IT in Education Subject-related Series:

Using 3D Printers and IT Tools to Enhance Learning and Teaching of Physics

TEN sets of learning and teaching (L&T) material in Physics

(including the lesson plan, L&T activities and operation instructions of using 3D-Printing technology in making parts/experimental setups,

where necessary in both Chinese and English language versions for course

"Using 3D printer for teaching concepts and conducting experience in Physics"

(Course Code: EI0020170446)

1. Open bottle cap – Turning effect of a force
2. An 'anti-siege' machine - Turning effect of a force
3. Balance bottle holder – Free body diagram
4. Ship - Centre of gravity
5. Right hand grip rule – EM
6. Fleming's Left hand rule & Right hand rule (FBI) – EM
7. DC motor – EM
8. Mirror stand – Optics
9. Wind turbine – Energy
10. Modelling - Electromagnetic Wave – Wave
11. Modelling - Stationary satellite (Geostationary satellite) – Gravitation

1. Open bottle cap – Turning effect of a force

Activity Name	**Open bottle cap – Turning effect of a force**
Description	Design several models of open bottle cap to let students know how it helps to open the bottle cap such as longer handler, couple (two forces of equal magnitude and opposite directions act on the object)
Objective	To find out how the distance from the pivot affect the turning effect
Time	30 mins
Apparatus	A bottle with cap, spring balance, and 3D printed open bottle cap (on handler, there are several holes that can hook the spring balance).
Procedure	**Activity 1** 1. Measuring the distance from the inner end of the handler of the 3D printed open bottle cap device (pivot) to holes on the handler. 2. The Students need connect the spring balance to different holes on the handler of the open bottle cap device. 3. Students need to apply a perpendicular force to the handler and record a spring balance reading. 4. Students need to record the distance from the pivot to the hole which hook with spring balance (d) and how large force is needed that can open the bottle cap into Table 1. 5. Students need to find out the relationship between torque (τ) and force applied ($F_{\perp}$), torque (τ) and distance from the pivot to the hole which hook with spring balance (d). **Activity 2** 1. Repeat the experiment shown on Activity 1 with a fixed distance from the pivot to the hole which hook with spring balance (d), say 10cm. However, vary the angle between the force (F) applied and the handler (θ). 2. Students need to record how large force is needed that can open the bottle cap and the value of angle between the force (F) applied and the handler (θ) into Table 2. 3. Students need to find out the relationship between the angle (θ), torque (τ), force applied (F), and distance from the pivot to the hole which hook with spring balance (d). **Activity 3** 1. By using another 3D printed open bottle cap device with two handlers, repeat the experiment shown on Activity 1 2. The Students need connect the spring balance to different holes on the handler of the open bottle cap device. 3. Students need to apply a perpendicular force to the handler and record a spring balance reading. 4. Students need to record the distance from the pivot to the hole which hook with spring balance (d) and how large force is needed that can open the bottle cap into Table 3. 5. Students need to find out the relationship between torque (τ) and force applied ($F_{\perp}$), torque (τ) and distance from the pivot to the hole which hook with spring balance (d). 6. Students also need to find out which model of 3D printed open bottle cap needed less force to open the bottle cap.
Online Resources	
References	https://www.thingiverse.com/thing:403031

Figure 1. Open bottle cap

Table 1

Distance from the pivot to the hole which hook with spring balance (m)	Spring balance reading (N)

Table 2

The angle between the force (*F*) applied and the handler (*θ*)	Spring balance reading (N)

Table 3

Distance from the pivot to the hole which hook with spring balance (m)	Spring balance reading (N)

2. An ‘anti-siege’ machine - Turning effect of a force

Activity Name	**An ‘anti-siege’ machine - Turning effect of a force**
Description	Using ‘anti-siege’ machine to let students know how the turning effect of force making the ‘anti-siege’ machine working.
Objective	Students need to design an ‘anti-siege’ machine that can throw the object to longer distance
Time	30 mins
Apparatus	3D printing different parts of an ‘anti-siege’ machine, rubber band and rubber acts as an object.
Procedure	1. Students need to construct an ‘anti-siege’ (video reference: https://www.youtube.com/watch?v=DM6yuGjCH-o&feature=youtu.be) 2. By replacing different length levers to construct “anti-siege”, students need to record the projection angle and distance of the rubber into Table 4. 3. Students need to use the projectile related equations to explain why different levers will provided different projection.
Online Resources	https://www.youtube.com/watch?v=DM6yuGjCH-o&feature=youtu.be
References	https://www.thingiverse.com/thing:967437

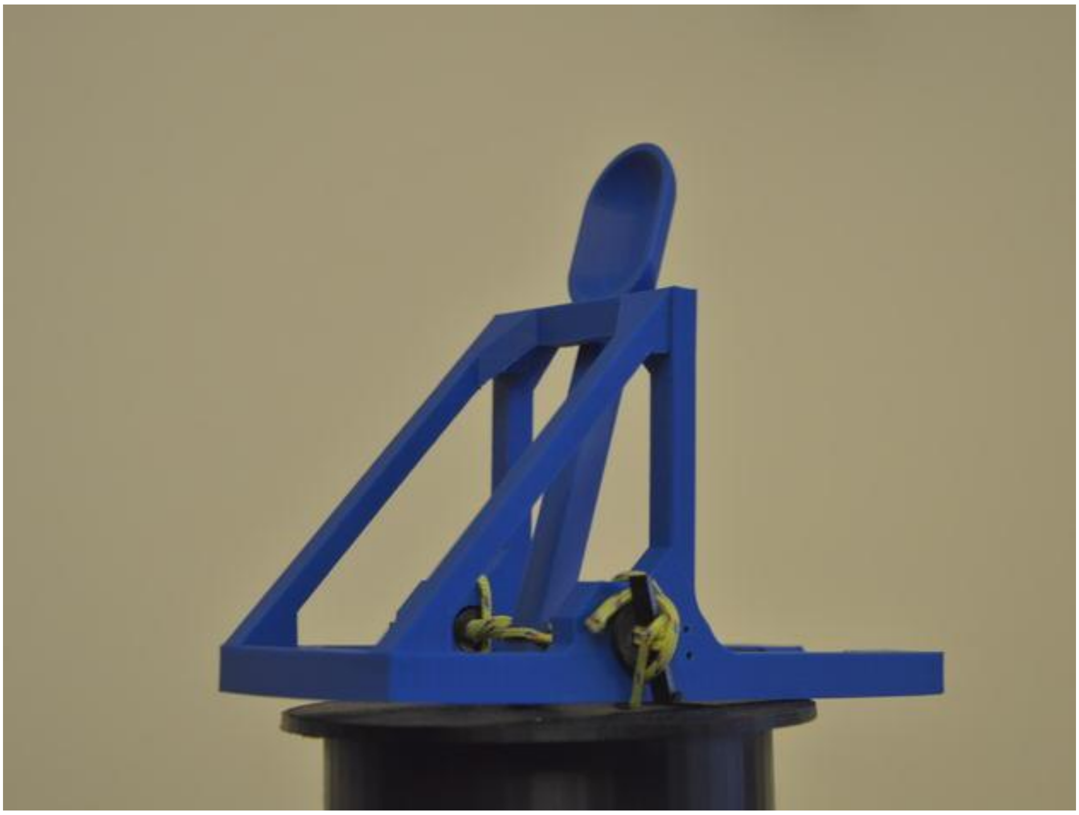
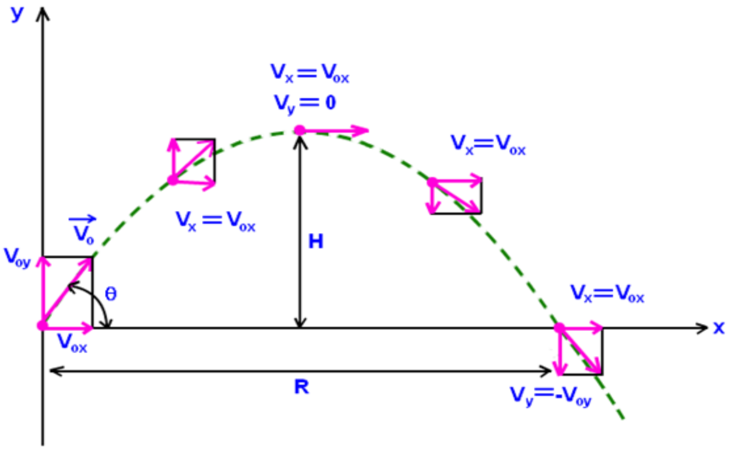


Figure 2. ‘anti-siege’ machine



$$\text{Time of flight, } t = \frac{2v_0 \sin\theta}{g}$$

$$\text{Maximum height reached, } H = \frac{v_0^2 \sin^2\theta}{2g}$$

$$\text{Horizontal range, } R = \frac{v_0^2 \sin 2\theta}{g}$$

Table 4

Length of the lever (m)	Projection angle (θ)	Projection distance (m)

3. Balance bottle holder – Free body diagram

Activity Name	**Balance bottle holder – Free body diagram**
Description	By using the Balance bottle holder, we can ask student how it works and how to find out the free body diagram (whole system, balance holder itself & bottle itself)
Objective	Students need to know why the bottle holder can hold the bottle by using free-body diagram
Time	10 mins
Apparatus	A 3D printed bottle holder and a small wine bottle.
Procedure	1. Before putting the wine bottle into the bottle holder, student need to use free-body diagram to show why the bottle holder cannot stand firm by itself. 2. Students need to put the small wine bottle into the bottle holder. 3. Students need to use free-body diagram (bottle holder, small wine bottle and whole system) to show why the bottle holder can hold the wine bottle and stand firm.
Online Resources	
References	https://www.thingiverse.com/thing:146885

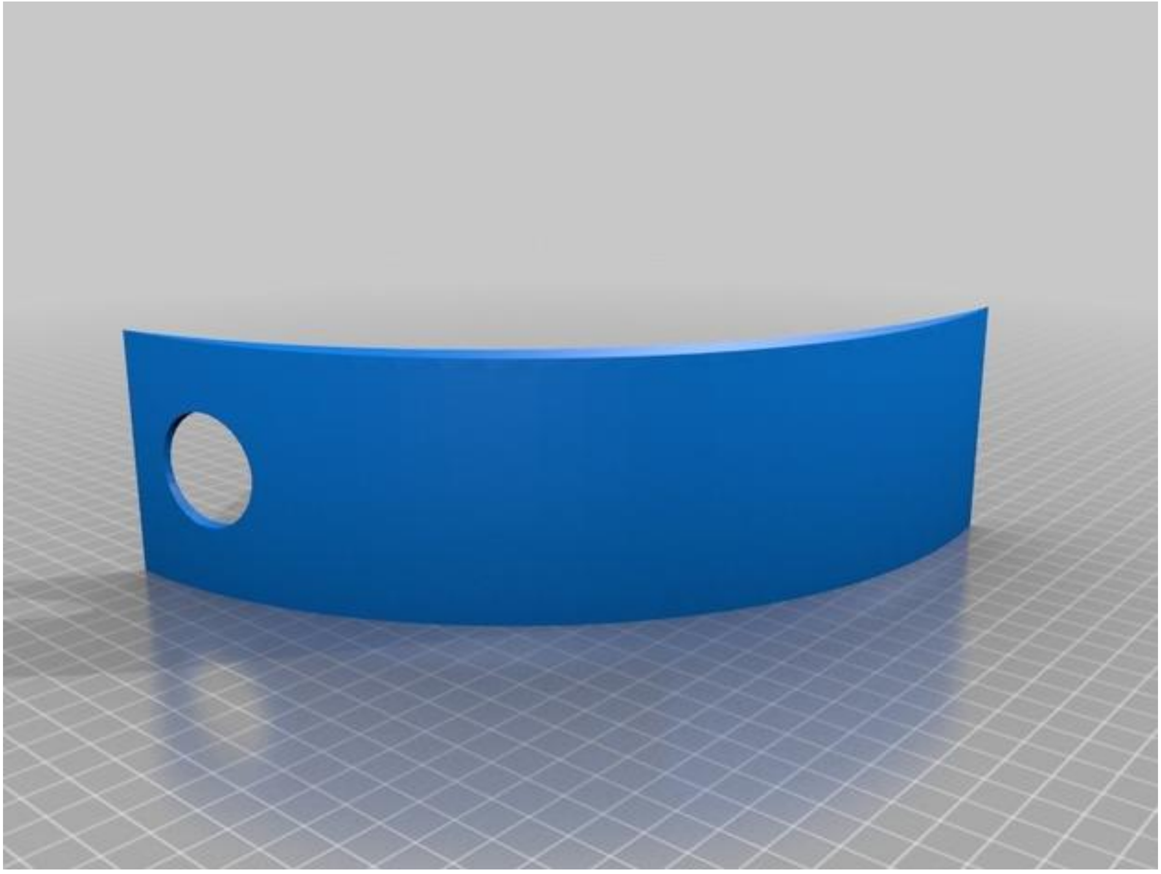


Figure 3. Bottle holder

Figure 4. by using a bottle holder to hold a small wine bottle horizontally

4. Ship - Centre of gravity

Activity Name	**Ship - Centre of gravity**
Description	Use the printed boat/ship to demonstrate the effect of base area and height affect • the centre of gravity • Moment • Pivot point
Objective	Student need to investigate why the ship has higher CG will sink easily
Time	20 mins
Apparatus	Two different 3D printing models of ship, mass and water tank
Procedure	Students try to add the loads onto the ships (one has lower CG and the other has high CG) until one of them sink. **Discussion:** Case study: Sinking of the Sewol • Discuss the case of sinking of the Korean cruise liner 世越號(Sewol) in Apr 2014. • It was investigated that the cruise sunk because of its high centre of gravity. • Bone fragments, personal belongings found from salvaged Sewol-ho ferry • https://www.youtube.com/watch?v=F0g-JCZNnsU • When the ship made a sharp turn, a large elevation angle was resulted • The displacement of the centre of gravity to the pivot point created a large moment that turn the boat beyond the critical angle. **Enrichment Content :** Floatation and Archimedes' principle **Grouping activities:** Discussion on the problem of a ship with high centre of gravity • A 3D printed model of a high centre-of-gravity ship and a low one will be used to illustrate the underlying physics: • **Newton 1st law (Inertia)** moment, centre of gravity and condition of toggling…etc. **Activity 1 for Extended Learning/STEM-related activity:** Make your Motor Boat (自製電子船) https://www.thingiverse.com/thing:320485 **Activity 2 for Extended Learning:** Centre of Gravity – the balancing birds Step 1: Explain the activity to students Step 2: Split students into groups of 2 Step 3: Distribute balancing birds to all groups **randomly** Step 4: Allow students to experiment to find out where the center of mass is/what position to place the bird that will allow it to spin without falling off a point of contact (ie: a finger) Step 5: Students will test their particular 3D printed balancing bird to see whether or not it is able to spin without falling off its axis of rotation

	Step 6: Discuss the concept of center of gravity with the students, weighing in on evidence from the spinning bird experiment. Source: https://www.thingiverse.com/thing:1710099 **Activity 3 for Extended Learning:** Centre of Gravity – other objects https://www.thingiverse.com/thing:332676
Online Resources References	
	Make your Motor Boat (自製電子船) https://www.thingiverse.com/thing:320485 Center of Mass Lesson - Balancing Bird https://www.thingiverse.com/thing:1710099 Physics Project https://www.thingiverse.com/thing:332676

Figure 5. Balancing Bird

5. Right hand grip rule – EM

Activity Name	**Right hand grip rule – EM**
Reason to apply 3D Printing into teaching	Sometimes, students may not really understand the right hand grip rule. We would like to design a model to let them learnt easily. Students sometime mix up the use of right hand grip rule for solenoid and for straight wire
Description	Before starting this activity, teacher need to use 3D scanning software to scan human right hand (Figure 6). Then teachers need to edit the 3D object that can provide the following 3D objects: ➢ Right hand, Thumb (represent for current) ➢ Four fingers (represent for Magnetic field) ➢ Thumb (represent for Magnetic field) ➢ Four fingers (represent for current
Objective	Students need to find out the relationship between Current (I) and Magnetic field (B) when the current passing through the wire / solenoid by seeing the compass signs.
Time	20 mins
Apparatus	Five different 3D printing models (Right hand, Thumb (represent for current), Four fingers (represent for Magnetic field), Thumb (represent for Magnetic field), Four fingers (represent for current)), solenoid, batteries, wires, small compass and magnetic (with label north and south pole).
Procedure	**Activity 1 (Current passing through a straight wire)** 1. Apply a current passing through a straight wire as shown in Figure 7. 2. Put several small compasses round the wire. 3. By observing the needle direction 4. Students need to use the 3D printing models to connect them together to show the relationship between Magnetic field (B) and Current (I). 5. Reserve the current direction and repeat step 2-4. **Activity 2 (Current passing through a coil)** 1. Apply a current passing through a coil as shown in Figure 8a. 2. Put several small compasses round the coil. 3. By observing the needle direction 4. Students need to use the 3D printing models to connect them together to show the relationship between Magnetic field (B) and Current (I). 5. Reserve the current direction and repeat step 2-4. **Activity 3 (Current passing through a solenoid)** 1. Apply a current passing through a solenoid as shown in Figure 8b. 2. Put several small compasses round the solenoid. 3. By observing the needle direction 4. Students need to use the 3D printing models to connect them together to show the relationship between Magnetic field (B) and Current (I). 5. Reserve the current direction and repeat step 2-4.
Online Resources	

References http://www.excelatphysics.com/magnetic-effect-of-a-current.html

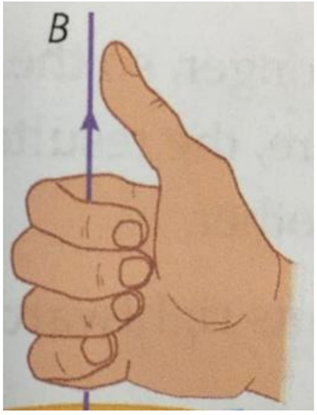


Figure 6. Human Right Hand Figure

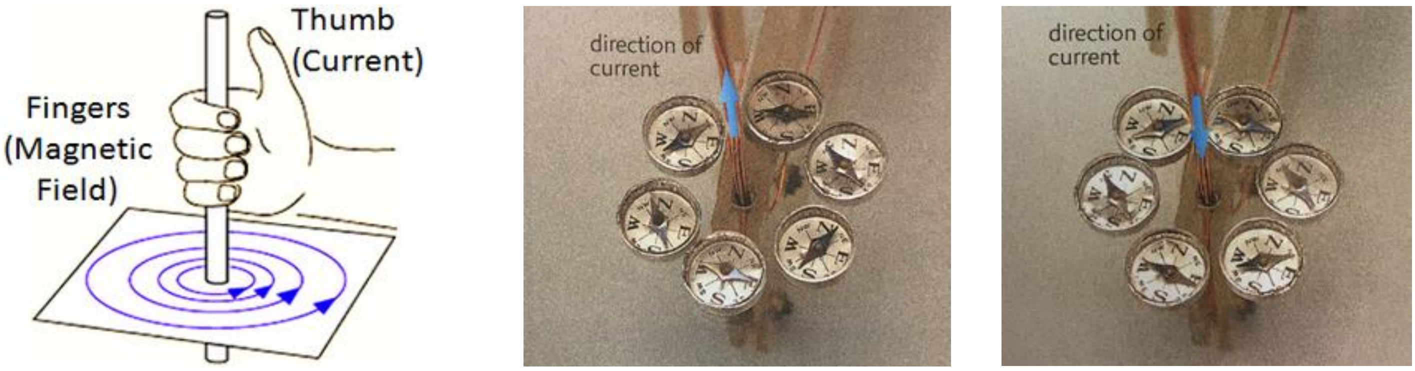


Figure 7. When current passing through a straight wire

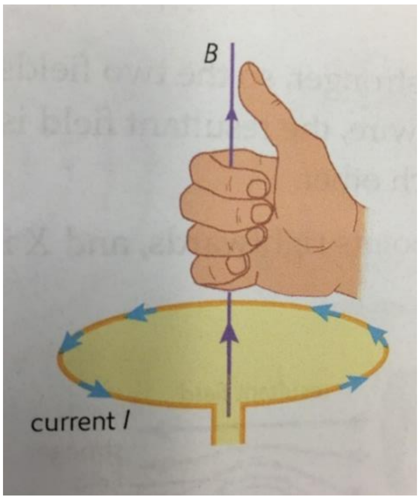


Figure 8a. When current passing through a coil wire

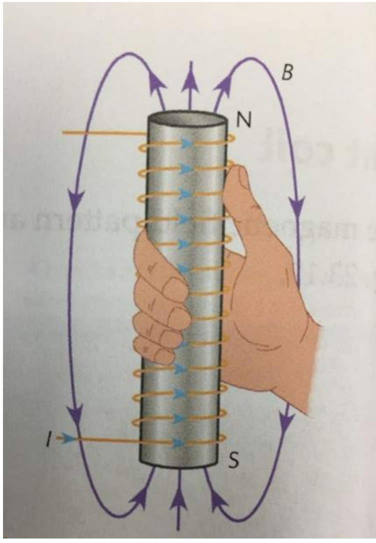


Figure 8b. When current passing through a solenoid

6. Fleming's Left hand rule & Right hand rule (FBI) – EM

Activity Name	**Fleming's Left hand rule & Right hand rule (FBI) – EM**
Reason to apply 3D Printing into teaching	Sometimes, students may not really understand and not well use their fingers on the Fleming's Left hand rule & Right hand rule (FBI). We would like to design a model to let them learnt easily. They sometimes move their fingers incorrectly.
Description	Before starting this activity, teacher need to provide the following 3D objects (Figure 9a): ➢ Arrow with "Current" sign ➢ Arrow with "B-field" sign ➢ Arrow with "Force" sign ➢ Cube that can plug the above arrows The 3D objects can form a Fleming's Left hand rule & Right hand rule model (Figure 9b & 9c)
Objective	Students need to find out the relationship between Force (F), Magnetic field (B) and Current (I) when the current put into the magnetic with current pass through the wire.
Time	20 mins
Apparatus	Four different 3D printing models (a stand, Force (F) arrow, Magnetic field (B) arrow and Current (I) arrow), copper wires, batteries, wires and magnetic (with label north and south pole).
Procedure	**Activity 1 (Fleming's Left hand rule)** 1. Put a conducting rider on a pair of copper rails. Apply a magnetic field over the metal rider as shown in Figure 10. 2. Send a small current through the rider via the rails. Observe what happens to the rider. 3. Try to use the 3D models provided to plug in the current, B-field and force direction onto the cube to find out the relation between the directions of the magnetic field, the current and the magnetic force on the rider 4. Repeat step 2 and 3 by (a) reversing the current, and (b) changing the direction of the field. **Activity 2 (Fleming's Right hand rule)** 1. Connect a long conducting wire to a centre-zero galvanometer. 2. Hold the wire in the magnetic field of a horseshoe magnet. 3. Move the wire up, down and sideways. Note the deflection of galvanometer pointer. (Figure 11) 4. Try to use the 3D models provided to plug in the current, B-field and force direction onto the cube. 5. Repeat step 3 by i. Moving the wire faster ii. Using strong magnet iii. Making a coil of several turns.
Online Resources	
References	

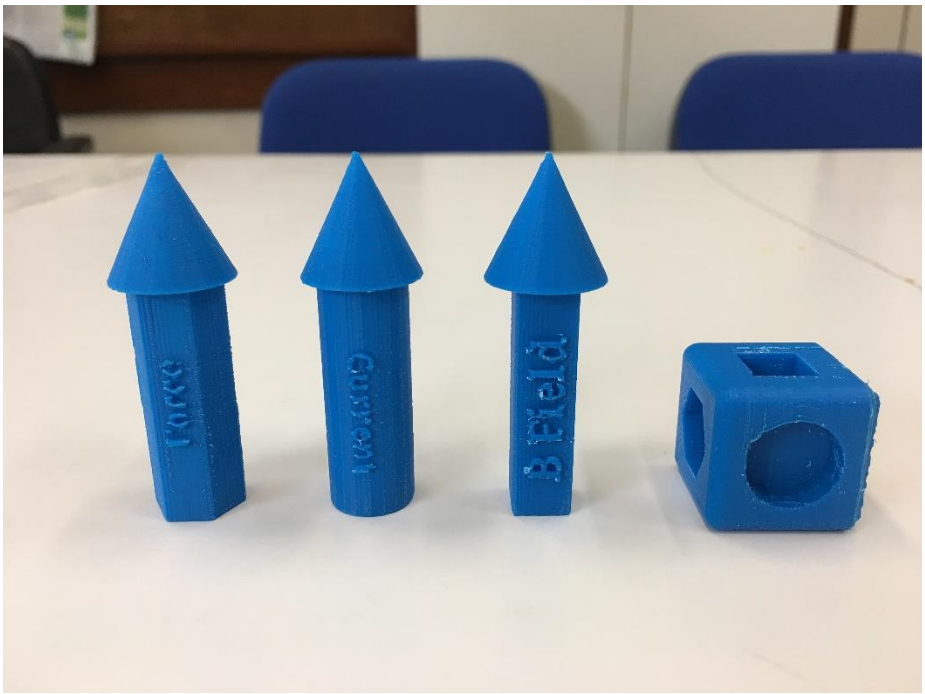


Figure 9a. FBI 3D printed objects

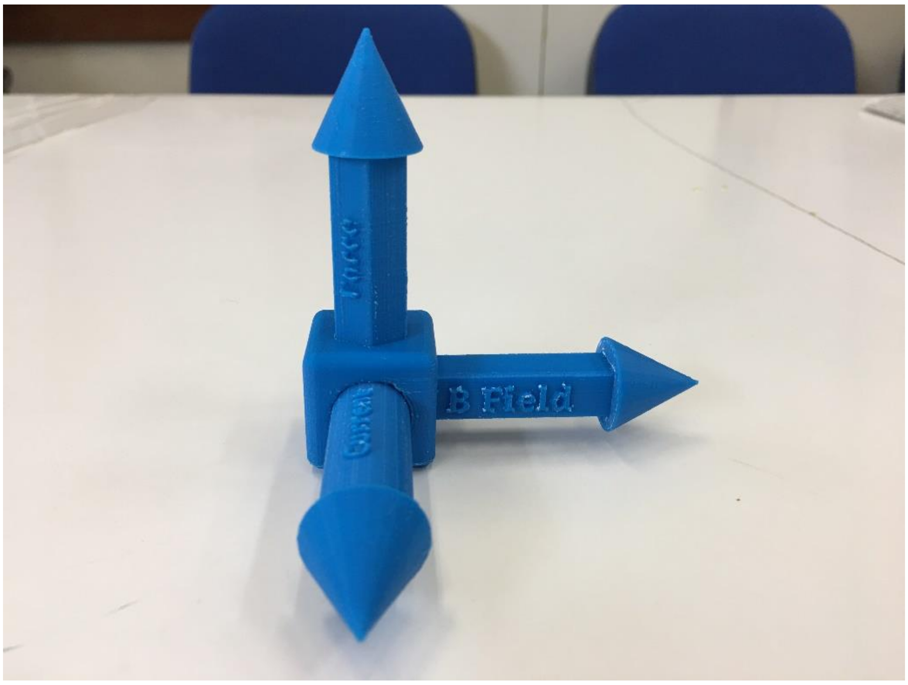


Figure 9b. Left Hand Rule

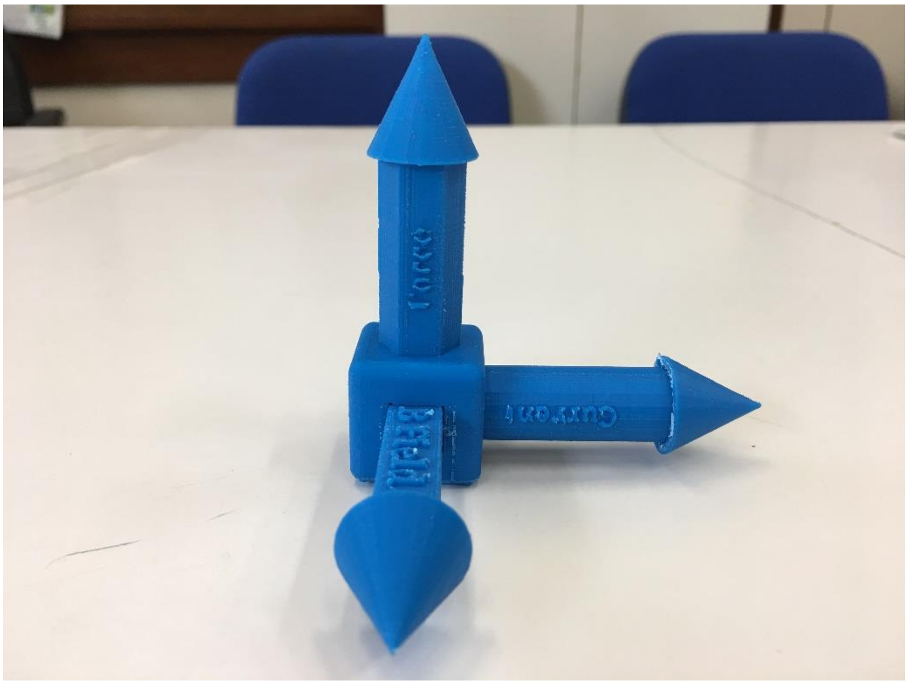
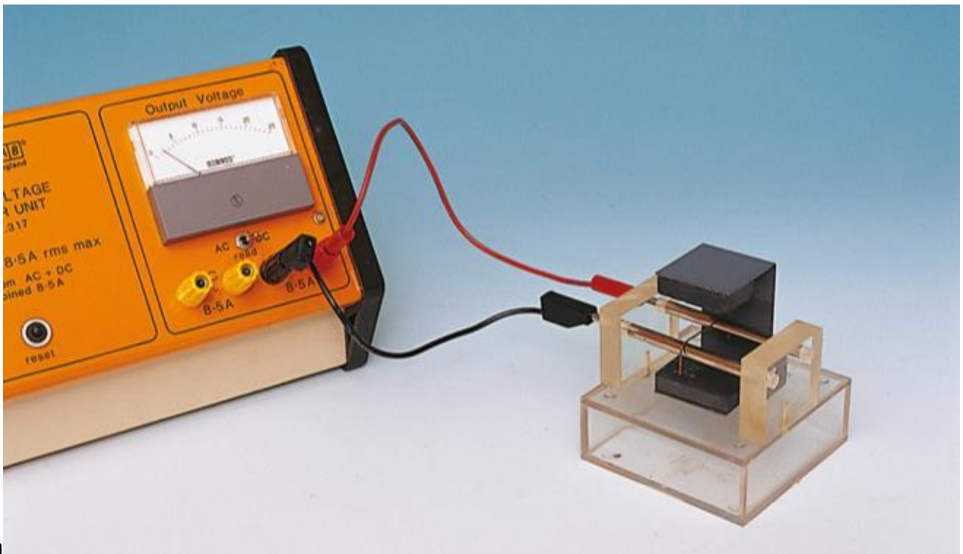


Figure 9c. Right Hand Rule



a

Figure 10. A current-carrying straight wire in a uniform magnetic field

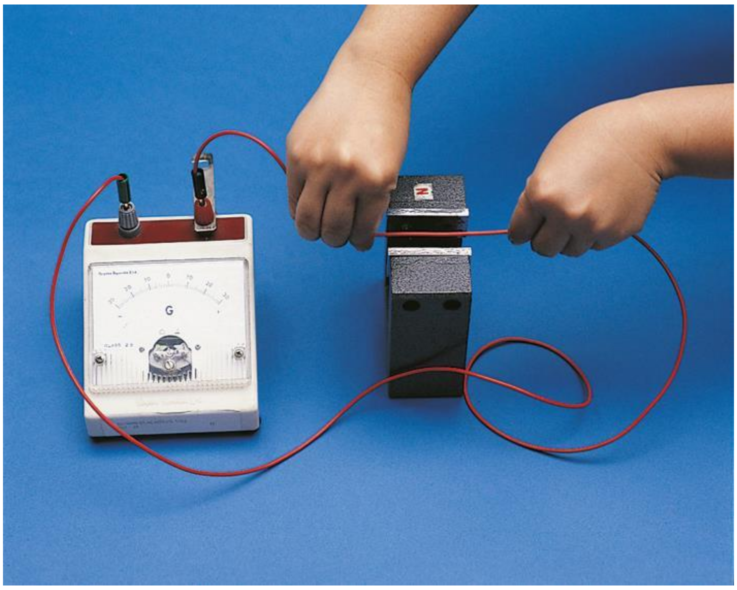


Figure 11. Electromagnetic induction

7. DC motor – EM

Activity Name	**DC motor – EM**
Reason to apply 3D Printing into teaching	The working mechanism of DC motor is also so abstract.
Description	We would like to ask student to make a DC motor by themselves and using the Fleming's Left hand rule 3D model to familiar in depth. Moreover, they need to balance the weight of the wire and no. of turn to make the DC motor turning faster.
Objective	1. To build up a DC motor. 2. To apply Fleming's Left hand rule in DC motor so that students could understand the turning effect in different situations. 3. To find out how no. of turns of coil affects the turning speed
Time	35 mins
Apparatus	DC motor kit, 3D Fleming's Left hand rule model (example 6)
Procedure	1. Students are requested to build their own DC motor with guidance of teachers. 2. Students need to address the main structure of DC motor. 3. Students are asked to use 3D Fleming's Left hand rule model to find the Force when the coil in perpendicular and vertical position. Therefore, they may appreciate the design of DC motor e.g. Accumulator. (Teachers at this point are suggested to show a practical DC motor to students to address their differences) 4. To compare the turning speed a coils with different no. of turns using Table 5. Then, ask students to explain the results. (Further Q: how we could measure the turning speed of the coil quantitatively? One of the methods may use a cotton rope adhere on the axis)
Online Resources	
References	https://www.thingiverse.com/thing:1613211

Table 5

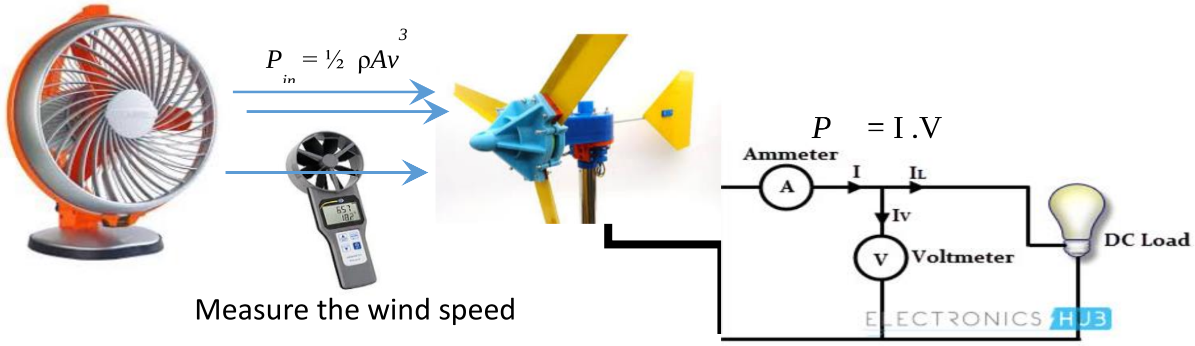
	Length of rope (m)	**Time taken (s)**	**Turning speed (ms^{-1})**
No. of turns of coil (N=10)			
No. of turns of coil (N=30)			

8. Mirror stand – Optics (Using in Law of reflection)

Activity Name	**Mirror stand – Optics**
Reason to apply 3D Printing into teaching	We found that it is not easy to stand a mirror perpendicularly for optics experiments. We would like to design simple tools to help students on doing these type of experiments. For example, Law of reflection.
Description	Investigation on reflection of light in plane mirror
Objective	To illustrate how 3D printer may help you to handle your experiment nicely
Time	10 mins
Apparatus	Plane mirror, paper protractor, ray box, mirror stand
Procedure	Before the experiment 1. Measure the thickness of mirror 2. Draw a desirable mirror stand in 3D drawing program (e.g. tinkerCAD). 3. Print the mirror stand by 3D printer. During the experiment. 1. Pointing a light beam to the mirror with different angle of incidence (i) 2. Measure the corresponding angle of reflection (r). 3. Write down the result in the following table.
Online Resources	
References	

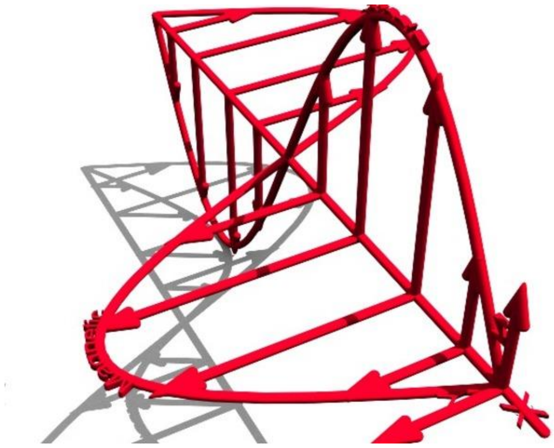
Angle of incidence (i)	Angle of reflection(r)
30°	
40°	
50°	
60°	
70°	

9. Wind turbine – Energy

Activity Name	**Wind turbine – Energy**
Reason to apply 3D Printing into teaching	Students could measure the output power of a wind turbine with different number of blades, size and tilt angles. Then, they could visual and experience how the formula $P = ½ \rho A v^3$ work out, that means, how the area affect the power output It is easy to design different blades with 3D printer for students to investigate.
Description	While students have different set of blades (e.g. different number, size or tilt angle), they could do their own investigation by measure the power output.
Objective	To explore how the number of blade, tilt angle and surface area affect the efficiency of the wind turbine.
Time	30 mins
Apparatus	Wind turbine kit, different set of blades, Hair dryer(or fan), digital multi-meter, conducting wire
Procedure	**Test the performance of the 3D printed wind turbine:** 1. Measure the wind speed and calculate the theoretical wind power 2. Measure the current and voltage of the load circuit 3. Find out the efficiency of power conversion = **P_{out}/P_{in}**  **Compare the performance difference types of wind turbine** 1. Vertical-axis turbine 2. Horizontal-axis turbine 3. the number of blade 4. tilt angle 5. and surface area
Online Resources	
References	

10. Modelling - Electromagnetic Wave – Wave

Activity Name	**Electromagnetic Wave – Wave**
Reason to apply 3D Printing into teaching	The electromagnetic waves that compose electromagnetic radiation can be imagined as a self-propagating transverse oscillating wave of electric and magnetic fields. It is very difficult to let students imagine self-propagating transverse oscillating wave of electric and magnetic fields. We would like to design 3D models to explain this concept.
Description	While a plane linearly polarized electromagnetic wave propagating, the electric field is in a vertical plane and the magnetic field in a horizontal plane. The electric and magnetic fields in electromagnetic waves are always in phase and at 90 degrees to each other. We would like to use an online resource to print a 3D model to show how this work.
Objective	To illustrate how 3D printer may help you to enhance teaching nicely
Time	5 mins
Apparatus	3D electromagnetic wave model
Procedure	Distributes the models to each group of students.
Online Resources	***https://www.thingiverse.com/thing:1105344***
References	***https://en.wikipedia.org/wiki/Electromagnetic_radiation***



11.Modelling - Stationary satellite (Geostationary satellite) – Gravitation

Activity Name	**Stationary satellite (Geostationary satellite) – Gravitation**
Reason to apply 3D Printing into teaching	Geostationary satellite is an artificial satellite that always remains at the same spot when viewed from the Earth. It is very difficult to let students know why the geostationary satellite orbit directly over the equator. We would like to design two 3D models with force directions to explain this concept.
Description	It is difficult for some students to imagine the 3D model in a 2D picture like figure 10.1 and 10.2. Therefore, 3D printing could help to illustrate how its work.
Objective	To illustrate how 3D printer may help you to enhance teaching nicely
Time	5 mins
Apparatus	3D earth model with satellite
Procedure	Show the model to student in different positions of satellite.
Online Resources	
References	

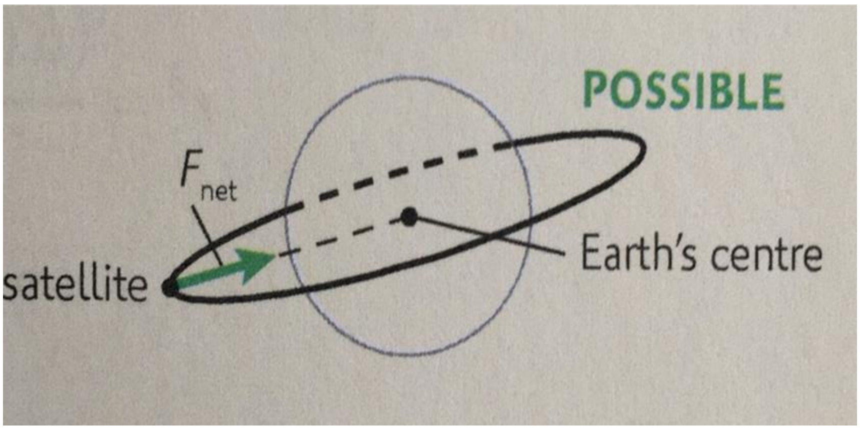


Figure 10.1

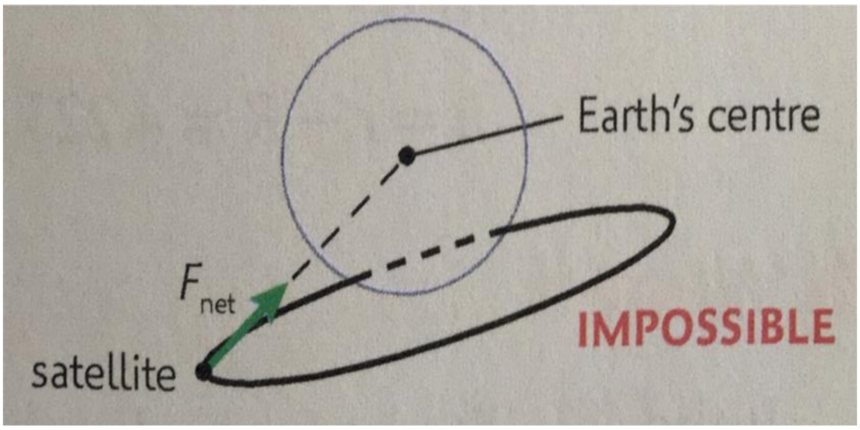


Figure 10.2