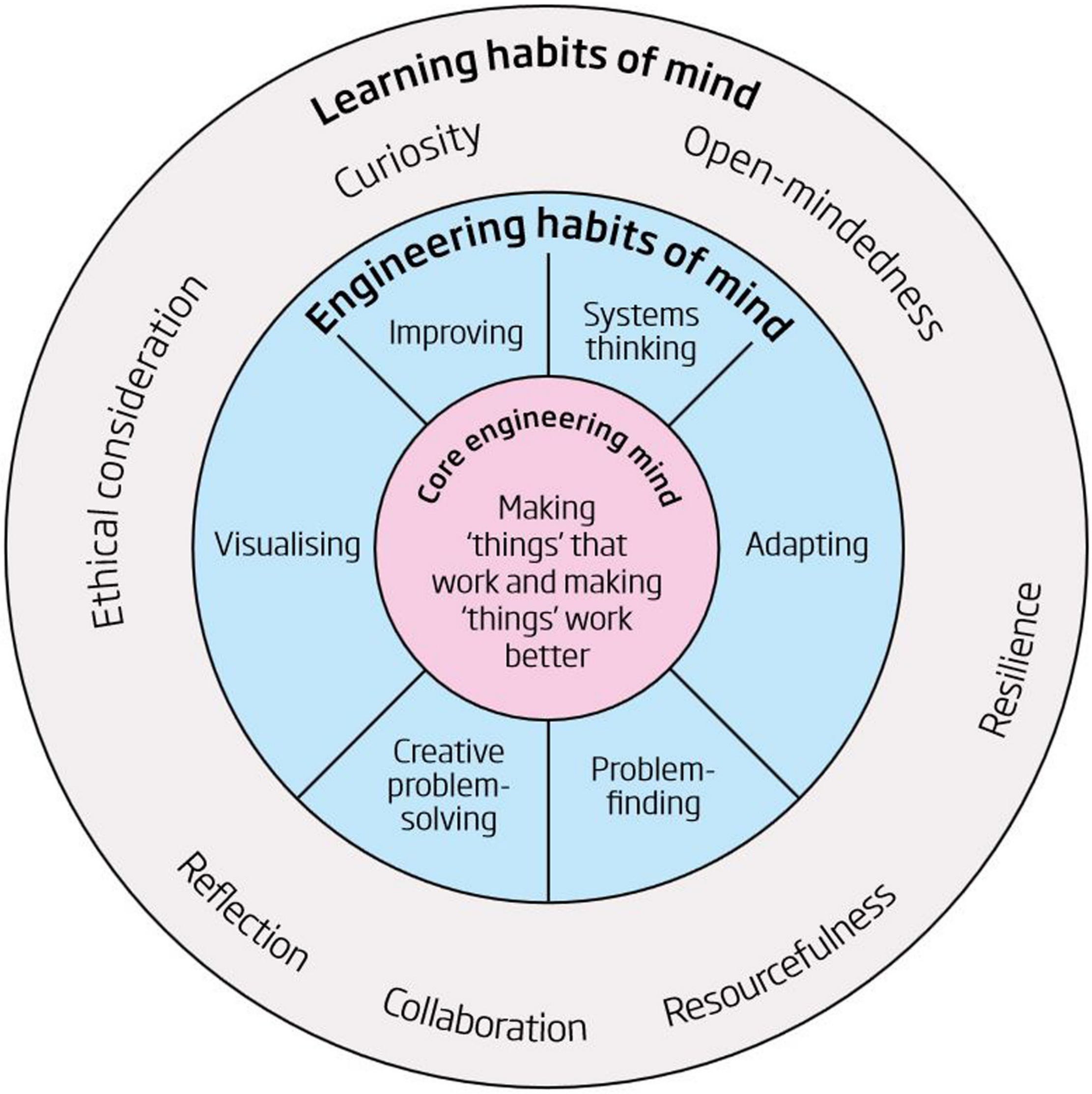
Engineering a new curriculum

Rather than just address STEM teaching as discrete subjects, primary and secondary schools would do well embed it within an engineering curriculum focused on the problem-solving orientations of engineers, suggests **Bill Lucas**.

Earlier this year, with my colleagues at the universities of Winchester and Manchester, I published the results of a two-year research project, which we believe has profound implications for the curriculum at all levels within the education system.

Although it addressed a particular problem, our inability to create, as a nation, enough high-powered engineers, the report **Learning to be an Engineer: implications for the education system**, found that a new reframing of the curriculum in terms of set of problem-solving habits of mind typically found in top engineers was more important to prioritise than the set of subjects typically associated with engineering, such as maths, physics and design and technology. One of the most effective ways of developing young engineers in schools is a playful experimentation with the use of authentic design processes, a kind of problem-based learning. For the teachers involved, it became obvious that, not only could they deepen their pupils' knowledge, they could also teach in a way that was engaging, creative and likely to develop young engineers.

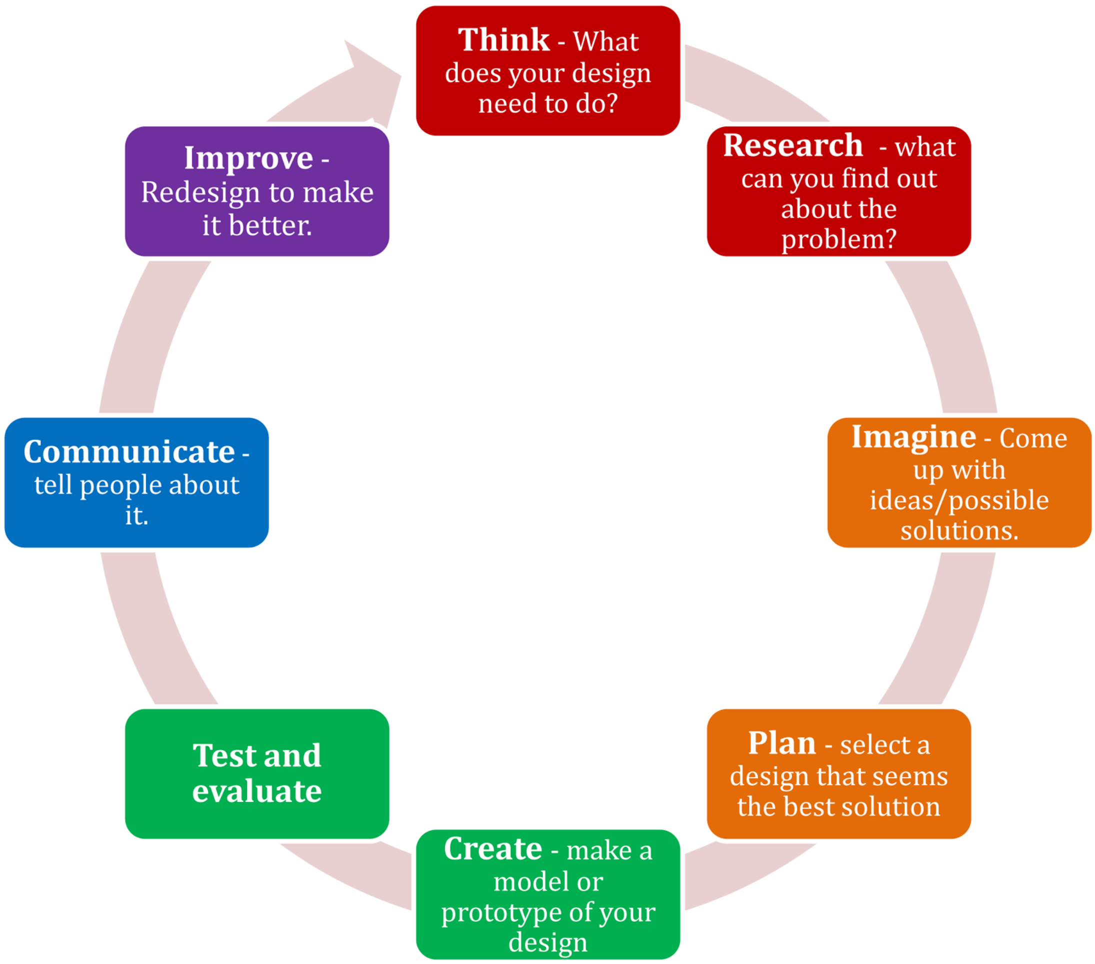
Rethinking pedagogy



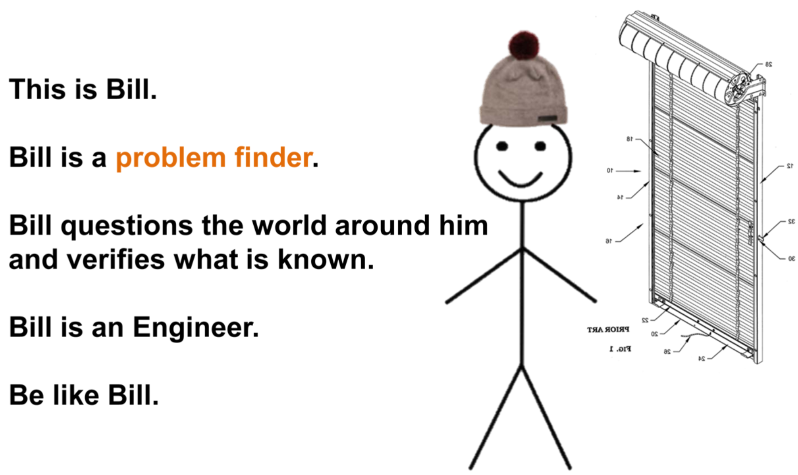
Centre for Real-World Learning's Model of Engineering Habits of Mind

The teachers taking part in our research realised that teaching engineering, like developing creativity, depends at least as much on experimentation and imagination as it does on subject knowledge. They drew on three 'signature pedagogies'[2] - the engineering design process, playful experimentation and authentic engagement with engineers. The signature pedagogies – teaching and learning methods – were selected as those most likely to help pupils think like engineers.

Gomer Junior School in Hampshire, for example, introduced *engineering sessions* in every year group each Thursday morning from 09.00-12.00. The sessions integrated maths, literacy, science and IT with the aim of motivating learners and fostering understanding of real-world applications of STEM subjects by experiencing hands-on activities, such as The Space Race project featuring Tim Peake's Principia Mission[3], and involved programming Crumble-controlled moon buggies. Underpinning their teaching and learning was a version of the engineering design process, the gSTEM Wheel.



By contrast, Medway University Technical College (UTC) in Kent focused on raising awareness among staff and students about the six engineering habits of mind, their usefulness and ways of integrating them into the curriculum. Whole-school assemblies were organised around each habit of mind and icons for use on posters and rewards postcards were created. The systems thinking one is shown below.



The popular 'Be Like Bill' social media meme (above) was also adapted to explain the meaning of each engineering habit of mind, in this case problem-finding.

Medway UTC's strategies to cultivate awareness of EHoM had an important impact on those teachers in subjects such as art and English, who felt much more included in the overall engineering mission of the school.

Some possible problems with problem-based learning

The teachers were, in essence, using a set of approaches associated with the approach known as problem-based learning (PBL). PBL is a hands-on method of teaching which focuses on messy, real-world problems and encourages students to explore these in depth and over time. Interestingly, PBL produces negative reactions from some researchers and, in the second part of this article, I explore some of these and offer some counter arguments.

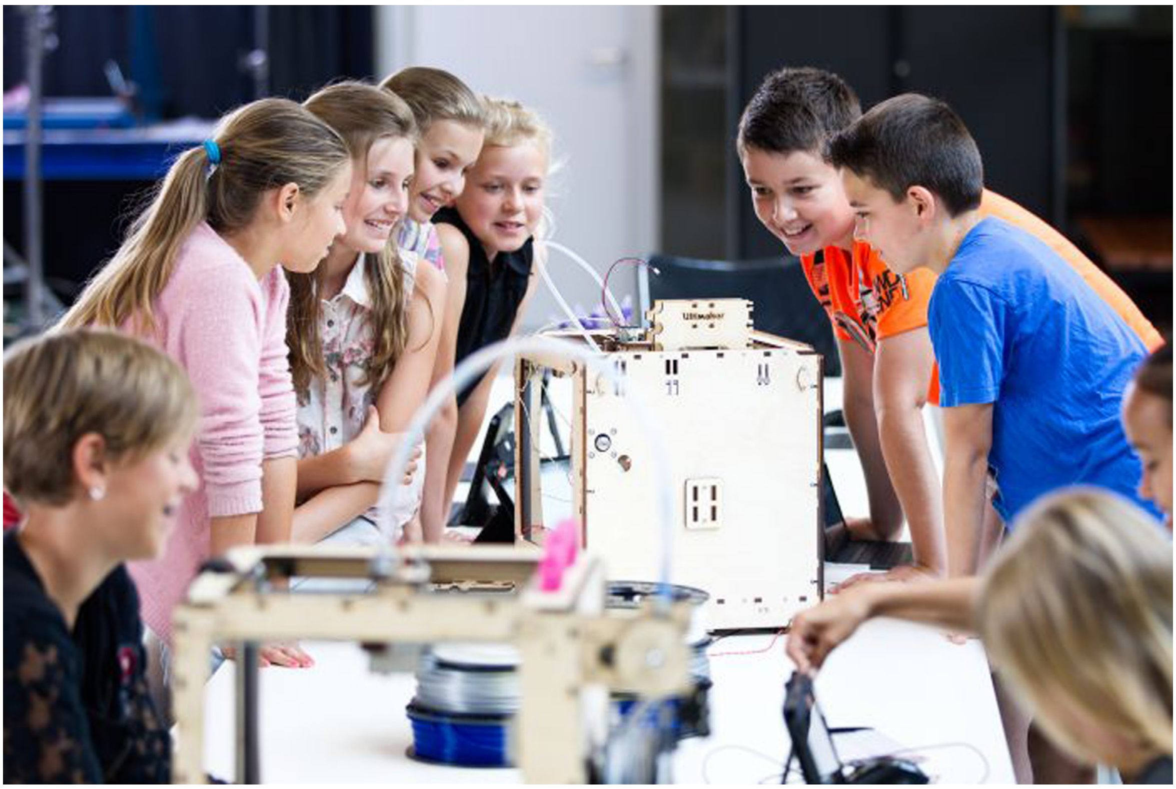
1. Constructivist teaching which allows pupils to explore problems in less structured ways is not as effective as direct instruction.

An example of such a critique is a paper by Paul Kirschner, John Sweller and Richard Clark. The first part of the title of the article suggests their line of argument - *Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching*[4] Kirschner and his colleagues draw on thinking about working memory and about the acquisition of expertise. They are right to remind us that novices and intermediate learners often need specific instruction to master core concepts and key skills, but they fail to ask a more fundamental question about the learning outcomes which are desired by teachers. Obviously, young engineers, for example, need to have some mathematical and scientific knowledge, but they also need to be able to apply this in the real world.

PBL was invented by those training doctors who had become concerned that trainees had good knowledge, but little ability to put this into practice with patients. There is now a journal devoted to understanding PBL with rigour and subtlety[5] and, from meta-analytical research, it is possible to understand its application a much more nuanced way. PBL does not have to be a binary alternative to direct instruction, nor was it in our engineering research. Rather, it can be combined with moments of didactic input as required. By the same token, the idea of 'minimal instruction' forces some unhelpful binary thinking about the nature of learning when, in reality, structures such as the engineering design process, when well used, bring structure to pupils' enquiries.

2. The concept of PBL is unhelpful

An extension of the previous argument, this one is easy to deal with for it assumes that there is a common understanding of what PBL is when there is not.



Johannes Strobel and Angela van Barneveld remind us that it has taken on a myriad of definitions[6]. They draw on earlier research to suggest some key elements, such as a focus on ill-structured problems, a requirement for students to determine their own investigations, the complex expert facilitative roles required from teachers and the need for real-world authenticity. In many schools, PBL, on closer inspection, is a more loosely conceived project-based approach, with teachers simply replacing subject labels such as 'science' for a theme or topic of their choosing, like 'the local environment'. We should not be surprised if such more loosely structured project experiences are not as effective as direct instruction.

3. PBL is a straightforward method of teaching.

This speaks for itself and is wholly wrong. For PBL to be effective, it needs commitment from staff, time for curriculum planning and professional development, extended periods of time, flexible classroom spaces, good processes for selecting appropriate problems and effective structuring processes to ensure that pupils' efforts are well spent. Too often a vital piece of this jigsaw is omitted. From our engineering research, the need for effective professional learning was one of the most important findings.

4. Assessing PBL is like assessing subjects

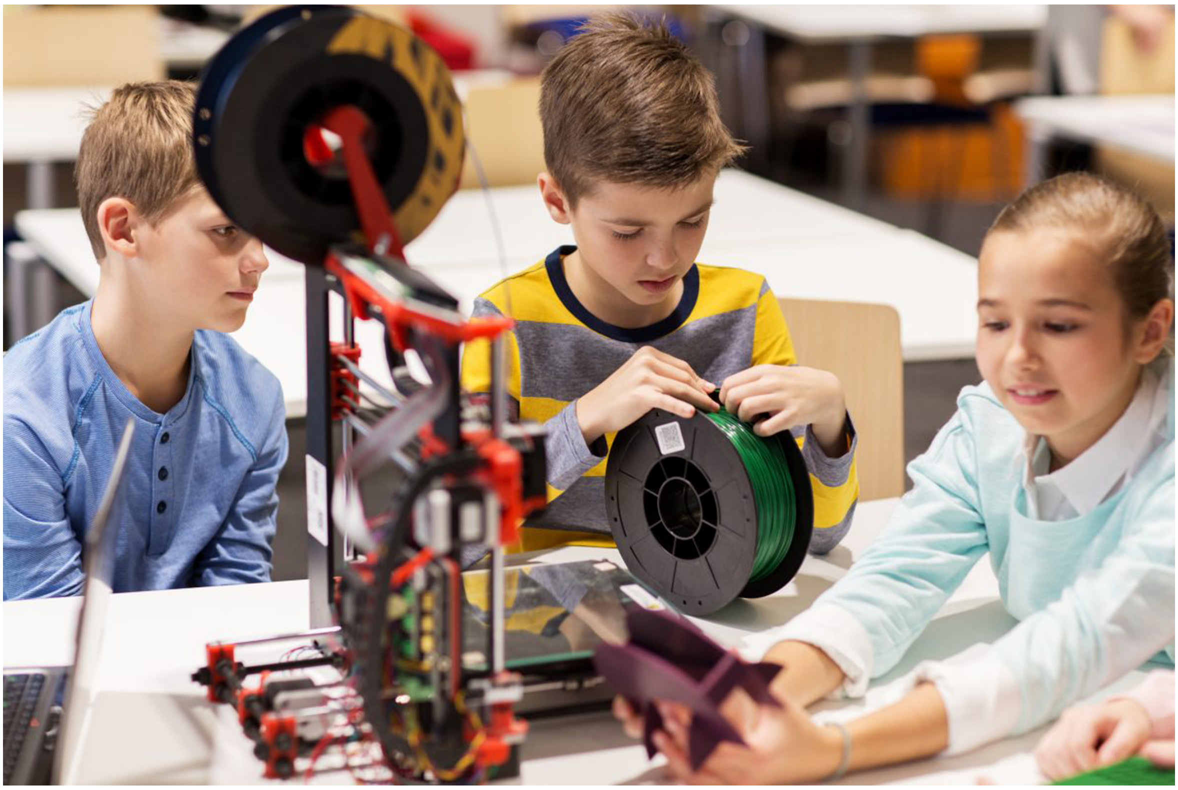
Traditional school subjects are, in the main, assessed by setting academic tests and, sometimes, practical tasks, which can be judged according to criteria by teachers.

PBL, on the other hand, requires some different approaches. For, whereas a class taught the same thing by a teacher can be reliably tested at key points along the way, this makes less sense with PBL where pupils will have had different experiences. In universities, assessment of undergraduate engineers is often undertaken by means of capstone projects. These are multifaceted assignments, typically at the end of a period of time in which students have been exploring a particular problem and involving presentation, display and performance of both final work and the learning processes which were used along the way. A similar approach can be used in schools and is an ideal opportunity to involve practising engineers and designers.

Learning for the real world as well as for success in examinations

Many of these arguments come down to what we think the purposes of school are, and, as this sub-heading suggests, my view is that we need *both* the knowledge and skills to excel in tests *and* the capabilities to thrive in the real world. Rigorously delivered PBL is a wholly plausible way of delivering such outcomes, but it requires skilled teaching and courageous and creative leadership in a period when so much focus is on individual subjects and, in England, on the English Baccalaureate.

Globally, there is near total consensus among educational researchers, economists and employers about the kinds of capabilities or habits of mind that society needs its children to acquire[7]. But the consensus does not yet extend to the methods most suited to developing these.



In the real, adult world much of what we do involves us responding to challenges around us and coming up with solutions. This could be as relatively simple as remembering where you have hidden your spare house key when you are locked out or making a new kitchen, or as complex as trying to figure out how to minimise your family's use of a dwindling stock of earthly resources for the good of the planet. The curriculum of life-long learning is full of situations which demand certain responses. We have to appraise a situation, determine a goal, think our way around the issue with words or gestures or images and work with others to effect a solution, all the while evaluating the degree to which what we are doing is producing our desired outcome. A timetable for such life-enhancing education (were it ever to be produced) would depict a series of problems arising out of the intersection of our curiosity, our needs and the demands of everyday living. It would, perhaps, be represented by a series of lines of activity - work, family, house, hobbies - along which key 'problem' moments would be indicated, possibly phrased as questions such as: how can we organise the busy family diary this week so that all children are picked up and taken to their various events? Where would we like to go for our holiday this year and how will we decide this amicably?

By contrast, the curricula of many schools are not like this at all. Their timetables tend to be organised around abstract concepts - science, maths, geography and so on - which are defined by disciplinary knowledge, happen in a pleasingly ordered and repeating way in hour-long units across a week and occur in specific locations. Much of what students learn as they move round schools organised in this way bears little relevance to what they will go on to do later in their lives. It is a glorious societal 'second guess' as to what they need to know in order to be able to function well in later life.

From such traditional timetables, it is not always at all clear what the real purposes of school are. Two possible answers, both entirely reasonable culturally, include creating young people with a level of all-round knowledge to help them to progress to the next step in their education, and ensuring that young people do their very best in the various examinations they will be required to take as they get older. But it seems to me that the schools which say things like this have only answered some of the questions which we, as teachers, need to consider. How best can schools prepare young people for a complex world, cultivating in them the capabilities to help them thrive, while at the same time developing in them a deep love and understanding of a number of subjects?

The answer it increasingly seems to me is by reframing a substantial part of school as a series of engaging problems for students to investigate rigorously, all the while being coached and taught by teachers who are skilled in the knowledge, skills and capabilities which are relevant to the contexts in which their students are learning. This is, in essence, what most people mean when they refer to problem-based learning. Go back a hundred years and it is what John Dewey was arguing for[8]. He was right then and his arguments still hold sway. And, today, we can combine aspirations for capable pupils confident in disciplinary knowledge with our knowledge about the kinds of creative teaching and learning methods which can cultivate the kinds of engineering habits of mind with which I began this piece.

Bill Lucas is Professor of Learning and Director for the Centre for Real-World Learning at the University of Winchester. His latest book, written with Ellen Spencer, is *A Practical Guide to Teaching Creative Thinking,* to be published in Autumn 2017.

Read the full Report at: www.raeng.org.uk/publications/reports/learning-to-be-an-engineer

Illustrations by Royal Academy of Engineering