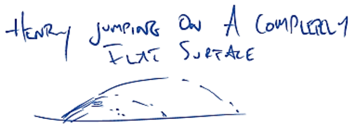
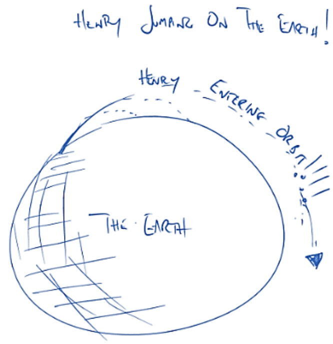
The science of orbit

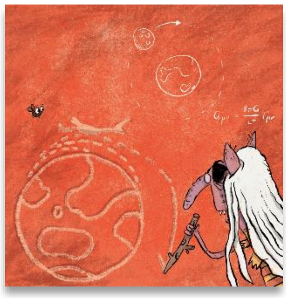
It's the same as what Wallagoot Jean said!

> *"The moon falls towards earth but just keeps on missing*
> *And so it goes round and round.*
> *Orbit's like falling down towards something,*
> *But never quite hitting the ground"*

If an object goes fast enough sideways that the earth curves enough before it lands, then it'll enter orbit!







We can calculate the speed that Henry needs to go into orbit with two equations. The first one is:

$$F = G\frac{Mm}{R^2}$$

This is the equation of gravity that Isaac Newton found out in 1687. It shows us that the gravity force between two objects goes up with how much they weight (their masses m and M) and goes down quickly with distance between them (R). G is a number that tells us how strong the force is.

The second equation is:

$$F = \frac{mv^2}{R}$$

This is the force that's needed to keep an object (with mass m) in circular motion at speed v, and is called the 'Centripetal' Force. If you've got a tennis ball in a sock (with length R) and you spin it around your head, it's how much force you need to pull on the sock to keep the ball going around (instead of flying off).

If Henry is orbiting Earth just above its surface, and the gravitational force is just enough to keep him moving in a circle, then we can equate the two forces:

$$G\frac{Mm}{R^2} = \frac{mv^2}{R}$$

Rearranging everything so that we can find v – the speed that Henry needs to reach, we get:

$$v = \sqrt{G\frac{M}{R}}$$

With the Earth's mass $M = 5.97 \times 10^{24}\, kg$, radius $R = 6.37 \times 10^6\, m$, and $G = 6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$,the velocity v needed to go into orbit at the Earth's surface is: 7900 metres per second or 28,440 kilometres per hour. Which is pretty fast!

But it's really just the same as what Wallagoot said…

- Nij

HENRY the flying emu

The science of flight – Teacher Resource Kit

The science of motion, flight and the magical Godwit migration

Age:
Primary: Yrs 1-6,

Students can:

- Explore the force of gravity and its effect on objects of different mass
- See how thrust can be provided through a variety of forms stored energy
- Investigate lighter-than-air flight
- Learn about the principle of conservation of momentum with a bike-pump rocket
- Explore air pressure and the concept of Bernoulli's effect
- Learn about large-scale migration of birds across the surface of the earth.
- Discover the biological connection between continents across the globe
- Develop their scientific skills of:
    - Enquiry
    - Prediction
    - Observation
    - Explanation

Key demonstration opportunities

- Gravity demonstration – dropping a basketball and a Lego man at the same time, while standing on a chair. Illustration of the force of Gravity.
- Balloon rocket – strapping a Lego man to a balloon rocket. Illustration of Thrust. See [1]
- Helium balloon – Illustration of Lift via lighter-than-air floating.
- Balloon copter – strapping a Lego man to a balloon copter. Illustration of Lift via a downward force. [2]
- Bike pump rocket + fins – strapping a Lego man to a bike pump rocket with air, and with water. Illustration of Lift via conservation of momentum.
- Spring demonstration – slinky spring and power springs demonstration to launch objects across a room. Illustration of stored energy to provide Thrust. See [3]
- Ethanol rocket skateboard – illustration of stored chemical energy to provide Thrust. Strap an office water-cooler bottle to a skate board and light a small amount of ethanol in it. [4]
- Leaf blower Bernoulli effect – holding a Styrofoam ball in the airstream of a leaf blower as an illustration of air pressure. See [5]

Procurement recommendations

- Ethanol
- Electric leaf blower
- Balloon copters, rocket balloons and helium-gas balloons.
- Skateboard with excellent ball bearings
- Slinky springs and strong 5cm springs
- Retort stand with clamps and a metal rod for spring launching
- Basketball
- Squash balls
- Lego people

Narrative recommendations

A suggestion for lesson narratives is to introduce an animal that would like to fly (like Henry the emu), but who must overcome the various forces of gravity and friction to be able to get there.
From here the session could:
Introduce gravity, then the various ways to counter it, then introduce the need for thrust and the various ways of using stored energy to provide it, then discuss drag and friction and the shape of an Emu. Students can be invited on stage as a target for the rocket balloon, to launch the power spring, and try to catch a Styrofoam ball being held by a leaf blower. At the end of the show, the presenter could discuss how flight is incredibly hard for an Emu, and he can't really fly without some large external forces applied to him – unless he goes into orbit!

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[1] https://www.youtube.com/watch?v=856Tpw1XU1U
[2] https://www.youtube.com/watch?v=SI_ZUQInfZo
[3] https://www.youtube.com/watch?v=VmJ0Z-9XUg4
[4] https://www.youtube.com/watch?v=zTwz6FGobCA
[5] https://www.youtube.com/watch?v=sIrJOrTAJjg

Potential hazards
Projectile hazards. Students will need to remain seated and within their designated area unless called out as a volunteer.
A full risk assessment should be carried out prior to any science demonstrations.

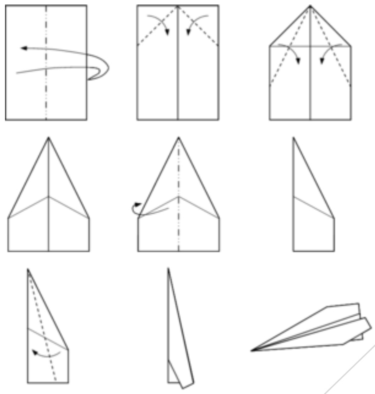
Curriculum links:

Formal curriculum sub-strands
Chemical, physical, biological and earth science

Links with Overarching Ideas:
- Matter and energy – energy can be used to generate movement and can be stored in various ways.
- Stability and change – changes in objects can affect how they move.
- Scale and measurement - Measurement of the size of different forces, identification of small and large amounts of thrust and inertia.
- Patterns order and organisation – living things live according to annual patterns. Identification of movement at different length scales.
- Systems – living things are connected in systems across the planet.
- Form and function – the form of objects can dramatically alter their movement. Living things have adapted forms to suit their particular needs.

Curriculum sections
- Forces can be exerted by one object on another through direct contact or from a distance (ACSSU076)
- Solids, liquids and gases have different observable properties and behave in different ways (ACSSU077)
- Living things have basic needs, including food and water (ACSSU002)
- A push or a pull affects how an object moves or changes shape (ACSSU033)
- Different materials can be combined, including by mixing, for a particular purpose (ACSSU031)
- Science involves asking questions about, and describing changes in, objects and events (ACSHE034)
- Living things can be grouped on the basis of observable features and can be distinguished from non-living things (ACSSU044)
- Objects are made of materials that have observable properties (ACSSU003)
- Everyday materials can be physically changed in a variety of ways (ACSSU018)
- Science involves making predictions and describing patterns and relationships (ACSHE061)
- Living things have life-cycles (ACSSU072)
- Living things, including plants and animals, depend on each other and the environment to survive (ACSSU073)
- Living things have structural features and adaptations that help them to survive in their environment (ACSSU043)

NSW Curriculum Outcomes: STe-6NE, STe-7NE, STe-8NE, ST1-11LW, ST1-9ES, ST1-7PW, ST2-10LW, ST2-1VA, ST3-1VA, ST2-4WS, ST2-5WT, ST2-6PW, ST2-7PW.



Henry paper airplane template!

Print out this page and the next one and follow the instructions to make a Henry the flying emu paper airplane..!
(Hint: the front two corners are folded inwards)

henrytheflyingemu.org

$$F = \frac{GMm}{r^2}$$

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

HENRY
the flying emu

"Orbit is gravity's way to keep falling
while staying up off the ground."

'First you must fly with your mind'

'First you must fly with your mind'

henrytheflyingemu.org

Physics and maths extension – calculating Earth's escape velocity

The speed at which Henry needs to go to enter orbit is given by the following equation that Wallagoot Jean sketched out.

$$v = \sqrt{G\frac{M}{R}}$$

But what is the speed needed to escape Earth's gravitational pull? If Henry wanted to shoot into space (if he wanted to fly to another star), how fast would he need to jump up? That is – what is Earth's escape velocity?

This can be calculated with the Gravitational Potential Energy (GPE) of Henry with mass $\boldsymbol{m}$ at the Earth's surface compared with his potential energy when he's a long long way away (far enough away that he wouldn't fall back to Earth).

If we set this potential energy difference as equal to the kinetic energy at lift-off, we can figure out the launch escape velocity.

The Gravitational Potential Energy (GPE) is found by integrating radially outwards from the Earth's surface (at radius R), out towards infinity (a long long way away…):

$$GPE = \int_{r=R}^{\infty} F.dr$$

$$= \int_{r=R}^{\infty} \frac{GMm}{r^2}.dr$$

$$= \left[\frac{-GMm}{r}\right]_R^{\infty}$$

$$= 0 + \frac{GMm}{R}$$

Equating this potential energy to the kinetic energy KE from the velocity of an object with mass $\boldsymbol{m}$, we can solve for $\boldsymbol{v}$:

$$KE = \frac{1}{2}mv^2$$

$$GPE = \frac{GMm}{R}$$

$$\text{if } KE = GPE$$

$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

$$v = \sqrt{\frac{2GM}{R}}$$

Which is $\sqrt{2}$ times faster than the velocity Henry went to get into orbit. With the Earth's mass $M = 5.97 \times 10^{24}\ kg$, radius $R = 6.37 \times 10^{6}\ m$, and $G = 6.67 \times 10^{-11}\,\frac{m^3}{kg\cdot s^2}$,the escape velocity $\boldsymbol{v}$ needed to launch from Earth to go out into space is: 11,200 metres per second or 40,250 kilometres per hour. Which is super fast!

This is how fast rockets need to go when blasting off from Earth! Henry would need to train for a little bit longer… :)

- Nij