FLH3 (Facilitating Learning in Higher 3 Physics) teacher workshop materials

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1 Introduction

Four runs of this 2-day teacher workshop were held between June 2017 and November 2018, facilitated by Kwek Leong Chuan.

Quite a lot of relevant resources for teaching and learning can be found here (including a link to the latest version of this document). A huge collection of simulations is hosted here.

1.1 Main Points

1. Encourage greater independence and exploration by students, encourage their intellectual curiosity and awesomeness. Help nurture their "taste" for beauty in physics.
2. Read the book by Gilbert Highet, *The Art of Teaching*. Learning, thinking, exploring... the path to happiness!
3. Informal learning experiences beyond the classroom will be important to complement syllabus-oriented instruction. These can include going for a symposium or colloquium talk, or even mini-projects and explorations.
4. H3 Physics should prepare students well for a range of future pursuits, be they in science, engineering, mathematics or even politics and economics.
5. A great variety of teaching and Learning (T&L) activities can be used. In physics education, we have the advantage of bringing in demonstrations (e.g. van de Graff generator) and experiments, and for mechanics there are many little toys that illustrate very interesting phenomena. Students can tinker around with breadboards and circuit components for electronics. Many videos and online resources like simulations are readily available, so students can learn the content on their own (flipped classroom). The physics education research literature is also quite rich, with education-focused journal articles suggesting ideas for curriculum delivery, documenting common student misconceptions, and exploring interesting physics phenomena from a pedagogical angle.
6. Students should not fear mathematics. Logic is essential in reasoning about patterns and relationships between variables. Basic techniques like dimensional analysis are very powerful.

2 Mechanics

The resources in this section are organised roughly in terms of the syllabus order.

2.1 Centre of Mass Dynamics

Javascript simulation for two-body spring-mass system, in a uniform gravitational field. Can possibly be used for a discussion about forces internal and external to a system, and to link this to the concept of the centre of mass of a system.

2.2 Friction

A basic physical example to explore is putting a block on an inclined plane and slowly increasing the angle of inclination until the block starts to slide down. Discuss the free-body diagram and how the contact force changes (calculate the ratio of the frictional component to the normal component).

An amazing demonstration of the effect of friction when a string is wound around an axis. This is shown in this video by Walter Lewin (starting from 30:50). Students who are interested can rewind to try to understand the physics and mathematics of this, which is explained earlier in the video.

2.3 Rotational Motion

Javascript simulation for a 2D spring-mass system, in a uniform gravitational field. This could serve as a basis for a rich discussion about rotational kinematics and dynamics for a point mass, before moving on to rigid bodies.

Concept map from hyperphysics.

For rigid bodies, the angular velocity is the same for the entire object, but the linear velocity is not. So the moment of inertia is a useful concept for calculating kinetic energy, angular momentum, etc.

Walter Lewin's YouTube channel with a lot of relevant lecture material, for rotational mechanics but also many other topics in physics. Notice how he delivers his lessons with passion (e.g. when he exclaims how he is always amazed to see that the motion of cylinders rolling down an inclined plane is independent of factors like mass and radius) and with pedagogical skill.

The physics of the ring falling into a chain (magic) trick(Vollmer and Möllmann, 2011). Students can take their own slow-motion videos if they have fancy enough camcorders or even mobile phones these days.

Double cone and plane (video) can be useful as a "dissonance" trigger. Maxwell's wheel is another simple demonstration for rotational motion.

A long video by an older Walter Lewin about the classic "who rolls down the slope first" investigation related to moment of inertia. He gives a clear and thorough exposition of the physics and mathematics in this other video (start from 2:37).

Another video by Bruce Yeany goes beyond simple geometric objects and might give you ideas for organising a student investigation.

2.3.1 Toys

While the detailed treatment of gyroscopic motion is beyond the syllabus, students can get a qualitative appreciation of this very cool phenomenon by various fun demonstrations, e.g. bicycle wheel on rotating stool, boomerangs, and other toys. For a demonstration of the bicycle wheel, continue to view this Walter Lewin video (starting from 14:05).

Hugh Hunt's webpage has a collection of material related to gyroscopes and boomerangs. This blended learning video includes detailed instructions on how to make your own boomerang out of cardboard.

An article in Gizmodo about the tippee top with a picture of Pauli and Bohr. Cheap wooden versions of this toy can be ordered online. An analysis of the physics due to (Pliskin, 1954) is written up here and uses Newtonian mechanics (with a rotating reference frame). This phenomenon has also been explored by (Cohen, 1977). Scanned PDF copies of these papers are online here and here.

Another type of cool spinning objects are hurricane balls (Jackson, Mertens, and Pearson, 2015). These can be made by using epoxy to fuse two ball bearings together and spun to high speeds by blowing through a straw, though some will say that simply using epoxy on metal surfaces is not safe at high speeds. You have been warned!

The rattleback is a curious toy that is also known as a celt and was probably used by druids to perform mystical predictions. The physics is discussed in (Garcia and Hubbard, 1988) and (Franti, 2013). While this toy can be bought as a specially designed piece of plastic, it's possible to bend it out of a metal spoon, or even discovered in "found objects" like a telephone receiver (e.g., see video I made a long time ago).

The gyro-ring is a custom-made toy, and illustrates the coupling of rotational motion through friction (link to student project write-up and video of someone performing tricks).

A coin spinning on a smooth surface shudders and whirs just before it comes to rest, and is an example of an Euler's disk. See (Moffatt, 2000), (Petrie, Hunt, and Gray, 2002), (Bildsten, 2002) and this arXiv paper. Interestingly, the dissipative "chirp" here bears some similarity to the astronomical merger of neutron stars, see this and this.

For more toy ideas, such as the Wobbler or even fidget spinners, see Christian Ucke's webpage and the one by Rod Cross.

2.3.2 Other Phenomena

Hard boiled eggs are convenient for demonstration and can be eaten at the end of the day. When lying with its long axis parallel to the table and spun fast enough in a horizontal plane, the centre of gravity of the egg will rise such that it spins with its long axis as the rotation axis. Discussed by (Sasaki, 2004) [arXiv] for various egg shapes, and also here for simpler cases.

With globalisation and the growing affluence of Singaporeans, the phenomenon of the rolling suitcase instability might speak to many of us (Facchini, Sekimoto, and du Pont, 2017). Rotation, oscillation, toy models...

2.4 Planetary Motion

Worksheet to accompany Javascript simulation, for topic of central force motion (two-body Newtonian gravitation). Develops concepts related to angular momentum and effective radial potential from an energy perspective. Suggested solutions for the worksheet also available.

Pulsars could provide an interesting topic of discussion, and various simple calculations can be done as student exercises.

Derivation of central force motion using polar coordinates can be done as in these notes. Key steps are to figure out the mathematics of acceleration in polar coordinates, write out Newton's laws in the radial and tangential directions, identify the constant of the motion related to angular momentum, substitute $u = 1/r$ and use angle θ as the "time" variable.

2.5 Extension: Continuous Mass Distributions

Some other resources collated around some phenomena of "chain physics", notably the chain fountain (self-siphoning beads).

The annoying-but-fun water bottle flip is also something that students will probably get a kick out of.

3 Electromagnetism

The resources in this section are organised roughly in terms of the syllabus order.

3.1 Fields

Wimhurst machine demonstration.

Derivation of the dipole field from first principles, using polar coordinates. Derive using an electric dipole, and show that the magnetic dipole formula is exactly the same after swapping electrical permittivity for magnetic permeability and some numerical factors.

Discuss applications of dipoles in liquid crystals.

3.2 Circuits

Dissection of an electrolytic capacitor.

Connecting up circuits to an oscilloscope.

"Physics by Inquiry" activities to investigate circuits with capacitors, inductors.

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