Teaching ideas for Topic 6: Circular motion and gravitation

From amusement park rides to satellites in orbit around the Earth that bring our television and communications, circular motion plays an important part in our lives. In this topic, students should try to adopt two ideas: (1) that circular motion is caused by a force that is always perpendicular to a body's velocity and (2) that circular motion requires that this centripetal force is present and is provided by the resultant force that acts on the body.

The work on gravitational fields should be relatively easy for students to absorb if they have already completed Topic **5**: Electricity and magnetism. It is worth pointing out that Newton's universal law of gravitation copes mathematically with the possibility of negative mass – to produce a repulsive force. Be aware that, as stated in the IB Physics guide, the equations given for gravitational force do **not** include the usual negative sign (showing the attractive nature of the force for positive values of mass). More experienced physics teachers may be troubled by this fact.

Some useful points to consider are:

- Circular motion requires centripetal force. This force is provided by real forces such as friction, gravity and tension. It is a good method for students to equate mv^2/r to whatever force is providing the centripetal force. The use of free-body force diagrams will be very useful here.
- If students have covered the concept of angular frequency, ω, in Topic **4**: Waves, then the equations $v = \omega r$ and $F = mr\omega^2$ will be a natural follow-on for students to learn. Otherwise, it is a good opportunity for taking time to make sure students understand this idea.
- Newton's law of gravitation, despite being shown by scientists such as Einstein to be flawed, has lasted for nearly 350 years. Based on observations and classical mechanics, it is still a strong feature of many physics courses. Teachers may find it a good exercise for students to research
their own knowledge of how Newton arrived at his law and how other observations (such as those of Tycho Brahe, Galileo and Kepler) have been able to add credibility and verification to Newton's work.
- Using the ideas that students met in Topic **5** about fields, it is important that terms such as 'gravitational potential' are properly understood.
- The similarities and differences between the equations for electric fields and gravitational fields is another thing worth spending time on.

Ideas for teaching the topic

- A good starting point would be to revise the ideas of period, frequency and angular frequency that students met in Topic **4**, using the circle as the way of teaching these ideas.
- Students should then become familiar with examples of circular motion. An easy start to this might be for students to fix a mass on the end of a piece of string and make the mass rotate in a circle by pulling on the string. Ask students to 'feel' what they are doing to make the mass go round in a circle. This should enable students to accept that a force is required and that this force is always directed towards the centre of the circle. Investigating how the size of this force depends on the radius of the circle, the mass of the object on the end of the string and the speed at which the mass is moving, even if done qualitatively, is of enormous benefit to students learning the equation for centripetal force, $F = mv^2/r$. Other examples can now be introduced, such as running around the curved part of an athletics track, riding a bicycle around a circular track, cars that follow curved paths on roads that exit from motorways and the motion of the Earth (and the other planets and comets) around the Sun and the Moon around the Earth. In each case, it is important for students to identify which force is providing the centripetal force.

- Drawing gravitational field patterns is a good idea, because students can be reminded of the importance of the vector nature of forces. This is particularly necessary in the case of two or more masses creating a complex gravitational field.
- Students should also appreciate the energy aspect of something that is in an orbit caused by a radial field. Adding the kinetic energy (always a positive value) to the potential energy (always a negative value in an attractive field) will give a total energy that is less than zero. This reminds students that the object orbiting is still being influenced by the field.
- Equating the centripetal force to Newton's law of gravitation (as the force that is providing the centripetal force) will lead to Kepler's third law of planetary motion. Students should understand that this provides observational verification of Newton's law; it also allows some excellent calculations to be made on celestial bodies.

Practical activities

- The starting point mentioned earlier of getting students to swing masses on strings will allow the measurement of force if a newton meter (or similar tension-measuring instrument) is available. If available, a tension force sensor could be attached to a data logger. Students can then investigate the factors on which this centripetal force depends. If this is not possible, students should try to do this experiment qualitatively. This links directly with aim 6 of the group 4 aims.
- There is some good scope in this topic for students to use video of various examples of circular motion, playing back the video in slow motion in order to take measurements and analyse the motion. Free apps on mobile phones will do this well, and this allows students great freedom to find their own examples. If this is not possible, then there are many videos of circular motion available on YouTube that can do the same thing. This links directly with aim 7 of the group 4 aims.
- Using a source of information about planets (an ideal use of a database – or even an opportunity for students to create their own database from their research on the planets in our solar system) it is a useful exercise for students to: (1) visualise the relative distances involved in the average radii of planets' orbits (a good way to do this is to take the students outside and, using a suitable scale, get students to stand at distances away from a starting point (the Sun) that represent the radius of orbit of each of the planets); (2) check that a graph of R^3 against T^2 produces a proportional relationship (and from the gradient of this, find the mass of the Sun); and (3) plot a graph of orbital speed ($v = 2\pi r/T$) against radius of orbit to show that the fastest moving planets are those closest to the cause of the gravitational force.
- If you are lucky enough to have access to a telescope capable of photographing Jupiter, a nice longer-term experiment is to photograph Jupiter and its four main moons (Io, Europa, Callisto and Ganymede) over a couple of months and use measurements of orbital period and relative radius of orbit to verify Kepler's third law. Historically, observations of Jupiter's moons were crucial evidence in putting forward the heliocentric model of the solar system.
- Please see the available practical notes for further ideas.

ICT

- Spreadsheets, particularly for their ability to produce graphs, will be very helpful in this topic.
- Some students might like to compile their own databases from the information they research on various orbits of celestial bodies in the solar system. This can be a useful exercise for students in deciding what information is useful and what is not. Such computer-based activities link directly to aim 7 of the group 4 aims.

Common problems

- Students tend to forget the important relationship of $v = 2\pi r/T$ for an object moving in a circular path. This is an important relationship for them to remember. Familiarity and practice should help students with this.
- As mentioned earlier in this topic, students often have trouble equating the centripetal force necessary for circular motion with whatever the net force is that acts on a body. This is worth reinforcing as a way for students to solve problems.

Theory of knowledge (TOK)

- The first manned space missions occurred in 1959 and 10 years later man walked on the surface of the Moon. At this time, the available computing power was less than there is now in many modern motor cars. To what extent has modern progress in computing affected our vision for exploration and discovery?
- Much of our knowledge of orbits has come from observations. How can we learn about things if observations are not possible?
- Gravity, as a force, is perhaps the least understood of all the four fundamental forces. Perhaps this is because we do not really understand what mass is yet, and we associate gravity with its effect on mass. And yet, what understanding we do have about gravity has formed part of our classical physics education for over 300 years, without much amendment. Modern physics (that is, quantum physics) has been able to relate to the other three forces with good agreement, so what is it about gravity that has eluded modern ideas for so long? Do other subjects suffer similar problems with their development?

International-mindedness

- Finding suitable launch sites for space missions requires considerable international collaboration. How do space research organisations decide on where their optimum launch sites should be? What political, economic or cultural difficulties does this pose?

