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tinkering for learning

Learning to teach engineering in the primary and KS3 classroom

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About the Science and Engineering Education Research and Innovation Hub at the University of Manchester (SEERIH) www.fascinate.manchester.ac.uk

SEERIH specialises in working with in-service primary and secondary teachers. Its vision is to develop inspired communities, of confident and curious teachers, striving together to drive the continuous improvement of teaching and learning in science and engineering education in the UK. Through a programme of professional learning, including events, courses, clusters and projects, it is supported by a range of educational bodies who share the passion to enhance young people's opportunities in STEM towards future careers and prosperity.

To contribute to the work in this area with SEERIH contact fascinate@manchester.ac.uk

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Executive summary

This report explores the ways primary school teachers can develop teaching approaches that lead to better and more engaging learning opportunities for would-be engineers. It has been developed with primary and Key Stage 3 teachers from schools across Greater Manchester and Cheshire in the UK. It builds upon the Royal Academy of Engineering's *Thinking like an engineer* report[1], which identified seven 'Engineering Habits of Mind' (EHoM): making things that work, problem-finding, creative problem-solving, visualising, adapting, improving and systems-thinking. It also complements the further work conducted in this series of reports into how these characteristics or attributes of engineers can be nurtured and cultivated in young people through the education system, which was presented in *Learning to be an engineer*[2].

Drawing on the professional learning from a previous University of Manchester study *Tinker Tailor Robot Pi* (2014–2017) and shared research with the Centre for Real World Learning at the University of Winchester, this report focuses on how 'tinkering for learning' can act as a signature pedagogy of engineering in primary schools. In contributing to existing schemes in this area, this report offers insight into *Seven Principles for Engineering in Primary Schools* distilled from evidence gathered by teachers in their classrooms to define and exemplify a model of teaching and learning approaches for engineering in primary and secondary education. The report offers insight into the 'habits of classroom practice', which are intended to provide practical guidance to teachers who aspire to encourage an ethos for engineering in the mainstream curriculum with young learners. By taking these principles and creating resources mapped to the mainstream curricula of computer science and science and design technology, they turn the concept of 'tinkering for learning' into a practical guide to grow a practice of engineering education.

The seven principles are presented below.

7 Principles of primary school engineering education	
1	Pupils are engaged in purposeful practical problem solving
2	Pupils take ownership of the *design and make* process
3	Pupils embrace and learn from failure
4	Pupils' curiosity and creativity is responded to
5	Pupils demonstrate mastery from other curriculum areas
6	Pupils draw on a range of thinking skills and personal capabilities
7	Pupils' learning experiences are guided by a whole-school approach

1 *Thinking like an engineer*, Royal Academy of Engineering and the Centre for Real World Learning. 2014 **www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report**

2 *Learning to be an engineer*, Royal Academy of Engineering, the Centre for Real World Learning and the University of Manchester. 2017

The report supports earlier findings in *Learning to be an engineer*, by demonstrating that:

- with targeted professional learning support, teachers can design, implement and evaluate ways to encourage the principles of primary school engineering education that capitalise on the mainstream curricula of computer science, design technology, science and other subjects
- teachers value planned opportunities, within their working day, to come together and share professional practice. This has been most beneficial when brokered with cross-sector colleagues including engineers, academics and students
- the investment in teacher professionalism leads to children's learning readily being reframed to embrace a culture and practice of engineering. The EHoM are helpful in moving beyond the often contested space of individual subject disciplines
- with senior leadership support, commitment and bravery, teachers can find the space for engineering education to underpin and thrive within the mainstream primary school setting.

This report further endorses the six broad recommendations offered by the Royal Academy of Engineering, with a keen focus on primary school education.

1. The need for more extensive promotion of EHoM as a mechanism for improving science (and engineering) capital in young people and the provision of more resources for teachers who wish to adopt the pedagogic approaches identified in the report.
2. The enhancement of existing professional learning networks for teachers to encourage collaborative professional learning and ensure the more rapid spread of effective pedagogies and curriculum design and implementation for engineering education in schools.
3. The potential synergies between engineering, design technology, computing and science, including the use of thematic curricula with real-world contexts, should be actively explored in all stages of the school curriculum.
4. A more strategic focus on school leadership in driving change in support of engineering education should be developed.
5. More research is required to understand how progression in EHoM can be measured.
6. More research is required on how more engineers can best be engaged in schools.

“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.”

Nichola Potts, Head Teacher
Christ the King RC Primary School, Salford, Greater Manchester

Introduction

This report is divided into sections that are representative of the flow of the study over three years. Working with teachers, using a project-based approach, key findings lead to further exploration and evidence that were discussed within and beyond the group. Peer review was sought through regular presentation of findings at national and international conferences and symposia, which challenged and further inspired new areas of development.

The landscape of engineering education in primary schools

There is ongoing recognition of the shortage of engineers in the United Kingdom[3]. Given shortages of teachers in key subjects leading to engineering, there are also questions as to whether the education system currently has the capacity to meet the forecasted demand for skilled engineers in 2024[4].

While significant investment is being made across the UK in engagement programmes and activities focused on increasing the number of young people in secondary education entering the STEM workforce, there is growing interest to encourage this to start earlier in the primary years[5]. Of course, few areas of development start in a vacuum and inspiration comes from development and professional challenge. It is encouraging that schemes such as Tomorrow's Engineers, Faraday Challenges, Greenpower and many other programmes of intervention and activity focus on enriching the opportunities for pupils to work with business, industry and the engineering profession. The prevalence of such schemes for primary school-aged pupils, and indeed professional development opportunities for teachers to enhance engineering education, is small with limited activity, so it is an area of potential growth.

With a specific focus on enhancing teachers ability to shape lessons for primary and secondary pupils within the *mainstream* curriculum (as opposed to providing extra-curricular activities), this report offers insight into how the 'tinkering for learning' project has succeed in contributing to existing programmes. It specifically explores the pedagogical approaches that lead to young children developing both the technical and thinking capacities for engineering from their infant years.

This report provides a summary of activity and impact from the *Tinker Tailor Robot Pi* (TTRP) project and more recent work towards the signature pedagogy of 'tinkering for learning'.

In 2014 and 2015, the TTRP project was carried out by the Science and Engineering Education and Research Innovation Hub at the University of Manchester among in-service primary and secondary teachers, university academic engineers, and pupils. It explored which professional learning opportunities could improve teachers' confidence to create engineering education learning experiences in primary and lower secondary school settings.

The key issues the project aimed to explore and solve were:

3 EngineeringUK 2018: *The state of engineering*. **www.engineeringuk.com**

4 *The UK STEM Education landscape*. Royal Academy of Engineering. 2016 **www.raeng.org.uk/publications/reports/uk-stem-education-landscape**

5 *ASPIRES. Science and Career Aspirations: age 10–14* Archer, L et al. Kings College London 2013 **www.kcl.ac.uk/sspp/departments/education/research/aspires/ASPIRES-final-report-December-2013.pdf**

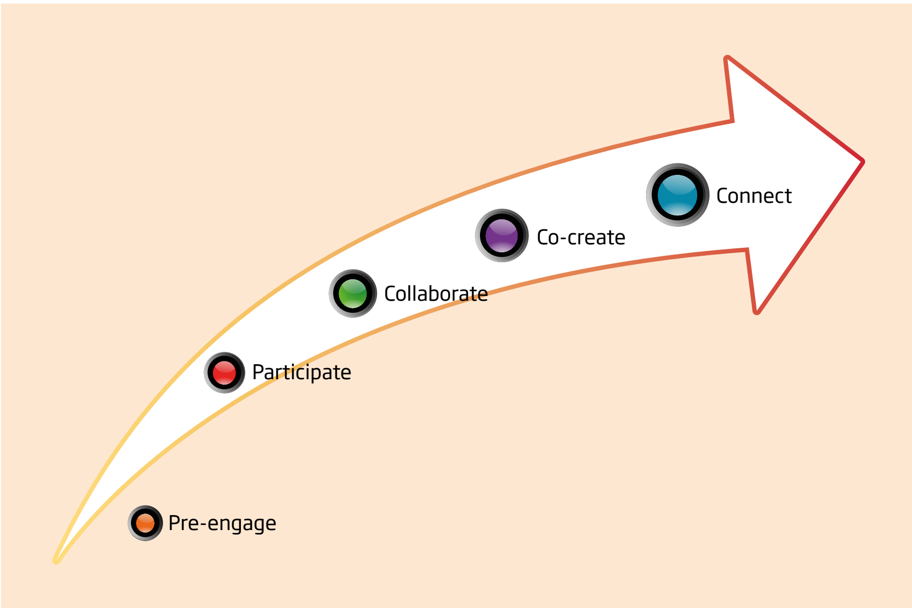
1. The missing or limited opportunities within the primary and secondary curriculum to genuinely exploit the links between science, computer science and design technology. This seemingly continued into secondary school.
2. The aspects of learning that were desirable to address, yet continued to pose significant challenges to teachers. In particular, the control aspects of programming within the computer science curriculum and how programming and control could be used within children's design and make activity in design technology and science.
3. There are few opportunities to explore and unpick what 'engineering' in a primary school setting would look like and the pedagogy that would best facilitate it. Engineering is not a subject in primary (or secondary) education, nor is there national discourse around its value to primary learners.

Working with teachers to innovate within the mainstream curriculum

A professional learning programme was designed for the research presented here based on the *trajectory of professional learning*[6]. This is presented as a five-stage development model that a teacher moves through from pre-engagement to participation through to connecting. This is called the Trajectory of Professional Development (TOPD) and is illustrated in **figure 1**. The upward movement along the trajectory moves towards teachers becoming leaders and influencers in a field of practice. These 'essential' stages guide reflection on professional development and support those developing it to offer the *'right development, for the right teacher, at the right time, and the right issue'*.

The arrow frames the development across five stages of professional growth and the context in which it happens. The TOPD denotes an increasing level of ownership and autonomy a teacher can adopt regarding their personal development and, in doing so, relates to the development of their identity as a leader – in primary school engineering education in this case. The TOPD model recognises that leadership development is defined and perhaps tightly related to a context, a setting or a place that has impact and influence on the teacher's position at one time.

Figure 1 – The Trajectory of Professional Development (TOPD): a model for teacher leadership



6 Bianchi, L., (2017) *A trajectory for the development of professional leadership in science education*, Journal of Emergent Science, Winter 2016/17, Vol 12, 72-83, The Association for Science Education.

In this way the model acknowledges how the school culture and senior leadership support, as well as national accountability, can advance or hinder a teacher's progress within engineering education. In the best cases it has been shown that, where a teacher embraces their own development along the trajectory and where the school context, culture and curriculum is supportive of experimentation, reflective practice and risk taking, learning can thrive and assist the refinement of teaching and learning approaches resulting in positive learner outcomes.

Alongside making the progressive nature of professional learning more explicit, the TOPD model emphasises the importance of 'co-creation', an interactional process essential for teacher development. This is a stage of development when a teacher goes beyond collaborating with others (to share information and explore existing ideas that they receive from others), into a role where they focus on improving teaching and learning for students through the creation of their own new ideas or approaches. At this stage the teacher takes what they know and have learnt to creatively explore new options, possibilities or designs for learning, whether that is an approach, a resource or behaviour.

In this way, by emphasising the need to co-create, teachers are found to be autonomous in using their pedagogical curiosity to refine and re-define their approaches to teaching and learning, or to respond to their own educational values and philosophy to create new methods or processes to influence success in classroom practice. This is a risky and brave approach to take within the current educational climate, and during the TTRP project was challenging to all teacher groups who were working to establish the culture for change within the STEM curriculum as well as experimenting with new approaches in their own teaching. Coming together as a community of practice, engaging in the activity as a cluster and community, and working with the University of Manchester, provided support. It also required the teachers to describe and justify their suggestions through research focused-questions. It is necessary to counter the assumption that teachers move seamlessly between one sphere or stage of leadership, but require and benefit from tailored, responsive and fit-for purpose professional development to enable effective change.

Teachers involved in the TTRP project were exposed to professional development that was designed at the levels of collaboration and co-creation and have since moved to the connect phase. By including co-creation in the TTRP projects, teachers were offered opportunities not only to respond to the reforms of others, but to define them through their own professional voice before disseminating to others. They have become knowledge creators inputting new learning into the STEM sector.

Establishing 'tinkering' as a bridge into engineering education

It may be appropriate to ask why this study focuses on 'tinkering' in the development of teaching and learning approaches for primary school engineering? What value does the use of this term, as opposed to 'engineering' bring?

The TTRP project coincided with the release of the *Thinking like an engineer* report. In doing so, the seven EHoM shown in **figure 2** were reviewed and built into the dialogue and thinking within the professional learning experiences that teachers and engineers shared together.

The lens through which the research was conducted was very practical and pragmatic and the EHoM were interpreted and exemplified through activity with teachers as well as their work with pupils. It was evident from teacher responses that greater depth of understanding about how engineers think and work better equipped them to design curriculum opportunities to integrate such skills. The EHoM provided a consistency in language for teachers from which to develop and reflect on learning methods and progress as young people developed in thinking as engineers.

At this time, tinkering was being used more fluidly by the maker movement[7]. In such spaces the intersections between art, science and technology seemed to be increasingly blurred and spaces open up where young people play with, make, refine, remodel or repurpose materials and machinery in creative, purposeful pursuits. Teachers found such processes and skills were found to be attractive and a stimulus for ideas and experimentation. It seemed that 'tinkering' released curiosity and excitement for engineering practice in schools, and the term soon became used pervasively across the project group.

The term tinkering relates to taking apart and rebuilding, repairing or improving something – historically these have been mechanical in nature, but more recently electronic and digital. A study on mathematical habits of mind extended this notion to 'taking ideas apart and putting them back together again'[8].

In *TinkerLab: A Hands-on Guide for Little Inventors*, Rachel Doorley presents strong alignment with the EHoM in suggesting that tinkering begins with problem solving and curiosity about how something works[9]. She further relates it to the process-based approach that embodies

7 Maker movement – an umbrella term used for a social movement of independent inventors, designers and makers. The Maker culture emphasises informal, networked, peer-led and shared learning motivated by fun and self-fulfilment. Tinkering activity and terminology in this domain includes tinkering studios, Tinkerlabs and Tinkergardens.

8 *Habits of Mind: An organising principle for Mathematics Curriculum*. Cuoco A., Goldenberg, E. P., Mark, J. 1996 **www.promys.org/sites/promys.org/files/assets/Habits%20of%20Mind%20by%20Al%20Cuoco.pdf**

9 *Tinkerlab: A Hands-on Guide for Little Inventors*. Doorley, R. Roost Books. 2014

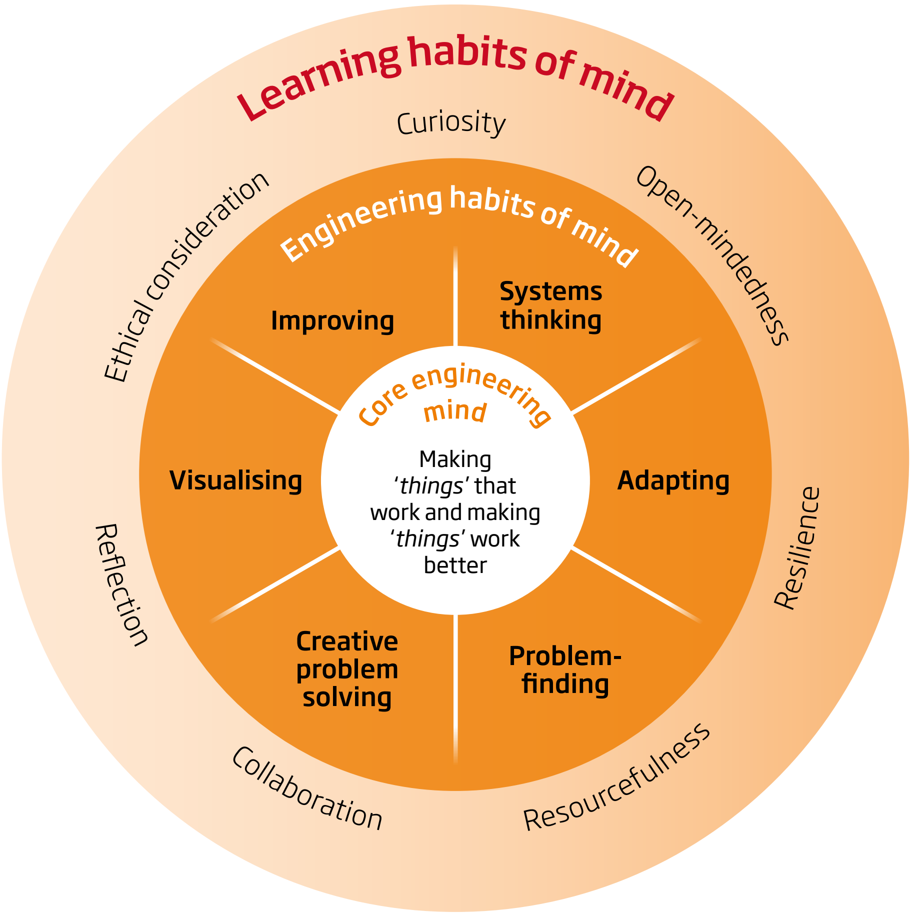


Figure 2 - Engineering Habits of Mind (EHoM)

tinkering, which is supported through discussion, tests, experiments and play.

However, Resnick and Rosenbaum caution against the overuse of the term *tinkering*, which they suggest can be used dismissively[10]. In addition, it has connotations with a lack of seriousness. The association of 'just tinkering' with someone working without a clear goal or purpose, or without making noticeable progress, is counter to the 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. The authors would share Resnick and Rosenbaum's perspectives, which suggest that when people are tinkering, they are constantly trying out ideas, making adjustments and refinements, then experimenting with new possibilities with clear purpose in mind, linking closely with the *Improving* EHoM.

What does emerge from the literature is a tension between tinkering and a 'traditional' linear approach to creating that is more constraining, for example we create a plan, we make what we have planned, and we review what we have made – typical of the engineering design cycle. By contrast, while 'tinkering' still incorporates all three stages, it is a more agile approach. In the education context, this method provides primary learners with the time and space to flit back to their plan to adjust it as they are making. In this way tinkering might be viewed as an inferior approach to planned scientific practice, and one that has a level of disorganisation or indirectness that frees an individual from getting things right, and 'to plan' the first time.

10 *Designing for Tinkerability* Resnick, M and Rosenbaum, E (Chapter 10) Honey, M & Kanter, D E, Design, Make, Play: Growing the Next Generation of STEM Innovators, Routledge. 2013

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

This study worked with teachers to further test how and why 'tinkering' could be a conduit towards inspiring novice teachers into working in these playful, experimental, practical and make-rich ways. The authors accept that using the term tinkering in this way could lead to potential misunderstandings with readers and teachers who may accept that the general premise of tinkering is an act of aimless exploration or activity, whereas the activities identified within this report are more structured and thoughtful, as suggested by Resnick and Rosenbaum (2013).

The term tinkering has been used by teachers as a bridge to move across the boundaries of engineering and education and as such promotes the ethos of play and experimentation within the curriculum and classroom. It has challenged them to consider alternative more agile teaching approaches that contrast with the more frequently found objective- or outcome-led approaches that are currently emphasised in UK schools. It is important that tinkering in an educational setting is presented as a productive pursuit and that the term is seen as a bridging concept allowing teachers and educators to explore how the agile, yet purposeful process of tinkering can encourage an ethos of engineering in primary school settings. In this way 'tinkering for learning' was defined as a means of clearly representing the tinkering promoted in this research had purpose and impact in mind and that young people's learning was the core and intended outcome.

Three approaches towards learning ‘to be’ a teacher of engineering

A core group of schools have remained with the project since its initiation. The professional learning journey can be brought together through the three phases as outlined in the diagram in **figure 3**. Four key learning approaches arise from these phases.

Approach one:

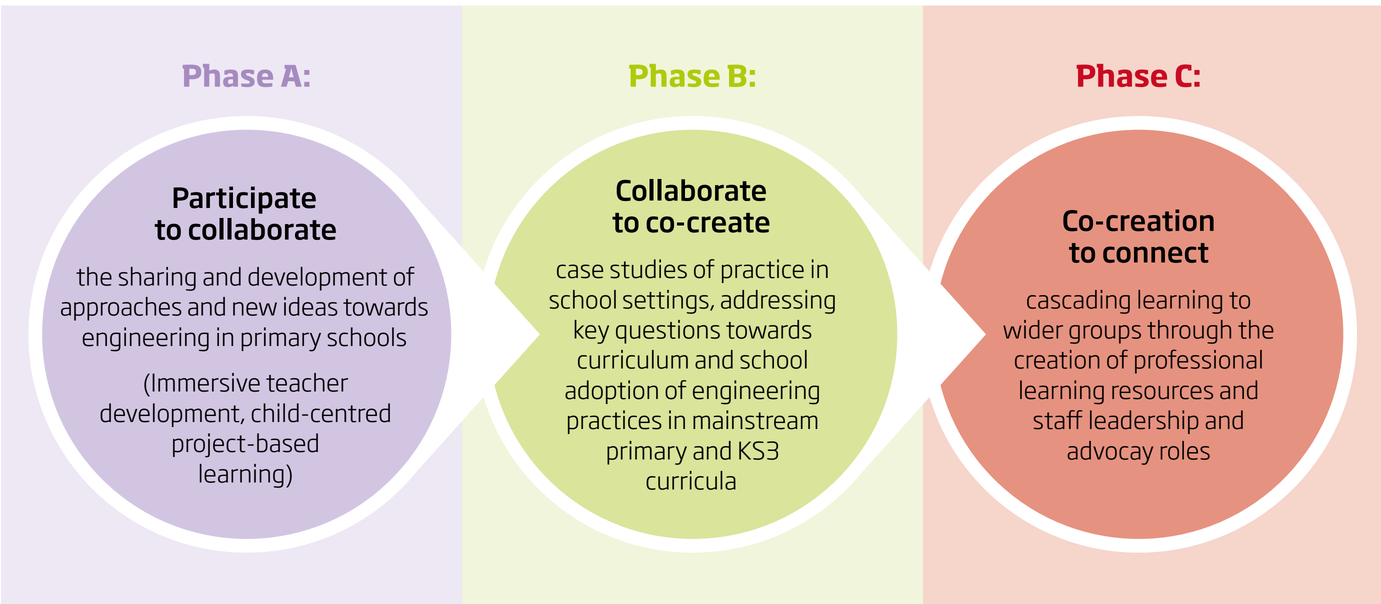
Teachers undertake planned opportunities, within their working day, to come together and share professional practice. This has been most beneficial when brokered with cross-sector colleagues, including engineers, academics and students.

Learning: Teacher commitment required with this approach is high. It is also challenged by current funding and accountability pressures in the school system, which require teacher classroom ‘release time’ to be limited, or targeted at high-impact activity.

The research team maintained a core focus on ‘*doing with, not doing to teachers*’, learning alongside teachers and drawing on their expertise, knowledge and insight. The team designed a range of experiential learning opportunities to support teachers to develop collaborative approaches and constructively and critically review each other’s practice. Immersion events have become a core feature of the professional learning, which are distinctive by:

- being experiential with significant periods for dialogue and debate
- problems or issues being posed, not solutions being given
- there being no blueprints to the area of learning – having an authentic opportunity to construct new meaning
- a sense of novelty, newness to the experience
- collaborative in the doing, recording and reflecting on practice
- crossing boundaries between professions
- reducing or eliminating power hierarchies, encouraging all participants including external experts to be co-creators, sharing and valuing all forms of individual expertise

Figure 3 - Phases of development within the TTRP projects, over four academic years



- being outcome focused, wanting a change in practice to be designed, trialled and refined.

Within the immersive experience (which for this research, lasted for up to two consecutive days), the following roles are orchestrated.

The project manager: The creator of a pallet of experiences that are 'hands on/minds on'; maintains focus and pace of activity; draws in what is needed in a responsive and systematic way; and listens to the needs of the group.

The thought leader/problem poser: Provides the grounding for the problem; why is it important? where does it fit with the current thinking? how could it make a difference? Reassures the group of the relevance of their challenge.

The inspirational other(s): Provide new learning, new contexts, vision and a sense of contemporary quality.

The bridge: A person who can broker the relationships between two professional groups; has authenticity on both sides and can bridge the language between them; builds ownership and nurses apprehensions.

The pragmatist: Gives some tangible hooks to current practice from which people can springboard; demonstrates the workings of new technologies; explains the meaning of new learning; provides subject knowledge and skills tuition.

The narrator: Someone who looks in on the experience; questions those taking part about the experience; acts in the role of participatory researcher/collector of 'the story' from different perspectives – emotional and professional responses through soundbites, visual records and reflective notes.

Watch and hear about the Immersive experience at: **www.raeng.org.uk/tinkering**

Approach two:

With targeted professional learning support, teachers can design, implement and evaluate ways to encourage EHoM and skills by capitalising on mainstream curricula of computing, design and technology, science and other subjects.

Learning: Engineering does not typically exist in school curricula. As such, interventions in primary classrooms need a clear fit and match with curriculum objectives in aligned subjects. Approach two focused on embedding engineering in mainstream, curriculum time, as opposed to extracurricular activities and after-school clubs. This approach poses a particular challenge for teachers because of current accountability measures on schools, which create a strong focus on core subjects such as english and mathematics, which in turn place a high demand on curriculum time. Engineering activities therefore needed to clearly support, add to, or revitalise learning objectives that were already prescribed in existing programmes of study.

Case studies of practice were published in a special issue of the Association for Science Education's *Primary Science Magazine*, written by the teachers engaged in the project for other teachers who are considering introducing engineering education in primary school[11].

Snap shot insights of curricular activity are presented here and further resources are also accessible at the 'tinkering for learning' website[12].

11 Primary Science magazine special issue. Association for Science Education **www.ase.org.uk/system/files/journal-issue/documents/PS2016-17%20Special%20Issue%20-%20Tinkering%20for%20Learning.pdf**

12 Science and Engineering Education Research and Innovation Hub. **https://seerih-innovations.org/tinkering4learning/**

Snap Shot 1: Abraham Moss Community School

EHoM FOCUS: Visualising and creative problem-solving

CHALLENGE: A robot dance competition, where primary (Key Stage 2) and secondary (Key Stage 3) pupils programmed an animation of a robot to dance on computer screens. These were then transferred to 'real-life' using tinkering to create actual robots and Raspberry Pi computers to control the dancing robots.

USP: The non-competitive nature of dance meant that no groups lost. It also gave opportunity for a variety of creative approaches. The project gave girls in the groups opportunities to shine, demonstrating their skills and enthusiasm for the project throughout the lessons. The TTRP project impacted on the wider school community through the introduction of robotics technology and the idea of setting a challenge that pupils must work together to solve. The challenge has been adapted and replicated with other year groups. Involving parents also meant that they had insight and understanding into how we have developed computing in school and the benefits this has for their children.

Watch the dance off: **www.raeng.org.uk/tinkering**

Snap Shot 2: Christ the King RC Primary School

EHoM FOCUS: Creative problem-solving, systems-thinking, adapting

TOPIC: An Ancient Greek ballista (Making Catapults)

FOCUS: History, science (forces), mathematics (angles), literacy (instruction writing)

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

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

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

Read more about this at: **https://seerih-innovations.org/tinkering4learning/resources/catapults/**

Snap Shot 3: Rode Heath Primary School

EHoM FOCUS: Developing a way of learning

Rode Heath Primary school has adopted a whole school approach to engineering by providing all pupils from Year 1 up to Year 6 with their own specially designed log book, into which they record their ideas, drawings, successes and failures for any project they undertake.

IDEA: Children use the language of EHoM and are encouraged to reflect upon which habit(s) they have been using in their lessons. Teachers aim to embed engineering throughout the curriculum, including choosing literacy texts that allow children to solve the characters' problems with an engineering solution.

USP: One day each term, a day is allocated which is dedicated to an engineering theme. Parents are invited to come in and work with their children, and there is a celebration assembly at the end of the day to share what has been achieved by the different year groups. The focus in November 2017 was on kite making.

Read more about this work at **https://thinklikeanengineerproject.com**

Snap Shot 4: Falinge Park High School

EHoM FOCUS: Adapting and improving

The target group was (age 14) pupils who are disengaged with science, technology and computing. These pupils did an engineering challenge with a school in Qatar, involving making a bridge and rolling a marble over the bridge. The activities promoted group work, collaboration and resilience, which led to deeper learning of the curriculum, increased engagement in the classroom and fewer passive learners.

USP: The school held a family 'tinkology' event, which allowed pupils and parents to 'tinker' with a variety of different materials and ultimately solve an engineering problem.

Approach three:

The investment in teacher professionalism leads to children's learning readily being reframed to embrace a culture and practice of engineering, in which the habits of mind are helpful in moving beyond the often contested space of individual subject disciplines.

Learning: Teachers responded positively to the opportunity for creative teaching and learning that the TTRP project offered. Feeling secure in their endeavour as a community of practice, much of their work with children was found to take on a project or challenge-based approach.

In the second year of the project many schools embraced the opportunity to be involved with the University of Manchester's *Citizen Engineering* national challenge, which was to create a 'Robot Orchestra'[13]. Responding to a call for young people to design and make a robot instrument, teachers used this as inspiration to work with the children and use their newly learnt skills in coding and prototyping to put forward robot musicians. Fundamental to many of these designs was the *crumble* controller, a small credit-card-sized programmable controller. The project team worked closely with the company that produces the controller in order to refine and adapt the controller systems so that it was more effective for the purpose of playing music for the orchestra. Working alongside professional engineers from Siemens, STEM Ambassadors, and parents with experience in engineering, the challenge allowed teachers to enthuse their own class, and the whole school community. The regional and national audience surrounding the orchestra added visibility and weight to the school's new found commitment to embedding engineering education within their curriculum.

Moving forward it is evident that a major challenge, that has regional or national interest supports teachers to legitimise their efforts with the senior leadership in their schools. By demonstrating that they are part of a wider community of schools, this enables them to lead engineering projects within their school and 'get it onto the curriculum map' as it has a focus, purpose and external visibility.

However, it was also apparent that where schools had a change in leadership, or lower than expected outcomes in Ofsted inspections, teachers struggled to maintain support for engaging students with projects and the lack of pace of innovation towards engineering education became apparent. The experience suggests that greater progress in engineering education is made in schools that have Good or Outstanding Ofsted inspection ratings. Further work is required to demonstrate to primary school leaders that there are clear cross-curricular benefits to engaging in engineering projects.

13 Films of the Robot Orchestra can be viewed at: **www.youtube.com/watch?v=SQdIGueRKj4** and **www.youtube.com/watch?v=9v1Jr8TDo0A&feature=youtu.be**

Approach four:

With senior leadership support, commitment and bravery, teachers can find the space for engineering education to underpin and thrive within mainstream primary school settings.

Learning: What has become evident throughout this research is the need for engineering to become a language within school and curriculum improvement. As government places greater emphasis on the industrial strategy, there may be a window of opportunity to exemplify the benefits of embedding a creative engineering thematic curriculum in primary school, working from the early years and developing such practice through Key Stage 1 and Key Stage 2 and into Key Stage 3.

However, there is a lack of guidance for head teachers and senior leaders who have little experience of engineering themselves. Science and engineering capital within school communities is a growing area of interest for many. This research has contributed to this area through the creation of 'Open Door Visits' in which teachers are supported to visit, observe and reflect as a collective group on engineering practices in schools. Such visits are undertaken with care and professionalism, benefiting from clear intentions, principles to guide observation and ethical consideration. This collective approach to improving teaching are found in leading international countries such as Japan and Singapore.

Moreover, these visits have been undertaken with university engineering academics, which has enabled them to experience the early stages of teaching and learning that lead eventually to their undergraduate courses. These insights, especially for academics educated outside the UK, have been successful in shifting perception and practice in the design of undergraduate course development.

Extract from *Tinkering from the Top*,
by Nichola Potts, Head teacher, Salford, Greater Manchester

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 – 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?

Open Door Visits offered an opportunity for teachers to test the teaching and learning theories that they had been developing as part of the programme. The interrogation of these principles formed the next stage in the project and provided the basis for the second development within this project; a teacher resources website. Teachers explained how they never had opportunity to visit other classrooms to explore and experience engineering practice in other schools at first hand. A typical reflective comment from a teacher after this event was:

"I have a better understanding of how Tinkering has been woven into the curriculum in this school. I have seen ways in which evidence can be reported, which has given me ideas for my own school."

Teacher

The Academy is supporting wider dissemination of case studies of engineering education in primary and secondary schools through national and international conferences. The collection and dissemination of these examples support the case for increasing engineering education with senior leaders in schools

The seven principles of primary school engineering education

After three years experimentation and reflection with teachers, from which there now thrives a community of *engineering champions* in primary schools, the seven principles of primary school engineering education have emerged, shown in **figure 4**. These are the consolidation of understanding, exploration and reflection in, and on, the core principles that underpin engineering education in primary school settings.

They provide a framework to review practice within schools and to enable primary teachers to consider themselves as *teachers of engineering thinking*. These principles focus directly on pupil learning and making a difference to their experience to 'learn as an engineer'.

A brief description of each of the seven principles is provided below:

Principle 1
Pupils are engaged in purposeful practical problem solving

- Purposeful challenging hands-on problems, which pupils can relate to real-life scenarios, are ideal for engaging for learners as they develop their EHoMs.

Principle 2
Pupils take ownership of the design and make process

- Engineering education is going well when it stems from the pupil's ideas and interests. It benefits from the teacher stepping back and letting pupils lead the way in their own problem solving. Embracing the practices of 'tinkering' as an approach to learning offers pupils the freedom this approach requires.

Principle 3
Pupils embrace and learn from failure

- Engineering is an iterative process. Pupils should have the opportunity to fail, to try again, to fail again, to try again, and to learn from failure. Failure shouldn't just be tolerated; it should be celebrated as a learning opportunity. (This principle closely aligns with growth mindset philosophy)

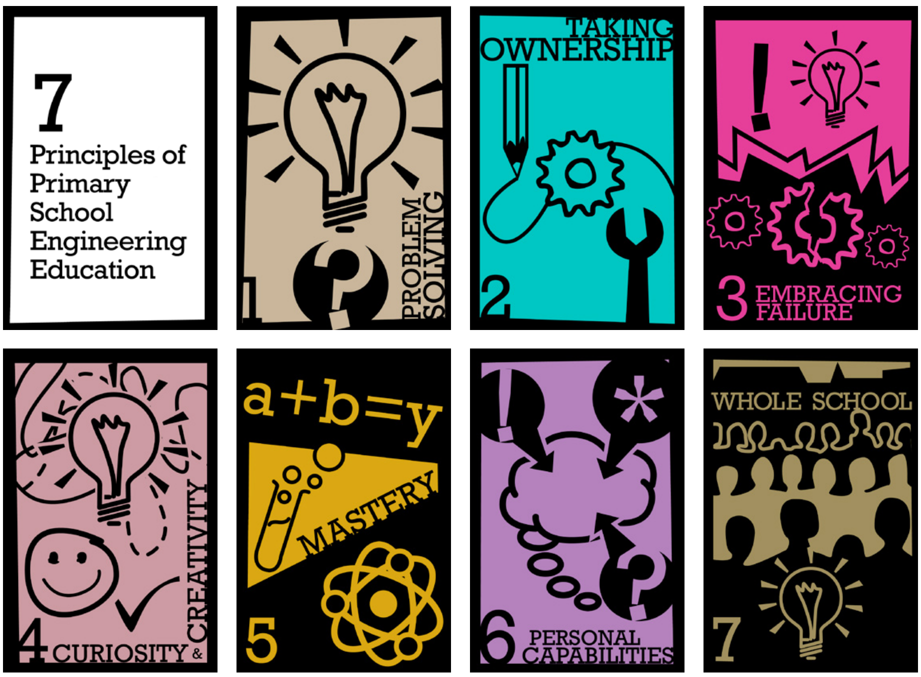


Figure 4 - The seven principles of primary school engineering education

Principle 4

Pupils' curiosity and creativity is responded to

- Engineering lessons need to be well planned, however the open creative nature of tinkering means this planning needs to be flexible. Planning shouldn't constrain pupils or teachers, it should offer guiding principles for learning-focused activities. Teachers need to strike a balance between planning for the expected, and embracing the unexpected.

Principle 5

Pupils demonstrate mastery from other curriculum areas

- Engineers make use of the discoveries made by scientists and mathematicians and apply them to solve problems. For pupils, engineering education offers opportunity to demonstrate mastery of their scientific and mathematical understanding.

Principle 6

Pupils draw on a range of thinking skills and personal capabilities

- Pupils' responses to engineering challenges provide opportunity to evaluate, analyse, apply and create and benefit from collaboration and communication with peers and professionals. Through the problem-solving process pupils develop perseverance, resilience and creativity.

Principle 7

Pupils' learning experiences are guided by a whole-school approach

- Engineering education happens most readily when it is embraced on a whole-school basis, supported by senior leaders and governors, and developed progressively from the early years.

As with all theoretical frameworks, and true to the nature of the EHoM, these would benefit from wider testing and reflection. For further insight into how the principles are implemented in the classroom and for further lesson ideas and reading material, visit the 'tinkering for learning' website[14].

14 Tinkering for Learning **https://seerih-innovations.org/tinkering4learning/**


Start

Recognition for the teachers and schools involved in the development of the 'tinkering for learning' approaches

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