Primary Science

Special issue: Tinkering *for* Learning

Winter 2016/17

special issue: Tinkering for Learning

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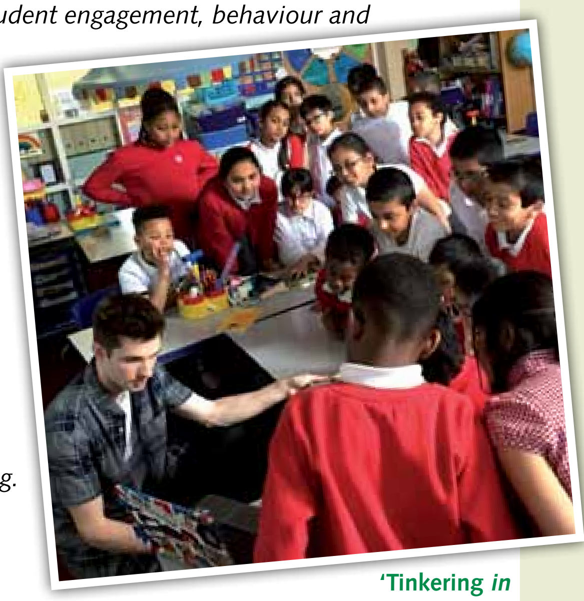

'Tinkering *in* action' (see article on page 18).

Cover photos kindly supplied by Christine Twigg of the University of Manchester's Marketing and Communications team

Primary Science

Special Issue

Editor Leigh Hoath

Focus on….

This Special Issue of *Primary Science*

Sometimes fate plays its hand in a very positive way. I love the notion of serendipity, and the evolution of this Special Issue of *Primary Science* stems from a series of fortunate conversations. The initial outcome of the Tinker Tailor Robot Pi project was not planned to be a publication in this form; however, I was asked to support the participating teachers in a writing workshop to capture their experiences. From there, a *'wouldn't it be wonderful if…?'* discussion took place, and here we are with the final product.

Having met with the teachers involved in this project, it amazed me just how great the impact of the work was on their teaching and children's learning. My hopes..? That the teachers who now see their work in print feel a massive sense of achievement; that readers are encouraged by the honest accounts of working with such a project in close association with university partners; that it makes teachers question what they are doing and why, perhaps encouraging a willingess to try something new, however challenging.

I have written before about being privileged in my role as Editor of *Primary Science* and this Special Issue adds to that. This issue reflects a great deal of hard work on the part of all who have been involved but, to me, it it goes a step further and offers a source of inspiration for those who read it.

Our thanks go to Lynne Bianchi and the team at SEERIH for their contribution to this special issue. I feel it is also important to thank the participating teachers who have written for *Primary Science* during their busy academic year. This is a fabulous outcome, reflecting their efforts to produce the articles themselves and the culmination of their work throughout the project. Our thanks also go to our kind sponsors, SciChem and *Primary Engineer.*

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Foreword

Lynne Bianchi

We know that there is ongoing recognition of the shortage of engineers in the United Kingdom. We also are aware that the education system does not have the capacity to meet the forecasted demand for skilled engineers in 2020 (EUK, 2014; BIS, 2013; Lucas et al, 2014).

Whilst investment is being made in England in campaigns and educational initiatives focused on increasing the number of youngsters entering the STEM workforce, there is still interest in encouraging this to start earlier in the primary years. It is encouraging to find that professional bodies such as the Royal Academy of Engineering, the Institute for Mechanical Engineers and Engineering UK have developed successful programmes of work, focused on enriching the opportunities for pupils to work with business and industry and the engineering professions. Their ambitions to improve awareness of and enthusiasm about engineering, and what engineers do, hits the heart of what I believe we need to do to give children the greatest choice and opportunity for their future.

Thinking Like an Engineer, produced by the Royal Academy of Engineering (Lucas *et al*, 2014) is one of the latest pieces of work that provide a new perspective on the issue of mobilising interest and understanding in engineering. This report has been the focus of work for us at the University of Manchester, as we have worked through the Tinker Tailor Robot Pi project to interest and engage teachers, and subsequently their pupils, in finding opportunities to 'think' and 'learn' like engineers. We recognise that this may not be an easy task, but we have learnt, through our engagement with engineers, how imperative the habits of improving, visualising, creative problem-solving, problem-finding, adapting and systems-thinking are in their professional work.

This Special Issue of *Primary Science* focuses on how teachers in Greater Manchester have found approaches to develop an ethos for engineering in their classrooms and schools. At a time at which we acknowledge that the accountability placed on teachers and schools is high, we have found creativity, innovation and a determination to succeed. We have found interest, excitement and engagement from children and their parents. These indicators are positive and spur us on to share our learning with others, so that they may feel encouraged also to see how engineering, through tinkering, might be supportive of their own school development.

Acknowledgement is extended to the Comino Foundation and the Royal Academy of Engineering for supporting this project.

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Dr. **Lynne Bianchi,** Director of the Science and Engineering Education Research and Innovation Hub (SEERIH) at the University of Manchester.

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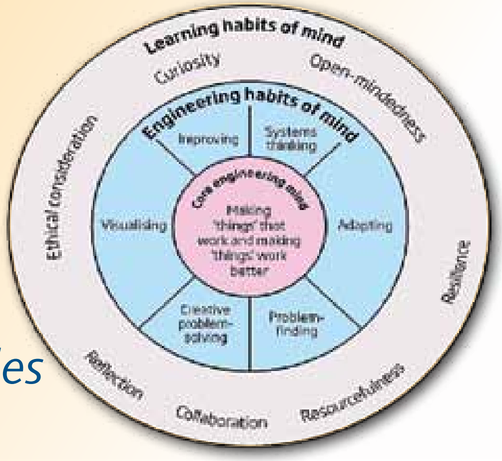
Tinker Tailor Robot Pi – the project

Lynne Bianchi *introduces a series of articles from teachers about their experiences in using tinkering as an approach to develop engineering education in primary schools.*



Engineering Habits of Mind

Tinker Tailor Robot Pi (TTRP) is an innovative curriculum development project, which started in September 2014. It involves in-service primary and secondary teachers, university academic engineers, business partners and pupils at Key Stages 1, 2 and 3 (ages 5-14). The focus of the work has been to explore how a pedagogy for primary engineering could be established within the mainstream curriculum setting. Ultimately, there is a strong desire to foster teacher confidence in the teaching and learning of engineering education by exploiting the opportunities provided within the computer science, design technology (DT) and science curricula.

Tinkering

Engineering can be said to be identified within an increasingly visible network of makers, within tinkering studios, Tinkerlabs and Tinkergardens. In such spaces, the intersections between art, science and technology are blurred and what emerges are spaces in which young people can play with, make, refine, remodel or repurpose materials and machinery in creative, purposeful pursuits. Such processes and skills are associated with 'tinkering', which Cuoco *et al* (1996) define as '*taking ideas apart and putting them back together again*'. Doorley (2014) presents strong alignment with the habits of mind outlined by Lucas *et al* (2014) in suggesting that tinkering begins with problem-solving and curiosity about how something works. She affirms the process-based approach that embodies tinkering, which is supported through discussion, tests, experiments and play.

Resnick and Rosenbaum (2013) caution the overuse of the term 'tinkering', which they suggest can be used dismissively. The association of 'just tinkering' with someone working without a clear goal or purpose, or without making noticeable progress, is counter to what they see as a valid and valuable style of working, characterised by a playful, exploratory, iterative style of engaging with a problem or project. In the TTRP project,

Project aims and objectives

Tinker Tailor Robot Pi explored how, through a partnership approach between primary and secondary teachers, university engineers and business partners, we can respond to the complementary project questions of:

How do we embrace engineering education and an ethos of tinkering, using computer science, design & technology and the science curriculum?

How can engineering have relevance and resonance within the primary and secondary school curricula?

The aims were to:

- encourage the sharing of professional practice and knowledge between teachers and engineers
- explore how engineers 'work' by deconstructing how engineers practice their profession (What it currently means to 'be' an engineer?)
- better understand current practice related to what currently takes place in primary school teaching and learning with regards to engineering education (What is currently happening in school?)
- identify where in the primary school curriculum (i.e. science, DT and computer science) would allow for a stronger ethos of engineering to be embraced (Where are the opportunities?)
- collaboratively develop, deliver and reflect on teaching and learning opportunities for pupils, which work towards identifying a signature pedagogy for engineering in primary schools (What can we achieve together?)

The project

The project spanned the academic years of 2014-16 and continues to progress to date, involving primary and secondary schools in Greater Manchester (20 school groups over two years).

School groups designed an approach to the project aims that best suited their pupils' needs, school interests and personal expertise. The approaches became known as testbeds, and three key ones emerged. There were interlinks between the three testbeds and, on many occasions, schools would touch on other areas whilst keeping their key focus in mind. The articles within this Special Issue provide you with information about what this looked like in specific school settings.

we discussed and shared Resnick and Rosenbaum's perspectives that suggest that, when people are tinkering, they are constantly trying out ideas, making adjustments and refinements, then experimenting with new possibilities with a clear purpose in mind.

We acknowledged that there might be a tension between tinkering and a 'traditional' linear approach to creating that is more constraining, i.e. we create a plan, we make what we have planned, and we review what we have made. In contrast, we championed 'tinkering' as a means by which we could encourage an agile approach to learning and making, and which affords pupils the room to flit back to their plan to adjust it as they are making. Whereas some may challenge 'tinkering' to be an inferior approach to engineering and planned scientific practice, due to a level of disorganisation or indirectness that frees an individual from getting things right and 'to plan' the first time – this project embraced it and found that it was something in which teachers also found freedom when in the classroom (Bianchi & Chippindall, 2016).

The project's working definition for tinkering was as follows:

Tinkering is exploring through fiddling, toying, messing, pottering, dabbling and fooling about, with a diverse range of things that happen to be available, in a creative and productive pursuit to make, mend or improve.

Tinker Tailor Robot Pi grabbed the interest and attention of the teachers and the engineering education community, as it enabled discussion to be shared with engineers and practitioners about their shared and specific working practices. It provided a context for both groups to talk about engineering in a way that teachers felt could be made accessible to children, and indeed their school staff. Tinkering soon morphed into 'Tinkology' (a word used within the project group to represent 'the science of tinkering') in some school groups and began to be seen as a signature pedagogy for engineering practice, mainly in schools.

Whether using the new technologies and programming techniques provided by Raspberry Pis, Pibrellas, Beebots, Crumbles, Scratch and Python within the computer science curriculum, or by broadening the range of approaches to teaching through problem-solving in Design Technology, tinkering seemed to be a language to which all teachers came back. They reflected on the process of learning through tinkering being the overarching objective in lessons and that the process, driven by a teacher- or pupil-led purpose, provided the rigour to learning that was required.

Teaching through a tinkering pedagogy emerged to involve collaboration and competition – children working together in teams incentivised to design and make a product that surpassed their peers. They faced and overcame challenges and persevered in adversity – coping with failure by accepting and appreciating this as part of the tinkering process.

Teachers described how their role changed from directive to supportive. They found it challenging to step back and watch, yet realised that, in order to enable the children to benefit the most from the tinkering approach, it was not useful to provide answers, but instead to question and scaffold thinking processes so that children retained the ownership of the product they were making. Teacher talked of creativity blossoming in this environment – which, although taking more time than 'standard' lessons, reached out to pupils who would usually not achieve as well as others, the lower achievers in particular.

The infographic at the top of this article was designed to capture the teacher's collaborative reflections and provides ongoing stimulus to explore and further consider how tinkering and the 'Engineering Habits of Mind' align with each other. Many questions still sit with the group:

Is tinkering reflective enough to capture the nature of engineering as a discipline?

Is tinkering a habit of mind in itself?

What are the models of progress that allow a teacher to plan for the development of children's ability to tinker?

How do we measure the impact of this technique within a school system that is so individualistic and product outcome-driven?

How best can engineers further help us unpick this as an approach to engineering education?

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SEERIH specialises in innovative curriculum development and research in the area of primary science and engineering education. Its 'fa**sci**nate' campaign engages children, their schools and their local communities in enriching science and engineering experiences from an early age.
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Tinkering from the top

Nichola Potts, Shane Nolan, Alan O'Keeffe *and* **Karen Hill** *explore how 'tinkering' can improve a school, claiming that 'the school that plays together, stays together!'*

Sometimes you just have to go for it. Breathe and expect the unexpected. A leap of faith can be quite liberating, especially when you are the new Headteacher of a 'Requires Improvement' school. Watching staff and children work tirelessly to improve, I realised that we, as adults, had to be risk takers, problem-solvers and learners, just as much as the children are encouraged to be. Developing a school improvement plan linked to developing engineering in our school curriculum, by adopting tinkering as a way of learning together, has been the focus for our learning over the past two years. In our school, we named this development project 'Tinkology' and the teachers and children were inspired by the name (for the purpose of this report, to maintain consistency across this Special Issue, we will refer to the process as 'tinkering' – although it will always be Tinkology in our hearts!). We worked with the University of Manchester to enrich our understanding about key pieces of research, in particular the Engineering Habits of Mind (EHOMs), which then led to us having inspiration and drive to work with these ideas to address the school's mission and vision of 'Inspire' and 'Create'.

My initial discussions with the school's Science Subject Leader showed that, if we were to get our vision for 'tinkering' rooted in, it had to be part of a whole school pedagogy. We wanted tinkering to inspire, create

From one Headteacher to another

Tinkering may or may not be for you, but what I can urge you to do, through any curriculum development project you choose to adopt, is to lead by example, lead by being part of the development – from the inside and consistently. I attended each and every training event with my teachers – we were a true team, we shared the ups, we shared the downs, but we shared…

Play – play – and play some more. Trust in staff that they will drive toward high standards – it's what they do best, they have ingrained senses to do the right thing by children. But they need to be fascinated too – they need time to experiment – talk and 'play' with ideas together. They need and benefit from external support – the University of Manchester's SEERIH team were our nectar from which we could make honey. All teachers, whatever their age or phase, need to feel the power to create.

Invest in failure. We all know that learning comes through failure, so don't fall at the first fence; embody and exemplify the Habits of Mind of perseverance, problem-finding, creative problem-solving, creativity, etc.

Tinkering made sense to us – it opened a door to our creativity – whether you call it 'Tinkology', tinkering or engineering, we have enjoyed the creative process of making. It has been the thing that has most changed in our classrooms, and when children are making with their hands they are personally seeking to find new ways to learn, new answers to their own questions, new understandings about the world around them. Isn't that what school improvement should be about?

and innovate learning opportunities.

As a result of these early discussions, the school improvement plan was drafted and staff attended an immersive INSET at the University, tailored to enthuse, motivate and inform them about engineering, what it meant to be an engineer and the practices that engineers use. I was aware of the importance of staff realising that tinkering wasn't just another thing to do, but was integral to the way we approached the planning and delivery of our curriculum, with the aim to improve the outcomes for our children.

Where did we start?

Very simply – with a whole school assembly focused on a particular Engineering Habit of Mind (EHoM).

Collective ownership is important to our school as it empowers us all. Every Monday, as Headteacher, I lead an assembly that challenges myself, adults and children to develop an EHoM for the week, for instance, Creative Problem Solving or Visualising. In this way, the school family learns together about what it means to develop positive learning habits, which stretch beyond science and can be used across the curriculum. These assemblies are the easy part. The hard work then begins inside and outside the classroom.

Staff plan together and lesson plans are short and succinct, if needed at all. This was a big shift change from the onerous detailed plans that the teachers were previously expected to do. Through staff discussion (and lots of it!), we realised that we needed to be uncompromising in our ambition and, at the same time, fulfil our statutory obligations directed from above! I have created and value an open discussion with staff; I make a point of really listening and, of course, challenging – but my staff needed time to talk together, think together and experiment together.

We constantly debate and reflect on the way that we teach and engage learners with the EHoMs, with science and other areas such as DT, computer science and across the curriculum. The commitments we made between us through this project were that:

- **The spoonfeeding of children's knowledge and support during learning had to stop;**
- **Planning wasn't to be laborious and neatly typed up;**
- **The focus for planning needed to be on resourcing and questioning, e.g. How do we 'hook' the children into a particular topic for the term? How are we going to develop cross-curricular skills around the topic?**
- **Subject leaders needed to consider how their subjects integrated and made visible the Engineering Habits of Mind, to ensure appropriate coverage of each EHoM and the curriculum objectives; and**
- **Creative planning would be celebrated and encouraged.**

What resulted was an evident excitement and thirst to learn together between the staff.

The following case studies showcase a little of what this looked like in classrooms, but I need to of course address the crucial issue of accountability – and how I, as a Head, could justify the whole school taking 'tinkering' (an ethos and approach to developing engineering) forward. I often reflect and talk with the governors about this and we even talked to Ofsted about it this year too!

A Mindset for tinkering in the Early Years

Karen Hill, Nursery Teacher, writes:

My 3 and 4 year-olds are little engineers every day in nursery, in all areas of the continuous provision and in the creative curriculum/environment. Typical examples include using the big wooden blocks outside to build The Great Wall of China as part of a Chinese New Year topic, or den-building using crates, material, wood and pegs with the challenge to keep warm in winter.

A visit to the zoo

Tinkering is alive and kicking in nursery and the ethos of tinkering further allowed us to develop our craft area, encouraging children to make models and explore how to fix and join things together.

What's noticeable about nursery children is they have so many of their own ideas, they are not influenced by others and are not yet afraid of getting it 'wrong'. If they're not happy with what they've made, they will naturally adapt it, start again and learn from their experiences. They can share their creations and ideas without apprehension, enjoying the 'show and tell' experience and learning from each other.

What happened in our Nursery Tinkering project

One of the most memorable learning experiences was our trip to Blackpool Zoo. Before we went, it was important for the children to be familiar with the animals they were going to see. We used information books, small world animals, a world map, *YouTube* videos of animals and the zoo's interactive website, including video clips.

Lemur and Monkey enclosures recreated with blocks

The week before the trip, I sent the children a parcel containing an A-Z book of animals and about 8 soft toy animals. They were asked to find out about these animals, where they came from in the world, their size, shape, etc. On the trip itself, we took lots of photographs of the animals and where they lived at the zoo.

The next day we shared our experiences and looked at the photographs. I read the story *Dear Zoo* by Rod Campbell with which the children were already familiar. We talked about our favourite animals and I focused on the size and shapes of the different animals we talked about.

The children went off to play in the continuous provision. Some painted, drew or made models with playdough of the animals from the zoo. Some made enclosures and put in the small world animals using wooden bricks, Duplo, Lego, etc. Two boys made a tree house for the monkeys with bricks and sticks, and others wrote about going on the double decker bus to the zoo. Outside big enclosures, dens were made using large plastic crates and trays.

In the 'Tinkering' area, the children were set a challenge to make a transport container for an animal from the zoo to be sent to their house, relating to the story *Dear Zoo.* The children had access to a wide variety of resources, such as boxes, paper, card, material, straws, lolly sticks, masking tape, cellotape, staplers, etc. Children freely chose to do this activity and had their own ideas of what their model should look like, depending on the animal it was for:

'I'm using these straws for the bars on the cage so the lion doesn't escape!'

'My cage is covered in red paper because red means danger.'

'I've got a big box to make my cage because tigers are big.'

As they made their models, the children were naturally absorbed and using such Engineering Habits of Mind as adapting, refining, being creative, persevering and collaborating, and their ideas developed. They were problem-solving, finding new ways to do things and not giving up. It's quite tricky to cover a box in red tissue paper and to stick on straws for bars when you're 3 or 4! My role as teacher was to talk, encourage, discuss with them what they were doing, and why.

At the end of the week, the children shared their models with each other and talked about what they had used and how they had made their models for the animals. It was interesting for them to compare the different ways they had covered boxes, cut doors or windows and made bars, and so on. They also had the opportunity to go back to their models to improve them and make changes.

By the end of the animal topic, everyone who chose to do this activity was pleased with the outcome and proudly took it home to show the family. I felt this was a great opportunity to watch the making process, with an eye towards the development and use of the Engineering Habits of Mind that I now knew more about myself. It helped me be more structured and thoughtful in my reflections with the children about their tinkering and its outcomes.

A Mindset for Engineering in Year 3 (age 8)

Alan O'Keefe writes:

Have you ever taught 7-8 year-olds? Do you ever wonder where all the natural curiosity of babies and toddlers has evaporated? Where have all the 'Why' questions gone?

As we developed tinkering by addressing the Engineering Habits of Mind in our Year 3 class, I watched that enthusiasm and energy being

How can we capture the enemy's base?

reinvigorated due to our focus on hands-on tasks that challenge our children to think, make and talk about engineering. I responded positively to our Headteacher's vision for the school curriculum to be infused with engineering, as I saw it as an opportunity to diversify the way I thought about my teaching. I enjoyed having the support, freedom and time to experiment.

Experiment 1: The School of Military (www.theschoolofmilitary.uk)

'The School of Military' is a group of ex-forces personnel who came in every Friday for a term. Along with presenting lessons based on the curriculum, covering such topics as bones and muscles, food and nutrition, and the benefits of exercise, they provided the children with real engineering challenges that soldiers may come up against in the field.

One of the most memorable challenges the children enjoyed was a challenge where they had to get a tennis ball from one end of the playground into a bucket at the other end without anyone touching the ball.

The engineering focus was maintained as the children worked collaboratively, changing and swapping adopted roles, discussing possible methods and then adapting and improving the system, having observed and evaluated the results of prior attempts.

Who can build a bridge to support the greatest mass?

Experiment 2: Designing a classroom for creativity

In my classroom, we were already following a Creative Curriculum, which in essence is using a theme or topic with which to engage learners in all areas of the curriculum. In order to further enhance this with the EHoM, I designed some of my own challenges based on the topics that we were covering. An example of this was in our 'Stone Age' topic, where I tasked the children to build a Stone Age shelter. Like engineers, the children had to visualise or think about the sequence of their build within their design documentation, in order to build the shelter.

In our 'Manchester's Rise to Prominence' topic, I challenged the children to design and build a bridge, drawing on their knowledge of the new passenger railway lines between Manchester and Liverpool in the 1830s, after the success of Stephenson's Rocket in the Rainhill Trials of 1829.

The children had to use their prior knowledge about what bridges look like and visualise the materials provided, performing the different functions of the different parts of the bridge. They had to think and test the strengths of the resources available for their build. They had to be engineers.

Experiment 3: Tinkering Corners

In order to place value on our new area of focus within school, we developed spaces in our classrooms that were 'Tinkering Corners'. In these spaces we placed craft resources and question stems to stimulate the children to construct or answer questions based on the science or the term's topic focus. An example of this was challenging the children to work independently or in pairs to design and make an amazing magnetic ornament.

My reflections as a Year 3 teacher

These experiments demonstrated that the new primary National Curriculum does present opportunities that lend themselves to focusing attention on engineering – but they don't happen by chance. There is a need to make the links explicit and orchestrate opportunities through dialogue and hands-on making experiences that allow EHoM to be highlighted, used, practiced and talked about. I soon found that what I was teaching had more purpose – for instance, the need to teach coding in computer science and many aspects of the DT Curriculum were in fact easier to make relevant through an EHoM and engineering mindset. The links flowed – magnets, electricity, materials, forces – all had more purpose and children increasingly used and applied their scientific understandings when engaged in hands-on making challenges. .

The impact was evident throughout the year. I can vouch that the children became much more independent in their learning. I saw them take increasing charge and responsibility for their own activity; they didn't seem to need me so much and looked for my support less frequently and more from each other. Initially, I had to spoonfeed them but, as the project progressed, they grew more and more into independent learners.

Their resolve grew as they started to see failures as learning events and ways to make improvements.

We talked, we talked and we talked – about what was happening when things went well, and didn't go so well, and we were sufficiently relaxed to find answers and solutions together. Of course, as you would suspect, this was seen the most in the specifically-designed challenges and tasks, but the great thing was that I also started to see the attitudes and skills flowing into other aspects of the children's learning and behaviour, as well as other areas of the curriculum.

Did it work for all children?

I can safely say that the large majority of both boys and girls thoroughly enjoyed and engaged enthusiastically in the group challenges. Did they all become leaders? No. A small number of middle- and higher-ability boys and girls naturally fell into this role, the remainder of the class becoming followers, though many still had good ideas. However, that said, they too grew in independence throughout the year. The children with less confidence or lower ability still required more support and guidance, but felt much more part of this type of lesson, as they had valued tasks to complete as part of the team.

A Mindset for Engineering in Year 5 (age 10)

Shane Nolan writes:

As computer science subject leader, I had a vested interest in seeing whether tinkering could support the development of the new curriculum across the school. My starting point was to develop a 'Tinker Corner' in the classroom and to develop Tinkering Lessons.

The Tinker Corner was a marked-out area for what we started to call 'tinkering'. There were display words and descriptions of the EHoM, with additional links to the Computational Thinking Skills. I used the **www.barefootcomputing.co.uk** resources to guide me on this and the stage was then set.

Further examples of tinkering in action:

Topic: An Ancient Greek Ballista (Catapult) – Lesson 1

Focus: History, Science (Forces), Mathematics (angles), Literacy (Instruction writing)

EHoMs: Creative Problem-Solving, Systems-Thinking, Adapting

Organisation: Group of four children

Resources: Each group provided with 6 mop handles and six rubber bands (garden canes and string work just as well), and eventually 6 tennis balls and a plastic bucket

Idea: Make a tetrahedron secured with rubber bands (although don't let the children in on that till they've had their chance to experiment)

Ethos: Children should work together, try things out, find solutions and learn from failure/trial and error.

Timing: 2 hours

The tetrahedron is the first attempt at making a catapult, in that it works, but the next step is that the children experiment with their own designs.

The purpose of this corner was for children to be able to access the area whenever there was a lull in a classroom activity, breaktimes and lunchtimes too. I made it clear to the children that this was 'their' area and not just a display to look at.

The Tinkering Lessons

Each new topic was introduced with a Tinkering Lesson. Working through the Humanities topics, such as the Vikings, the children learned how to light fires and make bread using an authentic recipe. I placed increased emphasis on 'making' – children had more opportunity, resources and time to make and refine models. The heart of the EHoMs diagram states 'to make and make better' and that was worked on as an approach when building *tipis* for the Native Americans. We even took our work one step further – giving the children a sense that their making had application and relevance – we worked outside the classroom boundaries, building and installing a 14-foot *tipi* for use as a small group reading area and fire shelter.

Impact on learning – mine that is, not just theirs!

I have learnt to step back and allow the children time to find their own routes through learning. So often the pace of school life doesn't let us stop to let the children think enough before we are expecting an answer. I've learned not to tell them how to do things and not to impose my solutions on their creativity. I recognise that I might at times have been the limiting factor on their chances to find a creative approach to a problem.

I have learnt that children can and should fail! Deep learning comes from failing, because it's not so much failing as it is trial and error. In September, the children found it very hard to think for themselves; even logging on to the school learning platform was a stretch for some. Now, at the end of the year, they have matured, but their maturity seems more than I have experienced previously in many years of teaching. The children became confident teachers of their younger peers – supporting and teaching Year 1 pupils, something I couldn't have tried at the beginning of the year. When you talk to them about their feelings and opinions on tinkering, they explain about being more resilient and more willing to 'have a go'.

Christ the King RC Primary School is in Salford and aims to provide a secure, happy and Catholic atmosphere within a stimulating environment, where children can develop and learn surrounded by support and co-operation. For further information, please contact **nicola.potts@salford.gov.uk** (Headteacher).

From 'Hack to Hallé' – making a robot orchestra for the Hallé Orchestra

Year 1 and Year 6 pupils from Bowker Vale working together to create a musical robot

Ainsley Moseley, Stephanie White *and* **Mike Knowles** *explore how young learners hack their way through engineering*

As part of the celebration of Manchester being the European City of Science 2016, schools across the City were invited to take part in a *Citizen-Engineering* project, which set out a quest to make a recycled robot orchestra. It is a unique project, which is an experiment itself – to bring people together to create, collaborate and care for the planet. It was dreamed up by engineer Professor Danielle George, and citizen science innovator Dr Erinma Ochu, based at the University of Manchester. Supported by an amazing set of partners, including Siemens and the world-famous Hallé Orchestra, it was seen as a prime opportunity to put the efforts we had invested in our Tinker Tailor Robot Pi project to the test by truly embedding and demonstrating the Engineering Habits of Mind (EHoMs) that the children had developed through their many opportunities to explore, tinker, programme and engineer.

So, if you're interested in making a robot out of recycled materials using what's serendipitously lying around the ICT graveyard in your school, then our experiences will encourage you to have a go too!

Our young engineers – the Queensgate approach

After a whole-school science week, a group of Year 6 (age 11) children who had shown an interest in engineering and computer programming were asked to participate in this project. We used the EHoMs to introduce and discuss the ideas of what an engineer might do on a day-to-day basis. The children's responses to this were varied, to say the least!

Becoming 'hackers'

To assist children in hitting the ground running, the University of Manchester organised a 'Robot Hack Day' – a day when young people from primary and secondary schools could come to begin their Robot Orchestra journey. Initially, the children were nervous and slightly overawed, just by the surroundings of the University. From the introductory talks by Danielle George, Siemens staff and, in particular, Steve Pickett from Hallé Education, the children were hooked and even began feeling and singing the rhythms that they wanted to create in their instruments. Feeling relaxed and confident, the children embarked on a range of workshops – these provided them with the skills that would create the foundations of their instrument-making. We needed to be able to create a programmable instrument that would connect to a master conductor robot and, for this, we discovered the 'Crumble'. This small microprocessor, not too dissimilar to a CodeBug or Microbit, was perfect for us, as it used a programming language very similar to *Scratch*, which we had previously learned. The children were particularly enthused by this, as they achieved a great deal in a short space of time – actually making a beater that was programmed in less than one hour. Another inspiration for us was 'Noisy Toys', which involved the children creating circuits and controlling sounds by fully exploiting their skills of tinkering. The children came away from the day recognising themselves as potential engineers and were enthused to be making a robot for a real orchestra.

Even younger engineers – the Bowker Vale approach

Year 1 (age 5) and Year 6 (age 11) classes worked collaboratively to create the

Impact on the learning back in school

Children benefited from:

- working collaboratively on a making project
- learning and applying their knowledge of and skills in computer science
- using and thinking about recyclable materials
- sharing the programming element of the process and the physical making of the robots
- having the time to evolve a design and the space to tinker with it
- succeeding when they overcame barriers, and they found themselves (without really realising) engaging in a variety of engineering habits of mind

Eventually, after a great deal of tinkering and then further tinkering, the children were happy with their finished robot, which they called 'Charlie "Watts"'.

Pros	Cons
Making provided opportunity for a wide range of EHoMs to be promoted, e.g. systems-thinking, improving, creative problem-solving, visualising	Making needs time within the curriculum (Spring leading into Summer)
Making encouraged collaboration and resilience in the children	Making needs commitment from the Senior Leadership Team (SLT) for long-term support for this area of work
Making put skills into a real life context.	
Making allowed both teacher and child to learn together.	
Making developed and gave purpose to coding skills in a 3D functioning robot	
Making gave an insight into how readily engineering could fit into everyone's curriculum, e.g. using EHoMS	

Pros and cons of generating enthusiasm for engineering through robot-making in school

The Robot Orchestra is one of many ways in which schools can potentially generate interest in engineering in schools. From our experiences, there have been more 'pros' than 'cons':

Bowkerbot – our very own musical robot. Our project linked with the Tinker Tailor Robot Pi project, so we too had developed a strong sense of what EHoMs were and we felt natural links to our school ethos on 'Growth Mindset' (Dweck, 2012). We had already noticed how EHoMs appeared to be a natural habit of mind in our younger children, especially those in Key Stage 1 (ages 5-7), and we were concerned that the older children seemed to lose their natural engineering qualities as they grew older – becoming reluctant to start making tasks for fear of getting them 'wrong'.

Becoming 'hackers'

Our children were the youngest in the Hack Day, with our Year 1 pupils working alongside those from Year 6, and even secondary-age pupils. What was great to see was the way that Year 1 children jumped straight in when making a musical bug, with very little direction. However, we observed that the Year 6 children watched those from Year 1 before they started to 'have a go'. Interestingly, the boys were the ones who needed prompts to get started. It was only when we moved to the building and programming of the robot that, with both age groups, collaboration really started to have an impact. Without direction, the Year 1 children started to build the robot with the junk modelling and the Year 6 pupils began to programme their Crumble Controller. Year 1 children moved between the junk modelling and the programming; Year 6 children listened to ideas from Year 1, and vice versa. Working together, the problem-solving appeared to have a more dialogic outcome, with the Year 6 children starting to talk through what they were going to do, testing, tinkering and trying again.

From a teacher's perspective, it appeared that each child, regardless of age, had a valued contribution to make to the end product and it was heartening to see that at no point did the Year 6 children take over, with Year 1 pupils confident to get involved and suggest ideas.

By bringing the two year groups together, it is possible to suggest that Year 6 children demonstrated EHoMs more than they did working within their own age group. It would appear that, by observing the Year 1 children not worrying about being right or wrong and embracing 'failure', positive emotions were elicited from the Year 6 pupils and a mentality of *'it is okay to fail'*, *'learning from your mistakes is part of what a "good engineer" does'*, was created. Embracing this positive approach to failure resulted in the Year 6 children developing an open mindset to new challenges.

The positive influence of the musical robot was noticed back at school, as Year 1 children continually used their EHoMs when faced with a variety of different tasks across the curriculum. The Year 6 pupils had learnt and understood the importance of a 'fail' and recognised that this is part of the process of what a good engineer looks like. It appeared that Year 6 pupils needed the motivation, enthusiasm and 'permission' to fail. Year 1 children needed the skills in and knowledge of tinkering to have a successful outcome. The 'Robot Hack Day' provided all these skills for both age groups.

What next?

Both schools have seen the value in adopting and embedding an EHoM strand within the science that occurs in school. Having trialled 'tinkering corners', we have found that some year groups are more suited to an area within the learning environment. We would like to develop these areas across the school, so that they are a worthwhile and accessible addition to the classroom. We also realise that engineering is a significant and creative medium for a variety of different skills (as witnessed through this project) and that, as part of action planning next year, we will be looking for opportunities to further extend and embed engineering activities.

For more information about the Robot Orchestra, please visit **www.robotorchestra.co.uk.** We are proud that our robot instruments played at the launch of the European City of Science on 24th July 2016, and will continue to be the legacy of school involvement in a unique engineering experience.

Reference

Dweck, C. (2012) *Mindset: How you can fulfil your potential*. London: Robinson.

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How the 'E' in STEM fights its corner

Ben Tipton *and* **Christine Brannan** *from Sacred Heart RC Primary School reflect on their year as collaborators in the University of Manchester's Tinker Tailor Robot Pi project.*

After reading the articles within this Special Issue, there are probably a number of questions that are evolving in your minds. Here are some answers to the questions that were really pertinent when we were becoming involved and which emerged throughout the process:

Challenges and questions	Our solutions and suggestions
Issue: We are already pushed for time with assessment, marking, feedback and planning. *How can you justify the introduction of yet another innovative approach to teaching into a ramped-up, jam packed curriculum?*	**Merge three disciplines that are already timetabled.** For us, this meant identifying areas of learning in science (electricity), computer science (programming) and DT (moving vehicles) in Year 6 (age 11). In that way, we were only reinvigorating what we already needed to do, not creating extra work or subject content.
Issue: We hear of many initiatives and opportunities and never find the moment to follow them up. *What first inspired you to sign up for the project?*	**Convincing and authentic shared experiences.** We heard from an incredibly enthusiastic teacher who spoke about his experiences in the first year of the project. He had us hooked. The possibilities and positive impact were too good an opportunity to miss. To hear it from a teacher, not someone with a vested interested, made it for us.
Issue: The initial enthusiasm was there as with all new projects…how was it going to be maintained? *What was the most inspiring aspect of the development opportunities that the University provided?*	**Realisation of the impact and 'everydayness' of the project.** There was an Immersion Event, where we met a range of engineers, from aerospace to materials engineers. We started to realise the practical, day-to-day impact that engineering has in the world today. Being inspired ourselves, we took this message back to school, and we decided that we should pay particular attention to the inclusion of girls after one of the speakers, Danielle George, made us think about this when telling us of her journey to be at the forefront of her career.
Issue: We often leave training enthused, but how were we going to ensure there was impact back in school? *What did you take back from this initial event?*	**Collaboration and planning.** We had time to create our project within the Immersion Event, which lasted two days. This was invaluable. Because we worked in a staff team of three, we collaborated to decide on introducing a robotics lunchtime club, as well as considering how we could map it into the main curriculum time. This planning and preparation meant a shared responsibility and inclusion of the work for a longer period of time. There was no chance of this fizzling out!
Issue: The fluid and dynamic nature of schools often creates interruptions for longer-term planning. *Did the project go according to plan?*	**Blending with passion!** The immersion event was in November 2015, yet timetabling issues in school meant that we really started our project in the Spring term. We blended the opportunities into our Summer term to coincide with our school's Science Week. It made us adapt our plans, but children were actively engaged and pretty passionate about the new experiences. They also had fun science assemblies, workshops and inspiring visitors, so did not feel they were missing out. The overall enthusiasm made sure that we finished our project and the buy-in from the children fuelled the process.

Issue: The project focused on the children working in a different way than they were perhaps used to. *What Engineering Habits of Mind were prevalent during the project?*	**Let them try and they will surprise you!** One of the tasks that the children were asked to respond to was to write to local businesses for sponsorship. We did this using the same iterative approach that the children would need in the engineering challenges they were set. They were asked to write, adapt and refine their letters, and we talked about these skills and how they would also be needed for the design, build and programming aspects of the project. They exhibited resilience, perseverance, collaboration, problem-solving and regularly assessed and adapted their work. Collectively, we felt that this was enhanced as a result of the project focus. In the making of their moving vehicles, which became one task, these skills helped move them along. We found the making activities provided richer opportunities to develop and practice communication skills. The children had to talk more to each other to articulate clearly their ideas to one another. A healthy competitive element was also observed between different groups keen to produce the 'smartest' vehicles or products. This happened within a safe space and the children were confident enough to talk more freely, more convincingly and accept alternative points of view than they had demonstrated previously.
Issue: These things are all good fun, but at the end of the day we are all held accountable through children's progress. *What was the impact on teaching and learning?*	**Relevance, context and enthusiasm.** Children's learning and achievement in Design and Technology was better than we had noted in previous years' outcomes. This was likely a consequence of both improved and more confident teaching from us, as we had been able to capitalise on expertise, and we also saw improvement in pupils' attitudes. In science, they were able to apply their knowledge of electrical circuitry to their designs and this provided a secure assessment opportunity in that aspect of the curriculum. As a result of our own increased confidence, we believe this was reflected in the children's abilities. In computing, the making experiences allowed children to identify how programming can contribute to product design and see how it can lead to a career path in computer science, or how it is applicable in many other jobs, such as marketing. This provided a real opportunity for the real-lifeness of the project to come to fruition. It moved the abstract to the concrete and, as a result of making more tangible links, the further application of knowledge by the children seemed to grow.
Issue: Momentum can be lost at the end of the formal input and support from the organisations involved in the project. *Where do we go from here?*	**Whole school buy-in – with support from the Senior Leadership Team (SLT).** The master plan is to roll out the approach to the whole school as of September 2016. The Headteacher is very much on board with the notion of developing children's Engineering Habits of Mind, as he believes in the Growth Mindset models to education and has implemented this throughout school. There is a strong link between the skills and qualities of engineers and the Growth Mindset principles of investing effort and learning from failure. We aim to look at the opportunities to embed EHoM throughout the curriculum, across year groups and to enhance our tinkering areas, and resources are to be strategically placed throughout school to encourage problem-solving through innovative tinkering attitudes. We also think that identifying whole school projects that demonstrate the progression of tinkering will be really useful to explore how children's skills develop over time, e.g. making marble run timers and using the school 3D printer to design and make pen pots. There is no doubt that the Robotics Club needs to expand due to the enthusiasm of the pupils, and especially with a focus on including more and younger children from Key Stage 1 (age 5-7).

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Engineering Habits of Mind… for better or worse?

Dan Hodgson, Peter Cloran *and* **Rory Johnson** *explore the question of whether Engineering Habits of Mind (EHoMs) improve student engagement, behaviour and achievement.*

The concept of EHoM was central to this project. As well as impacting on how children were working and thinking, we wanted to consider any wider benefits and tried to establish if there were positive changes in building parental relationships.

How we developed the EHoM

We first introduced the concept of EHoMs with a targeted group of Year 9 (age 14) pupils who we felt were disengaged with science, technology and computing. These pupils were invited to take part in an engineering challenge with a school in Qatar. This involved making a bridge and rolling a marble over the bridge. The pupils responded very positively to the competitive element of the task and it was soon evident that the challenge started to draw out the traits of EHoM. All groups were testing, then adapting and improving, what they had done with some very creative problem-solving.

Building on the successes of our 'Qatar Bridge Challenge', we wanted to take the project further and consider if we could develop a better relationship with the parents of our participating pupils to show the value that EHoMs could have in their future. But the biggest question, of course, was how could this be done?

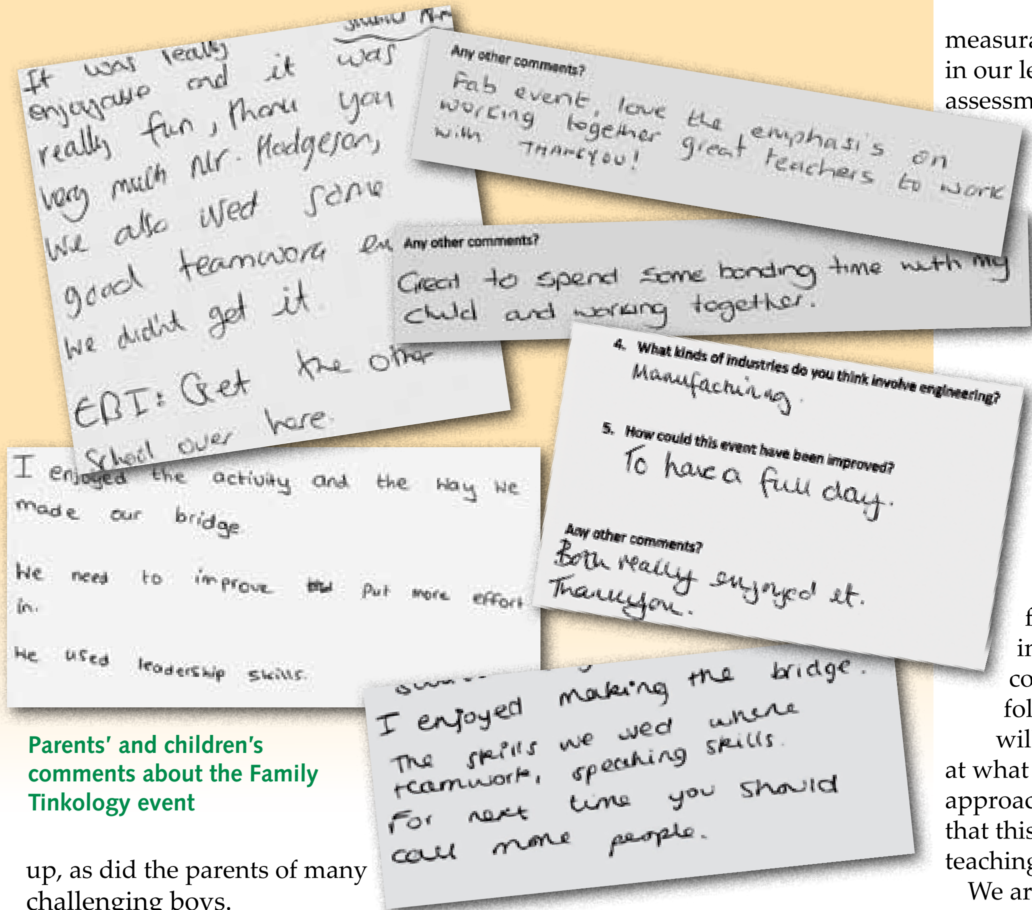
In February 2016, our school held its first Family 'Tinkology' event. This event aimed to allow pupils and parents to 'tinker' with a variety of different materials and ultimately solve an engineering problem. Teams had to build a device that simulated dropping emergency aid into a humanitarian disaster zone, in our case paper parcels of rice and sand. A wide range of materials was available, but these had to be considered in the budget. There was a real 'buzz' about the day, with parents and children making positive comments (see page 17).

With parental engagement being a school priority and the success of this event evident, we embarked on hosting a second 'Tinkology' event (aka 'Tinkology 2.0').

As we were now in the summer term, we decided to host this event outside and aim for something a little more active. This event involved building water bottle rockets.

In response to parental feedback from the first event, a number of changes were made. Firstly, it was an outdoor event and, although our first event was informal, the second had more of a 'picnic' feel to it. The other significant difference was that family teams could make modifications and re-test until they found the optimum solution, which is much more in line with engineering in the real world.

Both Family 'Tinkology' events were very successful and feedback from attendees was positive. Getting parents into school to work with their sons/daughters and each other gave us, as teachers, another strategy for behaviour management – this is particularly important with some of our most disengaged pupils. Relationships with parents who attended the events have improved. One mum who had flatly refused an invitation to a parents' evening from a head of community actually turned



Parents' and children's comments about the Family Tinkology event

up, as did the parents of many challenging boys.

Pupils visibly enjoyed working on EHoM problem-solving activities, which gave them ownership and greater involvement in their learning – allowing them to make further progress. Engagement in the classroom was increased and the activities promoted group work, collaboration and resilience, which led to deeper learning of the curriculum and fewer passive learners; this is a school priority here at Falinge Park.

Perseverance in technology, computing and science improved for a sustained period of time when Engineering Habits of Mind were adopted and incorporated into the curriculum.

Not without challenges…

Other than planning time (we never have enough time!), finding space in the curriculum is problematic, especially as this is undergoing massive changes both on a national level and within our own school. We also found that maintaining contact with parents outside of these events was difficult. Ultimately, the relationships built outside of the class with the pupils, and the engagement with parents, were overriding positives to these issues.

Where to next…

Embedding these events throughout the year will hone our organisational skills and, overall, reduce the amount of time we spend short-term planning during meetings. We have learned as teachers that we need to take more risks. We would like to attract more pupils and parents so, therefore, want to devise a challenge that uses larger and more specialist engineering equipment that people may not have had experience of, in school or at home. We realised that, with stronger links between the family work and the curriculum, we can have a measurable impact on pupil progress in our lessons. This will help us with assessment and meet the demands of evidencing pupil progress, but in a meaningful way. We have seen the benefits with a small group of participants, so we endeavour to widen participation to include younger students and more girls and take opportunities to showcase the work of professional female engineers.

Key to longevity and further success has to be maintaining enthusiasm – avoiding it becoming boring for staff, pupils or parents, is imperative. Risk-taking and the confidence to move away from following the curriculum *per se* will allow us to do this. Looking at what can be taught through similar approaches will hopefully mean that this becomes part and parcel of teaching in our school.

We are starting up an Engineering Club, which allows pupils to take apart, reverse engineer and fix everyday household appliances and products, again promoting the everyday contexts of work and supporting the pupils in bringing learning to life.

Our ultimate goal – introducing the EHoMs to other departments for a whole-school approach. The benefits are not limited to just STEM subjects…every pupil has the potential to benefit from learning to think differently.

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The Empire Strikes Back – Putting the 'E' into STEM

Melissa Loughran *explores what STEM means and how she was challenged to make the most of integrating engineering into learning and teaching.*

Are you looking for innovative ways to enrich your science curriculum? Could you incorporate STEM pedagogy into your school? What does STEM mean to you? Is it:

a. Part of a plant

b. Science and Technology Education through Maths

c. Science, Technology, Engineering and Maths

d. Yet another acronym

***(answer at the end)**

When I first heard the term STEM being used in education circles, I knew it had links with science and was an acronym for something important. But did I really know what it meant and what it stood for? I thought I did, until our school took part in an engineering project to introduce the concept of 'tinkering' into primary schools. By 'tinkering', I mean exploring through fiddling, toying, messing, pottering, dabbling and fooling about with a diverse range of things that happen to be available, in a creative and productive pursuit to make, mend or improve.

When my Head Teacher asked me to lead science, he also gave me the task of creating a 'buzz' about the subject as it was beginning to wither and die, suffocated by a push on English and maths and a busy foundation curriculum. When I heard about the Tinker, Tailor, Robot, Pi project at the University of Manchester, I knew I'd found the buzz he was looking for.

The challenge we faced was how to put the 'E' into STEM learning within our school's curriculum. We knew that National Curriculum Science, Technology and Maths learning objectives were already being met, so how could we justify adding another subject into the mix without making our colleagues keel over? As engineering is not a separate subject within the National Curriculum, it might have been a tall order.

However, introducing engineering-based activities and tinkering into our school ultimately helped us to build more cross-curricular links, thereby making teaching less restrictive for teachers whilst creating empowering learning opportunities for pupils. It also fitted perfectly with the TASC *(Thinking Actively in a Social Context)* approach to problem-solving, which we had already adopted in some cross-curricular lessons. With further creative planning and an interdisciplinary approach, it became increasingly do-able.

After conducting interviews with pupils in Key Stage 2 (ages 7-11), it was apparent that engineering was not perceived as 'cool' by the children. Their comments exposed misconceptions that engineering was a career for men wearing boiler suits and glasses, which may or may not involve engines, bridges and an element of plumbing and greasiness. At that point, we realised that we had a long way to go!

Following immersion training at the University of Manchester for the project, my colleague and I were surprised to find a healthy stock of resources when we returned to school. This included numerous Lego Mindstorms kits and boxes of regular Lego, some of which had been unused for some time. When we heard that we could also borrow some Lego *WeDo* kits from CAS (Computing at School), it made sense to use these kits to gain the children's interest across year groups with built-in progression.

The first step was to hook the children and whet their appetites, so a lunchtime

Lego Club was the perfect opportunity that did not require other staff to take on more work. This was a fantastic way to introduce children to the making and breaking approach to creativity. What we did not expect was that more than 95% of our pupils would apply to attend. It became clear that it was the resources and technology that were highly appealing to the children.

From then on, we took a multi-faceted approach in order to build momentum and interest; setting up tinkering tables in select classrooms, holding staff and parent workshops, plus an engineering-themed Science week. We also made links with real-world engineers, and participated in the Robot Orchestra maker project, for which children created a robotic musical instrument from Lego and recycled materials. This ultimately gave the whole endeavour a genuine purpose, in addition to a satisfying outcome with a high profile accolade for the pupils.

In a way, we had to effectively 're-package' engineering for children, in the form of tinkering, and it eventually became something that everyone wanted to be a part of. It was becoming cool.

Our parent workshops both explained the learning processes involved in engineering and provided hands-on access to the latest technology. The feedback was overwhelmingly positive and our children's family members told us that this was the kind of learning with which they wanted their children to be engaged. Parents, carers and 'engineering heroes' are also a valuable and underused resource, which we tapped into throughout the year. Inviting appropriately skilled adults into school to share the real life application of science in engineering makes the vital link between these subjects and the real world. There were moments of genuine awe and wonder when PhD student and engineering entrepreneur, Alec Owens, visited our children during a series of workshops with his child-friendly data logger. Pupils also relished the opportunity to chat to engineers from a variety of fields online about their early inspirations and day-to-day activities.

Whilst the majority of teachers do not have an engineering background, this should not be seen as a limitation. It has been a revelation to me that you don't have to be the expert – you can explore resources and be creative alongside the children, acting as more of a facilitator than an 'imparter' of knowledge. Verbalising that we, as adults and educators, do not have all the answers without enquiry is a powerful tool for modelling the process of becoming a competent lifelong learner, precisely what we want our pupils to be. This will require a growth mindset for many teachers, as we have been trained to acquire sufficient subject knowledge in order to be experts in everything we teach our pupils. To be a STEM educator, we must be brave and embrace our own 'fantastic failures' if we expect the same of our pupils.

For those teachers who remained reticent about new technology and unfamiliar with facilitating independent learning, we created pupil STEM ambassadors who were available 'on-call' as a source of support. This was a win-win for boosting the self-esteem of selected children, whilst creating an ethos of collaborative learning between adults and children in a two-way exchange.

It takes time to embed a new pedagogy into regular teaching practice, so holding a cross-curricular engineering week was a good starting point for us to involve the teaching staff. Applied science lesson plans (with engineering challenges) were provided, which then acted as templates for further planning. This introduced the terminology, problem-solving strategies and skills required for teachers as well as pupils.

Regular feedback from staff was important in order to address any teething problems or ongoing development, and ultimately led to the ever-pressing issue of assessment. What learning were we focusing on during guided tinkering sessions? How and what should we measure and record? For us, the obvious answer was through ongoing verbal feedback throughout the facilitation process, coupled with self- and peer-assessment.

We found that it was manageable to photograph children's activities as a permanent record, and then allow the children to evaluate their progress and next steps after the lesson using a tick sheet and short learning statement. The learning focus for lessons was a combination of curriculum knowledge, enquiry skills and key skills.

The phrase 'fantastic failures' has now become synonymous with success and has created an ethos that is in keeping with our school's language for learning. We have found that tinkering rewards effort, resilience, perseverance and ongoing reflection, which can often be difficult to foster in traditional lessons.

STEM learning has now had a very prominent 'E' put into it at Seymour Park Community Primary School. We still have some way to go before engineering is fully embedded into our curriculum, but progress has been rapid over the last 12 months, and the associated philosophies have had a significant impact in multiple areas of school life. Tinkering has taught us all the importance of collaboration, making links, perseverance and overcoming failures: teachers, parents and pupils alike.

***So, to answer the initial question – STEM is (c) Science, Technology, Engineering and Maths. Indeed, it is another acronym (d), but one that will hopefully be of increasing relevance within the Primary National Curriculum so that teachers can ultimately help to develop more highly skilled engineers of the future.**

Melissa Loughran is a Year 4 (age 9) teacher and also the Science Lead at Seymour Park Community Primary School. Throughout the Tinker, Tailor, Robot, Pi project, she has been supported by **Lucy Spellman**, a Year 1 teacher at the same school.
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To tinker or not to tinker?

Jon Chippindall *pulls together the thoughts and outcomes of this project and discusses the wider impact of tinkering.*

Figure 1 A billboard encouraging the US maker culture (Share and Share Alike License).

Every week, thousands of 'makers' worldwide indulge their passion for creating, inventing and meddling as they visit 'Tinkering studios', 'Tinkerlabs' and 'Tinkergardens'. Such 'makers' are inherently engineers; exhibiting many of the Engineering Habits of Minds described in this Special Issue as they draw upon their knowledge of science and technology to dream up and bring into existence their wonderful, and often wacky, creations.

Makers are a curious bunch. They like to fiddle with stuff; to play; to adapt; to pull apart; to improve; to pull apart some more; and to wonder how to get it all back together. It has been our observation that tinkering can help us describe these processes when they come together. Tinkering is an expression of this curiosity and plays a large part of makers' experience. Indeed, we can see how many of the environments in which makers work even title themselves using the tinker 'brand' – Tinkerlab, Tinkergarden, etc.

These spaces blur the intersections between art, science and technology, creating environments in which young people can play with, make, refine, de-model or repurpose materials and machinery in creative, purposeful pursuits. The interplay between curiosity and tinkering is interesting to consider; Loewenstein (1994) describes curiosity as being evoked when we become aware of what we don't know – we feel a desire to plug this gap in our knowledge. The interplay between curiosity and tinkering is something akin to the 'chicken and egg' debate. Tinkering allows us to explore the edges of our understanding, and this feeds our curiosity, which makes us want to tinker more, which feeds our curiosity – I wonder which came first?

Chat to makers and you'll hear them talk passionately about the value of tinkering for learning, often citing stories of their own experiences tinkering with various technology and tools as a way to develop skills and knowledge. Indeed, the author's early understanding of aerodynamics came from tinkering with (and regularly crashing/rebuilding) model aircraft.

Tinkering for learning

- **So how might tinkering work within a school context?**
- **What does tinkering look like in schools?**
- **What are the potential benefits and pitfalls of tinkering as a pedagogy for learning?**

The work over the last couple of years of participating schools in the Tinker Tailor Robot Pi project has helped stimulate discussion around such questions. Such discussions are constantly evolving, as we continue to tinker with what we know, or think we know, and would welcome input from the wider education community.

To review elements of this discussion, we need to recap our definition of tinkering, since variety in definitions exist. Our working definition for tinkering is as follows:

Tinkering is exploring through fiddling, toying, messing, pottering, dabbling and fooling about with a diverse range of things that happen to be available in a creative and productive pursuit to make, mend or improve.

Tinker time

Firstly, it was clear from discussions with participating teachers that the ethos of tinkering provided increased legitimacy to offer pupils time for exploration and experimentation – a learning experience that teachers deemed valuable to pupils' development and viewed as, perhaps, currently lacking in Key Stage 2 (ages 7-11). This aligns with Krieger *et al* (2015) who suggest that tinkering appears to be inextricably linked to exploration and exploratory behaviour. They state that *'it is generally considered an informal practice, often with a purpose of improvement, and is commonly associated with experimentation, or "trial and error" methods. As a problem-solving technique and learning strategy, it is often in contrast to formal, established, or prescribed methods'.*

Examples of children's tinkering activities were: making towers from blocks with a range of different requirements; looking inside technology such as old computers; using and making robots that could be programmed to move; designing building spaces from a brief; 3D model-making; building model bridges, etc. Whether using the new technologies and programming techniques provided by Raspberry Pis, BeeBots, Crumbles, Scratch and Python within the computing curriculum, or by broadening the range of approaches to teaching through problem-solving in design technology, 'tinkering' seemed to be a language that all teachers felt comfortable to use and a concept with which they found easy to work.

Discussions illustrated that teachers saw their role, when learning through tinkering, as being supportive rather than directive, even where they found it challenging to step back and watch things going wrong. Teachers refrained from providing answers to children, but looked to question and scaffold the tinkering process so that children retained ownership of the product they were making. In one particular case, the teachers explained how adopting a tinkering approach enhanced the opportunity for creativity (see further below) and, although taking more time than 'standard' lessons, such learning reached out to pupils who would usually not achieve as well as others, in particular the lower achievers.

Knowing what to do when you don't know what to do

Many teachers discussed the value of tinkering in developing pupils' skills in learning how to learn. This came about since the open nature of tinkering meant that pupils often encountered situations for which they hadn't been prepared, and so had to problem-solve. Many deem a metacognitive approach of 'learning how to learn' to be a critical skill for a fast-paced and ever-changing world driven by technological innovations. It was evident in the project that pupils were being proactive in thinking about who/what/when to ask for help – could they find an answer on a forum or *YouTube*, or should they just keep trying for the moment?

Tinkering, curriculum delivery and assessment

What was evident from the project was the inherent tension between the freedom that tinkering affords to a learning process and the requirement of teachers to cover specific National Curriculum content. Teachers will most likely find that it is difficult to guarantee complete coverage of the National Curriculum for every child, if solely relying on tinkering as a pedagogy. The use of tinkering has, like any other approach, to be fit for purpose and, as such, should be one element of a toolkit of creative

Tinkering approaches to learning

When considering what school-based tinkering might look like, teachers involved in the project used 'tinkering' to describe approaches to learning that were:

- hands-on and incorporated a 'making' experience
- child-led or child-centred, where teachers became facilitators, coaches or mentors in the learning process
- collaborative, where children worked with their peers, with older or younger children and with the teacher as co-learner
- playful, where taking time to investigate, experiment and try out ideas was encouraged and celebrated
- emergent in their outcomes, where teachers and children defined and refined their intended outcomes during the process of making and experimentation, rather than having them set from the outset
- sometimes competitive, where children worked together in teams, incentivised to design and make a product that surpassed their peers
- challenging, and prompted a need to persevere in the face of adversity, where children needed to cope with failure by accepting and appreciating this as part of the tinkering process

Tinkering and creativity

At the crux of tinkering is a sense of freedom and openness to try, explore and follow ideas, enabling creativity and feeding curiosity. This is in contrast to activities where we have a very definite end in mind before we begin, and the 'create' process simply funnels pupils towards this predefined outcome (see Figure 2).

Tinkering is iterative and messy and can be thought of in opposition to a more traditional linear process of plan-make-evaluate. Tinkering is more agile than this; we might, for example, make a brief plan before starting to create, and then adjust our plans in light of successes and failures in our project as we go – 'on the fly'. Tinkerers need to be reflective, as they are constantly evaluating what is and isn't working and what opportunities this presents.

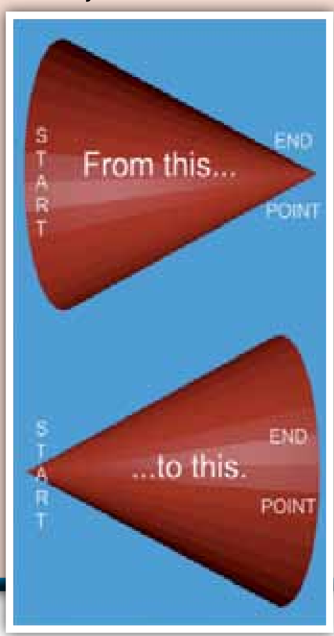

Figure 2. Changing working and thinking through tinkering

teaching and learning approaches that teachers employ, alongside and including more structured approaches such as guided discovery and direct teaching.

The challenge of taking a flexible learning approach through tinkering, and applying a metric or rigour to it via a framework, is in itself problematic. Yet, if tinkering is to be embraced as a pedagogy for engineering education in schools, then teachers will need to qualify and/or quantify learner outcomes. The English educational culture will require us to know and make visible the skills that pupils are developing. Bianchi's (2002) thesis on the development of personal skills and capabilities, including creativity, in science provides a supportive model of development that could potentially be applied to learning through tinkering. She describes how a learner can develop in four ways: knowledge and understanding about the skill; being able to critically self-assess one's own capability; having the know-how or strategies to improve; and demonstrating the skills in problem-solving settings. In this way, it is suggested that, in order to further consider whether tinkering can be progressed, further exploration will need to be undertaken that specifically examines this as an area of study. What was apparent within this study was that, across the project group, there emerged a shared understanding and explicit articulation about what tinkering entailed and the culture it created within classrooms, which, if captured, could begin to define the features from which a metric for progression could emerge.

Conclusions

At a time when the grand goals of STEM education continue to focus on the desire to inspire the next generation of scientists and engineers (The Royal Society, 2014; European Commission, 2015; CBI, 2015), the Tinker Tailor Robot Pi project continues to explore pragmatic questions about schools' cultural and curriculum challenges, and opportunities faced by teachers in English schools who have interest in enriching the teaching and learning of engineering education.

Observing pupils', and teachers', enthusiasm and engagement in tinkering challenges in project schools provides a strong indication of the value of tinkering as a pedagogy to develop engineering education and habits of mind. However, this comes with challenges, as the responsibilities of schools to deliver a set curriculum are very different to the requirements of hobbyist maker spaces.

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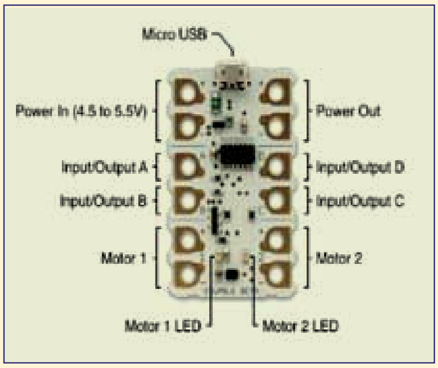
The Crumble Controller

www.redfernelectronics.co.uk

Designed for tinkering

At the heart of many of the Tinker Tailor Robot Pi projects sat the Crumble Controller. This low-cost, small programmable controller is capable of bringing engineering projects to life, as it can drive motors, light LEDs and take inputs from the physical world through a variety of sensors.



The Crumble controller

The Crumble Controller is made in the UK by Redfern Electronics (www.redfernelectronics.co.uk) and, with a starter kit costing just over £21, is an affordable way for schools to provide their pupils with experience of 'physical computing' – a requirement of the computing National Curriculum.

Redfern explain on their website how the Crumble was *'designed for tinkering'*; certainly, the block-based programming language inspired by MIT's *Scratch* does allow pupils to quickly and easily build programs by simply snapping together blocks of code (see screenshot below). Similarly, the hardware of the Crumble itself is designed for quick experimentation, as it can all be connected together with just a few croc clips and a USB lead.

A screenshot of the Crumble programming language showing a simple program turning a motor on and off.

The Crumble Controller

Programming language	Visual language inspired by Scratch (Available for Windows, Mac OS X, Linux)
Connection to computer:	Micro USB
Power:	3 x 1.5 AA Batteries in battery box
Motor connections: variable speeds	Can drive 2 motors in forward or reverse at
Inputs/Outputs:	4
Output devices available:	Multicoloured LEDs (sparkles), servos, motors
Input devices available:	Ultrasonic distance sensor, push button switch, line follower, light dependent resistor

What our teachers thought about using the Crumble:

'Throughout the year, our Engineering Club, which consists of children from Years 5 and 6, have been using the Crumble kit in a number of projects. I was very surprised at how quickly the pupils took to using what looks like a relatively complicated piece of kit. This is one of the major benefits of the Crumble, as it can be used in a relatively simple way and then, as the pupils grow in confidence, it can gradually be used to perform a variety of more complex tasks. More importantly, it showed pupils in a real life context what their codes were doing and it was great to see pupils solve a problem and the joy on their faces when their machine burst into life. After being supported to explore how something works the first time, our pupils could then normally use the kit independently. The pupils really understood the interface on the Crumble and took to the updates very well. Overall the Crumble was structured enough that pupils could find answers to problems independently, but also allowed them the freedom to tinker'
(Matt Hanley, class teacher at St. Chads Primary School – Tinker Tailor Root Pi Project School).

For more information, and to purchase the Crumble Controller, please visit: **www.redfernelectronics.co.uk**

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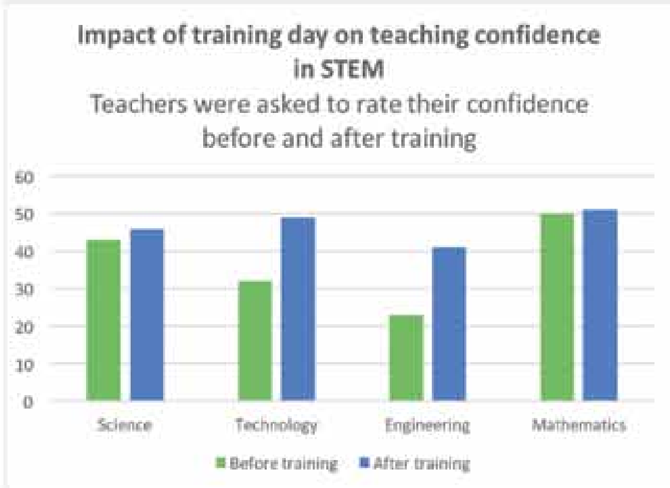
Primary Engineer have been developing teacher confidence in STEM delivery for over a decade through engineering classroom projects which, importantly, always begin with a one-day teacher practical CPD course. The rationale behind this is that if we want a project to be successful, we believe there is a need to upskill and inspire those who will be leading it.



Following one of our most recent training days, a teacher called it, "the best CPD I've ever had." The end-of-course evaluation demonstrates both the jump in terms of teaching confidence of STEM but also the very low starting point for teacher confidence in delivering the 'silent E' of STEM. And this trend is replicated across the hundreds of training days we deliver in the UK every year.

So what next for those teacher who enjoyed the course? And how to continue to build on the skills of teachers in this 'silent E'?

In 2015, with funding from Skills Development Scotland, we created a Professional Recognition course for teachers called Engineering STEM Learning. It provides teachers with the opportunity to engage with a deeper understanding of educational theory around STEM but, furthermore, the chance to increase their links in industry by connecting with engineers across a range of professional levels and engineering disciplines. The teachers then complete a cycle of action research and some of the interesting themes that have developed across their work has been their roles as influencers in combatting gender underrepresentation in STEM in further and higher education and in the workplace and reflections on their own teaching orientations and how it has / hasn't promoted the skills they have identified as important in engineering.

The course is currently being accredited as a PGCert at the University of Strathclyde, who have supported the programme since the beginning, allowing teachers to achieve 60 Master's level credits towards a MEd.

"The strengths of the course are the quality of training events, lectures and information we have received. The rigor of the course has been a strength. I really feel this has stretched me, deepened and broadened my understanding and given me real food for thought."

Primary school teacher
****Current course evaluation captured 14/10/2016***

http://www.universeofengineering.com/

For more information regarding the CPD course, please contact lise.mccaffery@primaryengineer.com

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