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Ready for the world

Empowering engineers of the future through climate change education

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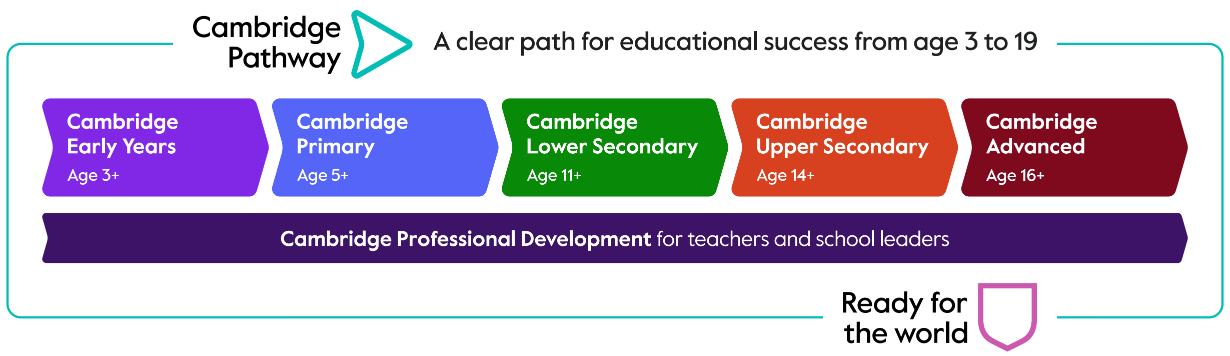
Contents

Preface

Cambridge University Press & Assessment and Cambridge Zero are working together to explore how climate-related research and teaching connects with the design, development and delivery of curriculum, assessment and resources across all ages and educational stages from ages 3 to 19.



Experts from both organisations came together for an **Engineering Convocation** on 19 March 2024 to explore how to create a link from school through to higher education in order to empower engineers of the future to tackle climate change. This paper presents key insights from the event and practical ideas to help embed climate change education in curriculum. For information on event participants, see page 15.

About Cambridge University Press & Assessment

As part of the University of Cambridge and a leader in global education, publishing and research, Cambridge University Press & Assessment can progress action and debate around the world's most pressing challenges. We believe that education is key to tackling the climate crisis. Together with schools worldwide, our UK and international awarding bodies (OCR and Cambridge International Education) are working to embed climate change education into the curriculum and empower learners to take action.

About Cambridge Zero

Cambridge Zero maximises the University of Cambridge's contribution towards achieving a resilient and sustainable zero-carbon world. It does this by integrating and enhancing the University's activities, in particular through:

- research and innovation to drive technological and social change,
- education and training to provide the skills needed to deliver a different future,
- engaging with a broad coalition of stakeholders to develop solutions collectively, and
- leading by example by supporting ambitious decarbonisation.

Introduction: empowering young engineers

Climate change is impacting our planet and our lives in foundational ways. As the Earth heats up, the rising temperatures are triggering destructive wildfires, storms and floods which affect the crops we grow, where and how we live, what we wear and our health. How can school-age education help prepare engineers of the future to work in a climate changed world?

Engineers are among those trying to find solutions to manage the effects of climate change. They are developing clean and renewable energies, sustainable materials and agriculture, new modes of transport and many other climate-resilient technologies and infrastructures. According to an international survey[1], 80% of engineers believe that they can help tackle the climate change crisis through their work, with 77% of them actively seeking out roles that prioritise climate change.

Some engineering courses at universities are beginning to incorporate climate change and sustainability knowledge into their curricula. However, as shown by a UCL Centre for Engineering Education study[2], more needs to be done across the higher education sector to embed climate change knowledge systematically in engineering qualifications. But what about students who choose subjects at school that feed into further engineering studies – do they already have an understanding of climate change and how this impacts their field?

At Cambridge University Press & Assessment, we are aware of our responsibility to students when it comes to embedding high-quality climate change education into our curricula. We recently published an introduction paper, *Empowering Learners Through Climate Change Education*[3], in which we outline our climate change education principles. In addition, we have also created an interactive resource for teachers that introduces climate change education and helps them to develop it in key areas of their teaching practice[4]. This Getting Started With guide underpins our belief that climate change education should be a whole-school endeavour. A 2023 study of Cambridge International Schools worldwide found that engineering was the second most popular subject[5] among Cambridge International A Level students who pursued university studies that year. To ensure that students arrive at university engineering courses equipped to work in a climate-changed world, climate change education must be integrated into all subjects, not just mathematics and science.

Engineers have the potential to influence and uplift communities (on both a local and a global scale) within the built and natural environments and across themes such as transport, health and wellbeing, ecosystems and urban infrastructure. As such, engineering for a sustainable future requires learners to understand and be able to engage with systems thinking and approaches through tackling real-world problems. These experts need quantitative, technical skills but also to be socially aware and ethically minded, resilient and innovative. Through formal education, future engineers should gain the ability to apply existing approaches to novel problems in creative ways because problems facing society are unpredictable and multifaceted. Learners need to be able to assess situations critically and respond in a way that recognises this complexity.

Creating this link from school to higher education was the aim of an event held in March 2024. The Engineering Convocation was convened by Cambridge University Press & Assessment and Cambridge Zero, the University of Cambridge's flagship climate change initiative. This event sought to identify mutual opportunities within key subjects (including individual sciences, mathematics and design & technology) for encouraging young learners to build relevant knowledge, skills, attributes and the motivation to study engineering.

Engineering Convocation, March 2024

Cambridge University Press & Assessment and Cambridge Zero are collaborating to incorporate the latest research and thinking around climate change into global education. We are bringing together colleagues from across the University of Cambridge to explore how climate-related research and teaching connects with the design, development and delivery of curriculum, assessment and supporting materials across all ages and educational stages from ages 3 to 19.

This latest event in a series of events and thematic conversations considered opportunities for engineering-related content, skills and baseline knowledge within Cambridge University Press & Assessment products and services. Academic researchers, practitioners and teams from Cambridge University Press & Assessment discussed opportunities to support the integration of current thinking around climate and sustainability within engineering-related learning, teaching and assessment. A range of emerging research was considered alongside examples of effective teaching and learning approaches.

Key insights[*]

1. Content and curriculum: competencies and other learning insights

Sustainability for engineers goes beyond implementing renewable energy solutions or identifying energy-efficiency measures. Engineers will need to design effective solutions in an unpredictable world and consider wider impacts on society and environment over longer time periods and wider geographical scales. They also need to address how systems interact with one another over time as these systems become more unpredictable.

Engineering education for climate and sustainability accordingly needs to address several challenges. Opportunities to meet these include the following:

- 'Systems thinking' helps learners to understand relationships between different components of a system, and to address effects over time.
- 'Systems approaches' allow problems to be understood holistically, potentially revealing opportunities for climate mitigation across industries and systems. Data-driven analyses are necessary to understand elements of systems but 'critical thinking' and understanding impacts of systems upon one another are also key for design and decision-making.
- Teaching engineering for climate and sustainability could address producing solutions to 'wicked problems'. Professional engineering is focused on the real world and its complexity, and there is often not only one obvious solution or correct answer. Sometimes solutions or answers have their own challenges or resulting negative impacts.

Read more: Teaching (Super) Wicked Problems: Authentic Learning About Climate Change (Cross & Congreve, 2020)[6]

Definition: Wicked problems

The classification of sustainability as a 'wicked problem', a term introduced by design theorists Horst Rittel and Melvin Webber in 1973, emerges from its 'multi-faceted and non-linear nature', its 'high stakes and high-risk nature with high levels of complexity and uncertainty', its 'instability within interconnected economic, social and ecological systems' and how additional problems may result from any perceived 'resolution'.

Climate change has been identified as a 'super-wicked' problem, comprised of a number of sustainability-related wicked problems (such as the biodiversity crisis and climate migration), based on Rittel and Webber's four elements of these: time to find a solution is running out; there is no central authority, or only a weak central authority, to manage the problem and coordinate solutions; the same actors causing the problem are those best placed to contribute to its resolution; they are inherently long term and large scale, so short-term amelioration is inadequate as a solution.

*This section of the document represents the views of event presenters and is not a consensus statement.

Key insights

Lesson activities

Example A: Building systems thinking and comprehension of wicked problems

The ability to think in systems and the ability to recognise the challenges of wicked problems are important skills to understand environmental systems, both in terms of their structure and function. Considering cultural, economic, ethical, political and legal interactions or intersections of societies with environmental and other sustainability issues offers an opportunity for building understanding of these connections as a system.

Sustainability is a wicked problem due to its high levels of complexity and uncertainty and, most importantly, additional problems may result from any perceived 'resolution'. Encouraging learners to consider these complexities helps them build their own resilience and understanding of real-world challenges and solutions.

To consider diverse perspectives on sustainability, one definition of engineering could be a human intervention to resolve environmental or social challenges. Where the Earth is viewed as a complex, interrelated system, each component of the image in Figure 1 offers a way 'in' for engineering problem-solving and topics.

Example discussion topics:

1. Warmer air can hold more moisture, leading to heavier rainfall. Climate change is increasing planetary temperatures and resulting in an increase in intensity and frequency of heavy rainfall. Heavy rainfall where there is more rain than soil or water systems can absorb – or existing infrastructure can protect – leads to increased risk of flooding. Responses to this risk may be subject to 'linear thinking' – one traditional engineering, linear response is to build more infrastructure to control water flow and protect settlements. However, attempts to control natural water flow can exacerbate flooding risk, and infrastructure built upstream can have detrimental effects for those downstream.

Who may be most affected by flooding within a particular community? What infrastructural solutions may mitigate this (for example, what materials are suitably permeable)?

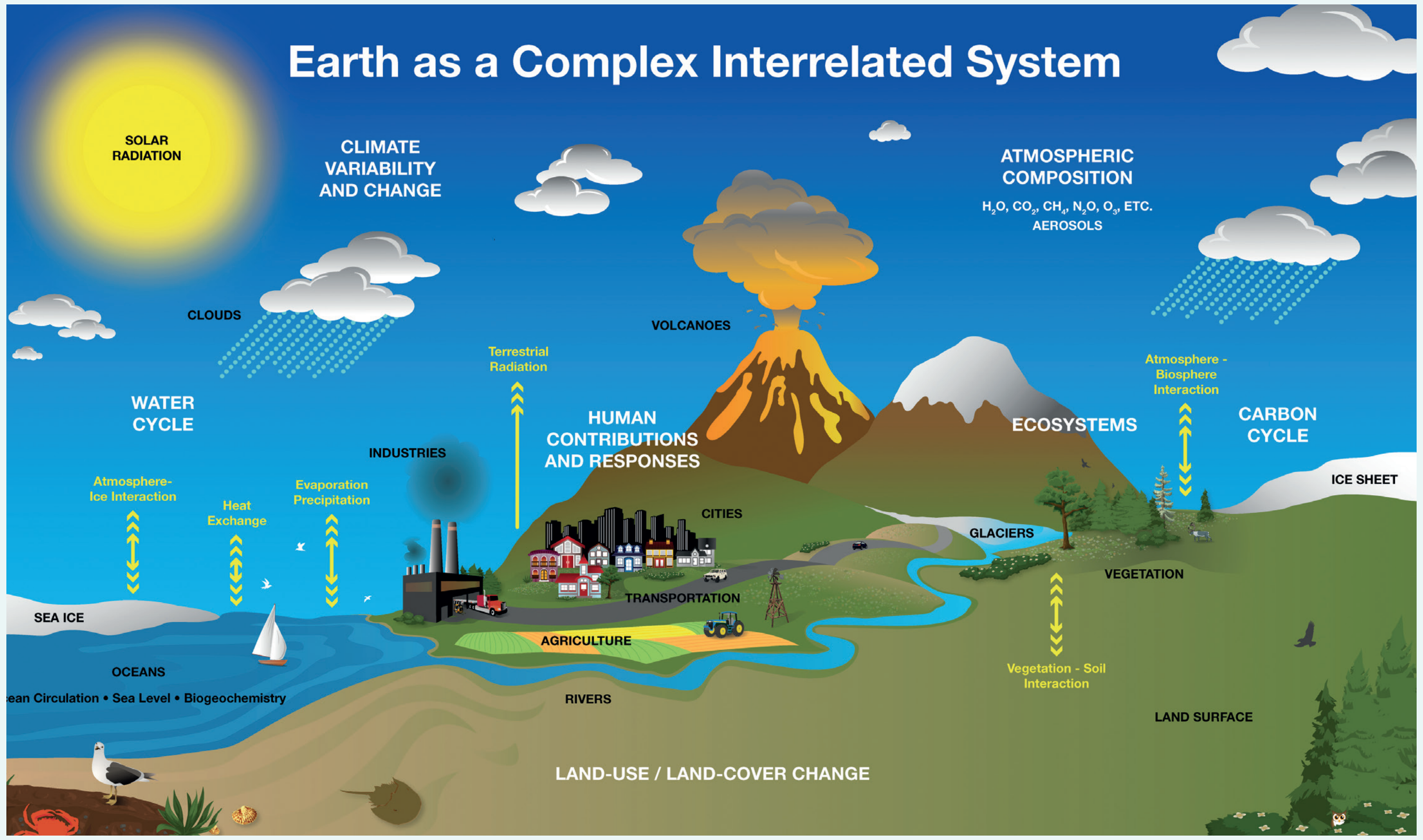


Figure 1: Energy and matter cycles (Source: NASA[7])

Key insights

What are the costs and benefits of different potential solutions, and what impacts might these 'solutions' have elsewhere within the Earth's system? Who can be involved in solutions, and who/what may cause or exacerbate the situation?

2. The carbon footprint of a building is heavily influenced by building design. How do different materials offer opportunities here? What percentage of carbon footprint can be saved by refurbishment as opposed to demolishing and building new? What are the wider impacts of building projects on the local environment / biodiversity / human communities?

3. Compare and contrast the energy outputs of different low-carbon technologies – what are the systemic impacts relating to materials sourcing / operation / disposal? Define and consider whole-life costs (including from production, in-use and disposal) and the ethical aspects of materials sourcing as part of the systems thinking element to this discussion.

Further resources:

- The NASA website offers visualisations and mini lesson plans about the Earth as a system: **mynasadata.larc.nasa.gov/basic-page/about-earth-system-background-information**
- Several young people in Finland are on a mission to update societies' climate strategies by integrating research and the development of climate interventions. The 'Operaatio Arktis' team have authored a public awareness publication on climate risks and how to prevent them, which could be a useful discussion starter and learning tool on climate repair: **www.operaatioarktis.fi/arctic-endgame**

Fundamental engineering knowledge and skills include high-level numerical skills skills, programming, knowledge synthesis, critical thinking, understanding broader global perspectives and systems thinking, writing and presenting, group working and the relevance and importance of equality, diversity and inclusion to engineers and engineering (for example, see the UK's QAA Subject Benchmark Statement for Engineering, 2023[8]).

According to the Royal Academy of Engineering, engineers of the future should be resilient, adaptable and future-facing, able to respond to issues beyond their careers; holistic in their approach and creative in their solutions; digitally fluent and equally comfortable working at digital or physical interfaces; commercially and economically literate; and socially responsible[9].

Learners need to be critical thinkers able to see through greenwashing; sustainability within the curriculum should enable meaningful change. Resilience against greenwash and climate change denial leads to a stronger foundation of understanding that there are multiple answers to and ways to challenge wicked problems around sustainability.

Key insights

Lesson activities

Example B: Building critical thinking

UNESCO[10] (2017) defines critical thinking as 'the ability to question norms, practices and opinions; to reflect on one's own values, perceptions and actions; and to take a position in the sustainability discourse'.

It is important for engineers to be able to demonstrate critical thinking in the context of problem identification, problem solving and design thinking capabilities.

At the highest level, learners should be able to question the goals and aims of an engineering project.

- Is this an engineering problem, or is it a problem which could be tackled with behavioural or social interventions? (An example is road building, which often induces demand and does not address congestion.)
- Do learners feel competent to do the work that is necessary? (Consider the ethical responsibility associated with the profession.)
- Whose interests are being served by this project? (For example, is it the client or the environment? What reflections should there be on professional responsibility?)

Critical skills include thinking about a problem's definition (and how that influences the solution space) rather than just thinking about solutions. For example, a solution-neutral problem statement tries to identify a description of a problem which is independent of the means that might be used to solve it (for example, if you are trying to move a package across a chasm, many people would start to specify the bridge that would be needed to get it across – but you could ask whether it could be launched across through the air, which might work if the package was robust and you only needed to do it once).

However most, if not all, solution spaces have embedded assumptions that need to be addressed and recognised. Being able to recognise the assumptions that are baked into problem statements and how they constrain possible solutions is a useful skill to cultivate.

Further resources:

- Widening Engineering Horizons: Addressing the Complexity of Sustainable Development[11] (Fenner, Ainger, Cruickshank & Guthrie, 2006)

Key insights

2. Approaches to teaching and learning: teaching insights

Hands-on, experiential learning opportunities provide learners with space to be creative and enable them to develop problem-solving competencies. Examples such as electric vehicles or differences in urban infrastructures can be adapted to different educational ages and stages, with applied learning helping learners to connect theoretical ideas to practical outputs.

Case studies, projects and problem-based learning are effective tools for students to develop competence in skills which relate to sustainability.

Drawing on real-world examples may particularly support learners' systems thinking capacity and encourage inter- and multidisciplinary thinking. For example, drawing on open-access digital tools and resources can be a valuable and inspiring teaching resource.

The Royal Academy of Engineering has developed a wide range of science, technology, engineering and mathematics (STEM) teaching resources[12].

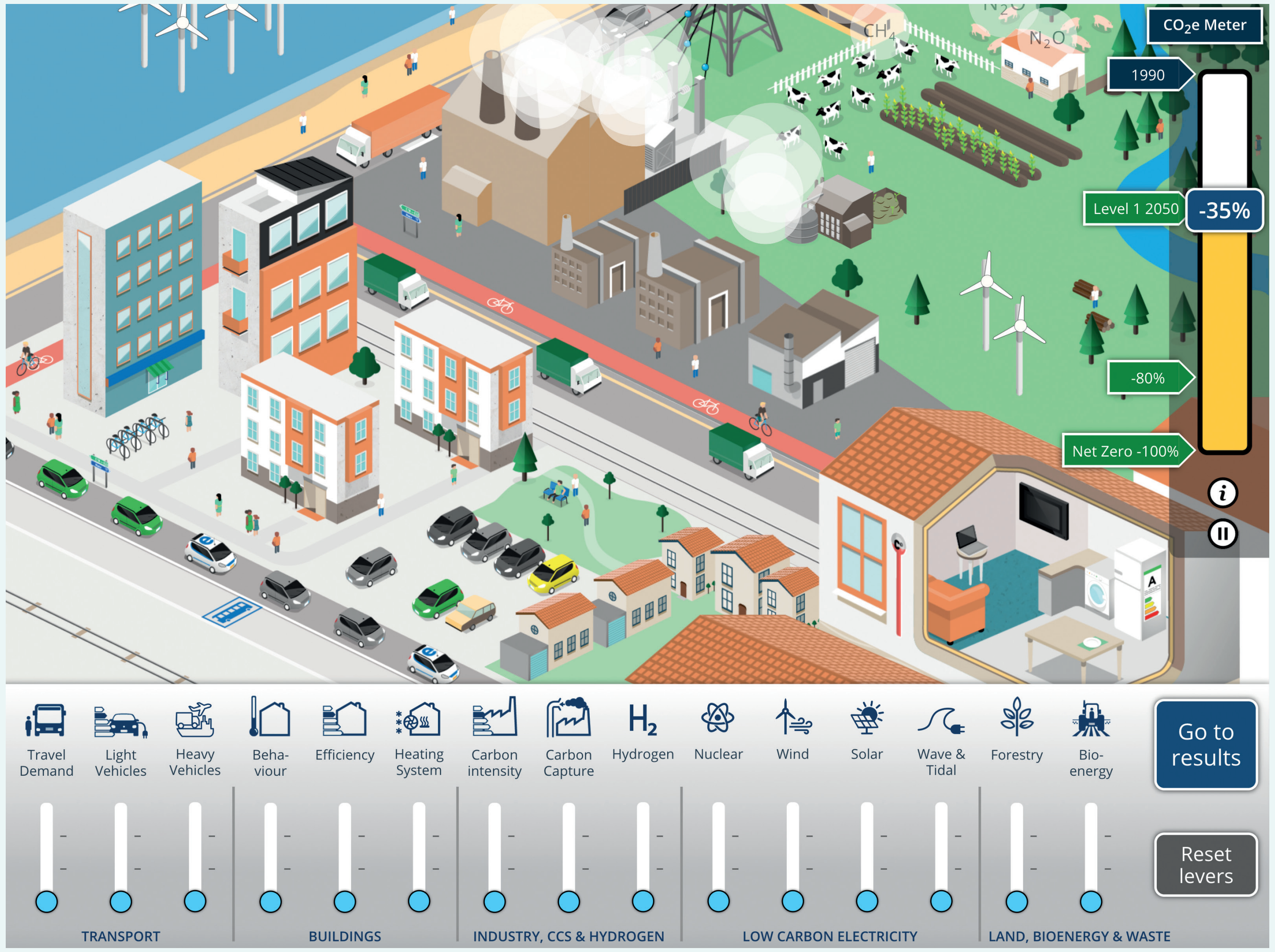


Figure 2: The My 2050 scenario-testing tool for a low-carbon UK by 2050 (Source: My 2050[13])

Key insights

Lesson activities

Example C: Climate and sustainability teaching and learning

1. Engage students through citizen science opportunities:

Search online for citizen science opportunities, including examples from universities such as UCL[14], and NASA[15].

2. Use open-source models and data to inform discussion:

One global example is the My NASA Data visualisation tool, Earth System Data Explorer[16].

Where should we put our effort to combat climate change? The MacKay Carbon Calculator[17] provides a model of the UK energy system that allows individuals to explore pathways to decarbonisation, including net zero by 2050. There are two online versions of the calculator, a universal version called My 2050 (see Figure 2) and the more detailed MacKay Carbon Calculator version.

Further resources:

- NASA holds an additional collection of multimedia images and resources: **airs.jpl.nasa.gov/multimedia/all**

The My 2050 version allows users to explore the impact of different technological solutions and to examine the consequences for greenhouse gas emissions, as well as energy demand and supply. By adjusting the decarbonisation levers and changing the animation, users can develop their own scenarios, discussing the reasons behind their choices and the associated advantages and disadvantages. For example, favouring renewable energy over nuclear may reduce costs and avoid harmful waste, but it also requires significant land and storage capacity. Demand-side management, which involves paying more during low production / peak consumption times or reducing prices during high supply times, is another useful aspect to consider.

Key insights

Lesson activities

Example D: Using satellite data in teaching

There are a few satellite datasets that could be used in teaching, although support materials would be useful to make these tools more accessible.

The European Space Agency (ESA)'s open-access data[18] are free to access once a user has created an account. Optical images are perhaps the most obvious content, but the data also include radar and pollution monitoring information. Tutorials and activities are available.

Place-based learning is an opportunity to engage learners through their local community/region, for example using radar images or Ordnance Survey materials.

Comparison can be used to reframe scientific content into an engineering challenge; taking one physics example and asking learners to compare it to another changes the framing of the problem into an engineering context, for example.

Further resources:

- An additional option is to use existing (free) software and programs, such as ESA's SNAP package[19] or Google Earth Engine[20]. These include a number of tutorials that take users step by step through various analyses. Examples include:
  - vegetation mapping
  - flood detection (comparing radar images before and after an event)
  - change detection
  - heat waves
  - air pollution mapping.
- See a variety of open-data satellite map providers[21]
- See the open-source datasets available from NASA[22]

Figure 3: Wikimedia Commons user: Elborgo, 'Corner reflector (Own work)'. Licensed under CC BY 3.0), 2007[23].

Lesson activities

Example E: Creating engineering challenges through experimentation

There are many activities that relate well to physics that involve a practical element and can be turned into an engineering challenge. One example is to use radar to mark points of the ground. Resources include access to a large open field or other area, and relevant materials.

Schools may make a 'corner reflector' out of many types of metal (see Figure 3). The reflector must be a specific minimum size. If these are set up in a field where there is no other reflection (or 'clutter') then, like a bicycle reflector, a satellite radar wave will hit the reflector, bounce around and be returned to the satellite. This enables viewers to pinpoint their installation.

The example on the next page illustrates work by Dr Sakthy Selvakumaran at the University of Cambridge.

Key insights

Three corner reflectors were installed, with Figure 4 illustrating the before and after photos. The reflectors show as white, bright reflection dots circled in red.

After the reflectors have been installed, users may access a range of apps to see when the satellite will pass overhead, and then download the 'before' and 'after' images.

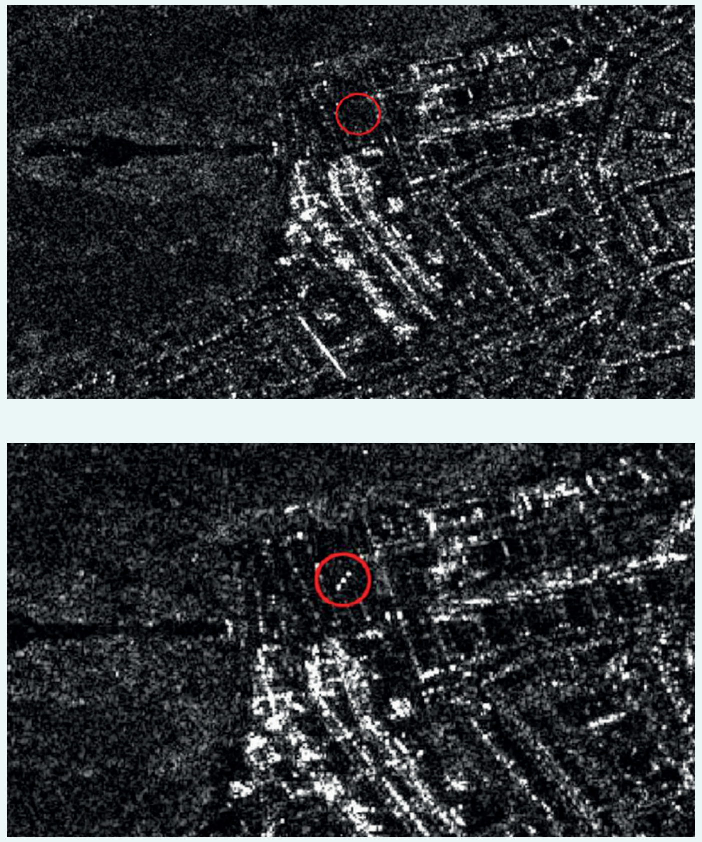


Figure 4: Satellite images before (top) and after (bottom) installation of corner reflectors, Cambridge

Participants in the Engineering Convocation noted that asking students to contextualise problems by asking 'Why are we doing this?' increases engagement with topics, while engaging learners with STEM subjects and design thinking at a young age also increases their 'science capital' and interest in these fields later in their education.

Tailoring activities and assessment to the age of learners increases engagement and motivation to learn, and including activities that challenge gender stereotypes around engineering and technology may help learners to see that these are accessible interests and careers for everyone.

Find out more:

- 'Science capital': supporting learners in 'what you know'; 'how you think'; 'what you do'; and 'who you know' – research from Professor Louise Archer[24] and an additional article[25]
- Rapid Evidence Review: Interventions to Increase Girls' Aspirations for Engineering and Technology Careers[26]
- Engineers Without Borders: article on the importance of the 'who' alongside the 'what' in engineering design considerations[27]
- Million Girls Moonshot: article sets out 10 practices for an engineering mindset[28]

Key insights

3. Cambridge University Press & Assessment insights

Cambridge University Press & Assessment is working to embed knowledge, skills and understanding of climate change across the curriculum to empower learners to take action against the climate crisis. Our international and UK awarding bodies (Cambridge International Education and OCR) are reshaping the content and assessment of their education programmes, and the accompanying teaching and learning materials, to achieve this objective.

Many Cambridge qualifications already require learners to demonstrate their understanding of aspects of climate change relevant to the particular subject and level of study. As such, a wide range of content relevant to climate change education is already included within Cambridge's UK and international qualifications, such as understanding climate change (for example, causes and effects) and responses to climate change (for example, mitigations, adaptations, resilience, justice and personal action).

This work continues and expands when each qualification is revised, with the intention to embed content related to climate change throughout each syllabus/specification. For recent examples, see the syllabus updates published by Cambridge International Education in September 2024[29].

Experts from Cambridge University Press & Assessment and Cambridge Zero at the Engineering Convocation noted that there are further opportunities related to assessment. Examination questions influence the education of many cohorts of students because both teachers and students use past papers for revision and to inform teaching activities. Therefore, including climate-related contexts in assessment materials (for example, data-handling questions in mathematics) could build a culture of teachers making links to climate change more often in their teaching programmes. It was noted that introducing contexts needs to be done with care so that candidates are not disadvantaged by unfamiliar contexts or vocabulary (this is especially important for those who do not have English as their first or preferred language).

An understanding of complexity and being able to demonstrate how to make decisions despite uncertainty are powerful strengths for climate action. Schools could evaluate their learners on how they make recommendations based on their analysis of sources of evidence of varied certainty. Coursework could include emerging research and able to include climate- and sustainability-related themes and related competence development.

Other options for engaging learners in engineering-related topics and routes include individual challenges and competitions. Examples include:

- Setting a 'Personal Change Challenge': these types of projects can assess self-reflection and personal knowledge as well as more traditional engineering skills.
- Science weeks, science fairs and competitions can be an outlet for developing skills in STEM, and for communications-focused skills development.

Lesson activities

Example F: Science competitions

A team of three students from Tzu Chi International School Kuala Lumpur in Malaysia won the first ever Engineering Award in the 2024 Cambridge Science Competition for their research into how to protect crops from flood and drought.

The global competition, run by Cambridge International Education, helps students connect science to solving real-world problems. It is open to teams of students aged 14 to 16 who study Cambridge IGCSE or O Level qualifications.

Figure 5: FBx prototype 1, top view

Key insights

From left to right: team members, Poon Han Kim, Chong Cheng Yi and Douglas Yip Shi Jie.

Conducting research into the effects of climate change, Poon Han Kim, Chong Cheng Yi and Douglas Yip Shi Jie found that, between 2021 and 2022, floods caused a huge total loss of MYR138.6 million (GBP22.9 million) in agricultural, fisheries and livestock sectors in Malaysia alone.

Inspired to find a potential solution, the team used 3D modelling to design a barrier, named Flood Blox (FBx) – see Figure 5 – that would fill with flood water to protect crops up to a height of 1.2 metres. This water could then be stored in the barrier and used when needed. The team even constructed two working prototypes using tarpaulin and water pipes, testing them by floating them in a tray of water and using a pump and waterproof switch to fill.

During flood seasons the FBx will act like a flood water barrier that can stand against water up to 1.2 metres in height. The barrier is stable as it uses the weight of water to make it stationary. The FBx was also designed to act as water storage to reduce the impact of drought conditions.

Chio Sheung Yong, KS3 Coordinator at Tzu Chi International School Kuala Lumpur, was impressed by the positive impact that being part of the competition had on the students. 'Through this project, we have witnessed the students developing and enhancing their soft skills in many areas. These include their ability for efficient time management, collaboration with individuals who have different opinions, data analysis, and presenting skills. The most notable improvements are their self-confidence and their ability to effectively communicate the idea and project to the public. This achievement is merely the start of their long journey toward making the world a better place for humans and all other living beings.'

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These Convocation events are designed to catalyse a knowledge exchange across the University of Cambridge in the form of collaborative dialogue. The overarching objective is to build understanding and drive age-appropriate climate and sustainability education through Cambridge University Press & Assessment qualifications, assessment and teaching and learning materials. We aim to identify links between OCR and Cambridge International Education products and services, and creative and innovative sustainability- and climate-related thinking and research.

Many thanks to all participants at this event for the contributions that led to the development of this paper. The authors would like to express particular thanks to Dr Sakthy Selvakumaran, Dr Dai Morgan and Dr Hugh Shercliff from the University of Cambridge Department of Engineering for their activity suggestions, and to Dr Judith Roberts from Cambridge University Press & Assessment for her editing support.

If you are interested in learning more:

- Read the 'Engineers 2030' report (published March 2024) – a policy project led by the Royal Academy of Engineering on behalf of the National Engineering Policy Centre: **nepc.raeng.org.uk/engineers-2030**
- Explore the Cambridge University Press & Assessment climate education web pages: **www.cambridge.org/people-and-planet/climate-change-education**
- Read 'Empowering learners through climate change education' – an introduction paper published by the International Education group at Cambridge University Press & Assessment – **www.cambridgeinternational.org/Images/707181-climate-change-education-introduction-paper.pdf**
- Find out about the work of Cambridge Zero: **www.zero.cam.ac.uk**

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For general enquiries about our work in climate change education, contact **press@cambridge.org**

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