Royal Academy of Engineering

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Progressing to be an Engineer: the Approach

Progression in engineering education for 5–14 year olds in the mainstream STEM curriculum

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Acknowledgements

- Beech Hill Community Primary
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- St Fagan's Primary School
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- Wales High School
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RAEng Connecting STEM Teachers network

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Why engineering in primary and secondary schools?

The rationale for why engineering education for young children has never been in question.

It's the entitlement of every young person to have the chances in education that give them the best opportunity to make informed choices for their future. In a world where science and engineering underpin society, from construction, to healthcare, travel and the music, engineering is all around us.

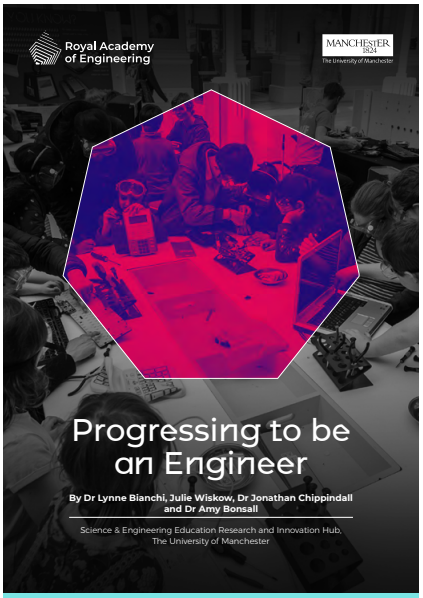
The pandemic only went to show how young people need to have the thinking acumen and practical skills to innovate in our modern world.

The challenges we will face in the future are not those of the today or the past. We believe that we are not starting learning about engineering in primary schools, but we are leveraging the innate engineering skills and habits of mind that children have and taking them to the next level.

There are many benefits to taking an engineering approach to the curriculum, which is reflected in the multiple reports that precursor this. Engineering with 5–14 year olds means a greater opportunity for:

- Practical learning
- Developing technical skills
- Collaborative work with peers
- Metacognitive reflective practice

This report invites teachers, educators, senior leaders and policy makers to review a sector-proposition – that of a cycle and framework for progression of engineering education in primary to lower secondary school. It is a clear marker that there needs to be more value and recognition of engineering through context-rich experiences that inspire young people to think and work as engineers – and for that to be open to *all* pupils on a regular basis.



Building on the insights from over 8 years of research and development

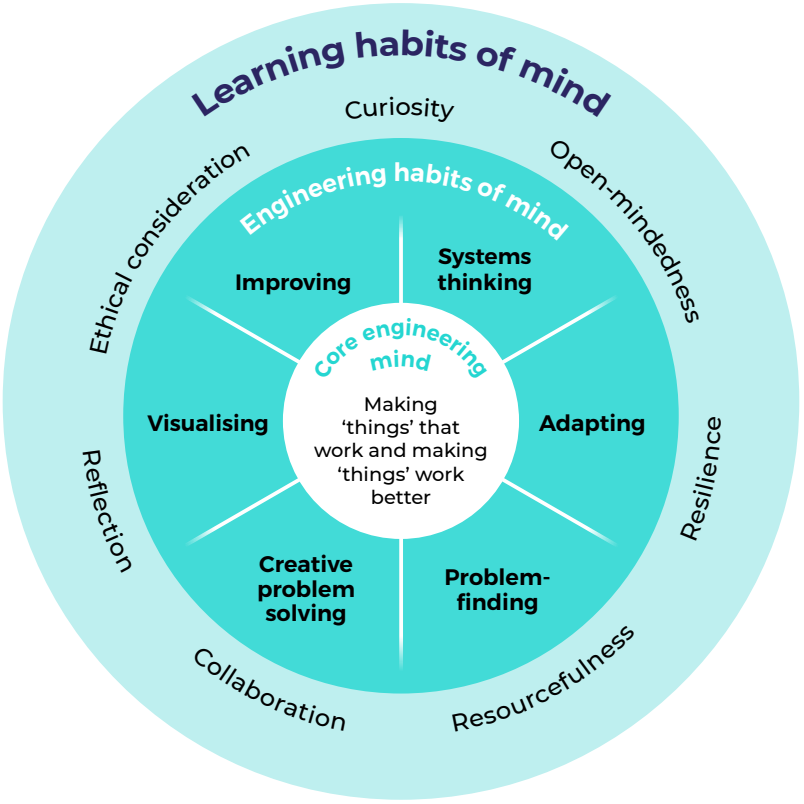
What is the Progressing to be an Engineer Approach?

The **Progressing to be an Engineer (PEng) Approach** supports teachers to embed knowledge, skills and understanding of engineering into the primary and lower secondary science, mathematics and design technology curriculum.

It builds on the **Engineering Habits of Mind** (Lucas et al, 2014) to support teachers to plan and develop high-quality learning experiences for pupils aligned to the **Engineering Design Process**.

The approach is forward thinking as engineering is not a subject discipline within the statutory National Curriculum for England. Based on the research and classroom-based experiences of the University of Manchester's Science & Engineering Education Research and Innovation Hub and their members, we know it is possible to enrich pupil's understanding and awareness of engineering – skills that are so vital to their own lives, their sense of responsibility within our global environment and to the job sector where there are ongoing significant skills shortages in the UK.

Using a teacher-informed strategy has been key to ensuring the approach and it's related resources provide both the description of intended learning outcomes and evidence of them applied in classroom settings with diverse groups of pupils.



Engineering Habits of Mind (Lucas et al, 2014)

The Engineering Design Process

What does the PEng Approach include?

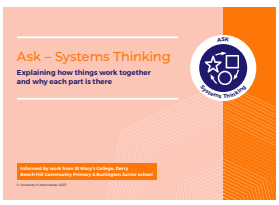
Progressing to be an Engineer Cycle

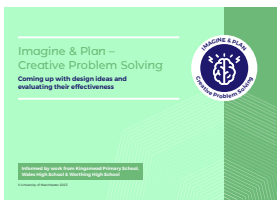
Progressing to be an Engineer Framework

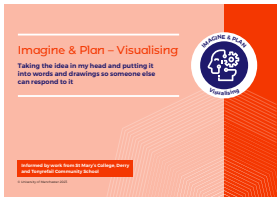
Purpose	Making 'things' that work and making 'things' work better										
Engineering design process	Ask		Imagine and plan				Create			Improve	
Engineering Habit of Mind	Problem-finding	Systems thinking	Systems thinking	Creative problem-solving	Visualising	Adapting	Systems thinking	Adapting	Creative problem-solving	Problem-finding	Improving
5-7 years	Make observations to inspire the asking of simple questions, finding out more information about how things work.	Explain how simple systems work.	Draw and label a design with different parts, showing how they connect together.	Come up with and describe how different ideas can solve a problem.	Communicate ideas in words and simple sketches.	Observe a range of mechanisms (how things are made to work), suggesting ideas for how they could be used for a different purpose.	Use components to create a product with multiple parts.	Take an existing product and repurpose it by using it in a different way.	Create a prototype by taking a 2D design into 3D.	Check things work by testing.	Identify areas for improvement in a product and suggest changes to make it work better.
7-11 years	Identify problems and ask questions to better understand their cause.	Explain how simple systems work, identifying how each part depends on another and predicting what would happen if there is a missing piece or link.	Draw and label a design that uses a system, explaining the role of each part.	Generate multiple ideas, effectively communicating their fitness for purpose and why certain ideas are better than others.	Use simple annotated sketches to turn ideas into words and drawings.	Plan a design that aims to solve a problem or task for a specific user, by transforming an existing mechanism (natural or man-made).	Use knowledge of how components work and interact to create a product that achieves a specific purpose.	Repurpose an existing product so that it can be used it in a different way, tailored to the needs of a specific user or purpose. Evaluate its fitness for purpose.	Create and evaluate a series of prototypes, taking 2D designs into 3D, making improvements based on observations and feedback.	Test that things work using a logical approach, gathering evidence to make an informed decision.	Evaluate how the product is working, identifying areas for improvement in a product and describing possible changes that can enhance the design.
11-14 years	Critically examine problems, asking questions to understand their cause and how they impact different users.	Explain complex systems, including subsystems, describing how they depend on each other and predicting what can happen if there is a missing piece or link.	Draw and label a design that includes a system, justifying why each part is there, and how it best suits a user.	Use research and experience to come up with designs to solve a problem, justifying choices by applying scientific knowledge and evidence.	Use detailed annotated sketches to turn ideas into words and drawings to create a design specification.	Plan and evaluate designs that aim to solve a problem or tasks by transforming existing mechanisms (natural or man-made), suggesting alternatives and trade-offs with due regard for criteria such as cost and safety.	Create a product for a specific purpose, justifying the suitability of choices based on local and global issues - e.g. sustainability, energy, circular economy.	Repurpose an existing product, tailored to the needs of a specific user or purpose. Evaluate based on ethical, social and economic aspects.	Create a series of prototypes, taking 2D designs into 3D. Use cycles of self and peer-evaluation to identify and make improvements based on testing, observations and feedback.	Test and evaluate products against a specification reacting to the views of intended or specific user groups.	Identify areas for improvement in a product and describe changes to enhance the design, recognising the ideas that are most feasible and desirable.

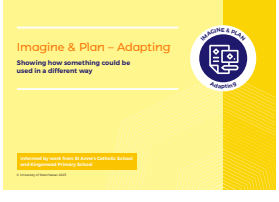
Progressing to be an Engineer Resource Packs

- Generic Tasks
- Embedded Lessons
- Exemplars of pupils' learning









The Progressing to be an Engineer Cycle

Engineering Habits of Mind applied to the Engineering Design Process

The Progressing to be an Engineer Cycle – explained

The cycle has been developed to be accessible to 5–14 year olds and emphasises the relationship between individual EHoMs and the stages of the Engineering Design Process. What is noticeable is that some EHoM are used more than others. The cycle provides teachers with a way to plan for pupils to learn to think as engineers in a science, technology and maths context.

Making the EHoMs work in the STEM curriculum?

It takes forward the original EHoM model by mapping it to the Engineering Design Process to create a method or way of working for pupils that reflects the way engineers think and do their job. We appreciate it may not encompass all practices of *all* engineering disciplines, however it has been shown to be accessible and relevant to teachers planning for engineering in school contexts.

What's special about the PEng Cycle?

- It suggests that when engaging pupils in engineering education they should be encouraged to engage in the **Ask** and **Imagine & Plan** stages in a thorough way before moving on to **Creating** and **Improving**. This cycle helps to illustrate the importance of these initial stages to pupils.
- It presents the opportunity to revisit EHoMs during the EDP stages, embedding and consolidating pupil's understanding in a meaningful way.
- It inspires the explicit teaching of individual EHoMs within each phase of the EDP.
- Emphasises the importance of developing the EHoM as the 'golden thread' that runs through 'engineering-themed' lessons.

The PEng Cycle includes:

Engineering Habits of Mind

- Problem finding
- System thinking
- Creative Problem Solving
- Visualising
- Adapting
- Improving

and embeds these within the stages of the Engineering Design Process:

- Ask
- Imagine & Plan
- Create
- Improve

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Progressing to be an Engineer Framework

Purpose	Making ‘things’ that work and making ‘things’ work better										
Engineering design process	**Ask**		**Imagine and plan**				**Create**			**Improve**	
Engineering Habit of Mind	**Problem-finding**	**Systems thinking**	**Systems thinking**	**Creative problem-solving**	**Visualising**	**Adapting**	**Systems thinking**	**Adapting**	**Creative problem-solving**	**Problem-finding**	**Improving**
5–7 years	Make observations to inspire the asking of simple questions, finding out more information about how things work.	Explain how simple systems work.	Draw and label a design with different parts, showing how they connect together.	Come up with and describe how different ideas can solve a problem.	Communicate ideas in words and simple sketches.	Observe a range of mechanisms (how things are made to work), suggesting ideas for how they could be used for a different purpose.	Use components to create a product with multiple parts.	Take an existing product and repurpose it by using it in a different way.	Create a prototype by taking a 2D design into 3D.	Check things work by testing.	Identify areas for improvement in a product and suggest changes to make it work better.
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How is the PEng Framework structured?

The **Progressing to be an Engineer (PEng) Framework** details the learning outcomes for an embedded approach to engineering education in mainstream classroom settings from 5–14 year olds. It is a planning tool for teachers when designing lessons and curriculum experiences for pupils.

- **It is progressive** by outlining learning outcomes for 5–7 years, 7–11 years and 11–14 years. The age boundaries are not discrete or limiting, and teachers should consider the ability of their pupils as the key driver for planning.
- **It is aligned to practices within the Design Technology curriculum** which means that teachers can capitalise on pupils' prior learning and skills, and integrate engineering education into mainstream curriculum lessons.
- **It's incremental** – the framework is carefully structured to provide a developmental programme of learning to fit within curriculum requirements.

For more information about the research underpinning the framework construction read:

Bonsall, A., Bianchi, L. & Hanson, J. (2020) 'A scoping literature review of learning progressions of engineering education at primary and secondary school level'. Journal of Research in Science and Technology Education. https://doi.org/10.1080/02635143.2020.1799780

Progressing to be an Engineering Resource Packs

The PEng Cycle and Framework are published with a set of downloadable resources that give teachers real insights into how the framework can be integrated into the primary and secondary STEM curriculum. Each of the resource packs provided are tailored to individual EHoMs.

How are the resources organised?

The resources are organised using a two-tier approach:

Tier 1: Generic learning – explicit teaching of each EHoM

Tier 2: Embedded learning – application of the EHoM in a topic lesson

Each resource includes the following content:

Overview

- A short paragraph defining the Engineering Habit of Mind in question.
- Key Learning Outcomes together with suggested activities to demonstrate pupils' level of understanding and application of knowledge.
- Assessment guidance across age groups.

Generic Lesson

- Examples of initial learning activities to **elicit and develop understanding**
- Annotated evidence of pupil learning aligned to the PEng Framework.

Embedded Lesson

- Examples of applied learning activities in a curriculum context
- Annotated evidence of pupil learning aligned to the PEng Framework.

Accessing the resources

Six resource packs are provided. Click on the icons to access the packs.

Inspiring reflection on engineering education 5–14 years

The commitment the Royal Academy of Engineering has shown to developing teaching and learning approaches to engineering for young people has enabled innovation and forwarding of practice across the sector. The journey is by no means over.

The Progressing to be an Engineer Approach includes a detailed framework and resources to support educators across the UK and beyond. Professional reflection on the process and outcomes in this report are welcomed, and will inform ongoing development of support materials related to the framework.

Teachers have explained that there are some key precursors to successful implementation of the framework in classrooms

- Pupils need to have developed technical skills and knowledge for engineering. In particular this relates heavily to the Design and Technology curriculum, where pupils benefit from focused practical tasks such as joining and combining materials, and creating and strengthening structures.
- Teachers benefit from explicit support from senior leaders to diversify from standard curriculum structures, and to exploit the connections across the STEM disciplines.
- Senior leaders should invest in upskilling and connecting STEM teachers so that they can share in a regular, collaborative professional learning approach to curriculum development.

Recommended further reading

Bianchi, L., Wiskow, J., Chippindall, J & Bonsall, A. (2021) *Progressing to be an Engineer.* The Royal Academy of Engineering and The University of Manchester

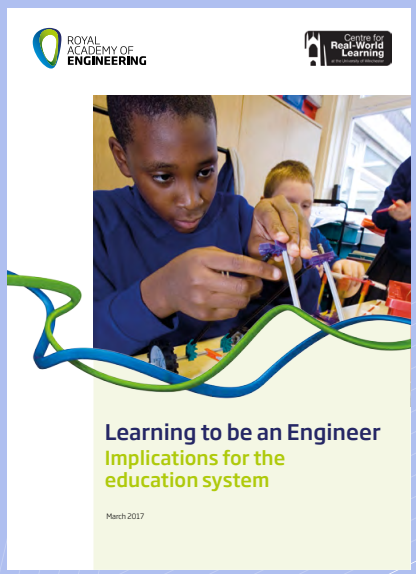
Bianchi, L. & Chippindall, J. (2018) *Tinkering for Learning: Learning to teach engineering in the primary and KS3 classroom.* The Royal Academy of Engineering and The University of Manchester. https://raeng.org.uk/media/idnpwi5p/tinkering-for-learning.pdf

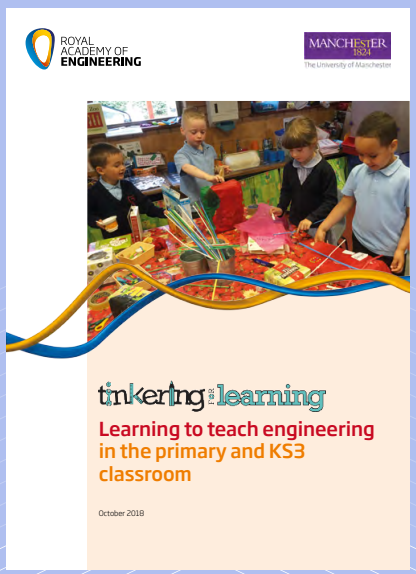
Bianchi, L. 2016. (Editor) *Tinkering for Learning Special Issue*. Primary Science Journal Autumn/ Winter 2016, Association for Science Education

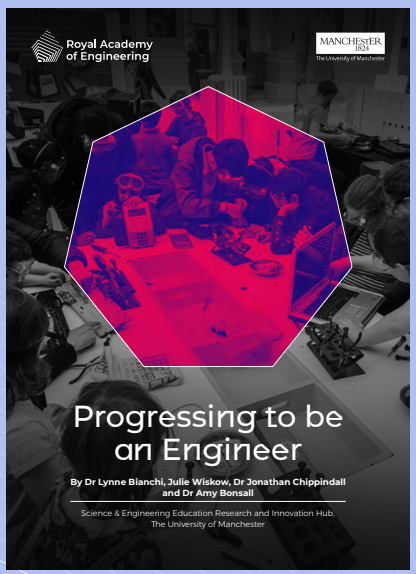
Bonsall, A., Bianchi, L. & Hanson, J. (2020) A scoping literature review of learning progressions of engineering education at primary and secondary school level. Journal of Research in Science and Technology Education. https://doi.org/10.1080/02635143.2020.1799780

Lucas, B., Hanson, J., Bianchi, L. & Chippindall, J. (2017) *Learning to be an engineer.* Royal Academy of Engineering. https://documents.manchester.ac.uk/display.aspx?DocID=63720

Lucas, B., Hanson, J. & Claxton, G. (2014) *Thinking like an engineer: Implications for the education system*. Royal Academy of Engineering







About us

Prof. Lynne Bianchi, Director of the Science & Engineering Education Research and Innovation Hub (The University of Manchester)

Lynne is a specialist in curriculum and professional development, innovation and research in primary science and engineering education working. Having qualified as a teacher, she worked in schools in Greater Manchester before achieving her PhD in Science Education.

She developed her work in curriculum and teacher development at the Centre for Science Education at Sheffield Hallam University for 14 years. In 2014, she launched SEERIH at The University of Manchester, developing it as a leading UK centre of expertise, with a vision to improve the attainment of pupils in schools in areas of high socioeconomic deprivation.

Lynne is a national leader in primary science and engineering education and passionate enhancing inclusive experiences through large scale campaigns, in particular the flagship Great Science Share for Schools campaign. In 2022, Lynne become the Vice Dean for Social Responsibility, Equality, Diversity, Inclusion and Accessibility, further enhancing her ambition to make a difference by championing and developing the very best educational opportunities for young people in STEM education.

Julie Wiskow, SEERIH Consultant

Julie has extensive experience in education and technology-based companies, having spent 10 years working in technology and marketing roles, before becoming a primary school teacher. She is passionate about fostering pupils' innate curiosity and problem solving skills by developing a context-rich curriculum, and has been responsible for initiating a number of successful whole school STEM projects.

Over the past few years she has worked as a consultant for SEERIH helping to deliver engineering projects including the Greater Manchester Engineering Challenge (GMEC), Progressing and Evolving to be an Engineer and the recently launched Engineering Educates Farmvention Challenge.

She is a Lead Facilitator for STEM Learning and is currently involved in producing a Curriculum of Excellence Programme for Cheshire East in her role as Science Lead for Rode Heath Primary school.

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