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Classroom physics

The magazine for IOP affiliated schools and colleges

Balance and stability

The science of staying upright

Sports science: hitting the heights with a low centre of gravity

The only way is up: a career in cranes

Bobbing along: the stabilising effect of pigeons' head movements

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IOP Institute of Physics

This issue

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Editor's note

This issue focuses on balance and stability and the pull-out section includes some activities to support teaching on these topics.

Key to understanding these ideas are the related (but distinct) concepts of the centre of mass and the centre of gravity. These enable applications in everything from building design to modern high jump technique (see page 6). And, as we've found, there's plenty of overlap with other school subjects and areas of interest for students, from sports to music. (Look out for the 'seen elsewhere' list on page 20 for a conversation-starter with your colleagues from the music department.)

We're grateful to the various contributors who have submitted guest entries, which highlight some interesting ways to approach teaching or contextualising these concepts – from industrial applications to better understanding the weather through atmospheric dynamics.

We have a particularly busy schedule of events with teachers and schools coming up at the end of this term, and a few dates for your diary for next term as well. Look out for our listings on page 20.

Last time round we shared some resources about inclusive practices for schools. We're pleased to be able to follow up on a couple of parts of this story in this issue (see pages 3–5). If you haven't yet accessed our inclusive teaching resources, they're still available online and do let the Limit Less campaign team know about your experiences using them. You can reach us with the contact details and social links below.

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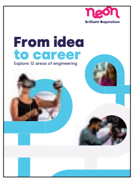
IOP affiliated schools and colleges will receive with this issue...

'From Idea to Career' – our guide to 12 different engineering disciplines for young people.



'From Idea to Career' is produced by the IOP in partnership with other professional engineering organisations.

More copies can be ordered from the Neon website: **bit.ly/IdeaToCareer**

Follow us on Twitter **@IOPTeaching**

Read Classroom Physics online and access previous editions at **spark.iop.org/classroom-physics**

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IOP activities round-up

Some highlights from IOP's work with teachers over the last few months.

It's been a busy few months for the Learning and Skills team at IOP.

During April and May we worked with the Royal Society of Chemistry on the Science Teaching Survey 2023. The survey looked into a range of areas including CPD, wellbeing and job satisfaction, issues facing teachers in areas of high deprivation, inclusivity, recruitment and retention. Thanks to those readers that took part. The survey closed too late for findings to be included here, but we will report on what we learned.

Video making skills

In March, as part of our teacher recruitment work, we ran workshops at Liverpool and Strathclyde for university students to develop their communications skills through video making. This was linked to our 'Do try this at home' video series **(iop.org/athome)**.

In Scotland we recently hosted the Stirling meeting and summer school for physics teachers. We will be sharing some reflections on these events in a future issue.

We're delighted to confirm that the Stimulating Physics Network (SPN) and Inclusion and Equity projects in Wales have received a further year's funding from the Welsh Government. Our programmes are all free to sign up for and led by experts in physics teaching and development. We cater for everyone in science education, from student teachers to those who lead development for their colleagues.

As the new curriculum for Wales rolls out, we will be focusing on supporting colleagues who are currently developing their school curriculum, signposting to resources and helping with ideas for local contexts.

In Ireland, we were delighted to return to an in-person format for our annual Tyndall Lecture in March. Transition year students and their teachers were welcomed to institutions in Galway, Limerick and Dublin to hear from Professor Caitriona Jackman on her work in astrophysics and what makes a great scientist. In April, we had the opportunity to meet with the Irish teaching community at the Irish Science Teachers' Association conference in Limerick.

Lee Reynolds represented the IOP at the Oireachtas Education Committee, where he demonstrated the need for a physics ecosystem built around a culture of inclusion, relevant and interesting curricula, and teachers who are given the ongoing support needed to develop their students and themselves **(bit.ly/IrelandSTEMreform)**.

Limit Less

Our Limit Less campaign took to TikTok in April to promote the Eurekas, our competition challenging 11–16 year-olds in the UK and Ireland to think about how physics powers their passion. At the time of going to print there had been about 4 million views on the competition homepage **(theeurekas.co.uk)**.

With our last issue we sent out a new leaflet from the Limit Less campaign on inclusive teaching. We've had some really positive feedback, and they are still available for teachers via the IOP website **(iop.org/InclusiveResources)**.

Commons and Lords committees consider physics education

Two parliamentary inquiries addressing teaching and the secondary education system in England took evidence in April.

The Commons Education Committee's inquiry on teacher recruitment, training and retention in England is seeking to identify barriers in the system to recruitment and retention, and to understand how these affect students. Within its scope are the impact of bursary payments to incentivise teachers in some subjects, and how well the teacher training system is preparing newly qualified teachers for the workplace.

The inquiry highlighted physics teaching as a particular concern, alongside maths and chemistry. Physics, out of all subjects, hit the lowest proportion of its recruitment target in 2022, recruiting just 444 teachers, or 17%.

Meanwhile, the House of Lords Committee on Education for 11–16 year-olds launched an inquiry to look more broadly at the challenges facing secondary education in England. The scope of this work is to assess the effectiveness of secondary education in a range of areas, including the provision of skills needed for the future economy.

Committee Chair, Lord Marylebone, commented: "Our inquiry will build on a number of important recent reports, looking critically at the effectiveness of the current curriculum and assessment model and exploring whether these are preparing young people for the job opportunities they will encounter in our future economy."

Charles Tracy, senior advisor on learning and skills, gave oral evidence to the Lords' inquiry. He made the points that physics teachers are "like gold dust" and should be given more opportunities, where they would like, to teach within their specialism – both for the sake of their students and to improve their workload and job satisfaction.

The IOP submitted written evidence to both inquiries, which are expected to publish conclusions and recommendations later this year.

Find out more
bit.ly/LordsEvidence

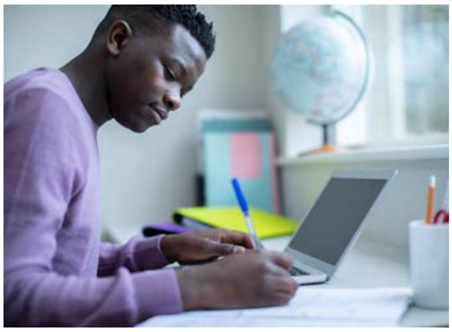
Call for engineers to teach physics

The Department for Education has launched a website to encourage engineering students to consider a career as a physics teacher, after IOP supported the creation of tailored PGCE courses.

The 'Engineers teach physics' programme is designed to promote careers in physics teaching to engineering and material science graduates and undergraduates. It is part of the government's wider 'Get into teaching' campaign.

With about 3,500 UK-domiciled physics graduates every year, it will not be possible to address the teaching shortage from recent physics graduates alone. Engineering graduates – especially mechanical, electrical, civil and aeronautical – have many of the skills needed to be excellent physics teachers. Most of them will have taken maths and physics A-level and their degrees will have extended their background and thinking in many areas of physics. There are close to 15,000 engineering graduates per year, but as things stand, they don't necessarily consider teaching physics as a destination after graduating.

Find our more:
bit.ly/CPEngineersTeachPhysics



Credit: Shutterstock

Final BTEC funding decision

The Government has reiterated its intention to press ahead with the removal of funding from BTEC programmes by 2025. A list of new courses to replace BTECs will be published in July 2024, for schools and colleges to begin teaching in September 2025. A campaign led by school and college leaders had urged a slowdown, saying they needed more time to ensure appropriately trained staff are in place, but a letter from Robert Halfon, Minister for Skills, Apprenticeships and Higher Education, confirmed there would be no delay to the published timetable.

The IOP, with the Association for Science Education, the Royal Society, Royal Academy of Engineering and Royal Societies of Biology and Chemistry, lobbied government on this issue in 2021, arguing that the immediate removal of funding from BTECs at that time would cut off routes to STEM careers for thousands of students who would be unlikely to qualify for A-level courses. As a result, around two thirds of courses that had been scheduled for defunding in 2022 continued to run, with the discontinued courses limited to those that had a clear T-level replacement in place.

Following the latest statement, it appears the remainder of BTEC courses will now be completely phased out by 2025. From then on, students' options after GCSEs will be either A-levels, T-levels or alternative academic and technical qualifications aligned with employers' skills requirements.

New programme to support inclusive practice for teachers of science

Credit: IOP

A scheme to support science teachers to improve inclusive practice within their schools is being launched by the Association for Science Education, with funding from the Department for Education.

The new programme, 'Inclusion in Science', will launch in September and is open to all teachers of science, with options available for anyone interested in delivering Inclusion training. It provides an opportunity for science departments to become experts in inclusive practice within their schools.

The announcement follows the publication of a report in March from the House of Commons Science and Technology Committee into diversity and inclusion in STEM. Its wide-ranging inquiry had heard from over 100 organisations (including the IOP) and 32 individuals, to develop a picture of the current situation facing women, people from certain ethnic backgrounds, people with disabilities, those from disadvantaged socio-economic backgrounds and those who declared themselves as being LGBTQ+ in STEM education, STEM research and STEM employment.

The report points to some particularly concerning findings about ongoing disparities across STEM settings, "from classrooms to research facilities, to boardrooms". It also considers the impact of the pandemic, which appears to have exacerbated under-representation. The report makes recommendations on areas including teacher pay, the importance of subject specialist teaching and availability of triple science options.

Vicki Parry, who wrote a feature in the last issue of Classroom Physics about ASE's 'Inclusion in Schools' programme, commented: "The evidence is all around us that there is a problem with diversity in STEM. Step into most A-level physics classrooms and you will likely see what is reflected in national data at school, university and employment level. The recent House of Commons report recognises these problems and makes some suggestions towards addressing them. From our work on the 'Inclusion in Schools' programme, we know this needs to go further than their recommendations. To build a culture of inclusion in STEM, where every person is safe, welcomed and represented, there needs to be high-quality training and time for implementation and reflection."

From September, ASE is offering 'Inclusion in Science' as a remote training programme with live online learning modules to build understanding and confidence in inclusive practice. It aims to reduce biases in students' learning and broaden their understanding of the world, and their potential within it.

Find out more:
ase.org.uk/inclusion-in-science

Credit: Pexels

SpaceX rocket launch

In April the maiden flight of SpaceX's new rocket, the most powerful ever assembled, launched.

The unmanned craft exploded after three minutes when its rocket boosters failed to detach. The company heralded the test flight as a success, generating large volumes of data for analysis and continued development of the project.

SpaceX has emerged as a leading player in commercial Space flight, with its reusable rockets substantially bringing down the costs of launching. The company has targeted manned Moon missions by 2025.

Reaching for the skies

Credit: Katie Kelleher

If you want to see the physics of balance and stability at work, go to any city centre and look up at the skyline. By lifting and moving materials, cranes enable modern construction to take place – shaping the world we live in. But how do they work? We asked crawler crane operator Katie Kelleher to explain…

Classroom Physics: What is a 'crawler crane'?

Katie Kelleher: A crawler crane is essentially a crane on tracks. We use them on construction sites during the initial phase of building projects. The crawler crane lifts to all different parts of the site, usually things people can't lift by hand or to places that are harder to reach, such as over buildings or down holes.

CP: How does the crane remain balanced when it is moving large loads?

KK: The crawler crane is generally very stable because its broad base and tracking spreads the weight over a wide area. Like all cranes, it also relies on counter weight in the form of ballast – weights placed on the back of the crane which keep it stable when it is lifting heavy loads. How much ballast depends on the maximum weight the crane can lift. Crawler cranes range in size from around 40 tonnes to 3000 tonnes and more.

CP: As the operator, what do you have to do to keep the crane stable?

KK: Operators rely on a computer (the 'rated capacity indicator' (RCI)) to keep us informed about the forces acting on the crane. The computer shows what weight we are lifting, the maximum load we can lift, and how much loading is over each corner of the crane. This is really important because cranes can turn through 360 degrees and the load bearings will change depending on the direction of the crane, the weight being lifted, where the crane is positioned, and where the counter weight is.

The computer also shows us wind speeds. The key to keeping the crane stable is working within these parameters.

Another factor is the ground: a crane can put a lot of stress on the ground and this stress changes position as the crane slews (turns around on the slew ring). It's important that the ground is checked by a qualified engineer before a crane is placed on it.

CP: How did you become a crane operator?

KK: Back in 2014, I started on a Lifting Technician Apprenticeship. I did around three months at Bircham Newton construction college in Norfolk where I completed my 'tickets' – training courses in different skills and systems needed around the site. After this I went to my company yards to practice operating on the tower crane and the crawler crane, and once I was deemed competent I headed to my first construction site. Even at this point I was still placed with a qualified operator to make sure I was able to operate to the standard required. You need 300 hours' operating time to turn your trained operator red ticket into a blue competent operator ticket. This also completes your NVQ.

CP: What skills and attributes do you need in your job?

KK: You need good team working skills, an ability to listen and follow instructions, patience and the ability to remain calm in stressful situations, attention to detail, and good spatial awareness.

CP: Describe a typical day at work

KK: I usually get up around 5am to get to work for 7am. Once on site I wait for the team briefing which outlines all the work we have to do that day. After the briefing, I complete the crane checks to make sure everything's in good working order, then I start work. I get two breaks during the day of 30 minutes each, and usually finish up around 6pm. Once finished I pack the crane away and lock her up for the following day.

CP: What projects have you worked on?

KK: I'm very lucky to have worked on some iconic London projects. I worked on the Tottenham Court Road section of the Elizabeth Line, and on the Tideway project – a 25km 'super sewer' underneath the River Thames which will protect the river from sewage spills.

CP: What is your advice to anyone interested in an apprenticeship in construction?

KK: Research, research, research! There are so many different jobs within the construction sector, some on site, some site office-based, some head office-based. There are degree and non-degree apprenticeships, there are training opportunities...

Honestly, whatever your interest I can guarantee there will be a position that works to your strengths.

CP: As a woman working in quite a male-dominated sector, what would you say to any girls reading this who may not have seen female role models in this industry?

KK: Some sectors certainly are more male-dominated but don't let this stop you. You can make your mark in any industry! And if you can't see the role model you should be the role model. Paving the way for other women is so rewarding. Don't let anything get in the way of what you want to do.

Sporting highs and lows

How the centre of gravity explains sporting success

This summer, the world's sporting gaze will shift to Australia and New Zealand for the women's football World Cup. As well as England's Lionesses, physics will, of course, also be at play.

Anyone with even a passing interest in football may be aware of certain diminutive but brilliant players whose seemingly miraculous speed and balance made them very hard to tackle.

Diego Maradona may have believed in the hand of God, and Lionel Messi would surely point to many years of intense training – but they also have Newtonian mechanics to thank for their careers.

Shorter players have a low centre of gravity, making them steadier on their feet and so able to change direction more quickly than taller players. Just like a partially filled juice carton (see page 10) having one's mass lower to the ground gives greater stability.

Footballers train hard to develop core strength (back, abdomen, legs), partly to improve their power and agility, but also because increased muscle mass in the middle of the body alters their weight distribution and lowers the position of their centre of gravity.

In many other sports, staying low for stability is also an important part of technique. In rugby and American football, where players push against opponents to drive them backwards, getting the body close to the ground is a key skill that coaches emphasise. American football coaches teach that the 'low man wins'. Squatting down to lower one's centre of gravity gives an advantage by making it harder to be knocked over.

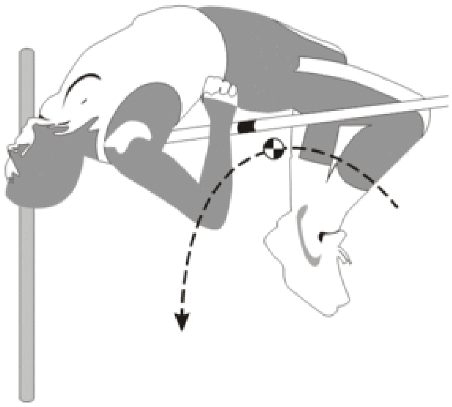
Flights of fancy

What about when the aim is to be as high as possible?

When footballers leap to head a ball, or basketball players launch themselves towards the basket, they can seem to defy gravity. Commentators talk about 'hang time' and, in slow-motion replays, players can seem to float in the air.

But even LeBron James has to work within the laws of physics. On Earth, in any unpowered motion through the air in which drag and other forces due to the air are small, the centre of mass of a body must follow a parabolic path. No amount of athleticism can change that. However, other points on an athlete's body are not so constrained. When sportspeople appear to float in the air, it is because they are able to manipulate their bodies around their centre of mass. Those that can do this best gain a competitive advantage, whilst creating the spectacular illusion of human flight.

The leaps of basketball players and footballers, like the pirouettes of gymnasts and dancers, all follow the same principle: extending the body during flight to give more time at peak height.



Credit: Wikipedia Commons

And what of the highest jumpers of all? High jumpers have a unique ability to achieve close to vertical take-off at high speed, but also possess the flexibility and coordination to manoeuvre their bodies around their centre of mass during flight, enabling them to get over a bar that is higher than the apex of their centre of mass's path. The American high jumper, Dick Fosbury, revolutionised the sport in the 1960s when he began to jump backwards over the bar, arching his back and flicking his legs up over the bar as they trailed behind him. The 'Fosbury Flop' achieved higher clearance for the same amount of lift, and rapidly replaced the traditional straddle or scissor-kick technique for all high jumpers after the 1968 Olympics, where Fosbury won gold.

A winning formula

If your students are planning to follow the football this summer, for all that VAR and the offside rule may play a part, it is players' ability to gain advantage by playing within the laws of physics that may be the difference between victory and defeat.

In this column, **James de Winter** (University of Uppsala and University of Cambridge) and **Richard Brock** (King's College London) highlight accessible and usable resources based on research into physics education.

Get involved with physics education research discussions by joining the **Physics Education Research** group on Talk Physics at **talkphysics.org/groups/physics-education-research-per** or email **research@teachphysics.co.uk**

Embodied cognition

Historically, researchers in the cognitive science tradition have assumed that concepts are purely abstract representations. In the context of physics education, the concepts of force and energy, for example, would be stored in memory as a collection of symbols and sentences. Embodied cognition research challenges this assumption and proposes instead that concepts will have both abstract elements and aspects that arise from the motor system that are not easily expressed in words. Students' concepts of force might involve both explicit propositional knowledge (for example, a statement of Newton's 1st Law) but also elements based on information developed from the motor system (such as the experience of accelerating or decelerating) that are difficult to put into words.

Proponents of embodied cognition have proposed approaches to teaching that supplement traditional methods with carefully curated experiences that activate and develop embodied concepts. The embodied cognition research programme is still at an early stage and its findings remain controversial, but one study in the context of teaching moments presents some provocative (if tentative) findings.

Credentials

A team of researchers (Pouw and colleagues) looked at studies of the use of animations to support learning in physics, which have failed to report benefits. They noted that animations can impose a high cognitive load and observed that those linked to bodily routines (eg, origami and knot-tying) are learned more readily than more abstracted animations. Research suggests that humans learn particularly effectively when stimuli include representations of the body.

To test this hypothesis, they used the context of learning about balance with students with a mean age of 12.5 years (n=74). They compared

Credit: IShutterstock

using animations of seesaws, with a human body with its arms stretched out along the lever superimposed on the seesaw, with simple seesaw animations. They found that the body-based animations promoted learning gains when prior ability was controlled for. The learning gain occurred for students with low prior mathematics ability but not for those with greater knowledge. The authors speculate that the body analogy may activate knowledge related to forces acting on the body.

Considerations for teachers

Several research programmes suggest results that are potentially of interest to physics teachers. Pouw and colleagues' finding that using body analogies supported learning for some in their sample is intriguing, but currently, the research evidence base isn't strong enough to recommend the implementation of the approach in the classroom. Pouw and colleagues' paper doesn't suggest that all forms of physical activity support learning in the context and more evidence is required about the nature of activities that can support learning (there are several other small-scale studies, in different contexts, that report similar findings).

We introduce the paper both as a potentially interesting finding but also to highlight the gap that exists between exciting results and concrete recommendations for classroom practice.

more...

A good introduction to the application of embodied cognition to physics teaching can be found in Weisberg and Newcombe's open access paper, available here:

bit.ly/EmbodiedCognition

There are some interesting articles on embodied cognition in education, including in physics education, on the Learning Scientists blog:

bit.ly/EmbodiedCognitionBlog

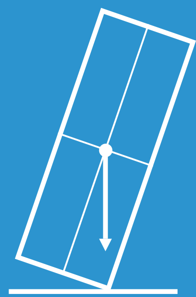
Reference

Pouw, WTJL, van Gog, T, Zwaan, RA & Paas, F (2016). Augmenting Instructional Animations with a Body Analogy to Help Children Learn about Physical Systems. Frontiers in Psychology. 7:860. doi: 10.3389/fpsyg.2016.00860

Pull out and keep!

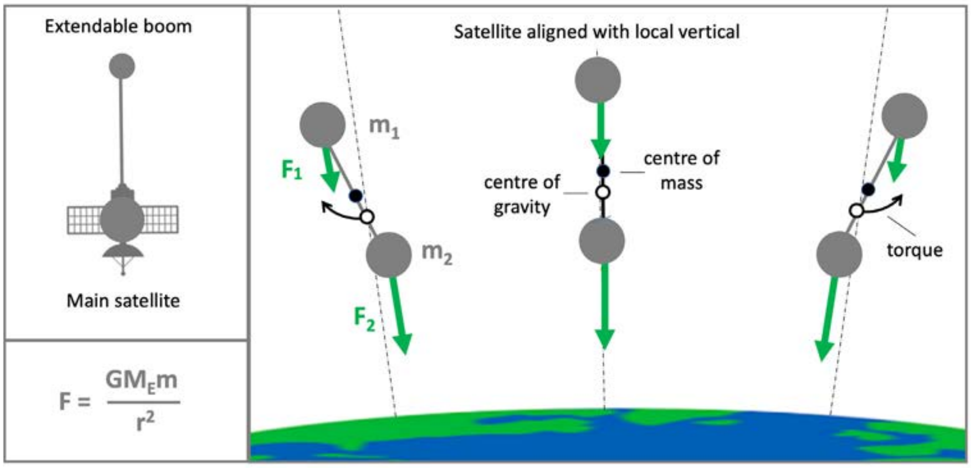
Forces (11–18)

Balance and stability



Inside this issue:

Balance and stability: on the ground, in the air, in orbit



Balanced objects have no net torques or forces acting on them. Stable objects are those that return to their original position when disturbed. For an object on the ground, the position of the object's centre of gravity relative to its base determines whether or not it is stable. For objects in flight or in orbit, balance and stability also depend on the position of the centre of mass. Inside this pull-out are two investigations on this theme.

In a uniform gravitational field, the centre of mass and centre of gravity positions coincide, but that doesn't mean that the two terms have the same meaning. If you wanted to discuss the difference you could ask your class to imagine an asteroid in deep space. Far away from any gravitational influences, it has no centre of gravity, but it will still tumble around its centre of mass. With older students, you can discuss gravity-gradient torques that arise in non-uniform fields, something that satellite engineers sometimes take advantage of to stabilise Earth monitoring satellites (see 'In orbit').

On the ground (11+)

In our 'Stable carton' activity on page 10, students explore the angle at which an object topples by considering the position of its centre of gravity. This principle applies equally to juice cartons and double-decker buses, which are subject to 'tilt tests' before being allowed on the road.

In the air (14+)

In our 'Balanced flight' activity (page 11), students build gliders to explore how the position of the centre of mass affects aircraft stability. Commercial aircraft are designed to have a forward centre of mass and a small upside-down wing called a tailplane at the rear of the aircraft. The downward force provided by the tailplane provides a balancing torque that will tend to return the aircraft to level flight if there is a disturbance due to turbulence.

A template and instructions for making a glider are included in the worksheet on page 12.

In orbit (16+)

Satellites that use gravity-gradient stabilisation have long extendable booms. If you wanted to discuss this with your class you could start with a simple satellite made of two equal masses connected by a light rod (as shown in the diagram above). The gravitational force F_1 due to the Earth is smaller than F_2 because mass m_1 is further away than m_2, and so there is a stabilising torque that makes the satellite 'want to' align its long axis to the local vertical.

Centre of gravity vs centre of mass

The centre of gravity is the one position around which the **weight** of an object is evenly distributed. On a force diagram, the gravitational pull on the whole object is shown with a single arrow drawn from this point.

The centre of mass is the one position around which the **mass** of an object is evenly distributed. A freely spinning body will rotate around this point, and it is used to analyse an object's straight-line (translational) motion.

More: For an introductory activity for teaching the concept of the centre of gravity, see 'Steady spoon': **spark.iop.org/steady-spoon**

Practical investigation: Stable carton

In this activity, students are introduced to the idea of stability by investigating how the angle at which a juice carton topples changes with volume of water added.

Equipment:

Each pair of students will need:

- An empty 1-litre cardboard drinks carton with cap
- 1-litre measuring jug or cylinder
- A semicircular protractor
- Sticky tape (optional)
- A phone with slow-motion video function (optional)
- Access to graph paper

Procedure

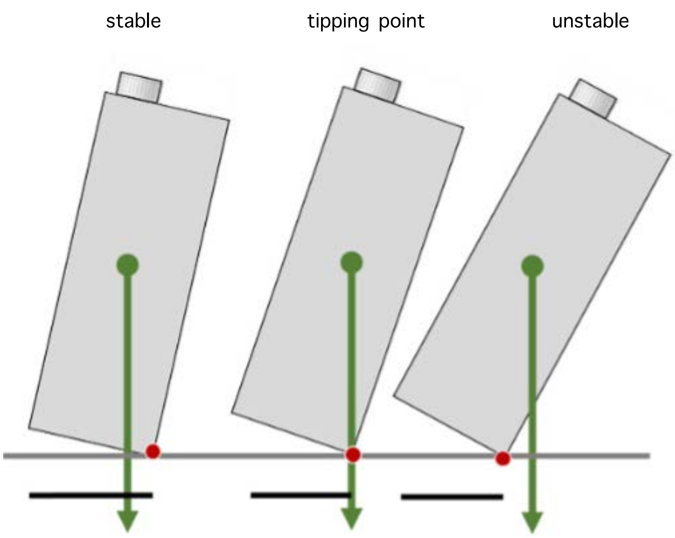
If students are unfamiliar with the terms stable, unstable and tipping angle, introduce them.

Ask students to work in pairs to:

1. Measure the tipping angle of an empty drinks carton, taking repeat measurements to find an average value.

2. Repeat for a full carton (1 litre of water).

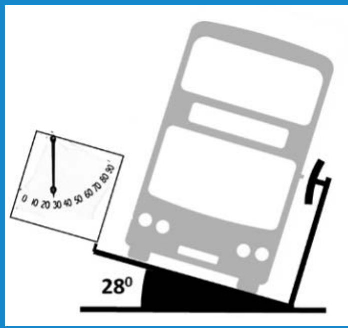
3. Plan and carry out an investigation of how the stability of the carton is affected by the volume of water inside it and determine the amount that makes it most stable.



Stable and unstable cartons

If the carton's centre of gravity is left of the pivot, the torque due to the gravitational force is anticlockwise and the carton returns to its original position. If the centre of gravity is directly above the pivot, the carton is at the tipping point. If it is right of the pivot, the torque is clockwise and the carton is unstable.

Real-world stability



Tilt tests have real-world applications. One example you could discuss is a double decker bus. They must be stable up to 28° to be allowed on the road.

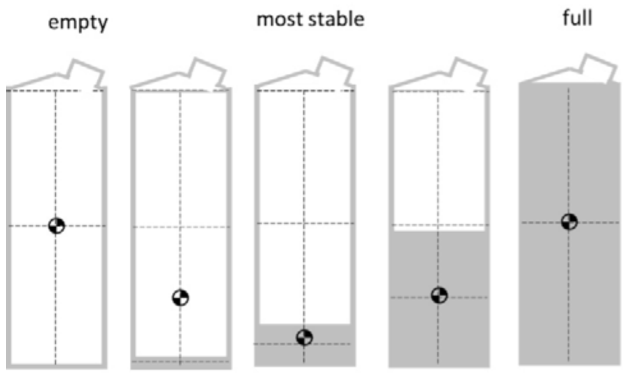
Teaching notes

This investigation allows students to practice their experimental skills. Encourage them to identify sources of error and uncertainty and ways in which they can improve their experimental technique.

For example, placing both protractor and carton on the bench produces a zero error. They can avoid this by taping the protractor to the edge of the bench and/or raising the carton (for instance by placing it on a book).

Taking repeat measurements will improve accuracy, and tilting the carton slowly will make it easier to judge the tipping point and so reduce the uncertainty in their tipping angle values. If available, they can use a slow-motion video capture on their phones as an aid.

The result that may surprise them is that the full and empty carton topple at the same angle. Encourage them to explain this by thinking about how the mass in each is distributed.



Empty and full cartons have an even distribution of mass and so their centre of gravity positions are halfway up the carton. Partially full cartons have an uneven distribution of mass with more mass in the lower half of the carton and so a lower centre of gravity.

STEM club activity: Balanced flight

In this activity, students build gliders to see how the position of an aircraft's centre of mass affects its balance.

Equipment

Each pair of students will need:

- Copy of the glider instructions and template (page 12)
- Cardboard (A5 sized or larger)
- Scissors
- Glue sticks
- Sticky tape
- Blu Tack
- At least 3 metres over which to test gliders (e.g. down a corridor)
- Colouring pens/pencils (optional)

Procedure

Ask students to:

1. Build their glider by following the instructions on their worksheet.
2. Test their glider by holding it under its wings and throwing like a dart (it will be unbalanced and pitch nose upwards).
3. Repair any damage from test flight and add Blu Tack to its nose (to move the centre of mass forward).
4. Place the glider on their partners' two upward pointing fingers and add/remove Blu Tack until it balances under its wings.
5. Test the glider again (this time it should be relatively steady in flight).
6. Repair any damage and add/remove Blu Tack to improve balance and stability. Test again.
7. Repeat, carrying out repairs and modifications until the glider is optimised for straight flight.

Teaching notes

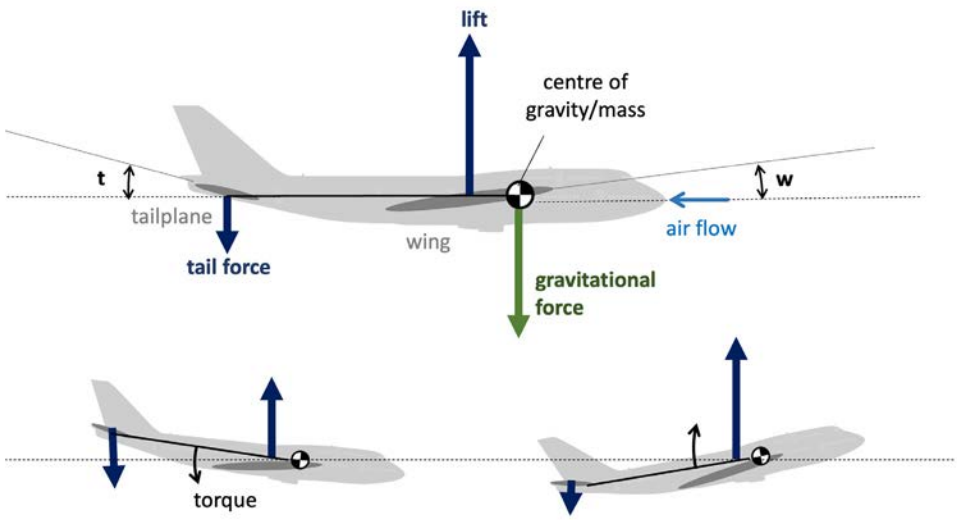
When they construct gliders, check that students have attached the fin to the rear of the fuselage (this provides directional stability), bent the wing edges upwards to about 45° (for lateral stability) and attached the wings to the sloping sections of the fuselage (for longitudinal stability). If students attach the main wing to the straight sections of the fuselage, explain why it must be on the sloping section to produce an upward lift force (it must deflect air downwards). The tailplane needs to slope in the opposite direction to produce the downward force needed for a stabilising torque (see diagram below).

On their first test flight, their glider will be unbalanced. This is because the glider's centre of mass – which acts as a 'pivot' – is located behind the main wing. The force from both wing and tailplane creates anticlockwise torques and so the glider pitches nose up.

Adding Blu Tack moves the centre of mass forward. The configuration they are aiming for is shown in the diagram. The centre of mass is a little forward of the main wing so that a clockwise torque from the wing balances the anticlockwise torque from the tailplane. Once they have optimised their gliders, you could introduce a competition element to see whose glider flies furthest and/or who is most precise when hitting a target.

Building STEM literacy: torque talk

In engineering contexts, the term torque is often used instead of the moment of a force. Explain that the two phrases have the same meaning. The magnitude of both is given by the force multiplied by the perpendicular distance to the turning point.



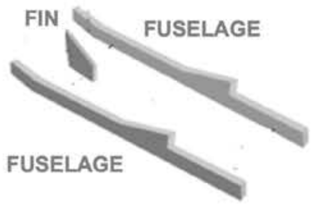
Balanced and stable flight

For level flight, the torque created by the wing must be balanced by that created by the tailplane. For stable flight, a tailplane that provides a downward force is used. If turbulence makes the nose pitch downwards, the angle the tailplane makes to the airflow (t) increases, increasing the tail force and hence creating a torque that returns the aircraft to level flight. If the nose pitches up, the tail force reduces and once again there is a torque that will restore level flight.

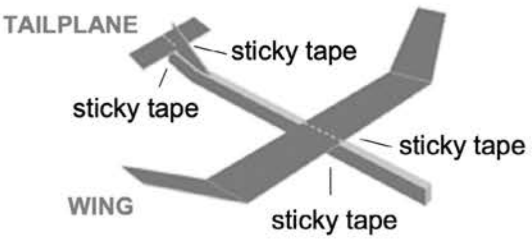
Building your glider

a. Cut out your glider parts
b. Stick to cardboard
c. Cut out the parts from cardboard
d. Colour in parts to personalise your glider
e. Place a ruler along the dotted lines on the wing and fold wing ends upwards. Fix at about 45° using sticky tape.

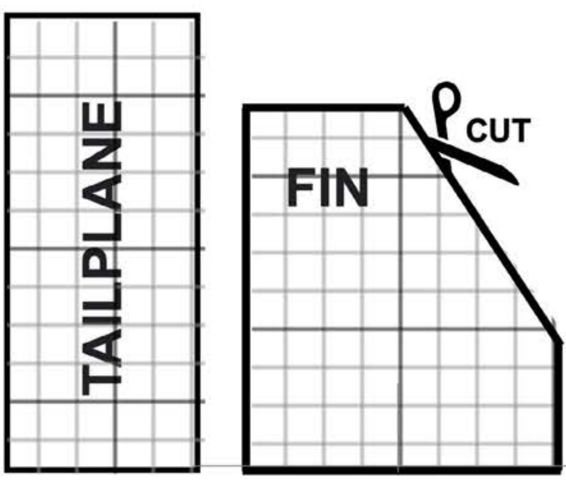
f. Place the fin between the two fuselage pieces and tape together

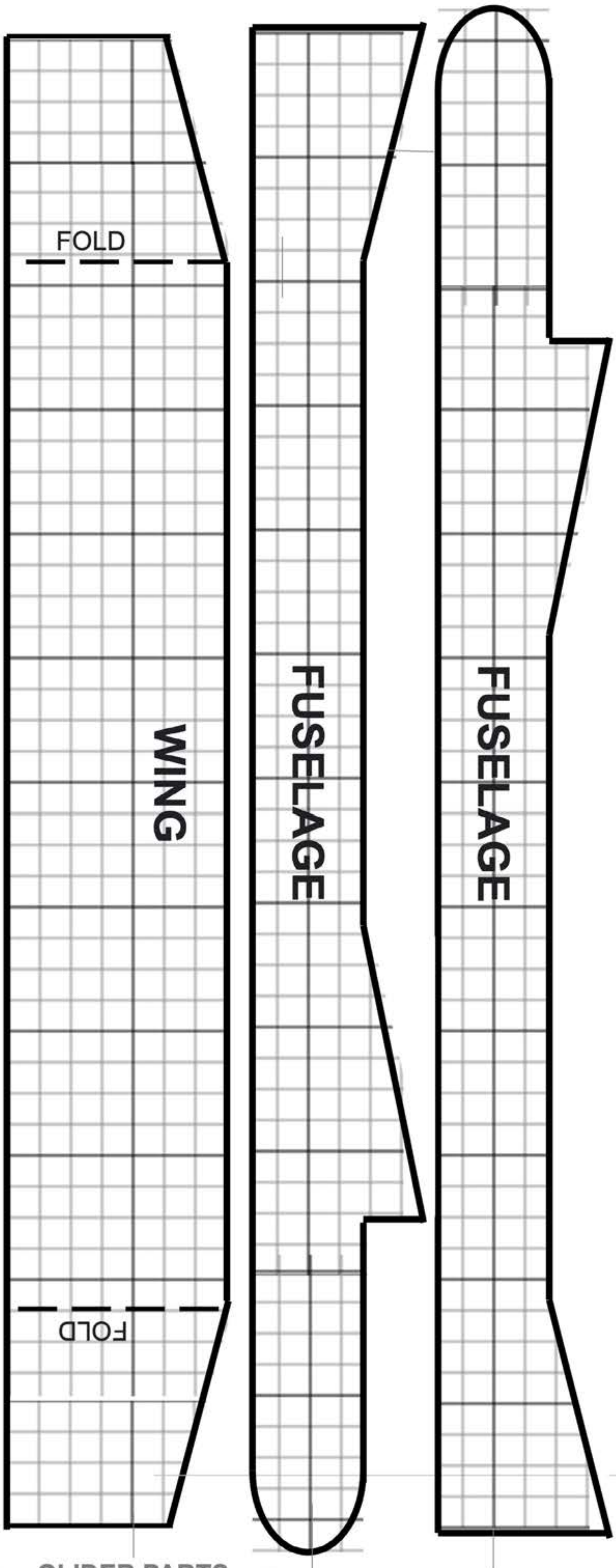


g. Stick the tailplane to the back and the wing to the front sloping sections of the fuselage.



h. Test-fly your glider. Why doesn't it work?
i. Place the glider on your partner's two upward pointing fingers. Add Blu Tack to the nose until it balances under its wings
j. Test-fly again, repairing and adding/re-moving Blu Tack as required, until you achieve steady flight.





GLIDER PARTS

Stories of balance and stability

Reproducing Coulomb's balance

An iconic measuring device from the history of physics is Coulomb's torsion balance, which uses the twisting of a wire to measure small forces. In 1785, Charles-Augustin de Coulomb (1736–1806) reported that he had used a torsion balance to measure electrostatic forces and hence determined that electrostatic repulsion follows an inverse square law (a feature of what became known as Coulomb's Law). Torsion balances are notoriously sensitive; many physicists failed to replicate the result and a historian of physics, Peter Heering, claimed that Coulomb's description wasn't a literal report of his experimental method, and his data couldn't have been obtained with a torsion balance. However, a replication in 2006, faithfully reproducing Coulomb's methods, concluded that he had obtained his results as described. The contemporary experiment produced an exponent for the distance between the centre of charges of 2.055 – close to the expected value of 2.

A toy Kibble balance

Following the 2019 redefinition of Système International (SI) base units, the kilogram is now defined in relation to the equivalent mass of the energy of a photon, and so based on Planck's constant. Before this change, mass was linked to a physical prototype kilogram. One approach to determining the mass of a reference kilogram was through a sensitive measuring device called a Watt or Kibble balance, which uses an electromagnet to generate a force which balances the gravitational force on the test mass. The electrical power supplied to the current-carrying coil is determined to calculate the mass, hence the term Watt balance, though the device is now more often referred to after its inventor, Bryan Kibble.
A potentially interesting project for teachers and students is to construct a Lego Kibble balance:

bit.ly/LegoKibble

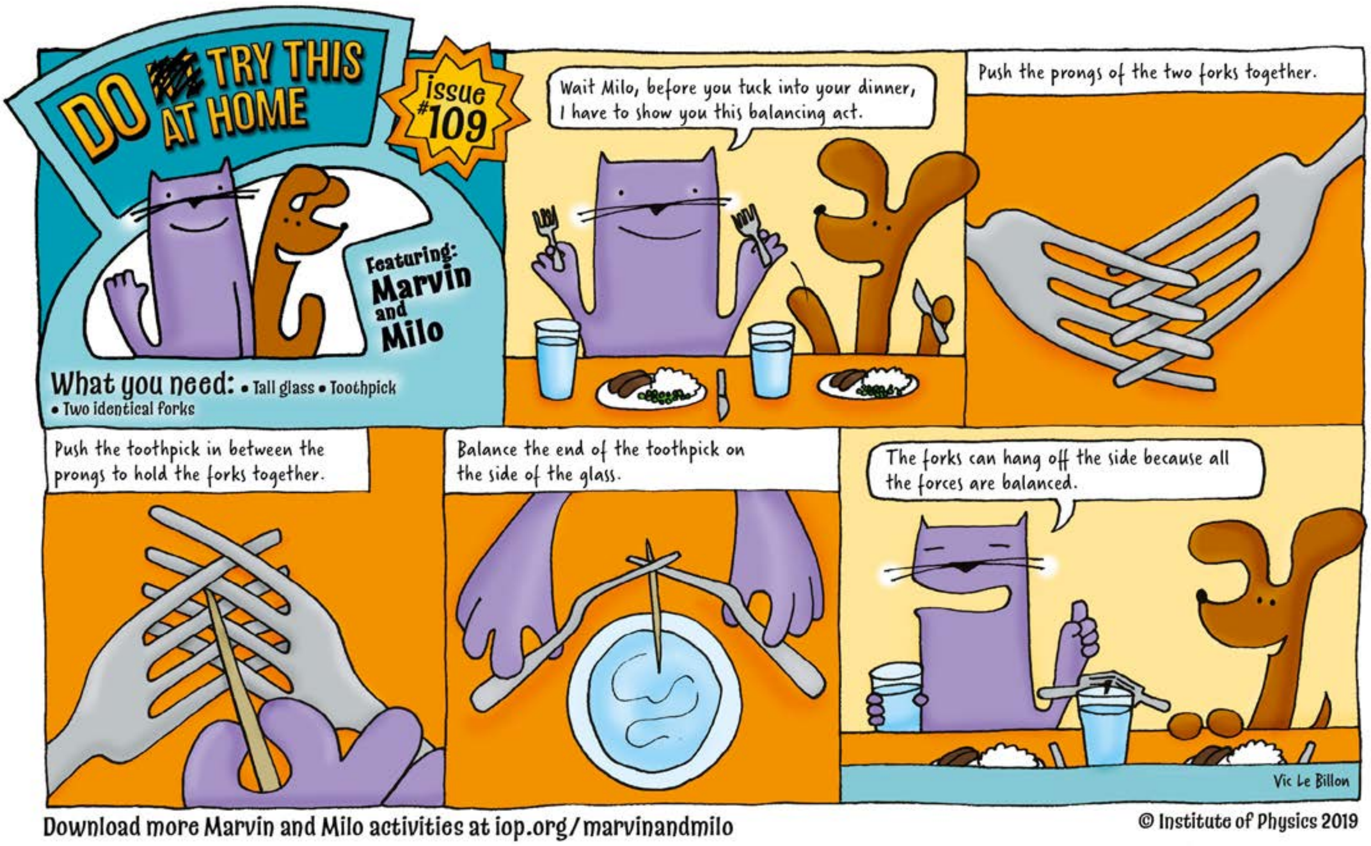
Pigeon stability

Pigeons (and some other birds) characteristically bob their heads forwards and backwards as they walk. It is known that the movement acts as a mechanism for stabilising the head to improve vision. However, the vision hypothesis doesn't explain why the motion of the head synchronises with the movement of the pigeon's legs. An alternative theory is that the head bobbing shifts the bird's centre of gravity to maximise stability. Researchers suspended frozen bird carcases along a thread to determine their centre of gravity. A video analysis of pigeons' gaits suggests that head-bobbing may stabilise the bird during the period of walking when only one foot is in contact with the ground.

spark.iop.org/stories-physics

Compiled by Richard Brock.

Follow him on Twitter at **@RBrockPhysics**



Credit: IOP

Physics*education*

Physics Education is our international online journal for everyone involved with the teaching of physics in schools and colleges.

Editor-in-chief Gary Williams highlights his favourite papers on **balance and stability** from the archive and the current volume.

Access over 50 years of articles at **iopscience.org/physed**

Affiliated schools have free access – email **affiliation@iop.org** for a reminder of your log-in details.

Credit: IOP

The stages in turning upside down for a tippee top

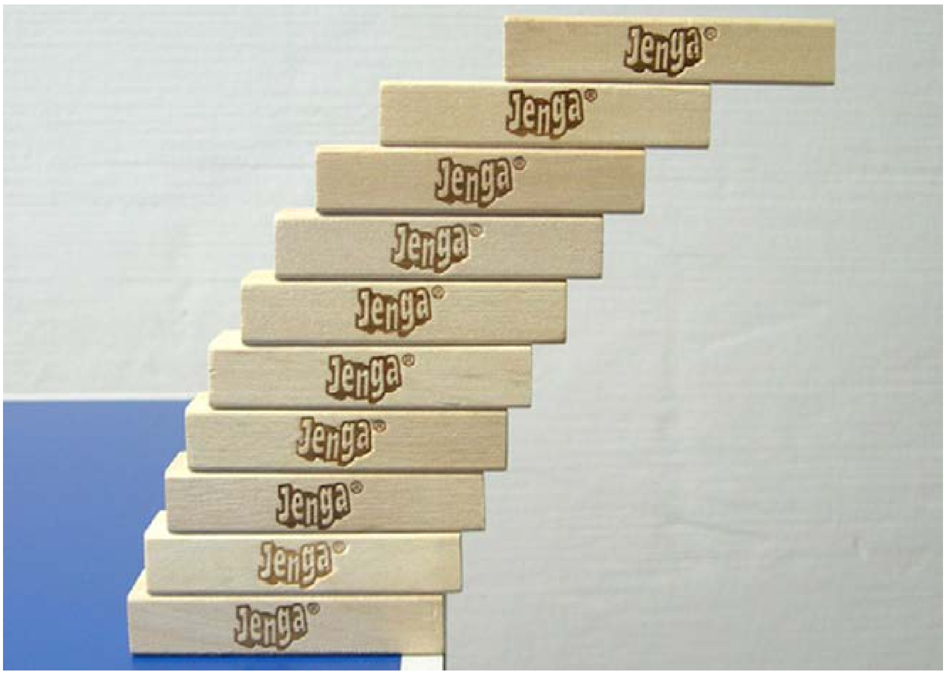
From the archive

There are a number of papers in the literature that discuss the stacking of plates or blocks, often looking at how far the stack might be able to overhang the edge of the surface it is built on. Given the low cost of small wooden block towers and playing cards, and their portability, there is a lot of mileage in these activities. **"Defying gravity with Jenga™ blocks"** looks at some simple ideas for stacking. As a set usually has 54 blocks in it, one set is enough for multiple groups.

I am indebted to a lecturer from Cardiff for suggesting another use of the blocks, which is to write numbers on the ends of the blocks relating to numbered questions. Students can see the questions in advance and remove blocks as the usual version of the game is played. Teams of students can score points by answering questions while removing blocks. A balance must be struck between choosing blocks you can remove easily and questions you can answer!

"A stack of cards rebuilt with calculus" starts off looking at stacks of playing cards or tiles. (Packs of large cards, A4 size, can be purchased online or on the high street if you wanted to try this as a demonstration). It then takes this further by looking at shapes other than rectangles. This is a neat extension to the balancing blocks activity and the plates are easy to make out of card.

Other interesting balancing acts that are often seen are the spinning top and the gyroscope. In **"Dare we teach tops?"** by David Featonby, the author takes the reader on a tour of tops of all types with a plethora of teaching possibilities. There are too many papers that discuss tops in Physics Education to list, but the same author



Credit: IOP

Jenga™ blocks being used to demonstrate balance and tipping points.

also added **"Spinning tops revisited"**, which carried on the tour. The tippee top, which spins up onto its stem if started fast enough, seems to be a physics favourite, but over the years there have been numerous fads of battling tops of all kinds that children have gravitated towards. The gyroscope is often referred to in these papers with interesting demonstrations, and the connection between these and the gyroscope chips we have in our mobile phones is worth noting. See **"Understanding the gyroscope sensor: a quick guide to teaching rotation movements using a smartphone".**

Things that balance are sometimes clearly linked to things that don't! In **"The physics of falling chimney stacks",** the theory behind what happens to chimneys when they stop balancing and get knocked over is covered in some detail. This can be linked quite easily to the hinged rod paradox where the end of a rod falls at a rate faster than the acceleration due to gravity because the centre of mass must fall at g. The demonstration, shown with steel balls in **"Falling beads on a falling rod"** is intriguing, and with the addition of the steel balls, students will see and hear more to help their understanding.

Defying gravity using Jenga™ blocks.
bit.ly/PEJenga

A stack of cards rebuilt with calculus.
bit.ly/PEStackofCards

Dare we teach tops?
bit.ly/PETeachingTops

Spinning tops revisited.
bit.ly/PETopsRevisited

Understanding the gyroscope sensor...
bit.ly/PEGyroscopeSensor

The physics of falling chimney stacks.
bit.ly/PEChimneyStacks

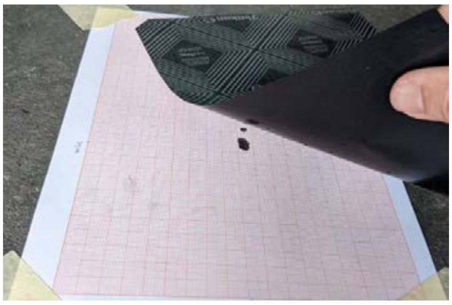
Falling beads on a falling rod.
bit.ly/PEBeadsRod

Recent papers

Although it is perhaps not as fascinating as the other papers mentioned here, I recommend a look at **"Resources on physics education using Arduino",** just to be aware of the possibilities of the Arduino. This small sense and control microelectronic board is inexpensive and versatile, as evidenced by over 400 papers looked at in this study. Applications cover all aspects of physics and the programming aspect allows students to make the connection between science and technology that will prepare them for the future. As Physics Education is the journal with the most Arduino papers, you'll not be surprised to hear there are too many to list here, but do search our pages for everything from beginners' guides to DIY AFMs!

The second recommendation is the open access paper **"Using measurement uncertainties to detect incomplete assumptions about theory in an experiment with rolling marbles".** An experiment is described with marbles shooting off the end of a ramp and hitting carbon paper where they leave a mark on underlying graph paper. This looks like fun and allows you to get students thinking about errors in measurements.

The final paper, also open access, is **"Development of hypothetico-deductive skills in an ISLE-based lab taught by novice instructors".**



Credit: IOP

A sheet of carbon paper is placed on top of the grid paper, marking the position of impact of the marbles.

It argues: "The Investigative Science Learning Environment (ISLE) approach to learning and teaching holds as one of its core tenets that students should learn physics by engaging in the same processes through which physicists develop new knowledge." Rather than rote learning, practical skills and reasoning are key.

Resources on physics education using Arduino.

bit.ly/PEArduinoPhysics

Using measurement uncertainties to detect incomplete assumptions...

bit.ly/PEMeasurementUncertainties

Development of hypothetico-deductive skills...

bit.ly/PEHypothetico

Quick Links

"ChatGPT and the frustrated Socrates"
Marking AI's homework.

bit.ly/PEFrustratedSocrates

"A demonstration of the Faraday's law of induction by means of a magnetized fidget spinner"
More fun with toys.

bit.ly/PEFidgetSpinner

"What happens next? Freefall revisited"
Another 'What happens next' curiosity fiom David Featonby.

bit.ly/PEFreefallRevisited

Open access

"Energy and mass misconceptions"
Eight common errors in thinking about energy.

bit.ly/PEEnergyErrors

"Staying recognised as clever: high-achieving physics students' identity performances"
Some students like to be recognised for being good at something 'difficult'.

bit.ly/PERecognition

"Collaborative data collection: shifting focus on meaning making during practical work"
Time saved by collaborating can be used to focus on reasoning.

bit.ly/PECollaborativeData

talkphysics

David Cotton, editor of our online discussion forum, shares TalkPhysics discussion threads looking at balance and stability.

Log in or register to join the conversation at **talkphysics.org**

Balance and stability are taught across the physics curriculum. Free body diagrams and forces are important concepts in teaching physics. The March 2023 edition of Classroom Physics has a good example of using cardboard force arrows. A good discussion on the free body diagram of a balloon stuck on a wall electrostatically showed the need to consider couples:

bit.ly/TPBalloonWall

A balancing bird worksheet can be found in the June 2017 edition of Classroom Physics. Here's a thread with some balancing ideas:

bit.ly/TPBalancingBird

Teaching moments with metre rulers and weights can be tricky. In the TalkPhysics group Support for Physics Technicians, David Ferguson shares his 3D-printable apparatus to make the student practical easier:

bit.ly/TPPivotHanger

A good thread, initially started as a request for an observation lesson for forces, has the idea of buoyancy being taught with self-inflating balloons on a digital scale. The results are counter intuitive. More ideas for balanced forces develop in the thread:

bit.ly/TPForcePracticals

You can see all back issues of Classroom Physics at **spark.iop.org/classroom-physics**

physicsworld

Stories from our magazine for the global physics community.

Visit **physicsworld.com**

UK physicist appointed head of science at NASA

A major news story is the appointment of Nicola Fox as NASA's chief scientist. Born in Hitchin, Hertfordshire, she studied physics at Imperial College London and the University of Surrey. She moved to the US after completing her doctorate, specialising in coronal mass ejection events from the Sun. In her role as associate administrator for the science mission directorate, she's responsible for 100 NASA missions and a budget of $7.8 bn.

bit.ly/PWNASAChief

Breaking barriers and opening up physics

This article examines the Bell Burnell Graduate Scholarship Fund, a scheme created by the IOP and supported by Dame Jocelyn Bell Burnell, which enables people from non-traditional backgrounds in the UK and Ireland to study for their PhDs. Bell Burnell was awarded the Breakthrough Prize for Physics in 2018, for her discovery of pulsars in 1967. The awards scheme has so far supported 31 individuals with funding of over £750,000.

bit.ly/PWBreakingBarriers

From student to mentor to trainee physics teacher

This blog is from trainee physics teacher Ellie Whitehall, who describes her journey into the profession. She writes: "I do sometimes struggle with impostor syndrome – I often wonder how I am responsible for all these children while only being 22 myself – but the connection with students over a subject I love, and that hopefully they will too, makes every difficult moment worth it."

bit.ly/PWStudentMentor

From war-torn Damascus to success as an aviation engineer

In this Physics World podcast, Maya Ghazal, a graduate research engineer at the UK's Manufacturing Technology Centre in Coventry, tells her story of overcoming disadvantage and prejudice to complete her education after arriving in the UK from Syria in 2016.

bit.ly/PWRefugeesJourney

RMetS Royal Meteorological Society

The Royal Meteorological Society's head of education, Sylvia Knight, explains that stability isn't just important on the ground.

Credit: CloudBank image library (Royal Meteorological Society)

Cumulonimbus clouds mark the top of the unstable troposphere

more…

Find out more about the science of weather at:

bit.ly/AtmosphericStability

metlink.org/resource/atmosphere/

futurelearn.com/courses/come-rain-or-shine

Stability in the atmosphere

The atmosphere can be described as stable if, when perturbed, it returns to its initial state or unstable if, when perturbed, the perturbation grows. The concepts of stability and instability are extremely important in meteorology – driving cloud formation, fog, and our wet and windy weather.

The troposphere – the bottom 10 km or so of the atmosphere which contains our weather – can be unstable to rising motion. If upwards motion begins locally, the air rises and cools as the atmospheric pressure falls with height. If the rising air is still warmer than the surrounding air, it carries on rising, resulting in distinctive convective, cumulus clouds. The stratosphere above, however, has ozone molecules which absorb solar ultraviolet. This causes air temperatures to increase with height in the stratosphere, and means that the stratosphere is extremely stable with respect to rising motion. Gases and particles rarely rise from the troposphere into the stratosphere above – and the tops of cumulonimbus clouds mark the top of the troposphere.

Fog is another example of atmospheric stability. When skies are clear in the autumn and winter, long wave infrared radiation from the ground is lost to space. Conduction in turn cools the air in direct contact with the ground, leaving the air higher up in the atmosphere relatively warm. Again, the atmosphere becomes very stable to rising air and, where fog forms in the cooler lower air, it becomes trapped.

Westerly winds blowing along the polar front, which is the mid-latitude boundary between warmer, tropical air and cooler polar air, are also unstable. Any perturbation introduced into the westerly flow grows, ultimately giving rise to the low-pressure systems which bring most of the UK's windy and wet weather.

CLEAPSS

If you're teaching about aerodynamic stability, you may wish to use an air rocket launcher. Samir Moezzi, CLEAPPS physics adviser, describes an improved design for this classroom favourite.

Credit: CLEAPPS

An air rocket launcher

A safer rocket launcher

Our friends at the IOP recently highlighted a more modern, safer version of the plastic air rocket launcher. These launchers typically involve a length of plastic PVC pipework connected to a valve.

The plastic piping is then pressurised with the use of a track bicycle pump. A paper rocket can be fired 50 metres or so by quickly turning the valve. CLEAPSS has, historically, had concerns about the use of PVC piping because it is typically used for water waste, and not pressure-rated in any way. Pressurising it could lead to a catastrophic failure, sending shards of plastic in all directions. The IOP build eliminates this risk by using John Guest speedfit piping. This is pressure-rated well beyond the 40–50 psi needed for a good launch. The fittings are all push-fit so there's no need for plastic cement. With some straightforward control measures, we're satisfied that this is safe for school use.

In our latest guide, rather than using a 2m length of wound-up pipe, we opted to use the same plastic push-fit series with a few elbows, to enable mounting onto a piece of wood. This design ensures the launch pad is stable, and the rocket can be fired away from the person responsible for opening the valve. Another advantage of this design is that it allows for easy, secure storage. The final launch pipe can be angled up or down, and in the down position will be safely tucked away in a pipe clip.

Students can make their own rockets using paper or card, experimenting with different nose cone designs and numbers of fins for best results. It's an activity that engages students and supports teaching about aerodynamics, gravity and forces.

All parts are available from a range of DIY stores.

more…

For more information, please search **science.cleapss.org.uk** for GL403 – Make it guide – air rocket launcher

The Institution of Engineering and Technology

Holly Margerison-Smith, education manager at the Institute of Engineering and Technology, describes some student activities linked to real-world applications of balance and stability.

www.theiet.org

From concept to technology

Balance and stability are fundamental concepts in engineering. Understanding these concepts is key to designing structures and systems that are safe, efficient and functional. Hands-on teaching resources that cover balance and stability can help students develop the knowledge and skills necessary to design and build these systems.

The Institution of Engineering and Technology has a wide range of resources introducing students to real-life, innovative examples of engineering and technology from around the world. For example, students can analyse boat design and then test their boat hull designs in a test tank in our 'Speedy boats' resource. Through this process, students will learn the importance of applying relevant scientific and mathematical understanding when refining and developing an idea.

Another activity focuses on pulley systems designed to lift heavy loads. These mechanical systems allow us to perform tasks that would otherwise be very difficult, such as cranes on building sites that move heavy materials. Students can model and construct three different examples of pulley systems and then consider an idea for a commercial product that would make use of one of the pulley systems they've constructed.

Hoverboards are another example of a system that requires balance and stability. Students can learn about the physics behind how hoverboards work, looking at different hoverboard designs and the materials used to see how they affect the hoverboard's stability and manoeuvrability. Additionally, students can use the knowledge and skills learnt to design a levitating hoverboard that works using magnetism – the same scientific phenomenon behind MAGLEV trains.

more...

See more resources at
education.theiet.org/

The Ogden Trust
making physics matter

Jackie Flaherty, head of teaching and learning at the Ogden Trust, writes about the Trust's work to ensure teachers deliver practical, meaningful classroom physics that can inspire students and embed physics principles into learning.

Purposeful, practical physics

Purposeful practical work features as one of the seven recommendations of the Education Endowment Foundation's Improving Secondary Science report (2018), but a recent paper by the Royal Academy of Engineering (Hanson & Lucas, 2022) states that 'a significant challenge to increasing practical learning in schools is the shortage of specialist qualified teachers'.

Practical work in physics can prove especially daunting for early-career teachers and those teaching out of specialism.

Discipline-specific support has been highlighted as an important aspect in a study regarding physics practical work. De Winter & Millar (2023) suggest that teacher educators should 'encourage reflection on practice in teaching specific topics and learning outcomes in that topic, rather than in teaching physics (or any of the other sciences) in general'.

The Ogden Trust provides free specialist coaching and mentoring for early-career teachers looking to build their core physics skills or develop a physics specialism; our fully funded Subject Knowledge for Physics Teaching (SKPT) develops teaching skills and confidence in delivering lessons that bring physics to life in the classroom.

Azan, a teacher at Norbury High School for Girls, completed our recent waves modules. "I found the SKPT course extremely helpful. The delivery was exceptional; presenter's subject knowledge was impeccable. I'm truly privileged to have been part of this teaching and learning."

Visit **ogdentrust.com** to find out more about the Trust's programmes including Subject Knowledge for Physics Teaching CPD and early-career support and mentoring.

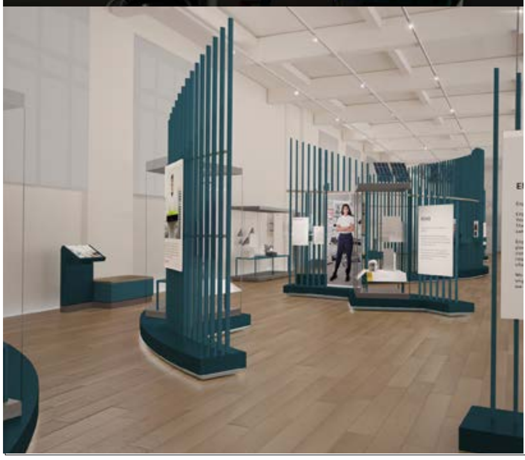
more...

Jackie spoke about the SKPT programme with Lewis Matheson. You can find them in conversation at:

bit.ly/OTInConversation

SCIENCE MUSEUM GROUP

Credit: Science Museum Group



Visit the new Engineers gallery at the Science Museum

CURRICULUM LINKS: Career Development, Design and Technology, STEM

KEY STAGE SUITABILITY: KS3, KS4

Opening on 23 June, a fascinating new gallery at the Science Museum celebrates engineers and their extraordinary stories across four sections: Bodies, Lives, Connections and Creating.

Human stories are at the heart of the Engineers gallery, where visitors will have the opportunity to take a closer look at iconic objects such as the first digital camera, the cutting-edge CMR 'Versius' surgical robot arm and a miniature atomic clock that the entire GPS system depended upon, as well as learn more about the remarkable people who invented them.

Find out more at:

sciencemuseum.org.uk/learning/engineers-school-info

Credit: IOP

IOP Institute of Physics

IOP's Quantum Hackathon

Are your students ready for the IOP's Quantum Hackathon?

What?
Learn to programme a quantum computer: an interactive day of coding and quantum challenges with talks from guest speakers from several of the UK's leading quantum computing companies.

When?
26 September 2023

Where?
Institute of Physics, 37 Caledonian Road, London

Who?
This is aimed at exceptionally motivated students aged 16–18 who are considering studying physics, computer science or a related subject after they leave school.

Why?
This is a great opportunity to experience some real-life quantum challenges with experts from the field. It's a fun day and great for UCAS applications!

We encourage all highly motivated students to apply, in particular those from underrepresented groups in physics.

Please note all travel expenses will be covered and lunch and refreshments will be provided. Teachers are not expected to accompany the student.

To find out more, email:
martha.hilton@iop.org

Coming up...

A celebration of physics

27 June, Aerospace Bristol

This event is to celebrate and recognise the achievements of our recent Award winners (2020–23), as well our membership, especially those that give their time to engage through our various programmes, serve on our panels and committees, and volunteer through our groups, nations and branches.

Get more information: **bit.ly/IOPCelebration**

Physics Community Days

28 June, University of Birmingham

1 July, Beaumont Collegiate Academy, Warrington

These events are dedicated to building communities to strengthen the teaching of physics. Join us for sessions on making physics teaching more inclusive, supporting physics specialists at all career stages (inc FE), networking time with introductions within and between career stages, and a teachmeet-style session for teachers and organisations to share knowledge.

bit.ly/BirminghamPhysicsDay
bit.ly/WarringtonPhysicsDay

IOP Wales in-person events

4 July, Swansea

7 July, Bangor

These events, in partnership with Swansea University's Reducing Industrial Carbon Emissions (RICE) project, will explore how sustainability can be linked to physics, chemistry and biology in a day of workshops and discussions for teachers of science.

Autumn events...

IOP Scotland conferences

4 November, Edinburgh

18 November, Inverness

Both conferences will include a range of workshops and seminar sessions, with many focusing on supporting the teaching of physics in BGE. Suitable for all science teachers and student teachers.

Contact **stuart.farmer@iop.org** for more information

Governors for Schools conference

26 and 27 September, online

The third Governors for Schools Conference will take place online during National Inclusion Week 2023. This year's event is supported by the IOP's Limit Less campaign.

Find out more at **bit.ly/GovernorsForSchools**

Seen elsewhere...

Go construct, plant machinery

For any students interested in the construction industry (see feature, page 6), this detailed run-down of the machinery commonly used on building sites may be useful:

bit.ly/ConstructionPlant

The physics of Swan Lake

This animation from TED-Ed (pictured, right) explains how ballerinas use the laws of physics to spin on their points.

bit.ly/PhysicsBallet

Planet possibility online events this summer

Full listings and more details at: **physicspartners.com/events/planet-possibility/**

26 June, 4–5pm
Teaching about radioactivity

26 June, 4–5pm
Thermal physics

27 June, 4–5pm
Teaching energy

28 June, 4–5pm
Teaching electromagnetism

29 June, 4–5pm
Teaching earth and space

29 June, 4–5pm
GCSE required practicals

3 July, 5–6pm
Gender representation and unconscious bias in physics

4 July, 4–5pm
What is physics and why we should promote it?

5 July, 4–5pm
Numeracy in physics

6 July, 4–5pm
Where can physics take you?

10 July, 4.15–5.15pm
Teaching electricity

11 July, 4–5pm
Embedding physics careers in the curriculum

12 July, 4–5pm
Teaching waves

Classroom Physics is published by Institute of Physics, 37 Caledonian Road, King's Cross, London N1 9BU, UK. Tel 020 7470 4800.