between the frictional force of a block of wood on a slope and the normal reaction force are also good for students to do. A careful free-body force

diagram will allow students to see the relationship between the frictional force, the normal reaction force and the angle of the slope at which the wooden block just starts to slip. Students should see that there are no other variables involved here (for example, the area of the block in contact with the slope). This will produce good discussion and questioning about the micro-scale nature of friction.

- Students must be familiar with the concept of conservation of energy. A selection of examples of situations in which energy is transformed from one form into another makes a good starting point for teaching Subtopic **2.3**. One example of this might be a mass oscillating vertically on a spring: students should consider the exchange of elastic potential energy, kinetic energy and gravitational potential energy, while accepting that, if frictional forces are neglected, the total energy of the system must remain constant.
- Another concept that some students find difficult is the work done in moving an object higher from the ground. In simple cases, where the force used is vertically upwards, the work done (often described as the **useful** work done) is simply the change in gravitational potential energy (gpe) of the object, and this is force × distance moved (in the direction of the force). However, in cases where the force is not vertical (for example, if the object is pulled up a slope) then the useful work done is still the change in gpe, but now this is the component of force in the vertical direction × the distance moved in the vertical direction. Students might like to consider larger-scale applications of this principle: for example, winding roads that lead to the top of a hill.
- Investigations involving momentum and its role in collisions are also good to do. An air track or similar friction-free motion provider is a useful piece of equipment to have. This can be combined successfully with a data logger to provide motion data. Conservation of momentum in one dimension is something that students must be able to deal with. Higher Level students might like to consider using vector components to deal with two or three dimensions.
- Please see the available practical notes for further ideas.

ICT

- This topic is good for using data-logging equipment, as suggested in the section above. Students can also use the analytical aspects of the software to help reinforce their knowledge.
- There are a number of free mobile phone apps available that students might like to download. Students can use these very effectively, from simple photographs to video analysis with slow-motion playback. These are to be encouraged, because they allow students more freedom in how they want to investigate various physical phenomena.
- Students can also use spreadsheets to simulate the motion of projectiles. By setting up the appropriate equations of motion, they can produce position vectors that can be plotted against time to show paths of projectiles. It is an interesting exercise to ask students to find out the ideal angle for a projectile to be launched from for it to have maximum horizontal displacement for any given initial velocity. This will also produce good discussion if historical examples, such as firing cannons, are considered.
- There are a number of useful simulations available from the University of Colorado website (http://phet.colorado.edu); these can be used to good effect by students on their own.

Common problems

- Use of SUVAT equations. Students commonly get confused with these. An important idea is to recognise which direction the force is in and that in all other directions there is no force and therefore no acceleration. As this is a popular area of the syllabus for examination questions, lots of practice on questions is good for students.
- The concept of useful work done is important, and students often find this confusing. It is the overall, or net, work that is the important thing. There is, in fact, some high-level mathematics

at play here: work is a scalar quantity, whereas force and distance moved in direction of force are vectors. So we have a scalar product between the two vectors. It is not important for students to understand this at this point, but if they are to calculate the total, or net, work done on a body, it may be easier for them to find the net force and the net distance moved in the direction of that force and then multiply these together to give the net work done.

Theory of knowledge (TOK)

- In this topic Newton's laws of motion form a central part. This should prompt discussion about what a law is and whether laws are universal or restricted to certain circumstances (in which case, should they really be called a law at all?).
- Newton's laws have been shown to be flawed, slightly, by more modern scientists such as Einstein, and the acceptance of quantum theory has caused a paradigm shift (a big step up) in what we now know and understand. How does a paradigm shift in scientific knowledge affect the way in which further knowledge is acquired? What other examples of paradigm shifts are there in the history of science?
- One of the basic ideas of science is that if we know all the variables for a given situation, we should be able to predict what will happen. Is this always the case? What does current research on chaos theory tell us about predicting the future behaviour of a physical system?

International-mindedness

- The scientific method, which is often defined as the way in which scientists go about their learning, is more than just a set of instructions for how to conduct experiments. It requires collaboration of all scientists, in all countries. However, it also requires a discipline of setting out answers to problems that is not dependent on a scientist's first language. Students are strongly advised to follow the rules and not to do it their way. (Interestingly, this is a valid TOK point too: does this prescriptive teaching prevent possible innovation that could break away from the norm and produce accelerated learning?)
- Without international collaboration, new ideas and laws are difficult to accept. The rigorous testing and re-experimentation that forms an essential part of peer assessment is an important aspect of scientific progress.