December 2024 | Issue 71

Classroom physics

The magazine for IOP affiliated schools and colleges

Your winter warmer

Teaching thermal physics

Focus on keeping warm – in homes, clothes and nature

Boyle's bedtime illuminations

Greenhouse effect misconceptions

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Editors' note

With winter fast approaching, a thermal physics theme feels particularly appropriate at the moment.

We've got a great set of classroom activities (see pages 9–12) where students model some of the strategies that different animals have evolved for getting warm and keeping warm – whether they live in hot climates and warm up by basking in the sun, or live in a cold environment and huddle to maintain body temperature.

The natural world is also the starting point for some of the man-made solutions featured in this issue. Check out our feature on insulation for outdoor clothing (page 7) and an interesting article from Physics World on new textiles deigned to imitate nature (page 16).

We've also focused on how we keep our living and working spaces warm with a feature on low-energy, super-efficient buildings (page 6).

Thanks to all the partners who have contributed content to this issue. As usual we're pleased to include a number of other sources of information and teaching resources to use in the classroom.

And a quick heads-up that we're looking at Satellites and Space Probes in our March issue, which should make for another exciting edition!

Until next time, have a great end of term and a relaxing (and warm) Christmas break.

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

Thermal Lizards Top Trumps

This card game shows the ways lizards, as 'cold-blooded' animals, have evolved characteristics to help them survive in a range of environments.

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@IOPTeaching

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

IOP activities round-up

The autumn term has seen a series of conferences and events for physics teachers throughout the UK and Ireland.

Credit: Edinburgh Napier University

Discussions in Scotland

The IOP Ireland team welcomed around 40 teachers and guests to the new Dublin office for this year's Frontiers of Physics conference. Attendees had the opportunity to hear from experts on topics from inclusion to explosions, and to network and share best practice with colleagues. Frontiers of Physics was the first teacher event to be held in the Dublin building.

Over 100 Irish teachers attended our online seminar on student misconceptions made evident in the marking of the 2024 Leaving Certificate paper. The session was delivered by exam marker Joann Dempsey, in partnership with the Irish teacher coaches Paul Nugent and David Keenahan, and highlighted the most common errors and misconceptions made by students in this year's Leaving Certificate exam.

In September, IOP was represented at the Irish Times Higher Options event, where young people meet with employers, educational institutes and training providers as they consider their options after leaving school. The team gave advice on the breadth of careers that physics skills can open up, as well as the possible routes to those careers, whether through a degree, an apprenticeship or straight into a job.

In early October, IOP Scotland hosted a conference, in partnership with Edinburgh Napier University, to explore questions around the future of the science curriculum for students in the Broad General Education stage (BGE – the phase up to S3 in Scotland). Over 70 teachers came from all parts of Scotland, including the northern Highlands. The opening keynote, by Colin McGill of ENU and IOP's Stuart Farmer, was titled 'Science: what should we teach and how should we teach it?' There followed 12 workshops covering topics such as climate change, skills development in science, physics practical work, and teaching about space. There was a great buzz around the excellent facilities at ENU including during breaks and over lunch, with many looking forward to future events as they left.

The Brecon Welsh Physics Teacher Conference consisted of three nights of online sessions provided by IOP coaches and guest speakers, followed by an in-person conference at Christ College, Brecon, in mid-October.

The online edition of Brecon was originally introduced as a replacement for the face-to-face event during Covid, but it has proved useful for enabling people to participate who can't attend in person. A total of 228 people took part in the 11 online sessions. Guests from Welsh universities, the Association for Science Education and the National Physical Laboratory, plus IOP colleagues from across the nations, delivered sessions on teaching at all stages of physics education, including 'The Science of Magic', 'The Physics of Food' and 'Diamonds – Not Just a Gemstone'.

The in-person event attracted a good mix of people with 73 teachers and PGCE students, 25 technicians and 15 exhibitors from a range of companies. Guests heard a keynote address from Neil Monterio of Space Forge, a company in Wales which hopes to manufacture in space using the benefits of microgravity. Helen Francis, from the WJEC exam board, updated on GCSE and A Level physics, and Sir Keith Burnett, current IOP President and a Rhondda Valley boy, spoke about his life and influences. The event also hosted four previous recipients of the IOP Teachers' Award, all from schools in Wales.

Meanwhile at its headquarters in London, the IOP hosted the inaugural Physics Education Research Symposium at the end of October. The event brought together the HE, ITE, and school and college communities to share ideas and opportunities for mutual support in making learning physics accessible for all.

‘Quality not quantity’ is key for secondary physics curriculum

The IOP has published a set of principles to underpin secondary physics curricula based on in-depth learning of a small number of big ideas.

The document, titled ‘The fundamentals of 11 to 19 physics’, sets out recommendations for new ways to organise physics education that are designed to help students develop a deep and lasting understanding of key concepts, and support the wider adoption of physics thinking.

Curricula should be structured around a relatively small set of big ideas which are ‘cross-cutting’ (applicable in all contexts, such as conservation, equilibrium or causation) and ‘domain-based’ (rooted in a selected set of key physics statements). Such statements could include ‘All matter is made of very small particles and this helps us to explain many behaviours of matter’ or ‘There are two ways to change the energy stored in a system: by working on it or heating it’.

Given that it's not possible to teach everything, there's a strong rationale behind being more selective in what is taught. The recommended approach avoids outcomes where students have a cursory and transient sense of physics, and instead focuses on instilling sound scientific understanding and ways of thinking about physics. The other key principles are that teaching should give an accurate portrayal of the endeavour of physics – including through plenty of practical work – and should focus on ‘real-world’ applications and contexts to bring the subject to life.

Whilst providing a strong grounding for pursuing physics further, the proposals are designed to provide all students with long-lasting transferable skills, which will help them in whichever path they choose post-16. By embedding ‘physics thinking’ more deeply, physics teaching will help students to become better informed citizens – with critical skills to help them evaluate information and avoid the dangers of disinformation.

The principles are published amid wide-ranging curriculm reviews around the UK and Ireland, and will contribute to those reviews. However, the IOP’s document and principles are designed to support and enhance existing specifications for physics teaching in all jurisdictions. As such, they are valuable for teachers and curriculum leads, and will be helpful for planning sequences of lessons and schemes of work.

Read the report at **iop.org/fundamentals-11-19-physics**

New rules on formula sheets in exams

The IOP supported proposals in a consultation from Ofqual, the exams regulator, to allow GCSE physics students to continue to use formula sheets.

Formula sheets have been permitted for maths, physics and combined science for exams since 2022, when rules were relaxed following the disruption of the Covid pandemic. The Department of Education subsequently revised its expectations for GCSE students in these subjects, having not seen any significant assessment issues from the use of the formula sheets.

The consultation proposed that for exams in 2025, 26 and 27, physics students should be provided with support materials in the exam hall instead of having to recall the 18–23 equations that were previously required.

The proposal was subsequently adopted, so formula sheets will now be permitted in exams for the next few years.

‘Godfather of AI’ awarded physics Nobel prize

British-born computer scientist Geoffrey Hinton, based at Toronto University, was jointly awarded the Nobel prize for physics for his work on artificial neural networks used in the development of artificial intelligence.

Professor Hinton also worked, until last year, for Google Brain, the part of Google concerned with AI, but left because he wanted to be able to speak openly about his concerns about the impacts of AI on employment and misinformation.

Credit: nobelprize.org

Geoffrey Hinton

2024 IOP Awards

During October, IOP announced several of its annual awards, including those for teachers, technicians and apprentices. Other awards were also made to individuals whose work has made a positive impact on physics education.

IOP Teachers of Physics Awards

These awards celebrate the success of secondary-level teachers who have raised the profile of physics and science in schools and colleges. Eight teachers were recognised this year:

- Dr Katharine Bridge, Haberdashers School for Girls
- Mr Ian Delaney, St Marys Catholic High School
- Dr James Perkins, Queen Elizabeth's Grammar School, Faversham
- Mrs Kulvinder Randhawa, Oldham Sixth Form College
- Mr Everton McClymont, Bonus Pastor Catholic College
- Miss Victoria Horlock, Bedford Academy
- Mr Jonathan Williams, Ysgol Maes Y Gwendraeth
- Mr Ali Panju, Wyggeston & Queen Elizabeth College

IOP School and Further Education Technician Award

This award aims to raise the visibility and professional status of technicians by recognising, rewarding and highlighting excellence in their vital work in education:

- Mr Nick Mitchener, Ferndown Upper School

Apprenticeship awards

The IOP Apprentice Award celebrates the skills and experiences of science and engineering apprentices, and their contribution to physics:

- Daniel Smith, Assistant Scientist in neutron metrology at the National Physical Laboratory, ‘for supporting the development of new technologies, managing a research project underpinning the realisation of next-generation nuclear reactor technologies and an outstanding contribution to outreach.’

The IOP Apprentice Employer Award recognises physics-powered businesses who are providing outstanding workplace experiences for young people working as apprentices:

- National Grid, ‘for creating a diverse and supportive apprenticeship scheme that enables apprentices to develop technical knowledge, interpersonal skills and collaborate on projects aiming to achieve net zero.’

Other awards

Two other physics educators were recognised with IOP bronze early career medals.

The Daphne Jackson Award recognises an exceptional contribution to physics education:

- Daniel Cottle, associate professor at the University of Birmingham, ‘for exceptional contributions to physics education by linking physics teacher training with widening participation in university physics and pioneering a whole life-cycle approach to addressing issues of inclusion.’

The Mary Somerville Award recognises exceptional contribution to public engagement with physics:

- Lara Stafford, an actor-turned physics teacher who founded Theatre of Science,‘for revolutionising how home-educating families access physics education, using drama and humour to support the learning of tens of thousands of children from key stage one to IGCSE.’

Congratulations to the winners across all categories.

A profile of each winner is published on the IOP website, along with information about other IOP Awards. Nominations for many of next year’s awards open in early 2025. See iop.org/about/awards for more information.

Passive progressive

Chayley Collis from the Passivhaus Trust explains how the application of physics principles is creating super-efficient buildings – including UK schools.

Sciennes Primary School extension, a Passivhaus building in Edinburgh

Credit: Holmes Miller and Chris Humphreys Photography

During the 1970s and 80s, following oil price shocks and growing awareness of the impact of carbon dioxide in the atmosphere, many countries began looking for ways to increase electricity capacity and move away from fossil fuels. In West Germany, a physicist called Wolfgang Feist was among a group of scientists who looked at the problem from a different perspective: instead of thinking about how to increase supply, why not try to understand why demand was so high in the first place? He analysed usage and was shocked to find that the single biggest – over a third – was for heating buildings.

For a physicist, the answer seemed obvious: if buildings could be better insulated, demand would fall. But his preliminary research wasn't promising. "I read that the construction industry had experimented with adding insulation to new buildings and that energy consumption had failed to reduce," Feist later said. "This offended me – it was counter to the basic laws of physics. I knew that they must be doing something wrong. So I made it my mission to find out what, and to establish what was needed to do it right."

Feist teamed up with Swedish structural engineer, Bo Adamson, and together they developed the Passivhaus ('passive house') concept, which uses a whole-building approach to create efficient buildings that are warm, comfortable and healthy.

Their method is based on a highly insulated, airtight structure, with a ventilation strategy that includes a heat exchanger, enabling incoming air to be warmed by the outgoing air.

For proof of concept, Feist needed a prototype. He invested in a small development of a few houses in Darmstadt, Germany, which was completed in 1991. The state government funded research into the performance of the new building, which required hundreds of sensors to be wired in during construction.

The results were compelling. Taken together, the Passivhaus measures were found to create buildings ten times more efficient than conventional structures.

Over the last few decades, the model has been taken up by architects and designers all over the world. Estimates vary, but it's thought today there are over 100,000 Passivhaus buildings globally, including houses, apartment blocks, offices and schools. While mostly used in new builds, it's also possible to retrofit existing buildings.

Today, as we grapple with the climate crisis, it's easy to see the appeal of an approach to construction that so significantly reduces the power needed for heating, while also creating healthy, comfortable homes with excellent air quality.

Passivhaus principles:

- Walls, floors, roofs and windows that are well insulated
- Junctions between building elements that minimise 'thermal bridges'
- Airtight construction
- Orientation of buildings to optimise solar gain
- Ventilation strategies that include a heat exchanger

Find out more at **passivhaustrust.org.uk**

Building Component	Typical U-values
Opaque components (eg walls)	0.15 W/(m²K)
Transparent components (eg windows)	0.80 W/(m²K)

Passivhaus schools

In recent years, the Passivhaus approach has proved popular for new-build schools, particularly in Scotland, where government policy ties funding for school-building to ensuring running costs remain low. Because of the strict standards applied, Passivhaus buildings have been shown to live up to the efficiency promises of their designers. With other approaches, the 'on-paper' energy efficiency doesn't always match what happens in the real world. This makes Passivhaus attractive to local authorities who need to ensure low running costs.

Watch pupils from Wilkinson Primary School explain how their school uses the Passivhaus building principles: **bit.ly/PassivHausSchool**

Peak performance

Mountain clothing expert Matthew Fuller explains how insulation in clothing keeps us warm, even in extreme conditions.

Credit: Freja Shannon, Senja, Norway. Photo: Fay Manners

Extreme locations require technical clothing that's warm, light and breathable

Clothing is perhaps the most important technological innovation in human history. Without it we couldn't survive cold conditions, so humanity would never have left low latitudes to settle across the globe – much less reached the world's poles or summited the highest peaks. Clothing design has come a long way since early humans began wearing furs and wool, but many centuries later we're still using natural fibres to keep ourselves warm.

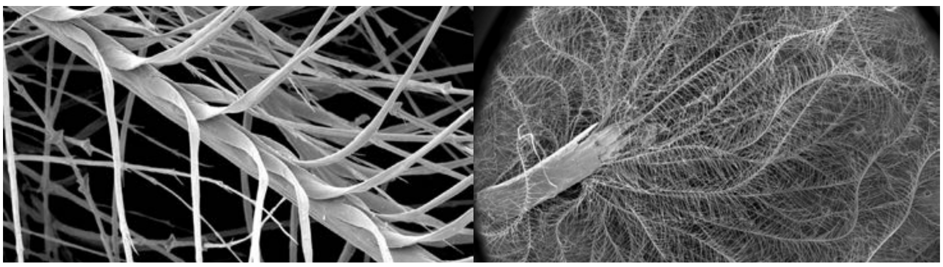
Wool is an incredibly complex fibre. Its internal structure was solved by devising X-ray diffraction techniques that were later used to uncover the structures of haemoglobin and DNA. Wool is relatively coarse and stiff, enabling it to be knitted into thick, air-trapping structures. It is this air-trapping that's key to almost all insulated clothing.

Because air's thermal conductivity is very low, keeping a layer of air captive provides high thermal resistance without adding mass. The thicker the layer of air trapped, the greater the thermal resistance and the better the material is at keeping you warm. But, as anyone who has slept on an airbed knows, air that moves around is useless at insulating, so if we're venturing outside we need windproof outer layers to prevent forced convection robbing us of the still air stored in and between our clothing layers. Furthermore, if it's raining outside then we need waterproof clothing to prevent water, with its thermal conductivity 25 times that of air, displacing the valuable still air in our clothes.

One of the greatest challenges facing technical clothing manufacturers is keeping the body dry from the inside as well as the outside. Sweat is our built-in thermoregulatory response, but its evaporation is hindered by clothing. Sweat makes clothing less effective at insulating us if it's allowed to accumulate and make our clothes wet.

The best material for trapping air is down feathers. Used for centuries in bedding, and in clothing for a hundred years, down is the underfeathers of geese and ducks. It has a fractal shape, almost tree-like, which evolved to trap the maximum amount of air for the minimum weight. This is why down is worn by mountaineers heading for high altitudes, where minimising weight is critical. Down is optimised for insulation: its finest fibres are a near-perfect diameter for reflecting infrared energy, while its thicker fibres are stiffer and so support the structure and allow the feathers to maintain thickness. These thicker fibres even have a 'memory effect', with a complex shape along their axis encouraging recovery from previous compressions. The finest fibres have barbs along their length, which prevent compression and further enhance the 'loft' that down is renowned for.

Despite decades of trying, humans still haven't managed to improve on the performance of down in dry conditions. Only in wet conditions, when its protective oils and cuticle can eventually be penetrated, can down be bettered by synthetic fibres. Developments in synthetic insulation may one day supersede down, but natural fibres – cotton, wool, hemp, and down – have been used for centuries and will remain for centuries more.



Credit: Matthew Fuller

Down feathers under a microscope

Matthew Fuller is a Product Engineer at Mountain Equipment, where he works on high-performance outdoor clothing and equipment. He has a PhD from the University of Leeds on the structure and properties of down feathers, an MSc in advanced textiles and performance clothing, and an MChem from the University of York. He lives in Stockport, not too far from the hills of the Peak District.

In this column,
James de Winter
(University of Cambridge and University of Uppsala)
and **Richard Brock**
(King's College London)
highlight publications and resources from physics education research and suggest how they may be used to inform classroom teaching.

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Forming good habits

We probably think of habits as regular behaviours we engage in without much deliberate thought, like brushing our teeth. Researchers have also considered the habits of expert thinking and behaviour, and this column considers some of these relating to physics teachers and students.

It is common for the development of scientific thinking and attitudes to be stated as an aim of a science education, but defining these is sometimes neglected. Building on previous work in this area, Çalik and Coll (2012) developed a questionnaire to measure what were seen as seven Scientific Habits of Mind (SHOM):

- **Curiosity:** A keenness to learn and ask questions.
- **Mistrust of arguments from authority:** Treating arguments sceptically, regardless of source or status.
- **Objectivity:** Considering evidence and bias when assessing claims and arguments.
- **Open-mindedness:** Being receptive to new ideas and changing our minds.
- **Rationality:** Looking for logic, evidence and sound arguments to support claims.
- **Scepticism:** Critically assessing new ideas or perspectives.
- **Suspension of belief:** Being prepared to wait until sufficient evidence is available before making a judgement.

The list is useful because it provides a specific way to describe to students what we mean by 'thinking like a scientist' and facilitate conversations about what this may look like.

In their work on pre-service physics teachers, Etkina, Gregorcic and Vokos (2017) consider desirable teacher habits. They suggest three different types of habits physics teachers should be supported to develop which can help them avoid "developing unproductive habits directed towards 'survival' instead of student learning" (p2).

- **Habits of mind:** Here, we see an overlap with the SHOM work. Habits of mind are described as a combination of 'thinking like a physicist' and 'thinking like a physics teacher'. The latter is exemplified by spontaneous thinking about how to explain new ideas to students.
- **Habits of practice:** Connected to the habits of mind, habits of practice relate to the actions and decision-making at the lesson planning stage, and the actions and adaptations made during lessons that will lead to student learning.
- **Habits of maintenance and improvement:** Here, the focus moves beyond the classroom to what physics teachers do to contribute to and learn from their professional community. The habits could range from informal conversations and sharing of practice with colleagues within and beyond school, such as on blogs or X, to more formal community interactions, such as conference presentations or writing for journals.

Etkina, Gregorcic and Vokos view the formation of good habits as a critical part of pre-service teacher education. However, their framing could help all teachers to reflect on where they are and what aspects of their professionalism they want to work on. It may also provide a language for those mentoring and supporting other teachers. The experienced teacher may need to externally verbalise and model their habits of practice to someone less experienced (e.g. "I know that I planned to cover resistance of the wire, but I dropped it from the lesson because…").

Reflecting on our habits and those of expert colleagues can help us stay alert to familiar and novel practices we may wish to change or emulate until they become habitual. Awareness of the habitual nature of many aspects of being a good physics teacher can remind us that change takes time, and we should be patient with ourselves and others when assessing professional growth and development.

References

Çalik, M., & Coll, R. K. (2012). Investigating Socioscientific Issues via Scientific Habits of Mind: Development and validation of the Scientific Habits of Mind Survey. International Journal of Science Education, 34(12), 1909–1930. **bit.ly/CalikColl**

Etkina, E., Gregorcic, B., & Vokos, S. (2017). Organizing physics teacher professional education around productive habit development: A way to meet reform challenges. Physical Review Physics Education Research, 13(1), 010107. **bit.ly/EtkinaGregorcicVokos** (Open access)

Pull out and keep!

Thermal physics

Heating and cooling

Inside this pull-out:

- **Activity 1: Huddling penguins**
- **Activity 2: Basking lizards**
- **Worksheet: Three bears**

Body temperature

Comparing thermoregulation strategies for different animals can be an engaging context to include in your teaching of heating and cooling. They illustrate the relevance of thermal physics not just to our lives but also to those of every other creature on our planet.

'Warm-blooded' animals (endotherms) have adapted to live in a wide range of habitats by maintaining tight control over their body temperatures. An extreme example is the emperor penguin, which breeds in the severe climate of the Antarctic, where air temperature may reach below -40°C, whilst keeping its core body temperature at around +38°C. Penguins have many adaptations that enable them to do this, such as huddling together in big groups, bodies with low surface area for their volume, and thick layers of insulating fat and plumage.

'Cold-blooded' animals (ectotherms) deploy different strategies that rely on the environment. They must frequently expose themselves to direct sunlight to reach and maintain an active body temperature necessary for all essential functions (such as foraging, mating, or escaping from predators). For example, many lizards have evolved flat bodies with relatively large surface areas to maximise absorption of solar radiation, and some combine this with an ability to change their colour to become darker or lighter to increase or decrease the power absorbed. They also use behavioural adaptations, such as making burrows in desert environments that they use to keep warm at night and to escape the hottest parts of the day.

Inside this pull-out are activities to help introduce some of these ideas. In our 'Huddling penguins' activity on page 10, students see that the cooling rate is reduced when hot objects cluster together. In our 'Basking lizards' activity on page 11, students are introduced to the idea that the absorption of sunlight raises an ectotherm's temperature and explore how the colour of a surface affects how quickly it warms up.

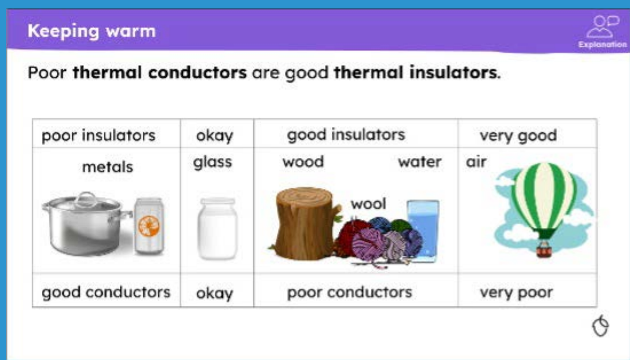
Niloufar Wijetunge is an IOP learning and skills professional support coach

Common misconception

Many 11–14 year-olds think that an object at a higher temperature has more energy in its thermal store than an object at a lower temperature, even if the hotter object has a much smaller mass.

See the Best Evidence Science Teaching diagnostic question on page 12.

Oak National Academy

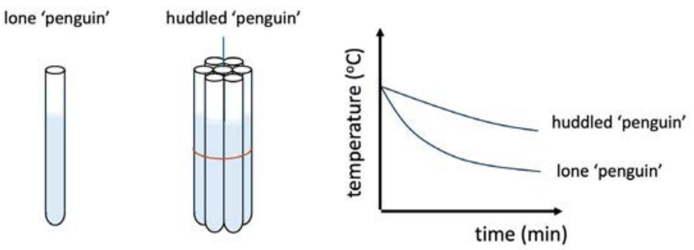


The new science curriculum resources from Oak National Academy are grounded in the Best Evidence Science Teaching research from the University of York Science Education Group. They're free to use and provide coherent learning threads from primary through secondary, with purposeful practicals and diagnostic questions to address misconceptions.

Download the heating and cooling resources at: **bit.ly/oak-heating-cooling**

Activity 1: Huddling penguins

In this activity, students model huddling penguins with test tubes filled with hot water and compare to the cooling rate for a lone penguin.



Equipment:

Each group of students will need:

- Eight identical test tubes
- Two glass thermometers
- Hot water (around 60°C)
- A stopwatch
- Rubber bands
- A measuring cylinder
- Two beakers

Procedure

Introduce the activity by showing an image or video of emperor penguins huddling. They will be exploring why this type of behaviour helps them keep warm.

Ask students to:

1. Place one test tube on the rack. This represents a lone penguin.
2. Group the remaining seven test tubes together to form a tight cluster with a test tube at the centre and secure them with a rubber band so they remain in contact.
3. Place the test tube cluster into a beaker. This represents the huddled penguins.
4. Pour hot water into the other beaker and place both thermometers in it. Ensure that the thermometers read the same (±2°C).
5. When the thermometers read 50°C, use a measuring cylinder to add equal amounts of warm water to the single test tube and each of the clustered test tubes.
6. Place one thermometer in the lone penguin and the other thermometer inside the central huddled penguin.
7. When the thermometer readings are around 40°C (the core temperature of a penguin is 38°C), record the temperatures at 0 minutes.
8. Measure and record the temperatures of both penguins every minute for 10–20 minutes, or until the temperature reaches room temperature.
9. Plot a temperature vs. time graph for both the single and huddled test tubes on the same graph paper.

Teaching notes

The students should find that the clustered test tubes take longer to cool down. This is because the cluster has seven times the volume of hot water but only about three times the surface area of a single test tube. The larger the cluster, the smaller the surface area to volume ratio (see 'Cube calculations' below).

Ask your class how they could improve the experiment to better represent emperor penguins. Suggestions could include:

- Adding more test tubes (up to 5000!)
- Wrapping each test tube in cotton wool to better simulate the insulating layers of penguins' bodies
- Surrounding the outside of the cluster with ice to better represent the Antarctic environment
- Adding a heater to each test tube to maintain the water temperature, simulating a 'warm-blooded' animal

Cube calculations

To illustrate that the surface area per volume decreases if you increase the size of an object, you could show your students how to calculate surface area to volume ratios for different sized cubes. For example:

For a cube with 1 cm sides:

- Surface area of one face = 1 cm x 1 cm = 1 cm^2
- Surface area of the cube = 6 x 1 cm^2 = 6 cm^2
- Volume of cube = 1 cm x 1 cm x 1 cm = 1 cm^3
- Surface area to volume ratio = 6 cm^2/1 cm^3 = 6 cm^2 per 1 cm^3

For a cube with 3 cm sides:

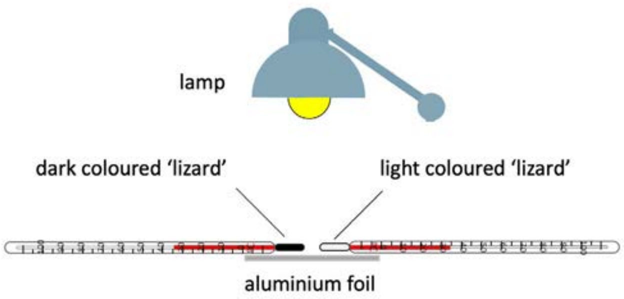
- Surface area of one face = 3 cm x 3 cm = 9 cm^2
- Surface area of the cube = 6 x 9 cm^2 = 54 cm^2
- Volume of cube = 3 cm x 3 cm x 3 cm = 27 cm^3
- Surface area to volume ratio = 54 cm^2/27 cm^3 = 2 cm^2 per 1 cm^3

Credit: Shutterstock

Emperor penguin colonies can contain over 5000 individuals

Activity 2: Basking lizards

In this activity, students explore how the colour of a lizard's skin affects the amount of sunlight it absorbs.



Equipment

- Black or dark-coloured plasticine
- White or light-coloured plasticine
- Two thermometers
- Desk lamp with 60 W incandescent light bulb or IR bulb
- Aluminium foil
- A stopwatch
- Graph paper
- Mass balance

Safety

Remind students that the glass thermometers are fragile and so to be very gentle when rolling plasticine over their thermometer bulbs.

Procedure

You could introduce the activity by showing pictures of different coloured lizards. Explain that they warm up to an active body temperature of around 35°C by basking in the sun.

Credit: Wikipedia commons

Mezquite lizards (Sceloporus grammicus) that live in colder mountain climates tend to have darker colouration than their desert-dwelling counterparts

Credit: Shutterstock

The ability to absorb sunlight isn't the only selection pressure for lizard colouration. Being light-skinned is an advantage when you want to stay camouflaged against a light-coloured background

Ask each group of students to:

1. Use the mass balance to measure out 0.5 g of dark plasticine and 0.5 g of light plasticine, and roll the two pieces into balls.
2. Insert the bulb of a thermometer into each ball and use their forefinger and thumb to roll the plasticine over the thermometer bulb until there is a thin layer of plasticine covering the whole bulb. These represent two different coloured lizards.
3. Place the plasticine-covered thermometers on the aluminium foil on the table.
4. Set up the desk lamp (initially switched off) so that it is above the lizards.
5. Turn on the lamp and stopwatch and record the time it takes for the light- and dark-coloured lizards to reach 35°C.

Teacher notes

Students should conclude that lizards with dark-coloured skin are better at absorbing sunlight than those with light-coloured skin. You could ask when they think being darker gives a lizard an advantage. (Suggestions could include that they can warm up more quickly and/or may have better camouflage).

Answers to Three bears diagnostic question on page 12

Daddy Bear has both the greatest amount of porridge and the porridge at the highest temperature.

Mummy Bear has the porridge at the lowest temperature. Hers will have the least energy in the thermal store when equal amounts are compared.

Baby Bear has porridge at a higher temperature than Mummy Bear, but less of it. Teaspoonful for teaspoonful, his has more energy, but Mummy Bear has more teaspoonfuls in total. Who has the most energy is uncertain, although it is likely that Mummy Bear has the most because she has a lot more porridge, and its temperature is just a little bit lower.

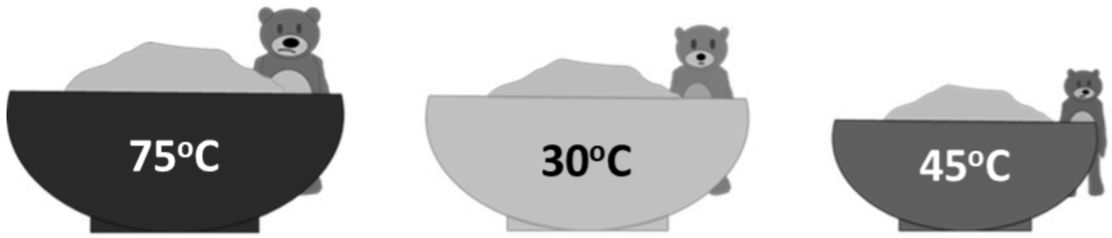
Answers A and B are correct.

C is wrong.

D is correct, but 'you can't tell' is equally acceptable

Three bears

The three bears are arguing. They can't decide whose porridge has most energy in its thermal store.



Daddy Bear   Mummy Bear   Baby Bear

Read the statement below about the bears' porridge. What do you think about each one?

For each statement, tick (✓) **one** column to show what you think.

Statement	I am **sure** this is right	I think this is right	I think this is wrong	I am **sure** this is wrong
A Daddy Bear has the most energy in his porridge				
B Mummy Bear has more teaspoonfuls of porridge than Baby Bear				
C One teaspoonful of Mummy Bear's porridge has more energy than one teaspoonful of Daddy Bear's porridge				
D Mummy Bear has more energy in her porridge than Baby Bear				

Adapted from the Best Evidence Science Teaching resources at **stem.org.uk/best-evidence-science-teaching**

Keeping warm

Boyle's diamond glow

Some crystals will glow when warmed. 'Thermoluminescence' occurs following the excitation of the crystal through background radiation, cosmic rays or exposure to radioactive isotopes in the Earth. The phenomenon is used to detect fake Ming vases, date geological layers and spot defects in the Channel Tunnel's concrete. One of the earliest accounts of thermoluminescence is found in the writings of Robert Boyle (1627–1691). In his 1664 "Experiments and Considerations Touching Colours", in a long list of experiments with a diamond, Boyle notes: *'Eleventhly, I also brought it to some kind of Glimmering Light, by taking it into Bed with me, and holding it a good while upon a warm part of my Naked Body.'*

The chicken warmed bomb

'*It does seem like an April Fool but it most certainly is not. The Civil Service does not do jokes.*' So wrote Tom O'Leary of the National Archives about a 1950s proposal, by the Royal Armament Research and Development Establishment, to build a ten-kiloton nuclear landmine. The device needed to be kept warm enough to function during the winter. Documents from the National Archives, declassified on 1 April 2003, report a suggestion to insulate the device with live chickens, held inside the casing and supplied with food and water. Calculations suggested the unfortunate creatures' body temperature would have been sufficient to keep the device functioning.

Sophie's warmth

Marie-Sophie Germain (1776–1831) was a French physicist and mathematician whose work included elasticity and number theory. Her parents were not supportive of her studies, feeling they weren't appropriate for a girl. To prevent her working at night, they took away Germain's warm nightwear and extinguished the fire in her bedroom. Undaunted, she stayed up working, wrapped in a blanket. Her parents would find her in the morning, asleep at her desk with her calculations before her, and the ink in her inkwell frozen solid.

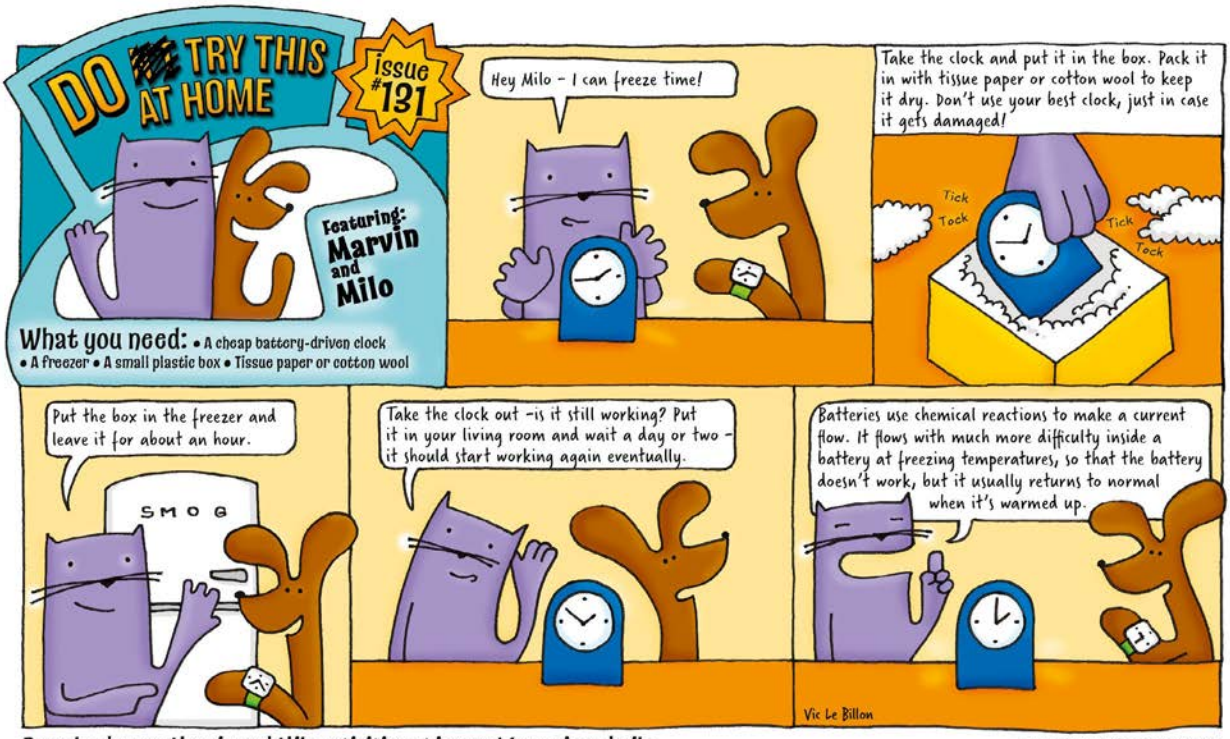
The hot chocolate effect

Next time you have hot chocolate, you can observe a curious physical phenomenon. Pour hot milk or hot water into a cup and stir in hot chocolate powder. Tap the bottom of the mug. You may notice that the note produced gradually rises in pitch (some sources report an increase up to 3.5 octaves) over a period of about a minute. Stirring leads to the pitch decreasing. The effect has been labelled the hot chocolate effect. When the fluid is stirred, bubbles form, lowering its density, reducing the speed of sound and lowering the pitch. After stirring, bubbles rise to the top of the mug, reducing the volume of liquid with lower density, and the pitch rises.

spark.iop.org/stories-physics

Compiled by Richard Brock.

Follow him on X (Twitter) at **@RBrockPhysics**



Download more Marvin and Milo activities at iop.org/marvinandmilo

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 **keeping warm** from the archive and shares some highlights from 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

A look at thermal energy changes on amusement park rides

At this year's Brecon Physics Teachers Conference in Wales, Dan Cottle from the University of Birmingham demonstrated a portable air-source heat pump as shown in an Open Access paper co-written with Robert Campbell, "Investigating the efficiency of air-source heat pumps in the secondary school physics laboratory". As technology has moved on and climate change has impacted the globe, there's definitely a need to bring up-to-date energy efficiency measures into the teaching lab. Loft insulation and double glazing are fine, but students might be seeing more of an obvious impact where they live as solar cells and air-source heat pumps are added to their homes.

The teaching of energy topics often seems to benefit from a systematic method. "Teaching thermal physics to Year 9 students: the thinking frames approach" describes how one such scheme was used in the classroom and the benefits it provided to students. The results were compared with a class learning the same topics by more traditional means and found to offer significant gains.

Happy campers

As someone who enjoys camping, reading "Investigating comfort temperatures and heat transfer in sleeping bags" by Trevor and Lara Hill was very useful for me. Trips out from school, especially for outward-bound type activities, can be a chance to see a different side of students, and demonstrating the usefulness of physics at the same time can help them to see how relevant some of the theory from the teaching lab is. Sleeping bags feature in this excellent paper, but sleeping mats are relevant too, as are solar rechargers for phones (of particular interest to students), solar water heaters for a shower (a bit cool I found) or a cup of tea (boiling!). There are even camping stoves that use thermoelectric generators to drive electric fans to fan the flames (have a look at **uk.bioliteenergy.com**). Camping can be a time when understanding how to keep warm really pays off.

"Investigating the efficiency of air-source heat pumps"
bit.ly/PEHeatPumps

"Teaching thermal physics to Year 9 students"
bit.ly/PEThermalY9

"Investigating comfort temperatures and heat transfer in sleeping bags"
bit.ly/PESleepingBags

Recent papers

You may have come across reflective bubble wrap, which has a variety of uses (I have some as thermal insulation on my shed roof). If so, you may not be surprised to find out that it is used as a thermal barrier in Australia where they sell ice in large bags from petrol stations. Steven Hughes describes experiments to look at how good a thermal barrier GIBS (the shiny bubble wrap) is in his Open Access paper "Keeping food cool to save the planet". With conduction, convection and radiation all getting a mention in an exotic location, this is an interesting context to bring to the lesson.

As the author of "How a soup bowl and a coffee cup cool down" points out, several times a day there's a hook into heating and cooling in most of our day-to-day lives. We don't want our salad warm, nor our chips cold. This paper describes simple experiments students can do at home that let them investigate the difference everyday materials make on their hot or cold food.

A number of papers describe experiments that use pencil lines and drawings as part of circuits in the Physics Education archive. "Pencil-drawn tunable electrical resistance and Joule heating demonstration using a smartphone-based thermal imaging camera" takes this idea further, using a thermal imaging camera to look at heating in these pencil-drawn circuits. Using different substrates to draw on, rather than paper, students can experiment with making resistors.

"Keeping food cool to save the planet"
bit.ly/PECoolFood

"How a soup bowl and a coffee cup cool down"
bit.ly/PESoupCoffee

"Pencil-drawn tunable electrical resistance…"
bit.ly/PEPencilDrawn

From the archive

An exciting (or terrifying) context like rollercoasters can make for a surprising context for thermal energy changes. The braking system uses metal fins and magnets to slow the coasters down. The heating that takes place can be shown by using a thermal imaging camera. In the paper "Stopping a roller coaster train", the amusement park physics expert Ann-Marie Pendrill, along with her co-authors, looks at this in detail and in the Open Access paper "With an infrared camera in an amusement park: heating and cooling of magnetic brakes" Ann-Marie looks at more thermal energy changes on a variety of amusement park rides.

Thermal imaging cameras have been mentioned a few times and, given that these tend to be a relatively major expense, it might be worth having a read of "Infrared cameras as accessories to smartphones: facts you need to know" before you decide what to buy. (See also page 17.)

Cool?

The title of the paper, "Investigating the Mpemba Effect: when hot water freezes faster than cold water", pretty much describes what the Mpemba Effect is all about. The original paper from Mpemba and Osborne in 1969, titled "Cool?", has been followed by a huge number of papers in many journals looking at this effect. The story is a nice one for students as it concerns a young student spotting something that didn't match the theory, and should inspire them to keep their eyes open so they too may make discoveries that are hiding in plain sight. There are plenty of quite accessible experiments that can be done in the context of the Mpemba effect – many of them documented in Physics Education.

Finally, the paper "Learning about insulation and the flow of heat never tasted so good", by Kerry Parker, describes a great demonstration activity that covers lots of thermal energy change concepts. It describes how to make a baked Alaska dessert, with the idea of looking at how the ice cream can be insulated when put in the oven. Shortcuts are given that mean you don't have to make a sponge cake, you just buy one and build a thermal shield with some meringue. I did this at home with my children and it was great fun and very tasty afterwards! A trip out of the lab to where the ovens are, plus being able to eat the results, should make for a very memorable lesson.

"Stopping a roller coaster train"
bit.ly/PERollerCoaster

"With an infrared camera in an amusement park…"
bit.ly/PEInfraRed

"Infrared cameras as accessories to smartphones"
bit.ly/PESmartphones

"Investigating the Mpemba Effect"
bit.ly/PEMpemba

"Cool?"
bit.ly/PECool

"Learning about insulation and the flow of heat never tasted so good"
bit.ly/PEInsulationTaste

Quick Links

"Pencil drawn meter bridge"
Another pencil lead circuit paper
bit.ly/PEMeterBridge

"Building aluminium-air battery on waste paper for DIY learning"
How to make a cell with pencil lead drawings!
bit.ly/PEAluminiumAir

"Ice melt—the answer"
Another 'What Happens Next?' demonstration from David Featonby
bit.ly/PEIceMelt

"Sir, are you wearing nail varnish?"
Did you know you can get thermochromic nail varnish?
bit.ly/PENailVarnish

Open access

"Weightlessness in a bottle"
A simple demonstration made easy with digital cameras
bit.ly/PEWeightlessness

"Physics card games to support knowledge organization: design considerations and teachers' attitudes"
Using card games in the lab
bit.ly/PECardGames

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Polar bear fur inspires solar-thermal textiles

This article from May 2023, by Physics World contributing editor Isabelle Dumé, describes a new fabric that mimics how polar bears keep warm.

Polar bears' dark skin and white fur work together as a system for regulating body temperature in a cold but sunny climate. The bears' white fur acts like a natural fibre optic and transmits radiation down to its melanin-rich skin, which absorbs light at a broad range of wavelengths – maximising the amount of warmth gained from the sunlight.

The new fabric, developed by a team at the University of Massachusetts Amherst, traps and maintains warmth in a similar way. A surface layer transmits radiation down to an interior layer that absorbs it.

Trisha Andrew, one of the researchers, said: "Our polar bear fabric could be very useful for managing space heating, which consumes huge amounts of energy, in a more energy-efficient manner, by heating people indoors using ambient lighting instead of room heating."

bit.ly/PWPolarBearFur

Huddling emperor penguins undergo phase transition

In this article from 2018, science writer Benjamin Skuse reports on a study by French scientists in Antarctica who observed the huddling behaviour of emperor penguins.

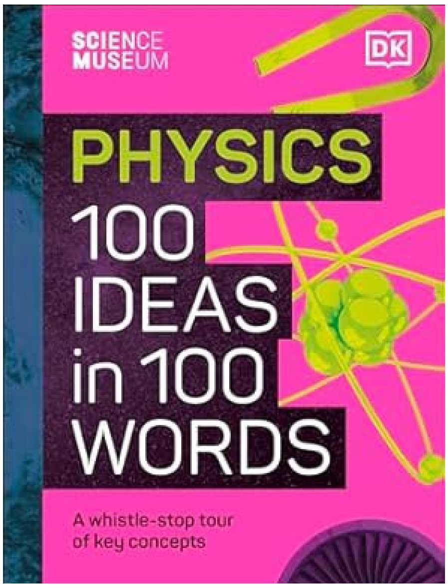
The researchers found that the penguins behave in ways analogous to a liquid changing to a solid. At a particular temperature they begin to huddle together into a tighter formation, enabling them to share body warmth. They then take turns to endure the wind and cold at the outside of the huddle.

By observing a colony of penguins with time-lapse cameras, the researchers could identify a trigger point at which penguins began the 'phase change' from being more spread out to clustering together. Essentially the researchers were measuring the point at which penguins 'feel cold' – though they acknowledge it's impossible to know whether that is how the penguins would understand the sensation.

The work may help conservationists to monitor penguin colonies more effectively.

bit.ly/PWHuddlingPenguins

Taj Bhutta looks at the latest book from David Sang, 'Physics: 100 Ideas in 100 Words: A Whistle-Stop Tour of Key Concepts'.



Book corner

David Sang is a name you have probably heard of. He has authored well over 100 text and popular science books and is someone I've had the pleasure of working with on a number on IOP projects over the years.

In his latest offering, published as part of a new series by the Science Museum, David has taken 100 physics concepts and described them in 100 words with his usual flair for clarity. He covers everything from foundational concepts in physics such as forces, to more modern ideas like the Fermi paradox. And, for our purposes in this issue, the entries on the theme of thermal physics include the laws of thermodynamics, entropy and absolute zero.

Along with the 100 entries are lists of key thinkers, notes on why the ideas matter, and quotes that bring the ideas to life. However, my favourite bit is probably the last six entries on "doing physics" – which show that physics isn't just a collection of ideas but a way of thinking.

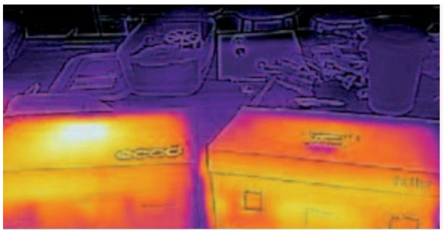
I enjoyed dipping in and out of this book, and highly recommend it as a quick reference guide for any teacher, or for a keen student who wants an introduction to ideas such as quantum entanglement and dark energy in an easy-to-digest format.

amzn.eu/d/99DKryz

CLEAPSS

Infrared cameras are key to detecting heat loss in homes – but are now an affordable classroom item, writes Samir Moezzi, physics advisor for CLEAPSS.

Credit: CLEAPSS



Modelling thermal insulation for houses

cleapss.org.uk

Infrared cameras

In the past, a decent infrared camera would have cost thousands. Now, for as little as £200, a device can be had which works with a mobile phone or tablet. There are ways of modifying webcams to remove the IR filter, but nothing will beat the *Predator*-like effect of seeing different temperatures as different colours. FLIR systems, a leading manufacturer of infrared cameras, produces the FLIR-One Gen 3, a camera which plugs into the charging port of your Apple or Android mobile device (there are two versions available – ensure you get the one which will work with your school's hardware).

Downloading the FLIR system app (instructions come with the camera), will enable you to view the world in infrared. You can snap pictures, or even take video clips, which will be saved to your phone's memory.

The device opens up interesting possibilities for classroom activities. For example, students can Investigate home insulation by modelling with shoe boxes, using a beaker of hot water to replicate radiators that warm the home. The picture (left) shows greater infrared emission from the house on the left, which has no insulation in the roof.

As well as assessing which materials make good thermal insulators, other practical activities that can be undertaken with this camera include observing how the colour and surface of a body affects the amount of thermal radiation emitted. It's also useful in investigating whether huddling penguins stay warmer, using test tubes for modelling (see our pull-out resource, page 10).

We believe this would be a good investment for your physics department. The FLIR One Gen 3 is available to order online, at around £150–200. We have also produced a guide detailing some of the work you can do with an infrared camera. Search for 'GL 195 – Using an infra red camera in science practical work' on **science.cleapss.org.uk** for further information.

The Institution of Engineering and Technology

Holly Margerison-Smith, education manager at the Institution of Engineering and Technology, describes a KS3 classroom activity to calculate the length of pipe required for a sustainable underground heating system.

theiet.org

Maths and a heating system

Sustainability is a key consideration in modern engineering practices. As the world faces pressing environmental challenges such as climate change and resource depletion, engineers must design solutions that not only meet the needs of society, but also minimise their impact on the planet.

Sustainable engineering involves developing systems, products and processes that are socially, economically and environmentally responsible. This can include reducing carbon emissions, minimising waste, conserving natural resources, and designing products that can be recycled or repurposed at the end of their lifecycle.

In this activity, students are introduced to an underfloor heating system where pipes have been laid below a playground. They then measure their own school playground and estimate the total length of pipe required to install a similar system, stating the assumptions they need to make to calculate this figure.

Students are encouraged to choose their own methods to estimate the total length of pipe required, and should reflect on how they can generalise the calculation. What if the playground were a different size? Can students find a formula to estimate the total length of pipe required?

The activity takes 60–90 minutes. By the end, students will be able to describe the operation of a sustainable underfloor heating system, and create and apply mathematical formulae in a practical context.

A free activity sheet can be downloaded from the IET website, **(bit.ly/MathsHeatingSystem)** including teacher notes, guidance, useful web links, and links (where appropriate) to the national curriculum in each of the four devolved UK nations. All the documents are fully editable, so you can tailor them to your students' and your school's needs.

THE ROYAL SOCIETY

Elizabeth Chambers, schools engagement officer at the Royal Society, describes some STEM projects looking at school heating.

royalsociety.org/partnership

Partnership projects for keeping warm

'Keeping warm' is a great theme to use as inspiration for practical projects. The topic can help link physics to other areas of the curriculum such as chemistry, environmental topics, computing, citizenship and mathematics, to name but a few.

The Royal Society's Partnership Grants provide up to £3,000 for schools and colleges to partner with professionals from academia and industry on an investigative STEM project. The project can focus on anything STEM-related that supports or extends the curriculum, with cross-curricular projects encouraged.

Prince Henry's Grammar School in Yorkshire and Humber received a grant to investigate whether the ground beneath their feet could be used to warm their school. They used Raspberry Pis wired to temperature sensors to measure the temperature of the ground over the course of a year, and data analysis to draw conclusions about the material properties of the soil and any effects on ground temperature.

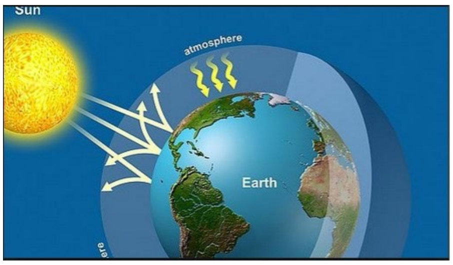
The Academy of St. Nicholas in the North West received funding to answer the question 'Can we reduce our school's use of fossil fuels by generating renewable energy on site?' Students at GCSE level worked with STEM professionals from AstraZeneca to better understand energy usage, and how best to utilise two common renewable sources – solar and wind.

Trumpington Park Primary School in the East of England was also funded to work with AstraZeneca on a similar topic, adjusting the project content to support the primary curriculum. They kicked off their project by visiting AstraZeneca Discovery and Innovation Centre to see a net-zero building first-hand.

What project could you run? Find out more at **royalsociety.org/partnership**

RMetS Royal Meteorological Society

The greenhouse effect keeps our planet warm, but is often misrepresented in diagrams and text. Sylvia Knight, head of education at RMetS, and Melissa Lord, freelance physics teacher educator, explain.



An example of an incorrect diagram

rmets.org

Greenhouse effect misconceptions

When it comes to the greenhouse effect, there are many misconceptions which are sustained by misleading information. Here are a few common ones to watch out for…

'Greenhouse gases work like a greenhouse.' No! A greenhouse stays warm because the glass stops convection currents and excludes the wind. Warm air inside the greenhouse is trapped. The Earth's 'greenhouse effect' happens because some of the infrared radiation emitted by the Earth's surface is absorbed by certain gases in the air; these gases re-radiate some of the radiation back to Earth.

Related to this, diagrams often show greenhouse gases as a layer high in the atmosphere – perhaps linking to the idea of the glass roof of a greenhouse, or maybe due to confusion with the ozone layer. In fact, the concentration of greenhouse gases is greatest at the surface, where the air density is highest.

Another common misconception is that greenhouse gases absorb sunlight. Solar radiation is composed of approximately 42% visible light and 52% near infrared light. At these wavelengths, our atmosphere is almost completely transparent.

Some solar radiation is absorbed by the Earth's surface, particularly by dark areas, and so it becomes hot. In turn, the Earth emits its own infrared radiation, as well as heating the air in contact with the ground through conduction with subsequent convection. It is this radiation emitted by the Earth that's absorbed by greenhouse gases.

Fortunately, there are some very good resources out there which explain the process well:

- NASA **go.nasa.gov/3CuUq4N**
- PHET simulation (greenhouse effect) **bit.ly/PHETGreenhouse**
- PHET simulation (molecules and light) **bit.ly/PHETMolLight**
- MetLink interactive climate change explainers **bit.ly/ClimateChangeExplainers**

SCIENCE MUSEUM GROUP

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How can we heat our homes sustainably to protect the planet? What does a heat camera reveal? And most importantly, can you power a light with your breakfast?

Uncover the answers to these questions and more with Wonderlab+ from the Science Museum Group. Ignite scientific curiosity through engaging videos, hands-on experiments and fun quizzes. Our new six-part series on climate change explores how we might live more sustainably, showing ways to keep our homes warm while reducing our environmental footprint. Plus, learn about thermal energy and explore how energy changes forms with short videos led by our expert Explainers.

wonderlabplus.sciencemuseumgroup.org.uk/

WONDERLAB+

PTNC

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Upcoming events...

For the latest information on IOP events, see **spark.iop.org/events**

IOP Ireland Tyndall lecture series February 2025

The annual Tyndall lecture series will return in February 2025, where young people across the island of Ireland will be invited to visit their local higher education institutions and hear from someone working in physics.

IOP Scotland Stirling meeting 21 May 2025

Details are now available online for the 50th annual Stirling Physics meeting, IOP's flagship event for teachers of physics in Scotland.

iop.eventsair.com/stirling2025

IOP Teaching Physics (16–19)

This set of free coaching sessions from IOP teacher support coach David Farley will guide you through key concepts, strategies for teaching challenging topics, and worked examples. Suitable for all experience levels.

All sessions are online and run on Tuesday evenings from 5.30 to 6.30 pm. Please see below for a list of dates and topics.

For full details see **spark.iop.org/events**

Simple Harmonic Motion
17 December

Field Theory
7 January

Energy
21 January

Maths Basics
28 January

Current Electricity and Circuits
11 February

Electromagnetism
11 March

Kinetic Theory and Matter
25 March

Waves
8 April

Logs and Exponentials
6 May

Radioactivity
20 May

Nuclear Physics
3 June

Astrophysics
10 June

Seen elsewhere...

How an igloo keeps you warm

A video explaining Inuit building insulation, from PBS

to.pbs.org/4fP7Jve

Credit: PBS

Credit: Shutterstock

Michael Rosen remembers his science teacher

Children's writer and Guardian columnist Michael Rosen considers approaches to learning

bit.ly/GuardianRosen

ASSOCIATION FOR SCIENCE EDUCATION

ASE Annual Conference

9–11 January 2025
University of Nottingham

Get ready for the UK's largest science education event, the ASE Annual Conference! Over three days, you'll have access to 250+ sessions, including keynotes, workshops, and an exhibition of science education organisations.

ase.org.uk/annual-conference

ASE CPD events this winter

Online Technicians Leadership Programme and Technician Network
28 January

International Teachers and Trainees in UK Network
29 January

Trainee and ECT Network
11 February

Physics Basics to Brilliance

The ASE has joined forces with Physics Partners on modules designed to provide subject-specific support for GCSE Physics teachers.

- **The Heat is On**
  17 December
- **Magnetic Mysteries**
  15 January
- **Cosmic Journeys**
  30 January
- **Radioactivity Revealed**
  6 March
- **Practical Mastery**
  19 March

Full details at **ase.org.uk/events**

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