Tinkering - a pedagogy for engineering education in the primary school?

Dr Lynne Bianchi*
Dr Jon Chippindall
University of Manchester

**Correspondence to: Dr Lynne Bianchi, Head of the Science & Engineering Education Research & Innovation Hub, The University of Manchester, England.*
Email: lynne.bianchi@manchester.ac.uk

Abstract:
This paper reports on the findings of a curriculum development project involving primary and secondary school teachers employing a semi-structured action research process to explore how an ethos of engineering could be developed through the Science, Design Technology and Computer Science National Curriculum (DfE 2014). It responds to the recommendations from the Royal Academy of Engineering (Lucas, Claxton & Hanson 2014) in building understanding of how the 'Engineering Habits of Mind' (EHoM) can be taught and learnt in school settings. The paper presents early insights into emerging models of practice to embed engineering within the primary curriculum setting. It focuses attention on 'tinkering' as a pedagogy for engineering and critiques the strengths and weaknesses of it in the context of the mainstream primary school curriculum. 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) this paper raises pragmatic questions about schools' cultural and curriculum challenges and opportunities faced by teachers in current English schools and whether 'tinkering' provides a model for curriculum design and delivery.

Keywords: engineering education, curriculum development, primary education

1. INTRODUCTION

There is ongoing recognition of the shortage of engineers in the United Kingdom and 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).

> *Filling the demand for new engineering jobs will generate an additional £27 billion per year for the UK economy from 2022, the equivalent of building 1,800 schools or 110 hospitals, according to new research published in Engineering UK 2015 The State of Engineering. To meet projected employer demand the number of engineering apprentices and graduates entering the industry will need to double. (EUK 2015)*

Investment is being made in England in campaigns and educational initiatives focused on increasing the number of youngsters entering the STEM workforce. Specialist University Technical Colleges, Further Education Colleges and school Academies are increasingly found to be focused on engineering as a subject area, promoting a range of qualifications and opportunities for learners. National Apprenticeship schemes are also proving increasingly attractive to school leavers where the development of mastery of engineering skills is embedded into work-based placement programmes, allowing students to gain hands-on learning within an employment setting. The increase in the number of apprenticeships and the number of engineering places at University provide a diversification of entry points into the profession.

Professional bodies such as the Royal Academy, Engineering UK, Institute of Mechanical Engineering and the Institute for Engineering & Technology offer programmes of support for young people who show interest and passion in science, technology, engineering and Mathematics. National schemes such as Tomorrow's Engineers offers a careers programme for secondary pupils delivered through a partnership between business and industry, the engineering profession and schools.

In 2014 the Royal Academy of Engineering published the 'Thinking Like an Engineer' report which offered the sector a different perspective on the issue of mobilising engagement and understanding in engineering as a profession. In contrast to profiling the range of engineering careers the authors reframed the educational challenge of developing the next generation of engineers by proposing that educators explore the issue from the perspective of the underpinning skills and thinking processes that engineers exemplify in their practice. They drew on Costa and Kallic's (2002) work into Habits of Mind and hypothesised that the shortage of engineers could, to some extent, be due to a lack of understanding about how great engineers actually 'think'. Their research promotes a range of skills or mindful approaches that define an engineer apart from other scientific disciplines, e.g. scientists or mathematicians.

They promote interest in teaching young people to 'think like an engineer' and outline the findings from research with professional engineers that define a range of dispositions typical of engineers. The authors, Lucas et al (2015), offer a framework that includes six Engineering Habits of Mind, namely Improving, Visualising, Creative Problem Solving, Problem Finding, Adapting and Systems Thinking (ref. Appendix 1). They suggest that by understanding how engineers think and work, that teachers and young people could be better equipped to develop a curriculum that explicitly identifies teaching and learning methods and evaluation practices that support young people to be or think like an engineer.

At a similar time, 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) defines 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 (2015) 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 & 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 the what they see as a valid and valuable style of working, characterized by a playful, exploratory, iterative style of engaging with a problem or project. The authors of this paper would share Resnick & 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.

What does emerge from the literature is a tension between tinkering and a 'traditional' linear approach to creating which is more constraining i.e. we create a plan, we make what we have planned, and we review what we have made. In contrast, whilst 'tinkering' still incorporates all three stages, it is an agile approach which affords pupils the room to flit back to their plan to adjust it as they are making. In this way tinkering could 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.

The bringing together of these two literature sets – engineering habits of mind and tinkering lead to the study presented in this paper. For this purpose the authors considered a working definition for tinkering as follows:

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

This paper reports on the findings of a curriculum development project involving primary schools employing a semi-structured action research process to explore how an ethos of engineering could be developed through the Science, Design Technology and Computer Science National Curriculum (DfE 2014).

The authors accept that using the term tinkering in this way could lead to potential misunderstandings with readers and teachers. They accept that the general premise of tinkering is an act of aimless exploration or activity, whereas the activities identified within this paper are more structured and thoughtful, as suggested by Resnick & 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 embracing of an ethos of play and experimentation within the curriculum and classroom. It has challenged them to consider alternative more agile teaching approaches which contrast with the more frequently found objective-led approaches that are currently emphasised in UK school settings. It is important that in this paper the reader acknowledges that tinkering in an educational setting is presented as a productive pursuit and that the term has been a bridging concept/model allowing teachers and educators to discuss and explore how the agile yet purposeful process of tinkering can encourage an ethos of engineering in primary school settings.

Method

The project spanned the academic year of 2014-15 and involved six primary schools and two secondary schools in Greater Manchester (England). Schools were recruited through invitation drawing on previous engagement with the University of Manchester, the Computers at School network and Local Authority recommendations. Two teachers were recruited from each school, who were Computer Science, Design & Technology or Science leaders in their school.

The teacher pairs were supported by two project leaders who liaised with head teachers/senior leaders to establish commitment from the school, developed a range of professional development opportunities and provided a framework for teachers to engage in short-term Action Research activity. The project leaders also visited school settings to see classroom based activity as well as to talk and review progress with the teachers.

The professional development opportunities spanned the academic year and were designed to be experiential and engaged teachers in hands-on activities and discussions alongside academic engineering lecturers from the University of Manchester. In total there were 4 days off-site professional development focused on topics including Computational Thinking (Barefoot Computing 2014), Engineering Habits of Mind (Lucas et al), an overview of literature on 'Tinkering' and Action Research (Kemmis et al., 2013). Teachers were actively encouraged to collaborate and share learning within the project sessions and also to support other teachers across the project.

Teachers were then asked to creatively respond to the project question:
How do we embrace engineering education and an ethos of tinkering using computer science, design & technology and the science curriculum?

Teachers designed approaches to address the question that best suited their pupils' needs, school interests and personal expertise. They were asked to trial their approaches in school, reflecting with each other and with the project team over the successes and challenges they faced. They recorded their activity using photographs, video, pupils' work and notes. Each school provided a written summary of their findings using an '8-minute Magic Moment' presentation, which involved a review of outcomes using a 4-slide PowerPoint based on Guskey Professional Development Model (2000). The slides were framed as:

- what happened?
- impact on teachers and teaching;
- impact on children and learning;
- impact on the whole school.

Each case was reviewed alongside the others by the project leaders who drew out common themes (successes, issues or questions) that arose across them. The project case studies were presented at a dissemination conference at the Royal Academy of Engineering where this project was positioned against other schools involved in similar school-based developments in the UK.

Findings

The cases reflect two areas of interest, firstly with regard to the development of engineering practices in school using tinkering within the Computer Science Curriculum and secondly to tinkering within the Design & Technology Curriculum. None of the cases focused on the integration of engineering specifically within the Science curriculum. Table 1 provides an overview of five cases and outcomes reported by the teachers. Three schools also started but did not complete the project and hence are no represented in the table.

Case	Approach	Impact on Children & Learning	Impact on Teachers & Teaching	Impact on Whole School Community
1	• Whole school focus on 'Tinkology' • Focus on developing children's resilience • Tinkering tables/spaces in every classroom as well as use of homework activities • Focus on taking things apart and making	- Children noted to be asking thought provoking questions in a scientific way - Raising children's awareness of engineering with a focus on female engineers	- project rekindled teacher enjoyment of teaching - provided a sense of purpose outside the constraints of the national curriculum - supporting innovation in teaching and learning approaches	- invitation of past pupils who now work in the engineering sector (ARUP) to work with the children. - Securing of own funding grant due to interest and enthusiasm for the area of work
2	• Secondary teachers creating tinkering experiences for primary pupils • Computer Science focus	- Children enjoyed making and 'putting things together' - The project gave girls	- Engineering identified as a specific area or subject within the curriculum - Exploiting the	- increased awareness of robotics technology and collaborative problem solving.

	• Involvement of parents and community/business partners • Making and programming car buggies	opportunities to demonstrate their skills and enthusiasm for learning - Many pupils were motivated by the competition event at the end of the project.	opportunities to work with the new Computer Science curriculum objectives in a creative way	- A competition enabled collaboration with parents, increasing their understanding of how Computing is being taught in school
3	• Involvement of two classes • Design Technology focus • Peer-to-peer learning, children learning together across year groups • Use of external partners to enhance teacher confidence/knowledge	- Children learnt that mistakes are part of the learning process - Children were noted to take responsibility for their own learning and challenge themselves. - As peer tutors they have develop confidence, social skills, self-motivation, perseverance and resilience.	- Lesson structure was changed to give children an end point to work towards without giving them the steps to reach them - Explicit focus on tinkering and EHOM encouraged teachers to support children in finding their own route through - Teacher's role was overseer and facilitator and minimal structure to lessons. - Emphasis on the process of learning rather than the creation of a final product.	- Children have transferred their skills and approaches to problem solving to other curriculum areas - Project raised awareness of innovation and experimentation within the curriculum – a 'have a go' attitude - Development of home-school links through competition and homework tasks
4	• One Year 6 (10-11 years) class • Focus on developing Growth Mind Set and 'fantastic failures' • Use of 'pre-tinkering'tasks • Emphasis on 'process over outcome'	- Children followed a learning framework, of *Ask it* → *Think it* → *Speak it* → *Try it* → *'Break' it* → *Fix it* - Pupils' reasoning skills in Maths and Science noted to improved as well as children's confidence to share ideas and voice their opinions about the world around them. - Children applying their skills to a range of contexts, with notable understanding of failure being part of the learning process	- Approach changed style of lesson planning, with increased focus on pupil-led learning - Teachers role was facilitory and collaborative, stepping back and working with the children to set attainable goals and explore how to achieve them	- Computer Science & Science staff have merged into a STEM team, enhancing cross-curricular opportunities - Project informed school leaders about the open-ended approach to teaching and learning and this is being considered at a whole school level
5	• Secondary school focus • Focus with secondary pupils on Design Technology using Computer Aided Design • Support for partner primary pupils focused projects model making.	- Increased awareness and use of the language of Engineering Habits of Mind - Specific focus on problem finding that stimulated new ideas for design	- Teachers felt re-energised about teaching approaches, inspired to buy new resources and materials to allow pupils the opportunities in lesson to tinker and explore - Key challenge to integrate flexible working practices with Year 9 (GCSE) year groups	- Greater awareness of action research and the impact of focused approach to curriculum development

Table 1: Case Study Overview

Of the six case studies, Case Study 4 is detailed for exemplification (ref. Appendix 2) addressing the development of engineering practices in school using tinkering within the Computer Science Curriculum.

Discussion

All the cases provide insight into the way 'tinkering' was adopted as a pedagogy for enhancing children's engineering practices in the classroom. This paper focuses in particular on these aspects of the project findings, whereas future papers may address other project outcomes in relation to the way teachers and children responded to the different Engineering Habits of Mind.

‘Tinkering’ as a concept was introduced to the project group during the initial immersive professional development event. An increased level of interest was emerging in the educational field. As the maker communities had begun to consider how at-home tinkering could be linked to in-school learning practices (Lamers et al, 2013). The release of on-line open courses, e.g. those provided by Coursera called ‘Tinkering Fundamentals: A Constructionist Approach to STEM Learning’ has provided stimulus for increased use and discussion of tinkering and learning. Within this project it was of interest to harness the concept of tinkering as a means through which to explore, compare and if possible align school based learning of engineering and the engineering habits of mind.

Tinkering provided a concept that enabled teachers with varied levels of expertise and experience of engineering to talk about the practices of an engineer. Teachers seemed at greater ease to draw relationships between tinkering and child-led learning than ‘engineering’ as a discipline. This was most prominent with primary teachers. Some project groups coined new phrases for tinkering for their own school settings, describing ‘pre-tinkering’ or ‘tinkology’ tasks or activities. These were found to engender a sense of ownership and inspiration, something that the project leaders were keen not to suppress, and something they explained was not often possible in current context of primary school education.

Whatever the term being used, teachers invariably 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.

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, Pibrellas, Bee-Bots, 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 that all teachers felt comfortable to use and a concept they found easy to work with.

The cases illustrate the teachers’ 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 the ownership of the product they were making. In one particular case the teachers explained how adopting a tinkering approach enhanced the opportunity for creativity, 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.

Three considerations related to the use of tinkering as a pedagogy for learning and developing engineering in primary and secondary schools emerged from the project. Each one is discussed here.

1. *Tinkering provided opportunity for flexible, exploratory, child-led learning approaches. Such learning styles could be said to counter the approaches towards teaching and learning that are increasingly sensed within a standard curriculum model where teacher planning, learning outcomes and pupil progress are highly defined goals.*

The ethos of tinkering provided teachers with increased legitimacy to offer time for exploration and experimentation. 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.’*

Such practices could be viewed by education authority figures as an ‘excuse’ for teachers to do limited lesson planning or to have too free a focus on what children will learn or how they will progress within a lesson environment that uses tinkering. Indeed Lewis & Friedrich (2016) further explain that tinkering is ‘a kind of suspension of learning, an interruption of any smooth, linear narrative that culminates in measurable outcomes’ (p238). The challenge for the education system, if considering tinkering to be a pedagogy that could allow for engineering education to begin to be framed or realised within school settings, would be to overcome the potential prejudices that might arise from such viewpoints.

Tinkering provided teachers with a stimulus through which an ethos of exploration was enhanced and could be understood by children, teachers and parents alike. Using the term provided a common interest/language within schools and is suggested to have been received in an ‘easier’ way than the term ‘engineering’.

In a similar way to Lewis & Friedrich (2016) this project’s outcomes stimulate questions about whether and how ‘tinkering’ which has a certain *temporal* dimension suggesting a loss of definitive ends, uncertainty of outcomes, and the simultaneous rhythms of withdrawing and progressing, can be held in equal esteem to the ‘teaching to the test’ culture that predominates the lives of many schools, or the requirements to produce evidence of pupil and teacher effectiveness. Tinkering would need to be valued within the primary education system as being a means through which the skills of experimentation and exploration might become the ‘pure means’ and outcomes for learning.

2. *There is a good relationship between the skills represented by the Engineering Habits of Mind, Scientific Enquiry and Computational Thinking. What does the concept of tinkering provide teachers with that further develops the connections between the skill sets, e.g. of visualisation, adaptation, pattern seeking etc.?*

Computational thinking is a new term to the National Curriculum. At its heart computational thinking is about effective problem solving, either with or without a computer. The Barefoot Computing Project (2014) proposes six computational thinking concepts of logic, algorithms, decomposition, patterns, abstraction and evaluation (Ref. Appendix 3)

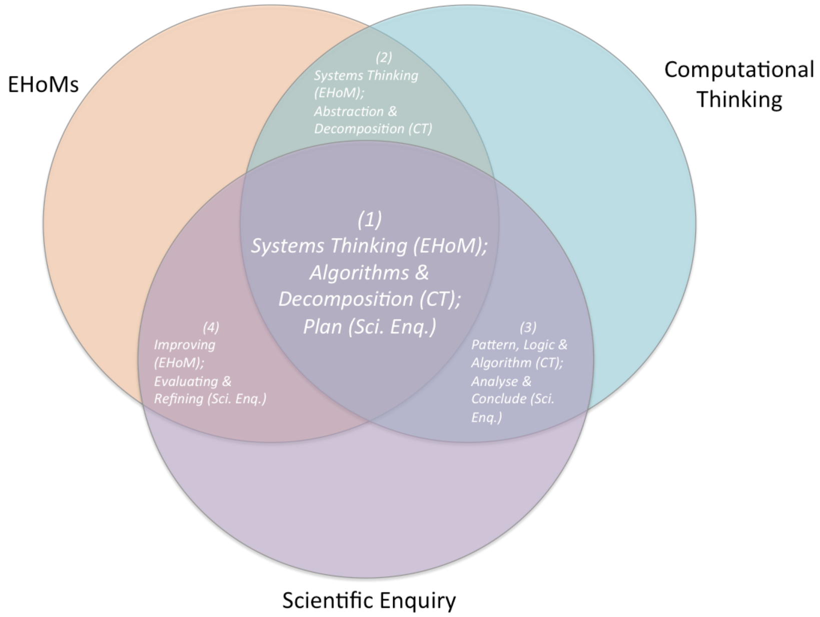

Figure 1: Connections between the skills of Computational Thinking (CT), Scientific Enquiry (Sci.Enq.) and the Engineering Habits of Mind (EHoMs).

These concepts and those identified by Lucas et al (2014) as 'Engineering Habits of Mind' can also be associated with skills that school science teachers encourage through the teaching of working scientifically in primary and secondary school. Here pupils are taught to ask questions, plan, observe, measure, present information, analyse and draw conclusions, communicate outcomes.

When reviewing the connections between the three skill sets it is helpful to reassure ourselves of the direct relevance of one skill set to another. For instance, System Thinking, Algorithms & Decomposition, Planning are fundamentally interlinked when pupils plan an enquiry as they decompose the process into a series of steps - an algorithm. The ability to think algorithmically can further support a pupil when planning by encouraging a systematic step-by-step approach. The use of science equipment also provides experience in developing system thinking, as pupils need to show understanding of how equipment works together, and can even provide opportunity for the refinement of measurement with the use of digital/computational equipment e.g. how measuring equipment such as light gates are built into the experimental apparatus.

However, the risk to the contemporary teacher may still emerge from the fluid and serendipitous nature of tinkering which may fail to capture the rigour of the defined opportunities, especially where a novice teacher may be employing it as a pedagogic approach. Tinkering risks being assumed as too playful in its approach for a National Curriculum or school-based setting, especially as learners become older and face academic challenges related to standardised testing and qualifications. The perception that any outcome from tinkering is a worthy outcome because it engenders the use and development of skills may be found not to be worthy enough.

Lewis & Friedrich (2016) suggest that, 'even if one tinkers in order to achieve a specific goal, what is unique about tinkering is that its meandering and its improvisational pacing push toward a goal while also delaying its eventual arrival…Tinkering is recursive and highly experimental. Indeed, it is an educational activity released from any *towards.*' (p239)

Although the project schools were able to overcome these challenges on a sort term basis it is questionable as to how the value aligned with a skills-based, process-orientated learning can ever be on a par with or more highly than other knowledge-focused aspects of the primary and secondary school curriculum. Can this challenge be resolved such that tinkering might offer a pedagogy for engineering education in primary and secondary schools?

3. *Is people's interpretation of what 'tinkering' too broad, and consequently result in it meaning anything to anyone?*

Within this project it became increasingly considered that tinkering is characterised by an iterative agile approach to problem solving and creating. When people tinker they could be found to make a quick plan before commencing activity, or indeed none. As they tinker, which is often synonymous with a 'making' process, they may come across new ways of doing things, then leading them to change tack, veer off from their original plan and continue to redefine their approach. 'Tinkering' was viewed by the project group as allowing them the freedom to do so.

During this process there is interdependency between head and hand activity. A tinkerer might make a quick alteration to their plan in order to get our *head* to accept or thing around any changes or outcomes they are noticing. One acknowledged it is back to *hand* – the making, to continue the ongoing exploration and development. The flitting between head and hand, together with the iterative re-evaluation of the direction of travel within the work stream is in contrast to 'traditional' forms of making in which we follow a constrained linear path of design, make and evaluate.

What was evident from this project was that there were inherent tensions between the freedom tinkering affords to a learning process and the requirement of teachers to cover specific National Curriculum content. Teachers will most likely find 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, need to be fit for purpose and as such, should be one element of a toolkit of creative teaching and learning approaches that teachers employ, alongside and including more structured approaches such as guided discovery and direct teaching. This would then enable us to clarify the value of tinkering as a process for learning, and although not identified as one of the engineering habits of mind, it rather provides an approach which lends itself to the development of them. As pupils were encouraged in the project to use tinkering and to engage in making activity and challenges, teachers suggested that they had opportunity to support the development of the EHoMs by making the skills explicit and talking with the pupils about what benefit they could find in focusing attention on the processes they encouraged.

4. *Knowing how a child's learning progresses when using a tinkering habitus is unclear. If tinkering is to be used as a pedagogy for engineering education, can a teacher adequately articulate progression in learning?*

The ambition to develop metrics for progression in creative approaches or learning have been the interest of many researchers (Fillis & McAuley 2000; Ferry, 2003; Craft et al. 2006, 2007; Spencer et al., 2012). Suggested methods have included tests, ratings scales; interviews; checklists; peer, parent, or teacher rating; observations; assessment of end products; personality tests; biographical sketches; aptitude and ability tests. This project did not look for a tool for measuring an individual's abilities in tinkering, or one for Engineering Habits of Mind or Computational Thinking. Scientific enquiry skills have however been formatively assessed through levels descriptors until the proposed revision of assessment frameworks for science (DFE, 2015).

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 to know and make visible the skills 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 which 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, that 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 that if captured could begin to define the features from what which a metric for progression could emerge.

Summary

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) this paper raises pragmatic questions about schools' cultural and curriculum challenges and opportunities faced by teachers in English schools who have interest to enrich the teaching and learning of engineering education. The paper provides a range of insights into how teachers, working collaboratively on a professional development project, attempted to design curriculum opportunities for an ethos of engineering to be developed. This took place in a range of forms with common focus on making explicit and defining the skills that engineers use and the integrating them into cross curricular making activities. The concept of 'tinkering' grew to provides a model for curriculum design and delivery and assisted the teachers in introducing a language for engineering in their schools and classrooms, once which was received with interest and enthusiasm by teachers and pupils.

The project outcomes as reported in this paper are encouraging and provide indications that tinkering supported the development of an ethos of engineering in primary schools. It does not however provide enough insight into whether it was an overarching concept that stimulated pedagogy to change to being more explicitly attuned to engineering concepts and making activities or the actual fundamental processes of 'tinkering' that enabled children to think like engineers. Further exploration in the development of tinkering as a pedagogy and to work with teachers to define where and how within mainstream curriculum practice this type of work can be taken out of a project context and scaled up as an approach to curriculum design and delivery, thus furthering the knowledge about where and how tinkering can have relevance and resonance in the primary curriculum, and indeed the impact on the secondary curriculum.

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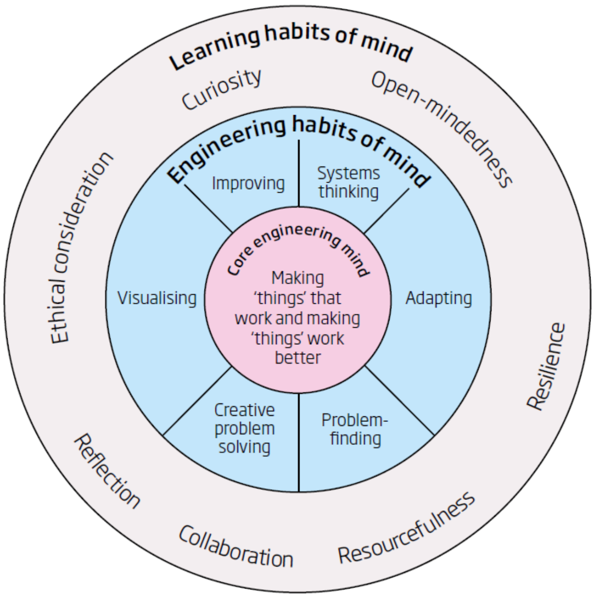
Appendix 1: Engineering Habits of Mind



Appendix 2: Case Study 4 Example

This case was from a large, inner-city primary school with over 650 pupils, roughly half of whom qualify for free school meals. The school community is one of the most diverse in England, with over 90% of our children having English as a second language (26 different languages are spoken in school). As such the teachers we particularly keen to consider how this project could align with the development of communication skills within the context of developing engineering across the curriculum. The school is newly built and demonstrated established practice of Computer Science teaching across the school.

A teacher (Computer Science Subject Leader) and a teaching assistant (with responsibility for Computer Science) worked as a team and combined the project with wider learning goals that permeated the school curriculum, in particular the development of 'Growth Mindset' (Dweck 2012). This approach was a contemporary intervention to support a positive culture for learning in schools and provides an approach through which teachers focus attention on enhancing children's self-efficacy and esteem for learning. It encourages all children to consider their innate learning potential which can be accessed by investing effort, time and dedication to their work. Using this methodology pupils were encouraged to think for themselves, try things out, not fear failure or mistake making and consider that through investing effort in learning they will achieve. The teachers suggested that the Growth Mindset approach aligned well with the Engineering Habits of Mind, where adapting, resilience and refining practice were incumbent.

In this case the teachers also exploited the opportunities to explore cross-curricular learning opportunities which enhanced and extended the time available for the project. By working in this way the teachers suggested that could afford more time to the focus on engineering, as they could capitalise on designated teaching time for associated subjects, e.g. Design Technology (DT) as well making links to where else in the curriculum engineering habits of mind were being used in other areas of learning.

The teachers defined their project question as:

Can a Growth Mindset approach to cross-curricular engineering have an impact on children’s confidence & communication skills?

A summary of the teacher’s outcomes is provided here:

What happened?

- A series of introductory tasks were developed which were designed to get the children into the ‘head space’ to tinker, examples of these were tower-building using a variety of materials such as newspaper, wooden blocks, recycled scrap.
- Teachers emphasised the focus on ‘process-over-outcome’ and resilience to failure.
- Learning was then applied to a DT context where children built prototypes of moving vehicles.
- Lessons encouraged children to ‘visualise’ the product they were making, and to begin to realise these ambitions through a making process. They were encouraged to understand the concept of prototyping, where a model is constructed and refined, and not used as the final product.

Impact on Teaching

- The introductory tasks altered the teachers approach to lesson planning and teaching by an increased emphasis on child-directed learning
- Teachers encouraged children to interpret challenges and come up with their own creative designs and solutions.
- This contrasted with their usual teaching approach which provided less opportunity for flexibility for the children.
- Teaching focused on the use of a series of open-ended computing tasks, using programmable devices such as the Lego Beebots, and on-screen software such as *Kodu* and *Scratch*
- ‘Systems-thinking’ skills were described, modelled and encouraged through the focus on making the robots move.
- Teachers consolidated systems thinking in other lessons, e.g. through Maths investigative challenges and English lessons.
- Teachers reported they found themselves increasingly standing back, observing and facilitating children’s learning.
- They also reported collaborating with the children to set attainable goals and together explore different ways to achieve them.

Impact on the Children

- Children became familiar with the use of a framework for learning that the teachers designed specifically for this project. Each session followed this framework which was found to translate the EHoM into an accessible approach for children:

  Ask it → Think it → Speak it → Try it → ‘Break’ it → Fix it

- Children used the framework explicitly which teachers reported as providing a common language for the communication and collaboration when on task.
- Teachers noted that children’s reasoning skills in Maths and Science had particularly improved, as had their confidence to share ideas and voice their opinions about the world around them.
- A ‘tinkering mentality’ was described to be shown in the children’s acceptance of failure. They illustrated a comfort with having a ‘fantastic fail’, when something didn’t go to plan, they saw this as a learning opportunity.
- Teachers also noted that the ‘average’ and ‘low’ achieving children made the most progress in this area of work, demonstrating ability to think creatively.
- The project also impacted on the children’s understanding of the job/career of an engineering.

Wider Impact

- Other teachers within the school were also involved in professional development from the project teachers and also outside agencies. This raised their awareness of the project and its outcomes
- Teaches expressed interest in furthering the project approach to support the development of

children's communication, problem solving and life skills.
- Opportunities were arising with a newly restructured STEM leadership group which teachers saw as an opportunity for taking the project ideas to more staff and impacting on a wider group of children.

Appendix 3: Barefoot Computing Figure of Computational Thinking

Computational thinking is a thought process that supports effective problem solving, either with or without a computer. Guidance for teachers defines six computational thinking concepts of logic, algorithms, decomposition, patterns, abstraction and evaluation (www.barefootcas.org.uk)