Engineering the future:

training today's teachers to develop tomorrow's engineers

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Authors

Dr Janet Hanson

Researcher at the Centre for Real-World Learning, University of Winchester

Sally Hardman

Senior Lecturer in Education (science and design and technology), Institute of Education, University of Winchester

Sue Luke

Senior Lecturer in Education (science and early years), Institute of Education, University of Winchester

Pam Maunders

Senior Lecturer in Education (computing), Institute of Education, University of Winchester

Professor Bill Lucas

Director of the Centre for Real-World Learning, University of Winchester

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About the Centre for Real-World Learning at the University of Winchester (CRL)

CRL is an applied research centre focusing on the teaching of learning dispositions. Its ground-breaking work in identifying creative habits of mind has been influential in the decision by the Organisation for Economic Development (OECD) to introduce the 2021 PISA Test of Creative Thinking. Since 2014, CRL has been undertaking research into engineering habits of mind (EHoM) on behalf of the Royal Academy of Engineering.

About the Institute of Education within the Faculty of Education, Health and Social Care at the University of Winchester

The Institute of Education offers both undergraduate and postgraduate programmes leading to the award of Qualified Teacher Status. It has been recognised by Ofsted as a provider of 'outstanding' Initial Teacher Training in England and, according to the Good Teacher Training Guide 2017, is the top undergraduate teacher training provider in the south of England.

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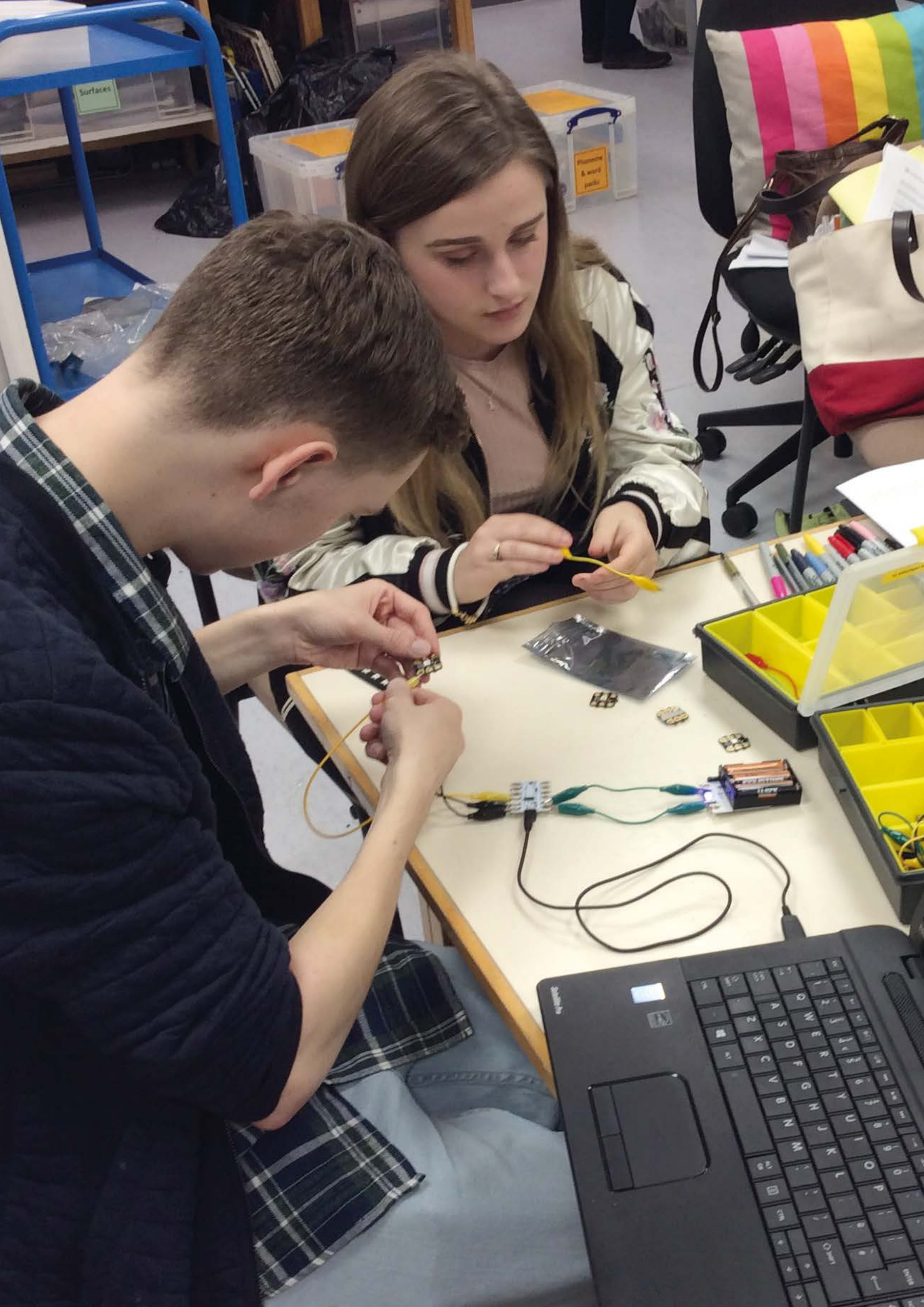
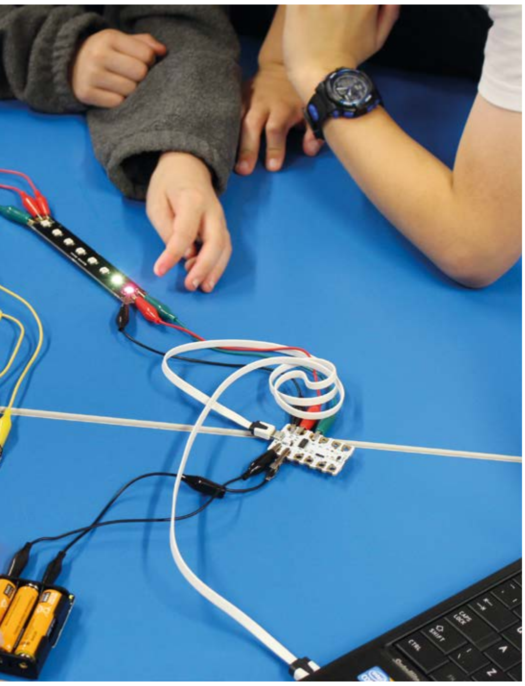
Glossary of abbreviations and terms

AR	Action research
Attainment 8	A school accountability measure used in England for the attainment of a pupil across eight qualifications
BEd/MEd	University undergraduate programme leading to a Bachelor of Education degree or a Master's of Education and qualification as a teacher
CRL	Centre for Real-World Learning at the University of Winchester, UK
D&T	Design and technology
DfE	Department for Education
EBacc	English Baccalaureate
EHoM	Engineering habits of mind
ITE	Initial teacher education, sometimes referred to as initial teacher training, includes programmes combining academic and practical study leading to a qualification to teach in UK schools
ITE provider	Organisation providing approved undergraduate or postgraduate programmes of study to prepare students to qualify as teachers
Key Stage	Blocks of years by which the National Curriculum in England is organised, each having its own prescribed course of study. Key Stages 1 to 2 cover ages 5 to 11; Key Stages 3 to 4 cover ages 11 to 16
NAE	National Academy of Engineering, a US non-governmental organisation providing independent advice to the US government on engineering and technology matters
NGSS	Next Generation Science Standards, US science content standards that set the expectations for what students should know and be able to do from Kindergarten to Grade 12 (ages 4 to 17/18)
Ofsted	Office for Standards in Education, Children's Services and Skills
PGCE	Postgraduate Certificate of Education
Progress 8	School accountability measure that aims to capture the progress a pupil makes from the end of primary school to the end of Key Stage 4
QTS	Qualified Teacher Status
STEM	Science, technology, engineering and mathematics
STEM Ambassador	A volunteer from a STEM-related job or discipline who supports schools in bringing STEM subjects to life and generates enthusiasm for STEM careers


Surfaces



Executive summary

This report explores the potential for supporting university students training to become primary teachers in computing, D&T, and science to develop a better understanding of how engineers think using an engineering habits of mind (EHoM) framework. Its hypothesis is that if student teachers understood more about the ways in which engineers think and more about the environment in which they work, this will increase the likelihood of them introducing engineering topics into their teaching, initially during teaching practice, but potentially when they begin practising as qualified teachers. EHoM include six specific ways of thinking that engineers use when tackling problems: systems thinking, adapting, problem finding, creative problem-solving, visualising, and improving.

Young people understand the value of engineering, but this awareness often comes too late to translate into career choice

Young people can see the value of engineering and can be motivated to study relevant school subjects but they may not become aware of the possibilities engineering offers as a career until they are in secondary school. However, by this time they may have developed subject preferences or made choices that make it more difficult for them to work towards an engineering career. In order to translate the early enthusiasm that young children often exhibit for science, technology, computing and mathematics into a persistent enthusiasm for engineering, they need to be introduced to engineering and the 'made world' during primary school, preferably through the curriculum rather than solely through after-school enrichment such as STEM clubs or visits to science fairs.

Primary teachers are generally unfamiliar with the breadth of engineering opportunities and lack confidence and incentive to find out more

Some of the barriers to introducing engineering into the primary curriculum arise from teachers' unfamiliarity with it as a career option and their lack of confidence to introduce engineering-related themes or projects into their teaching. When this is combined with a highly pressured school environment and an intense accountability focus on standards of literacy and numeracy, often leading to reduced timetabled time spent on science and D&T, it takes a teacher with considerable courage and confidence to introduce something not normally found in primary teaching. Therefore, the authors speculated that if trainee teachers were introduced to EHoM and guided to develop greater understanding of engineering's role in society, they might be more willing and able to incorporate EHoM into Key Stage 2 lessons during a teaching practice visit in a school.

With this in mind, CRL and the Institute of Education at the University of Winchester designed a small-scale intervention to investigate the extent to which trainee primary teachers were able to understand EHoM, incorporate them into their lesson planning and notice when pupils were using them in the classroom. The authors were also interested in the extent to which the students were able to align the six EHoM with the disciplinary ways of thinking that they were meeting in their subject specialisms, including computational thinking, design-make-evaluate and working scientifically.

Some lessons learned

The study showed that:

- a focus on specific engineering challenges, seen as an engineer might view them through EHoM, can motivate education lecturers from different subject disciplines to collaborate to develop and implement cross-curricular engineering learning opportunities for ITE students
- engaging practising engineers (STEM Ambassadors) raises the status of the experience in the eyes of both lecturers and student teachers, as well as injecting real-world authenticity into the learning experience
- with support, student teachers can plan and teach computing, D&T and science lessons that incorporate EHoM
- student teachers and their lecturers find EHoM a useful way of seeing connections between subjects and combining theory with real-world practice
- students noticed when children were using EHoM and named the thinking skills they observed.

This study has led to a revision of the EHoM model (**figure 1**) and the descriptors associated with the 12 EHoM sub-habits (see pages 27 to 29).

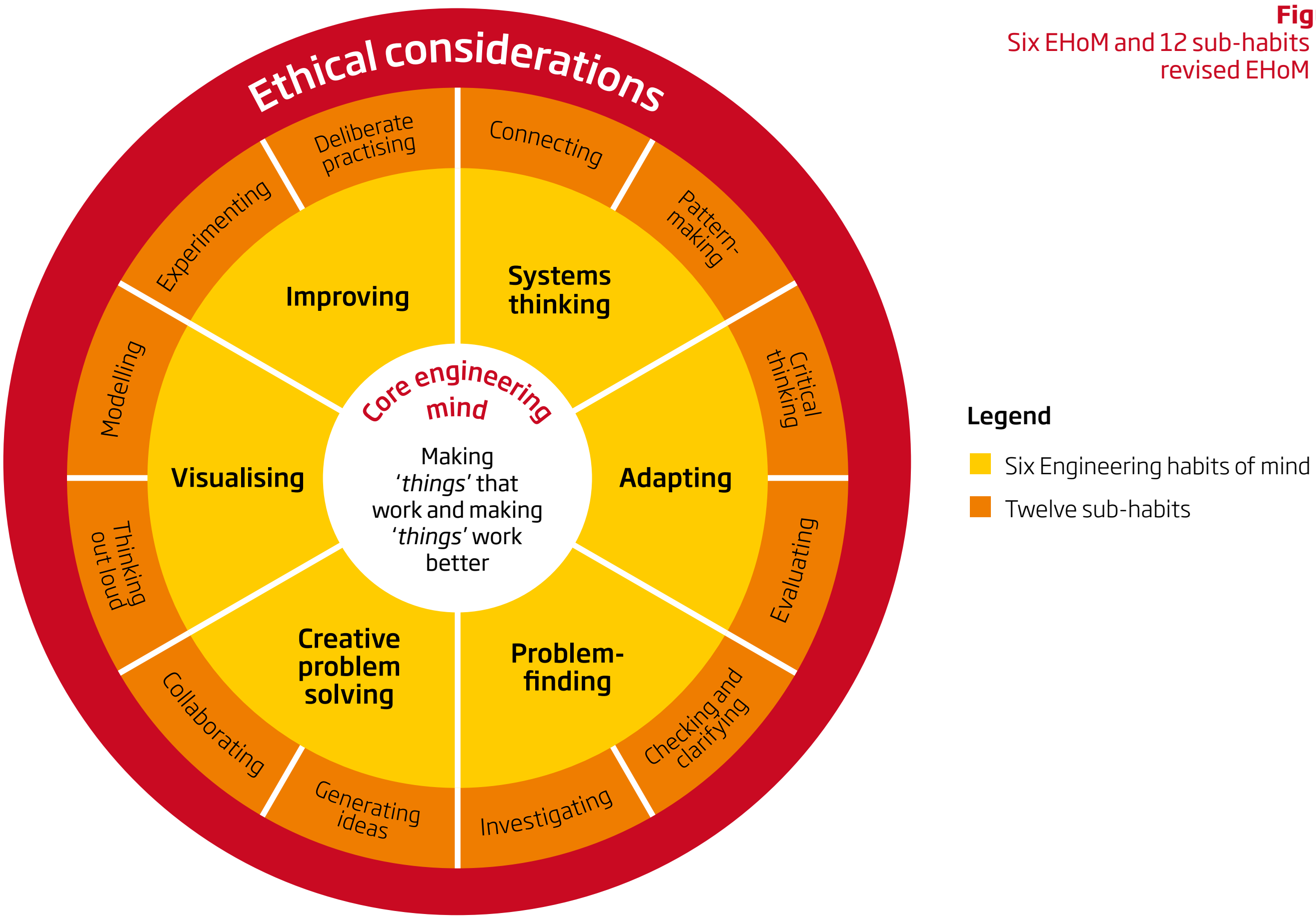


Figure 1: Six EHoM and 12 sub-habits -CRL's revised EHoM model

Student teacher discussing plans with Halterworth pupils

Recommendations

To university providers of ITE:

- Give it a go! You just need enthusiasm for helping students look at their teaching creatively through a different lens to open their eyes to the possibilities of engineering.
- Look at your own curriculum subject specialism through the lens of EHoM, which offers an approachable way of introducing engineering to ITE students, schools and children through almost any subject in the curriculum.
- Provide an introductory lecture on EHoM and introduce the concept to students early in the module in which you plan to incorporate an intervention, such as the one described in this report.
- Provide examples of possible projects, but consider giving the students something that is a work in progress so that they can explore it for themselves and plan how to teach it.
- Use STEM Ambassadors to support your EHoM initiatives and enthuse teachers and students about the real world of engineering.
- Seek the involvement, where possible, of your university's engineering department.

To schools and providers of school-centred initial teacher training:

- Encourage subject leaders and mentors to support new teachers to have the confidence to suggest innovations in their teaching practice, such as those illustrated in this report.
- Use STEM Ambassadors strategically as part of the school's careers strategy and within teachers' professional development or initial training.
- Designate a lead teacher for employer contacts to seek and coordinate engineers' contributions to the curriculum.

To engineering employers and professional bodies:

- Engage with primary schools, they are keen to have your support.
- Promote ways in which engineers can engage with trainee teachers and newly qualified teachers.
- Reach out to ITE providers, whether university or school based, to engage them in the idea of using engineers, for example STEM Ambassadors, to support EHoM initiatives and increase understanding about engineering.

1. Introduction

1.1 Background

The world of engineering is very gradually becoming more visible in primary schools. Primary teachers can find a wide range of resources to help them integrate engineering into the curriculum and extracurricular activities, for example, through STEM Learning. A Royal Academy of Engineering report identified at least 600 organisations or initiatives supporting STEM education in the UK[1]. With resources like these children from Key Stage 2 upwards are tackling cross-curricular projects that help them understand the relevance of subjects such as mathematics, science and technology in solving real-world engineering problems. Engineers are going into schools and helping teachers run projects and after-school clubs, introducing children to the wide variety of opportunities involved in being and thinking like an engineer. EngineeringUK reports that the proportion of 11 to 16 year olds considering a career in engineering has risen from 40% in 2012 to 51% in 2016[2]. After gaining a more informed opinion about engineering, parents also think more positively about engineering as a career for their children[3]. Nevertheless, engineering still has a long way to go before it is on everyone's lips in primary schools. Many initiatives aimed at enhancing teaching quality in subjects that inspire young people's interest in engineering appear to be concentrated on the professional development of in-service teachers[4]. The authors therefore decided that an intervention in ITE would be an interesting direction in which to take research into education for engineering.

Since 2014, CRL has been supporting the integration of engineering into primary and secondary schools through its research into the ways of *Thinking like an Engineer*[5] and the six specific EHoM that engineers use when tackling engineering problems: systems thinking, adapting, problem finding, creative problem-solving, visualising, and improving (**figure 2**).

In the two years that followed the publication of *Thinking like an Engineer*, a proof of concept trial was undertaken in 33 schools and one further education college in England and Scotland involving 84 teachers and more than 3,000 students. The trial established that, with appropriate support as part of a professional learning community, teachers could move away from solely focusing on the disciplinary (content) knowledge of subjects and reframe students' learning as a series of EHoM[6]. Furthermore, they could achieve this not just in the core STEM subjects but also in other subjects such as English and art.

As well as establishing that teachers found the use of EHoM to be a practically useful way of teaching many aspects of the curriculum, the research also established four key principles underpinning the kinds of teaching likely to develop a passion for engineering in today's busy schools and colleges:

1. Clear understanding of EHoM by teachers and learners.
2. The creation of a culture in which these habits flourish.
3. Selection of the best teaching and learning methods, the elements of a 'signature pedagogy' of engineering.
4. An active engagement with learners as young engineers.

Using this four-stage process, the authors identified many positive outcomes for learners taught to 'think like an engineer'. These included increased fluency in habits of mind such as problem-solving and collaboration; the development of 'growth mindsets'; improvements in literacy, numeracy and oracy; enhanced self-management skills; and better understanding of engineering.

Figure 2:
EHoM (Lucas, Hanson and Claxton, 2014)

It also increased teachers' capability and confidence, in particular to engage with practising engineers to support the curriculum.

There were also some barriers to progress. These included the limitations of a subject-based curriculum in facilitating a subject such as engineering that has so many necessary connections with different disciplines; a lack of confidence among many primary teachers; the particular pressures in the English system at secondary level resulting from new accountability measures such as Attainment 8 and Progress 8; and many complex issues to do with the underrepresentation of women.

The role of school leadership is crucial in overcoming these challenges. One area of concern to school leaders wanting to embed engineering into the curriculum is recruiting teachers with appropriate knowledge, skills and dispositions to act on their vision for the curriculum[7]. This is an area where university researchers, teacher training providers, schools and employers can work in partnership to increase recruitment of newly qualified teachers prepared to engage young people with engineering thinking.

The absence of a strongly defined focus on engineering in primary level curricula, apart from notable exceptions such as the *Curriculum for Excellence* in Scotland[8], means that pupil engagement is mainly achieved through subjects such as technology, science, computing and mathematics. Although careers in engineering still involve the practical application of science and mathematics, they now also demand a high level of creativity and cover a very broad spectrum, including everything from more traditional areas such as construction and transport to clothing, food, medicine and music. Therefore, an interest in engineering could be sparked through almost any curriculum subject given an appropriate treatment using EHoM.

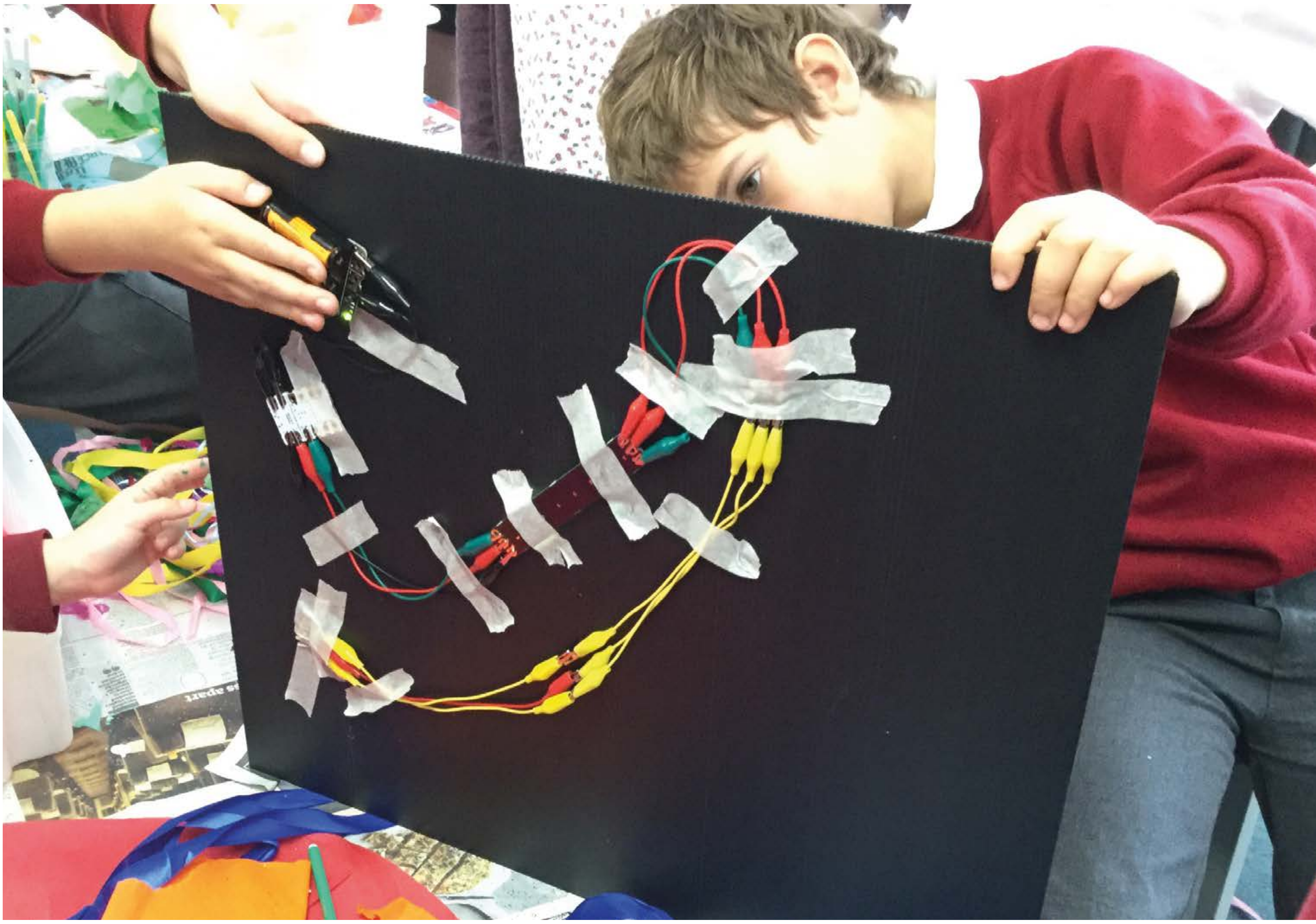
The authors' decision to focus on student teachers aiming to specialise in STEM subjects in primary schools was a pragmatic one based on the backgrounds and experience of the research team.

1.2 Supporting student teachers to cultivate tomorrow's engineers

Much of the previous research into EHoM has involved collaboration with qualified teachers through their continuing professional development activities. This report describes the outcomes of a small-scale piece of research in which the authors considered how to introduce trainee primary teachers to EHoM during their ITE programme, rather than through professional development after qualification. So, in collaboration with the Institute of Education at the University of Winchester, CRL worked with three senior lecturers to explore how students training to become primary teachers could incorporate EHoM into their teaching practice as part of their initial training. The three senior lecturers (SH, SL, PM) collaborating with the CRL research team (JH and BL) were already familiar with CRL's research and EHoM. All three have an interest in promoting STEM learning through engineering. They wanted to develop students' confidence in teaching STEM subjects and enable them to identify links between the subjects of science, computing and D&T in support of pupil learning. More broadly, they wanted to develop creative contexts for learning in their subjects within the ITE programme; a focus on EHoM appeared to offer them the opportunity to achieve these aims

With the increased emphasis on literacy and numeracy as core subjects in the primary curriculum, the teaching

Halterworth pupils designing their display



of science appears to receive less attention in school. SL was searching for ways of redesigning how science might be presented in school, giving her ITE students tools for seizing opportunities to engage children in science and help them to see the wider benefits of this subject.

There was a similar aim for D&T, since SH also felt that the subject might appear to be a less attractive option for ITE students to choose when having to make decisions about their options. This was perhaps because D&T teaching did not appear to them to be a current priority for primary schools.

From a computing perspective, the project's aim was to encourage the students to facilitate a real-world scenario that encouraged the pupils to solve a real challenge. The students needed the subject knowledge to be comfortable in their role as facilitators and have enough confidence to allow the pupils to solve their own problems without excessive teacher intervention. The inclusion of EHoM offered another important way of demonstrating the synergy between the STEM subjects.

The project's overall aim was to explore the potential for helping students training to become primary teachers in science, computing and D&T to develop a better understanding of how engineers think using the EHoM. This would increase their confidence in introducing engineering topics into their teaching of these three subjects. The authors wondered if trainee teachers who were introduced to EHoM, and guided to develop greater understanding of engineering's role in society, would be willing and able to incorporate EHoM into lessons to teach topics within the Key Stage 2 curricula for their chosen subjects.

The authors also wanted to give the students an initial introduction to the value of forging links with engineers to bring the world of engineering alive in the classroom. This aspect of the project used the STEM Ambassador network. STEM Ambassadors are volunteers from a wide range of jobs and disciplines across the UK. They offer their time and enthusiasm to help bring engineering to life and demonstrate its value in support of young people's future careers choices. They undertake a wide range of activities, including coming into schools to support after-school clubs, giving talks to pupils and helping teachers to introduce engineering topics into the curriculum[9].

This report explores reasons for introducing ITE students to the concept of EHoM and 'thinking like an engineer'. It then describes the students' experiences of incorporating EHoM into their lesson planning and teaching. The authors evaluated their experiences and how readily they noticed the pupils using EHoM in the classroom while they engaged with the activities planned by the students. The report begins with an overview of the research approach and a description of the activities undertaken by the lecturers with their students for this study.

2. Approach to the research

2.1 Overview

This was a small-scale intervention study designed to investigate the extent to which trainee teachers were able to understand EHoM, incorporate them into their lesson planning and notice when pupils were using them in the classroom. The authors were also interested in the extent to which they could align the six EHoM with the disciplinary ways of thinking, computational thinking, design-make-evaluate and working scientifically, from their subject specialisms. The principal research question was:

How can future primary teachers develop understanding of EHoM to support their practice to grow tomorrow's engineers?

The three sub-questions were:

- What opportunities and challenges are there for primary trainee teachers to develop awareness of EHoM within an ITE context?
- How can primary trainee teachers confidently prepare, plan and teach activities that encourage children to begin to think like an engineer?
- How can primary trainee teachers identify EHoM through computing, D&T and science?

The authors adopted an action research[10] approach to the study well-suited to enabling 'teachers as researchers' to engage in professional development relevant to their own contexts[11,12]. Teachers work collaboratively on an area of common concern to identify how they might improve their practice, reviewing relevant research about the issue, undertaking a teaching intervention based on this review, and collecting data from a range of sources to triangulate their results. Ethical permission to undertake the research was gained from the Faculty Ethics Committee at the University of Winchester. The rest of this section describes the stages of the project, how the authors recruited the students, and how they collected and analysed data to inform the report.

2.2 The research project

In order to investigate how students would engage with EHoM and the notion of incorporating engineering into their teaching plans, the authors designed an activity in which the students would plan and teach a problem-solving activity, related to a topic within the computing, D&T or science curriculum, to children in Key Stage 2. In addition to showing how they would develop the children's subject knowledge, the students were also asked to indicate where they thought they could incorporate EHoM.

The students were introduced to EHoM by the CRL research team during the project's launch at the start of the autumn semester. With the support of the three lecturers, the students worked in small groups and spent the first part of the semester developing their activities, which they subsequently taught to a class in a local primary school. The D&T and computing students collaborated on planning and teaching an integrated topic for year 5 and the science students designed separate activities aimed at years 2, 3, 4 and 5. The ways in which the lecturers supported their students was critical to the success of the project and is explored in greater detail in section 4.1.

2.3 The student participants

The recruitment of students for the project was undertaken by the three lecturers. Twenty-nine undergraduate students (22 female, 7 male) from the second and third years of the University of Winchester's BEd/MEd education programme volunteered to participate. These primary education trainee teachers were science specialists, computing specialists and students with an interest in D&T who wanted to gain further expertise in the subject. The students were invited to participate in the research at the end of the summer semester and the research itself took place during the next autumn semester over a period of 12 weeks. The computing

Student teacher discussing teeth activity with Ropley pupil

Student teachers planning with their lecturer

and science students participated in the research through their modules, the D&T students became involved in the project as an additional activity, anticipating the value it would add to their CVs to be engaged in such a relevant extracurricular activity.

2.4 Partnership with schools

Partnership with local schools was essential for the project to be realised. The lecturers approached head teachers of two Hampshire primary schools, who agreed to participate by allowing the students to teach their EHoM activities to selected classes during the autumn term. These were both schools that had an established relationship with the university's Institute of Education and regularly welcomed student teachers into their classrooms to undertake teaching practice. The importance of the partnership with the schools is explored further in section 4.1.

2.5 Partnership with STEM Ambassadors

The authors included STEM Ambassadors within the project to enable students to learn about their role and appreciate the opportunities for involving engineers in classroom activities to raise the profile of engineering. Establishing and maintaining contact with engineers is an important factor in developing teachers' confidence in teaching engineering, either as a discrete subject or through one of the other STEM subjects. In earlier research[13], the authors found that it was important to help teachers negotiate access to engineers for links between them to be successfully established. The Winchester Science Centre, which manages the Central South STEM Ambassador Hub, supported the authors in this by inviting participation from engineers on their behalf. Seven individuals expressed interest in being involved in the project and once they had had been contacted to establish their availability, four (three males and one female) actually participated by attending the project launch and the final evaluation sessions.

2.6 Data collection

Three main sources of qualitative data were used: unstructured observation[14] of the students by the lecturers; structured focus group discussions[15] with students, lecturers and STEM Ambassadors led by the CRL researchers; and documents[16] produced by students and lecturers during the intervention. When students were planning the lessons with the lecturers, they were encouraged to think about how to embed EHoM and how to notice when children were using them. The three lecturers guided their student groups in preparing their lesson plans and teaching activities, and used staging points during the semester to encourage the students to reflect on their understanding of EHoM by referring to the EHoM diagram (**figure 2**). The lecturers photocopied the students' annotated diagrams and lesson plans, with their permission, to use in the data analysis.

The lecturers each kept a reflective diary during the semester, recording their thoughts on their progress in organising their modules, the challenges of incorporating the research requirements and observing the reactions of their students. They met with each other at regular intervals and kept notes of their discussions. In three meetings with the CRL team, the discussions were recorded and transcribed. Having gained permission, photographs were taken of the students during their planning activity and while they were teaching the children in the school classroom.

After the students' teaching activities had finished, a final session was held at the end of the autumn semester. During this session, the students and lecturers reflected on their experiences and talked about their perceptions of EHoM and their impact on the ways in which they might be embedded into the three subjects. Four STEM Ambassadors attended the launch event and the final event and contributed their views on the project.

2.7 Data analysis

A combination of thematic analysis and discourse analysis was used to analyse the data[17] gathered from students and lecturers. This enabled the authors to identify themes that informed their understanding of the opportunities and challenges of enabling future primary teachers to develop awareness of EHoM in ITE programmes. In addition, the language used in the students' written reflections and lesson plans was also explored to evaluate the extent to which they recognised examples of EHoM in use or used alternative words to construct their own meaning of EHoM. Their interpretations of EHoM were used to expand and update thinking on the original 12 EHoM sub-habits and to suggest how EHoM and subject-thinking skills might be aligned.

2.8 Summary

This was a small-scale research project that was incorporated into the normal work and study routines of ITE students and lecturers during a busy semester at one university, so the outcomes are inevitably limited in their scope and generalisability. Nevertheless, the findings should be relevant to all those wanting to enhance the visibility of engineering in schools and to develop the confidence of novice teachers to contribute to this aim.

Student teachers creating lesson plans using EHoM

3. Teaching engineering in primary schools

3.1 The need for a 'new narrative' for engineering education in schools

Concerns about recruiting enough young people to study engineering to fill the estimated shortfall of professional engineers in the future have led to calls to radically change the ways in which children are introduced to engineering at school[18]. As noted in section one, there are many exciting informal learning opportunities for schools to introduce children to engineering at an early age. However, professional engineering bodies are now calling for a 'new educational narrative' for engineering in schools, including making the "presence of engineering and the 'made world' more explicit from primary school upwards"[19]. Specifically, Finegold and his colleagues at the Institution of Mechanical Engineers argue that engineering should be presented in school not just as an interesting career opportunity but as a "methodology that humans employ to improve their lives"[20]. Incorporating such an approach into the increasingly subject-oriented curriculum taught in primary and secondary schools that rarely includes engineering as a discrete subject could be challenging. One way of approaching this might be to align the curriculum with the thinking skills or dispositions underpinning Finegold's methodology. The authors began to investigate how, for example, EHoM might align with the thinking skills in STEM subjects as taught in schools and then how they might be introduced to trainee teachers. This section briefly describes the routes into teaching before examining challenges for teaching STEM subjects in primary schools, how they are perceived and how this might impact upon how they are taught. It then discusses how an alignment between computing, D&T, science and EHoM might be articulated through the disciplinary ways of thinking that are promoted in those three subjects. The authors hoped that this alignment might be useful in encouraging trainee teachers to consider incorporating EHoM into their lesson plans and eventually increase the presence of engineering in primary schools. The authors also briefly discuss the value of inviting engineers into the classroom to work alongside teachers to enhance learning and increase children's awareness of engineering's role in society, since this was another strategy they wanted to explore with trainee teachers.

3.2 Summary of routes into teaching[21]

The ITE landscape has become increasing complex[22] with around 260 providers of programmes leading to QTS, of which around 180 are school-led providers and 80 are university-led providers[23]. Students can train through undergraduate programmes provided by universities or postgraduate programmes provided by both universities and school-led providers. Whether the provider is school-led or university-led, partnership between schools and higher education is an essential component of providing a quality experience for the student teacher, enabling them to develop both subject knowledge related to the National Curriculum and the specific pedagogies for teaching a subject to different age ranges. On all routes, student teachers spend a minimum of 24 weeks in school[24].

For those wanting to become a primary teacher, the route can be through a school-led or a university-led partnership programme. Primary teachers, as classroom teachers, are normally expected teach all subjects in the curriculum to their class. However, within a training programme, students would have the opportunity to specialise, particularly on a postgraduate programme. Government bursaries and scholarships are offered to well-qualified graduates as an

Student teacher planning activity with Halterworth pupils

incentive to train to teach STEM subjects at secondary level, including physics, mathematics, computing and D&T, but only for mathematics at primary level[25].

3.3 Effective teaching in primary D&T, computing and science

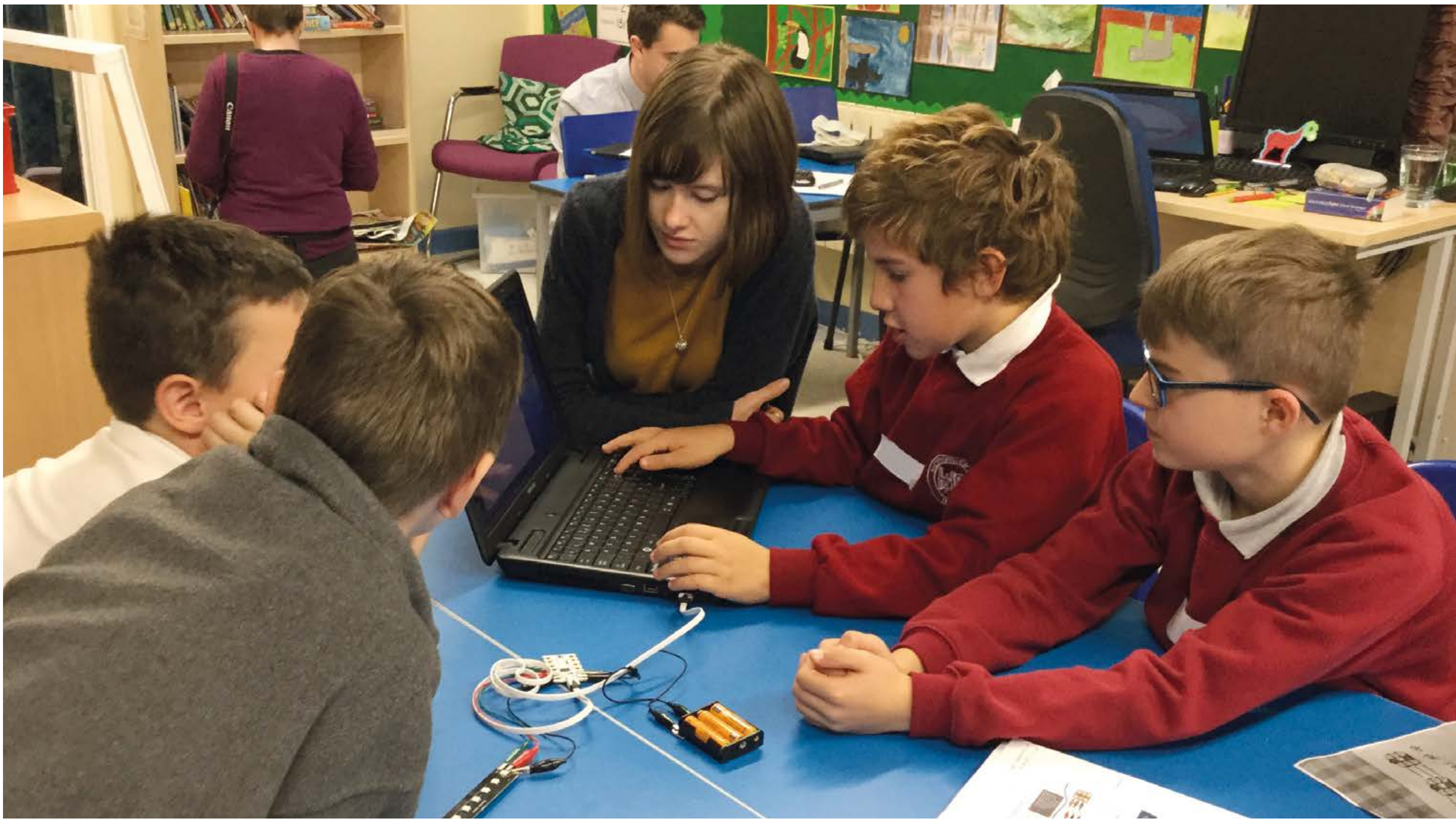
The bursaries and scholarships to train as a teacher were put in place in response to concerns about the shortfall in recruiting sufficiently well-qualified graduates into the teaching profession, particularly in STEM disciplines. Although subject qualification is an important factor in teachers' effectiveness regarding pupil outcomes, there are many other teacher-specific factors that have an impact on pupil achievement[26]. Their confidence in their subject knowledge, their knowledge of appropriate pedagogies for their subject and their beliefs about teaching significantly affect their adoption of teaching methods that can improve student achievement[27]. We can see these factors at work when we examine reports about the teaching of STEM subjects, concentrating on the three in which the report's trainees were involved; science, D&T and computing. Science is one of the National Curriculum's three 'core' subjects for primary schools, together with English and mathematics, while computing and D&T are two of nine 'other foundation' subjects[28].

Accountability measures encourage primary schools to concentrate on securing pupil achievement in literacy and numeracy, which can be taught not only through English and mathematics but also through all subject areas. However, there is the perception among teachers that subjects such as science and D&T are being marginalised[29,30], and even Ofsted reports that the emphasis on literacy (reading, writing, spelling and grammar) can 'create a risk that the curriculum becomes narrowed'[31] and that science is being 'squeezed out' of the curriculum[32]. As less time is given to science and D&T with fewer regular slots on the timetable, teacher have fewer opportunities to engage pupils through cross-curricular projects that foster subject connections, or even incorporate appropriate pedagogies that encourage development of the inquiry processes that are the fundamentals of disciplinary identity in these subjects.

This is a particular problem for D&T, which is essentially an interdisciplinary subject. It not only provides a valuable introduction to designed products, materials, their properties and control systems, but also enables children to better understand theoretical aspects of science and mathematics through their practical application in D&T projects. This presents an ideal opportunity for generating awareness that engineering has an impact on almost every aspect of life, especially since the D&T curriculum encourages teachers to relate activities to "a range of relevant contexts [for example the home and school, gardens and playgrounds, the local community, industry and the wider environment]"[33]. A group of teachers in Manchester have demonstrated some exciting examples of shaping the primary curriculum to introduce engineering thinking through mainstream subjects including D&T[34]. Elsewhere, however, D&T teachers appear reluctant to embrace teaching its component subjects in an integrated approach[35,36]. This may be down to timetabling but may also indicate a lack of confidence in teachers to teach the full spectrum of the D&T curriculum. With the number of teachers qualified to teach D&T falling[37] and primary teachers receiving little or no subject knowledge input or special training to plan and teach D&T effectively as part of their ITE course[38], it is not surprising that their self-confidence to teach the subject is reduced[39]. Subject areas in the D&T curriculum that teachers lack most confidence to deliver are systems and control and electronics. This is particularly acute at secondary level and where D&T teachers' degree background is predominantly in art and design rather than technology[40] but could also apply at primary level. Other issues with D&T primary teaching identified by Ofsted[41] included insufficient time spent on the subject and, in particular, the limited time that pupils spent on the iterative design process, since they were often designing products that could not be realistically tested and improved.

The new subject of computing, which replaced information and communications technology (ICT) in the National Curriculum, has

Student teacher discussing coding with Halterworth pupils



strengthened the requirement to teach programming and control, which tended to be overlooked in the earlier syllabus. This has been challenging for primary teachers who may have been confident at teaching the uses of ICT, as in word-processing and databases, but their lack of experience of computer science reduced their level of confidence with the new syllabus. Waite[42] suggests that there is an urgent need to provide teachers with more evidence from robust research as to which pedagogies should inform their teaching of computing. It has already been suggested that support materials and sample lesson plans tended to encourage a 'recipe style' of teaching and restricted classroom dialogue between teacher and pupils rather than encouraging active discussion, questioning and experimentation[43].

Primary science teachers are broadly confident in their ability to teach the subject and confidence increases in teachers with higher science qualifications[44]. However, teachers can still experience embarrassment when their carefully planned experiments fail in front of a class full of pupils[45]. Primary teachers' perceptions of subjects may be influenced by their own experience at school and those with a less positive attitude towards science have lower self-confidence in their ability to teach the subject[46]. So, a lack of opportunity for pupils to learn through practical scientific investigation may have as much to do with the lack of separate timetabled science sessions[47] as it does with teachers' lack of confidence.

These examples of how teachers' lack of confidence and/or timetabling restrictions might undermine opportunities for teaching the thinking processes at the heart of these three subjects are worrying. These processes not only foster valuable learning skills and dispositions such as problem-solving and teamwork, but they also contribute to fostering children's sense of identity or affinity with the subject, motivating them to continue studying it. So, not only is children's confidence in studying the subject undermined by teachers' lack of confidence, but also the teaching of these syllabi suffers from less coverage of the core thinking skills now emphasised in each through 'design-make-evaluate', 'computational thinking' and 'working scientifically'.

3.4 Preparing future teachers to teach creatively with confidence

ITE programmes broadly include the same core material such as: subject knowledge development; subject-specific pedagogy; evidence-based teaching; child and adolescent development; behaviour management; planning; assessment; differentiation; special educational needs; and development and professionalism[48]. Despite the existence of the DfE's Teachers' Standards[49] the Carter Review noted variability in the way that subject knowledge and subject-specific pedagogy were addressed across ITE provision. In light of the relative lack of subject experience in science, mathematics and computing among primary trainees, the review suggested that ITE providers needed to address these areas, in particular to boost trainees' confidence in planning practical work, such as experiments in science[50]. The Wellcome Trust noted a renewed emphasis on the pedagogy of practical science in primary teacher training provision[51]. However, in the same report, ITE providers and students also reported a lack of time during training to concentrate on science at the expense of English and mathematics.

A few ITE providers have introduced cross-curricular modules where D&T and computing students collaborate with each other to plan and teach an activity in school. This can increase students' confidence in their ability to be more innovative and creative in their future lesson planning[52]; develop their subject knowledge of control techniques; learn how to scaffold subject learning; respond to children's potential anxieties about open-ended enquiries; and develop the confidence to manage open-ended activities within a classroom environment[53]. It can also serve as an opportunity to help trainee teachers develop the interpersonal and communication

Student teacher discussing teeth activity with Ropley pupil

skills necessary to negotiate cross-curricular learning opportunities in the future with their colleagues in school[54]. For students training to be science teachers, it is important to experience failure of a science experiment or investigation during their training, so they learn not to be embarrassed by failures but use these unexpected results positively as an opportunity to create learning points. By doing this, they are developing their pedagogic skills, cultivating their own and their students' scientific habits of mind such as curiosity[55], and modelling resilience as they set about improving on their results.

3.5 Alignment between EHoM and ways of thinking in STEM subjects

As noted earlier, teachers' subject knowledge has an influence on their teaching effectiveness, but just knowing the subject is not enough. Developing trainee teachers' 'pedagogical content knowledge' – a combination of a deep knowledge of subject matter, knowledge of how to teach it and knowledge of how students learn its specific concepts and content[56] – is an aim of ITE providers. Within the curriculum of STEM subjects, this knowledge now includes ways of thinking in the subject: the design-make-evaluate process (D&T), working scientifically (science) and computational thinking (computing). The authors have previously explored with in-service teachers how they can align the teaching of subject content and these disciplinary ways of thinking with the six EHoM – systems thinking, creative problem-solving, improving, adapting, visualising and problem finding[57] – and wanted to continue this exploration with primary teacher trainees. Clearly, it is important to respect the integrity of each individual subject and acknowledge the distinctive nature of each discipline's ways of thinking, since they aim to achieve different ends.

Science is the body of knowledge that explores the physical and natural world, while engineering is the application of knowledge to design, build and maintain technologies, and technology is the body of knowledge, systems, processes, and artifacts that results from engineering, according to *Engineering is Elementary*[58]. Working scientifically "focuses on the key features of scientific enquiry, so that pupils learn to use a variety of approaches to answer relevant scientific questions. These types of scientific enquiry should include: observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing (controlled investigations)…

Pupils should seek answers to questions through collecting, analysing and presenting data"[59].

As a subject in the English National Curriculum, D&T is "an inspiring, rigorous and practical subject. Using creativity and imagination, pupils design and make products that solve real and relevant problems within a variety of contexts, considering their own and others' needs, wants and values"[60]. Design-make-evaluate form the three core activities that serve to organise the D&T curriculum during each Key Stage. However, there is little to indicate in this programme of study that these activities might be underpinned by a 'design process' as a coherent way of thinking in the subject. The conceptualisation of that approach was led by the National Curriculum Expert Group of the Design and Technology Association. Its publications include advice for schools on implementing the D&T curriculum, six design principles that describe the features of a 'genuine design and technology experience for pupils' and a progression framework that develops pupil learning cumulatively across Key Stages[61]. A scan of the framework reveals numerous occasions when EHoM could be incorporated.

Computing has at its core "computer science, in which pupils are taught the principles of information and computation, how digital systems work and how to put this knowledge to use through programming"[62]. Computational thinking (CT) is, in the narrow sense, "about looking at a problem in a way that a computer can help us to solve it" and involves six different concepts (logic, algorithms, decomposition, patterns, abstraction, evaluation) and five approaches to working (tinkering, creating, debugging, persevering, collaborating)[63]. However, computational thinking can also be thought of as "a shorthand for the thought processes involved in formulating problems and their solutions" and is therefore not only important for coding but can also be "an important life skill for solving problems"[64]. This conceptualisation of CT separates it from an association solely with electronic computing devices and positions it as "a link to cognitive competencies involved not only in science and engineering but also in everyday life"[65]. This broader view also aligns well with the six EHoM while the Computing at School's six concepts align more with the EHoM sub-habits, which are discussed in section 4.4. For example, the decomposition of complex problems into smaller more manageable chunks helps pupils better visualise.

There have been attempts to establish links between scientific, computational and engineering thinking[66,67]. It has even been suggested that computer science teaching should include more aspects of design to enable pupils to relate computational solutions to real-world problems[68]. Nevertheless, with problem-solving at the root of these disciplinary thinking processes, there is clearly scope for thinking more deeply about how EHoM, the ways of thinking about engineering problems, might be aligned with other disciplinary ways of thinking in STEM subjects.

EHoM offer a relatively new way of thinking about engineering in the UK, but they are well established in the US. Six EHoM were proposed for school-level engineering (**Table 1**) by the US NAE[69] and incorporated formally into the curriculum when engineering design was included within the new standards for science education, the *Next Generation Science Standards* (NGSS)[70].

This thinking informed the authors' research as they explored new ways of reframing engineering education for schools in the UK[71]. The six EHoM, which built on but were slightly different to the NAE's six, were developed in collaboration with engineers and engineering educators in the UK. The authors subsequently developed 12 sub-habits, two for each EHoM, as a way of offering teachers a more accessible breakdown of the six habits to incorporate into their teaching, particularly with primary children. A brief review of how EHoM have been further conceptualised in the literature since the original investigation provided some updated thinking about EHoM in several ways.

Engineering Habits of Mind - National Academy of Engineering (Katehi et al, 2009)
Systems thinking equips students to recognise essential interconnections in the technological world and to appreciate that systems may have unexpected effects that cannot be predicted from the behaviour of individual subsystems.
Creativity is inherent in the engineering design process.
Optimism reflects a world view in which possibilities and opportunities can be found in every challenge and an understanding that every technology can be **improved**.
Collaboration leverages the perspectives, knowledge and capabilities of team members to address a design challenge. Engineering is a 'team sport'.
Communication is essential to effective collaboration, to understanding the particular wants and needs of a 'customer,' and to explaining and justifying the final design solution.
Ethical considerations draw attention to the impacts of engineering on people and the environment. Ethical considerations include possible unintended consequences of a technology, the potential disproportionate advantages or disadvantages of a technology for certain groups or individuals, and other issues.

Table 1: Six EHoM - NAE (Katehi et al, 2009)

Individual EHoM have been further analysed, for example visualising[72,73], communication[74] and problem finding[75]. The applicability of EHoM in other subjects has been explored, for example in technology[76] and in science[77]. There are examples of EHoM use in all phases of education from kindergarten (early years)[78] to higher education[79]. Furthermore, one of the US primary engineering programmes, *Engineering is Elementary*, has expanded the NAE's six habits to encompass 16 EHoM[80] (**Table 2**).

Given this ongoing conceptual development of EHoM, it seemed appropriate for the authors to re-examine their own understanding of EHoM, particularly around the sub-habits, as they discovered how they appeared to a new group of interested stakeholders, namely student teachers. The outcomes of this thinking are explained in section 4.

3.6 Preparing future teachers to engage with engineers

Employer engagement with schools has many benefits for young people; it can enhance their understanding of jobs and careers, provide skills development, help with successful school-to-work transition, provide

Children who develop EHoM...	
use systems thinking	persist and learn from failure
consider problems in context	see themselves as engineers
investigate properties and uses of materials	work effectively in teams
apply math knowledge to problem-solving	construct models and prototypes
apply science knowledge to problem-solving	make evidence-based decisions
innovate processes, methods, and designs	make tradeoffs between criteria and constraints
envision multiple solutions	communicate effectively
see themselves as problem solvers	assess the implications of solutions

Table 2: Sixteen EHoM (*Engineering is Elementary*, 2018b)

an authentic context to aid learning, and, particularly for primary children, it can increase aspiration to pursue STEM subjects[81,82]. However, there are many reasons why primary teachers may not be able to make the most of employers' support, not least their lack of knowledge about what is available[83]. While there are opportunities for teachers to update their knowledge and gain experience of industry, such as STEM Insights placements[84] where serving teachers spend time in industry, there appear to be few opportunities for trainee teachers[85]. One ITE provider offered its D&T undergraduate teacher trainees the opportunity to undertake a one-week placement with an engineering company during their final year. The students' understanding of the breadth of engineering, the variety of roles and the importance of skills such as teamworking, were all greatly increased because of their experience[86]. Another important resource for teachers wanting to work with employers to enhance understanding of STEM subjects, which appears to be underused in teacher education, is the network of STEM Ambassadors supported by STEM Learning[87]. For this reason, the authors were keen to ensure that the ITE students participating in the project were introduced to some STEM Ambassadors who could talk to them about their role as engineers, and also provide examples of how they had worked with primary teachers in the classroom.

3.7 Summary

STEM subjects and others offer many opportunities for embedding engineering but current pedagogic practice to deliver the primary curriculum seems to be obstructing rather than helping this goal. Many of the challenges, for STEM teaching in general and engineering more specifically, arise from teachers' lack of confidence. Therefore, the authors were interested to find out if by introducing students training to be teachers to a way of thinking about engineering and offer them a way of reframing how they teach D&T, computing and science in the light of this, they might be more confident to continue this approach when they enter professional teaching. The need for engineers to develop a new mindset about the way they 'do' engineering, to develop the ability to communicate 'as if people mattered'[88], has encouraged the authors to review how EHoM can be used by teachers to cultivate an interest in engineering during the early period of a child's educational journey.

4. How some future teachers learned about EHoM during their ITE programme

This section begins with a brief summary of the ITE programmes at the University of Winchester. It then reports how the trainee teachers engaged with the challenge of incorporating EHoM into their teaching and on their experiences of cultivating them with pupils in the classroom.

4.1 Opportunities and challenges for incorporating EHoM within ITE programmes

ITE at the University of Winchester is the responsibility of the Institute of Education within the Faculty of Education, Health and Social Care. In 2018, Ofsted recognised the university's primary and secondary ITE programmes as outstanding. Most of the programmes prepare students to teach in the primary sector, including two PGCE programmes (one for ages 3 to 7 and one for ages 5 to 11) and a three- or four-year BEd. If students opt for the four-year BEd route, they gain credit towards a Masters. The student volunteer participants for this research were studying on the primary BEd; seven were aiming to become specialists in teaching computing, nine were interested in developing their knowledge of D&T teaching, and 12 were aiming to become specialists in teaching science.

Computing - BEd - Year 3 Computing Specialism Module - seven students

This module enables students to examine the issues surrounding the management and delivery of computing at primary level. Students engage with current debates and thinking relating to good practice in the use of ICT and new media to support learning across the curriculum. During the module students were developing their own pedagogic knowledge of teaching computing and this project gave the students a real-world scenario, the incorporation of the need for programming to solve a problem, in the same way it was hoped that the students would give the pupils a real-world challenge to solve. The computing and D&T students were taught as one group for this project, which helped both groups to establish cross-curricular links between their subjects that would hopefully give the students the confidence to replicate this with the school pupils. The project offered the possibility of introducing innovative learning experiences by enabling students to develop their own ideas and take ownership of the process, again, aimed at developing their confidence to replicate this with the pupils.

D&T - BEd - Year 2 students with an interest in teaching D&T - nine students

All BEd Year 1 students undertake sessions in D&T in which they broadly examine the nature of the subject and explore practical contexts; in Year 2 they can take a D&T option module. However, the planned D&T option module did not run in Year 2 at the time of the study, so this group comprised students who expressed an interest in looking at D&T within the context of engineering and volunteered to take part in the research project. The aims of the D&T control option were incorporated into the students' group work because it aligned well with the material the computing students had to cover in their module. It included the exploration of a range of mechanical and electronic control technologies and resources, as well as a task to plan, create and evaluate a resource using control technologies and reflect critically on their own development through study and practice. Students had to document their progress and discuss any design decisions made.

Science – BEd – Year 3 Science Specialism Module – 12 students

This module aims to prepare students for their future role as subject leaders of science. It encourages them to consider how the subject is led and developed at primary level in a variety of contexts, related to current initiatives and models of good practice. Students critically examine policy statements, schemes of work and action plans to support their growing understanding of the subject leader's responsibility for monitoring standards. Students consider their role in auditing the needs of their non-specialist colleagues and identify possible strategies to enhance the quality of provision. The module explores the ethos and underlying values and theories about how children develop in primary science and enables students to examine the role of the subject leader in schools.

Lecturers' reflections on choosing, organising and teaching their modules to incorporate EHoM

Conceptually, the modules supported student teachers' learning about working scientifically, computational thinking and the process of design-make-evaluate, which, as noted above, do share some of the features of EHoM. Nevertheless, there were several other factors that influenced the choice for their inclusion in this research. The interplay between wanting to provide opportunities for the students to experience the research project and the need to ensure that the requirements of the module were met was recorded by the lecturers in their reflective logs. There were the practical matters such as timetabling; curriculum issues such as the requirements of the course programme, its outcomes and assessment; and the capabilities and interests of ITE students themselves.

Collaboration between lecturers working across subject boundaries in a busy academic department is not always straightforward because of workloads and timetables, nor between the students who are taking different option modules. So, from a practical perspective, the lecturers had to ensure that the computing and science modules were running on the same day during the autumn semester, and that the D&T students, who had volunteered to participate in the research despite having chosen other options, were also free to engage at the same time. The practical issue of getting the students to the schools that were hosting their lessons was met by hiring a minibus to ensure that the students did not incur additional expense, but also to ensure that all the teaching resources they would need for their lessons were available.

Each lecturer wanted to ensure that the research activity with the students could be integrated into the existing module plans. These plans are approved through a course planning and approval process that results in a Definitive Document for the overall programme, which sets out what the student can expect from the programme and its modules. The lecturers had to ensure that the learning outcomes and assessment requirements for the modules could still be met through the EHoM activity.

One aspect of this was to ensure that the integrity of the subject was maintained but also that students were encouraged to recognise opportunities for cross-curricular teaching, a way of working that is not always evident when trainee teachers enter schools. The successful collaboration between the D&T and computing students as they focused their learning activity on control exemplified this. These students had worked together the previous year and had been introduced to EHoM, which probably accounted for the more overt integration of EHoM into their lesson plans that can be observed in 4.2.

The science students had not had any prior exposure to EHoM and it is possible that they saw this project as an opportunity to enhance their subject knowledge. As their lesson plans demonstrate, they are focused more on the subject content they are teaching and how to correct children's science misconceptions, rather than EHoM. However, these students could make two visits to their school and the period for reflection between the first and second visits proved to be an important feature in the overall effectiveness of their second teaching session.

A reliable school partnership was essential for the success of the research activity since the schools provided a meaningful context in which students could apply EHoM and observe the children's reactions. When approaching the schools to seek their engagement, the lecturers sought to demonstrate that the school would benefit from the students' visit by offering their children an experience that they would not readily obtain otherwise. Furthermore, both schools that agreed to participate were already focused on enhancing science in the curriculum and developing children's thinking skills, so were intrigued by the reference to EHoM.

4.2 How future teachers encouraged pupils to 'think like an engineer'

In the weeks following the project launch session, in which all the students were introduced to EHoM and STEM Ambassadors, the students met in their subject groups to begin to explore how EHoM could be reflected within their own subject areas and how this could be transferred into the primary classroom. Guided by their lecturers, the students designed an activity to teach in one of the two local primary schools that had agreed to collaborate in the project.

When working with teachers to develop habits of mind or learning dispositions in pupils, it is important to emphasise that dispositions can be cultivated in parallel with subject knowledge during the lesson; they do not have to be approached as something separate or additional to the subject teaching. A four-stage process[89] for cultivating learning dispositions, or habits of mind, addresses factors that influence the effective deployment of dispositional teaching. It includes developing understanding of the disposition to be learned, for example improving; creating a classroom culture in which the disposition can flourish; deciding on an appropriate pedagogy; and securing pupils' engagement with the disposition (**figure 3**).

This process formed part of the introduction to EHoM for the students

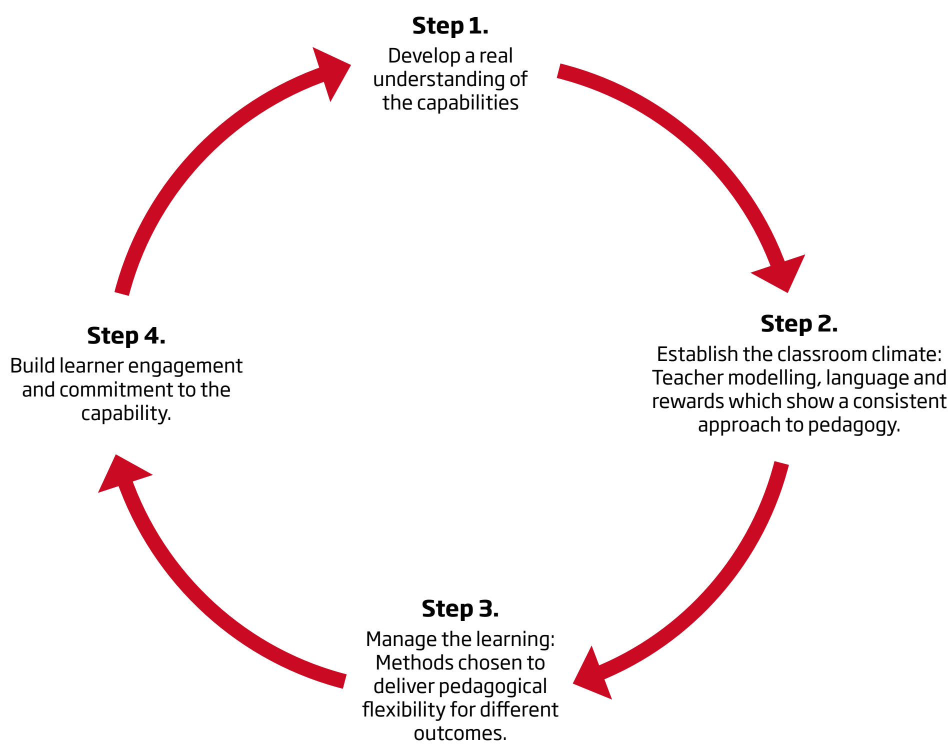
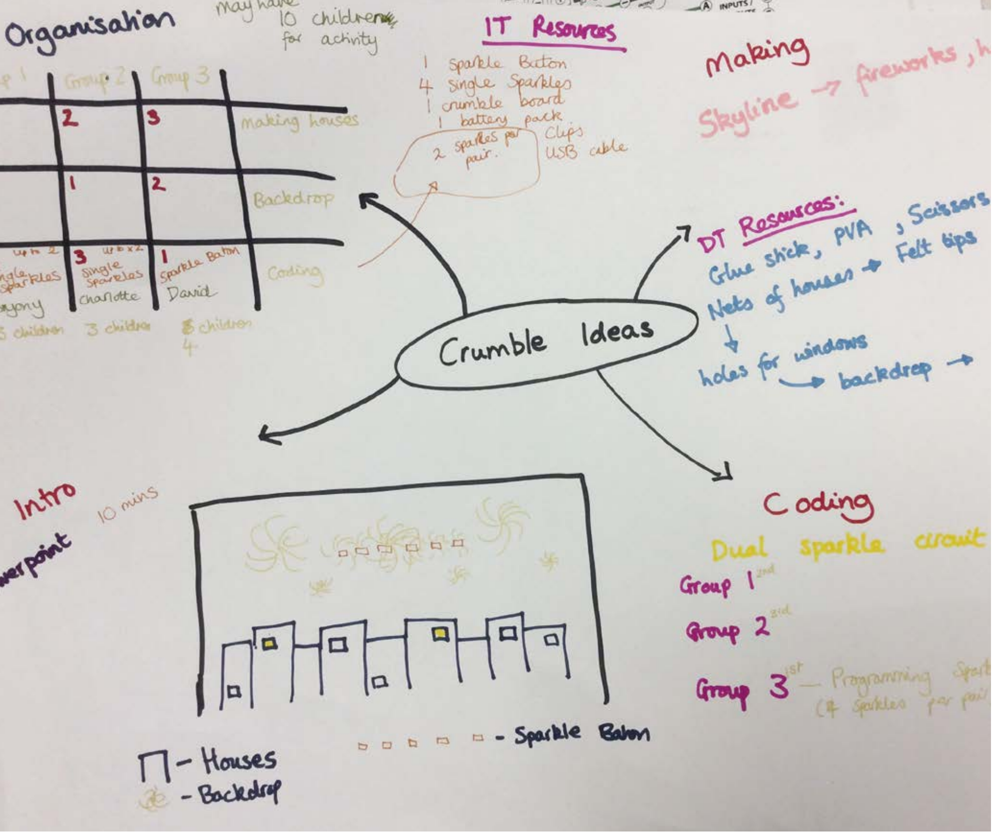


Figure 3:
Four-stage process to cultivate learning dispositions (Lucas and Spencer, 2017)



Student teachers' mindmap to guide their lesson plans using Crumble

at the start of the project. Despite the very brief amount of time that the students actually had in the classroom with pupils, the authors found that they did focus on establishing a positive classroom climate. They also chose to use appropriate active learning methods and succeeded in building learner engagement, as the following examples confirm.

The **computing and D&T students** collaborated over the design of their teaching activities. The school in which the students were delivering their activity combined two Year 5 classes (10 year olds) and asked the students to teach the whole group of 60 pupils at the same time. The students worked in groups of threes and fours. Their lesson plans demonstrated that they recognised they would have to manage the class by dividing it into two halves. The focus for the lesson was on creating an interactive display based on the theme of 'through the window on bonfire night' and engaged children in problem-solving activities that involved sequencing instructions linked to programming. This involved block coding using the Crumble board software (similar to Scratch) to control a series of coloured sparkle lights to represent a firework display. The lights were located behind a black plastic sheet 'sky', through which holes had been bored to display the lights.

After giving a combined briefing session to the pupils to introduce the programming software, which included a recap on algorithms, one half of the class worked on the electronics while the other half concentrated on designing the 'night sky' to provide the context for the 'fireworks'. The students supported the pupils by dividing them into groups of seven to eight children. All children had time to program, so although they were split up they worked on both design and programming. The two halves joined together in a plenary to complete the task and reflect on the outcome.

As part of the planning process for this activity, it was made explicit to the students that pupils should be encouraged to think computationally and be introduced to the correct computing terminology and computational thinking. Students were encouraged to allow the pupils to analyse what needed to be done and decide on the steps required to complete the task, a process that had strong links with the D&T design principles. The students' lesson plans indicate that they actively planned to use this approach that encouraged problem-solving and collaboration. The plans included instructions such as:

> "Allow small groups to experiment with the crumble kit."
>
> "Try to allow pupils to work through problems on their own as much as possible."
>
> "Ask questions: why are you doing that? What do you think you could do?"
>
> "Use questions to prompt the children to use self-enquiry and de-bugging techniques."

Their lesson plans also included 'notes to self' style reminders to the students to notice EHoM and gave them more specific hints about drawing attention to EHoM such as improving and adapting. They also encouraged the pupils to experiment, or tinker, with the Crumble kit and built in time for giving feedback on the design and the programming. During the evaluation phase, they planned to discuss improvements for next time, using phrases such as:

> "Talk about improvements for next time."
>
> "Talk about what the Crumble can do other than using the sparkles to make lights."
>
> "What else could you use Crumble to do?"

The computing/D&T students realised that to create a climate in which the EHoM could flourish, they had to step back and allow the children to lead the activity. They often accepted that there was no right or wrong answer, as long as the children could justify their solutions. This required them to be flexible and open to amending their plans when the situation demanded, for example when the software on laptops they had taken to use in the classroom required rebooting.

The **science students** could go into school on two occasions to teach their lessons. The four topics around which the activities were developed were porous materials (with Year 2), rocks (with Year 3), teeth (with Year 4) and separating materials (with Year 5). Each student group used their first lesson to elicit pupil knowledge on the topic, which allowed them to focus the second session on engaging children in scientific inquiry and problem-solving activities, such as choice of materials for making a teabag, investigating the properties of rocks, deciding on the functions of animals' teeth, and cleaning water using sieving or filtering. Through the lesson plans, the students developed activities that would involve the children in several of the processes linked to working scientifically. In the first lesson the children were engaged in making observations, classifying and grouping:

> "Introduce next activity – now your challenge is to use equipment to separate all the materials from the jar, one at a time thinking carefully about what piece of equipment will separate a selected material"

> "Split into groups to do carousel activities investigating tea.
>
> Group 1 – Looking at tea leaves, identifying the flavour by smelling them. (using the skill classifying)
>
> Group 2 – Looking at tea bags with microscope. Shape of teabags, material of tea bags. What do they have in common? What are the differences?"

These activities would, in turn, support the development of problem-solving and improving as further activities were organised in the second lesson:

> "Split into groups (take a group each) – work in small groups, each with a bottle of dirty water create a hypothesis, and work out what they would like to find out, what equipment you might use, predictions, results table."

> "Give children the materials while sat at tables – children will make four teabags, one from each material, using the method they decided before the break. It's fine if they decide to change the shape/method of attaching tea material together to make tea bag."

4.3 How future teachers engaged with engineers

The four STEM Ambassadors, who contributed to the project by attending the initial launch session and the final evaluation session, supported the students in several ways. They were excellent role models, reflecting the diversity of engineering jobs and opportunities. One is a graduate civil engineer working for an international company on smart motorways. Another is a technician, working for the Royal Air Force (RAF) maintaining electrical systems on aircraft. His feedback on how he entered engineering demonstrated to the students just how necessary their intervention to promote engineering to children was:

"The reason I ended up in engineering is by pure fluke. It was the job that sounded the best when I joined up. I never had any careers advice on what path to follow and never understood what engineering was. I always had a passion for how things worked and building things. I wouldn't change my career path but a better understanding would have helped."

The third joined an international civil engineering company as an apprentice three years ago. The fourth has a background in chemical engineering and currently works as a project engineer for a company in the biopharmaceutical sector. Like the second Ambassador, she also reported that she had initially been unsure of which career path to follow, but having been good at science at school, went on to study chemical engineering at university.

As they were talking with the students during the launch session, the Ambassadors demonstrated the validity of EHoM by reflecting on how they themselves used these skills in their work. Teamwork and communication skills figured strongly in their accounts; the RAF technician had recently become an instructor educating newly appointed technicians how to operate the helicopters that he was responsible for. The chemical engineer frequently liaised with multidisciplinary teams of engineers and clients:

"… to make sure our automated process is user friendly. I also get heavily involved in performing tests with the customer to make sure the equipment works efficiently for their site installation."

They helped the students with practical ideas on how to approach their lesson planning by telling them about the activities that they had led in schools. One ambassador followed this up by sending through a teaching plan for a project he had led on a school visit.

While observing the students during the launch session, at first they seemed quite reluctant to talk when they were asked to introduce themselves and say what they knew about engineering. Many felt that they didn't have much to say, as they knew so little about it. A couple of the students talked about an interest in engineering prior to choosing teaching, but decided not to pursue this because they felt that they didn't have the mathematical ability. After the input and given time to discuss what they had heard they became very animated and very quickly started to explore possibilities for including EHoM within their teaching. The students enjoyed talking with the visiting STEM Ambassadors and it particularly helped the students to see how skills that children were developing and using in the classroom were being used in the real world. Having the STEM Ambassadors present prompted the students to think about how they may use this resource in the future.

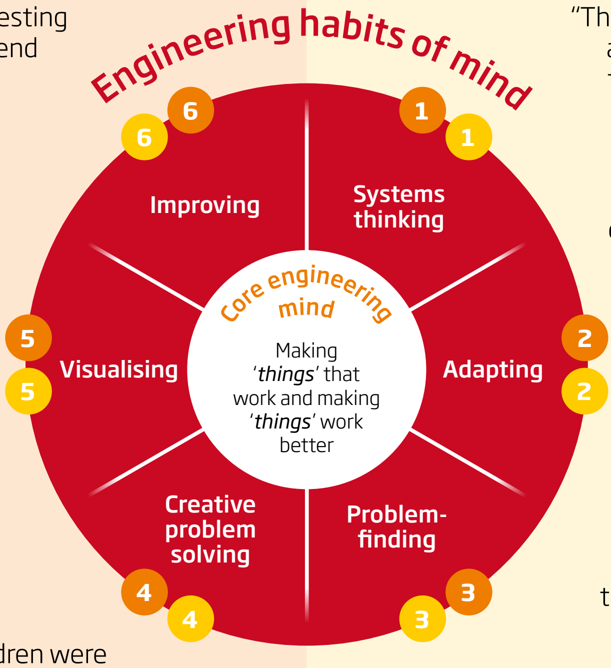
During the evaluation session at the end of the project, the Ambassadors strongly endorsed the ways in which the students had planned and taught their EHoM activities. They stressed the importance of planning but also of recognising that it was acceptable to fail and then think how you can adapt to the new situation. They advised the students to build in time to improve and make things better; an engineer can always find ways to improve something.

4.4 How future teachers noticed pupils using EHoM in the classroom

The students had clearly made sense of the EHoM by the time they went into school to teach their activities. Using evidence from the students' reflections on their teaching activities, gathered at the evaluation session, this report presents some examples of the ways in which they recognised pupils' use of EHoM through their classroom talk and behaviours (**figure 4**).

Science

1. "[Pupils] were able to change their mind after investigating which method was best for making tea. Predicted one, changed to the other"
2. "Constantly changing equipment to make the experiment more effective: more efficient, testing and analyzing results, defend own thoughts and ideas through scientific explanations"
3. "Check solution, methodically and effectively. Questioning, curious and skeptical. Finding that solutions already exist."
4. "Children came up with suggestions as to how they would seal their tea bag; children were able to work in groups to decide on the best way to create a tea bag"
5. "Water test sink/float. Children were visualizing what was going to happen to the rocks based on their appearance"
6. "Consistently improving the efficiency of their experiments through trialling different types of equipment (changing their method and strategies"



D&T/ Computing

1. "The children were beginning to predict what the sequence for programing the lights would be and also then began to work out themselves what it would be for flashing lights. I feel this was because they began to understand the system"
2. "The children had one plan for a design and then adapted the light sequence to fit to the new scene which the other group has designed."
3. "They then visualised the end product ...and realised that one of their sparkles was in the wrong place in relation to the DT model, so together they worked out how to change its position."
4. "Once the children had become confident in creating the crumble sequence they also used their own initiative to solve any problems themselves before asking."
5. "The DT group decided that as they were making a skyline, they would like a light in a window, so they passed this onto the coding team [who] quickly changed the colour of the light to represent this. ...they visualised the finished display and then realised that they would need to swap the order of the wires, otherwise the lights would be in the wrong place on the display."
6. "When programming the sparkles, one child said 'that looks really good but it would be better if we made it faster so the lights looked like they were shooting across the sky'"

Figure 4:
Student teachers' identification of pupils using EHoM

Engineering habit of mind	Sub-habit one	Sub-habit two
CREATIVE PROBLEM-SOLVING is … generating ideas and solutions by applying techniques from different traditions, being resourceful, critiquing, giving and receiving feedback, seeing engineering as a 'team sport'.	**Generating ideas:** comes up with practical suggestions in a range of situations, constructs convincing arguments to support or refute claims; explains solutions to problems.	**Working in team:** **Collaborating:** has good people skills to enable idea and activity sharing; good at giving and receiving critique and feedback, works well in a team to address a challenge.
IMPROVING is … making things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping; this necessarily requires resilience, perseverance, reflection and open-mindedness.	**Experimenting:** makes small tests or changes; sketching, drafting, guessing, prototyping.	**Evaluating:** making honest and accurate judgments about 'how it's going'; comfortable with words and numbers as descriptors of progress **Deliberate practising:** perseveres through the hard parts, learns from failure.
PROBLEM-FINDING is … being curious, deciding what the actual question is, posing a different problem or re-framing the original one, finding out if solutions already exist by clarifying needs, checking existing solutions, investigating contexts, verifying, thinking strategically.	**Checking and clarifying:** checks understanding, seeks clarification, questions apparent solutions methodically and reflectively.	**Investigating:** has a questioning, curious and, where appropriate, sceptical attitude.
ADAPTING is … using ingenuity, making something designed for one purpose suitable for another purpose, by converting, modifying, transforming, adjusting, changing, re-shaping, re-designing, testing, analysing, reflecting, rethinking.	**Critical thinking:** analyses ideas, activities and products; able to defend their own thoughts and ideas in discussion and also to change their mind in light of evidence.	**Deliberate practising:** disciplined; able to work at the hard parts **Evaluating:** evaluates solutions to problems, sees alternatives and trade-offs and has due regards for criteria such as cost, safety and possible impacts.
VISUALISING is … a specific form of communication, seeing the end product, being able to move from abstract ideas to concrete, manipulating materials, mentally rehearsing alternative practical design solutions and communicating them to multiple stakeholders.	**Thinking out loud:** puts 3D ideas images into words, as they become pictures, rehearses possible lines of thought or action, verbalises learning.	**Model-making:** **Modelling:** moves between abstract and concrete, making uses 2D or 3D models to capture generate and communicate making models to capture ideas ideas.
SYSTEMS-THINKING is … seeing essential connections between things, seeking out patterns, seeing whole systems and their parts and how they connect, recognising interdependencies, synthesising.	**Connecting:** looks for links, connections, relationships; working across boundaries.	**Pattern-making:** uses metaphors, formulae, images etc. to find patterns to illustrate new meaning, or explain unexpected effects.

Table 3:
Six EHoM and 12 sub-habits – revised descriptors
(New suggestions in **green**, previous text in **red** and scored through)

4.5 Extending understanding of EHoM

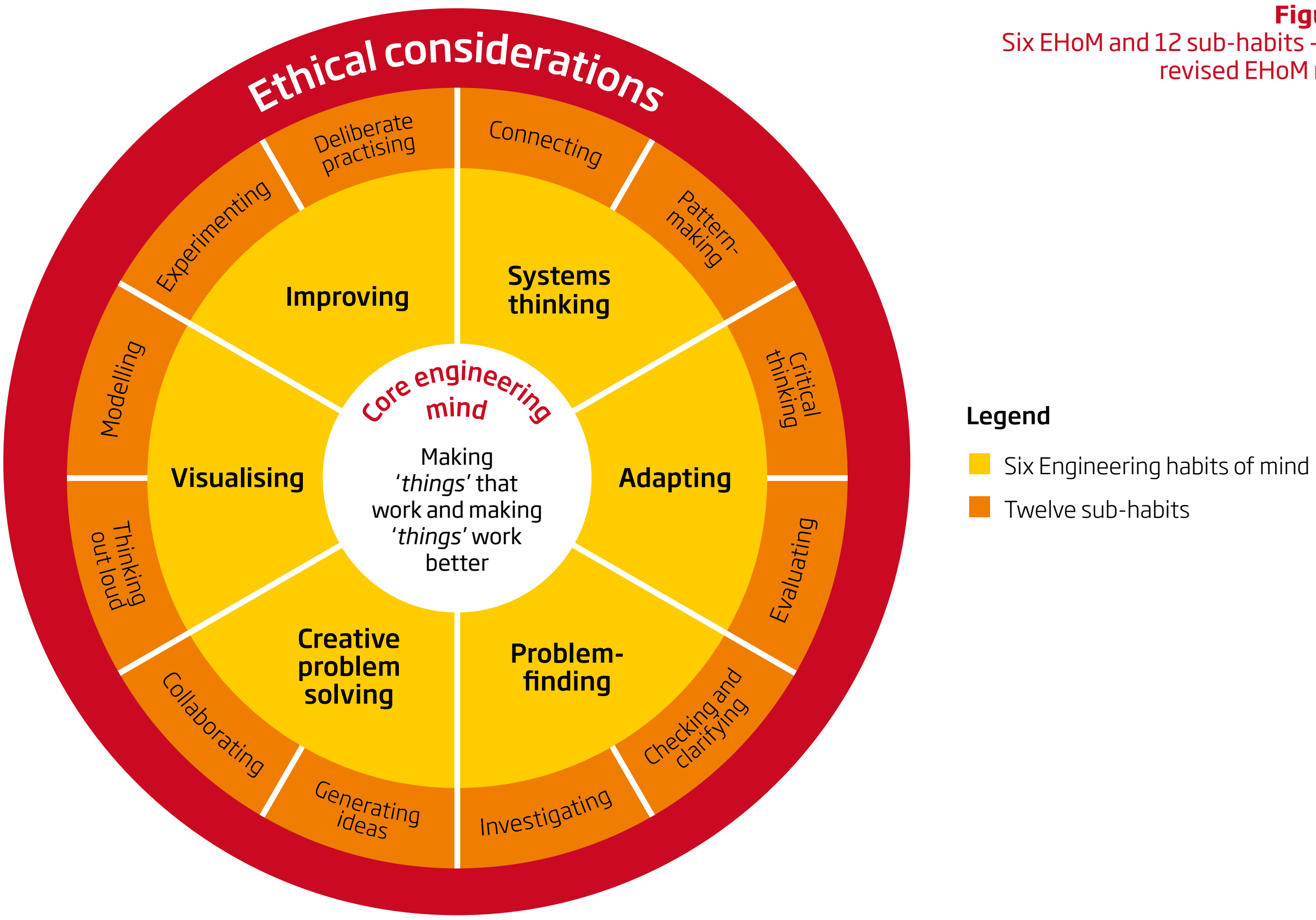
The students could clearly see links between the EHoM and their subjects but they acknowledged that to incorporate them into lessons required planning and subject knowledge to support the child and develop the EHoM. The six EHoM were originally developed in 2014 in discussion with engineers, so this detailed consideration of EHoM by another group of potential users provided the research team with an opportunity to sense-heck the ways in which the meaning of each EHoM and its sub-habits was understood by those new to them. The authors also decided to reconsider the original descriptions of the EHoM proposed in the US[90] and update thinking on how well the authors' EHoM aligned with the original source of the ideas. The changes suggested as a result of this new thinking are noted in **Table 3** as the revised descriptors of EHoM and their sub-habits.

In **figure 5**, the revised EHoM model shows the 12 sub-habits and the six EHoM clustered around the core engineering mind – 'making things that work and making things work better'. The whole is surrounded by 'attention to ethical considerations', which has an impact on all aspects of engineering. Since the original model was developed in collaboration with engineers and engineering educators, this revised model will also need to be validated by teachers and engineers.

4.6 Aligning EHOM and disciplinary thinking ways of thinking

To help teachers develop the confidence to incorporate EHoM into their teaching, it is important to show them that this is not something extra but can be used as a way of developing and building on the thinking processes that are already within National Curriculum programmes of study. The authors analysed teachers' reflections on pupil classroom behaviour and

Figure 5:
Six EHoM and 12 sub-habits – CRL's revised EHoM model



EHoM	Computational thinking	Working scientifically	Design-make-evaluate
Improving	**Evaluation:** W "they noticed that someone else had made their lights flash, so my group then decided that they would like that idea, as it would fit better with their project."	**Observing:** R "Child suggested that wet rock (chalk) wouldn't scratch off and we needed dry chalk."	**Evaluate:** W "The pupils 'Magpied' other groups' ideas in order to make their piece better."
Problem finding	**Debugging:** E "When one of the lights did not change the pupils realised they needed to go through the programming to see where it had gone wrong. They followed the sequence on screen as the lights flashed to help them find where it needed."	**Investigations:** F "Activating new knowledge and using it to inform further investigations and allowed curiosity."	**Evaluate:** W "They then visualised the end product ... and realised that one of their sparkles was in the wrong place in relation to the DT model, so together they worked out how to change its position."

Table 4: Mapping of EHoM and disciplinary ways of thinking

talk to identify some preliminary examples of where this alignment might occur. In **Table 4**, the matrix begins to suggest where the students' identification of the EHoM they thought the pupils were exhibiting in class might be mapped against the elements of computational thinking, working scientifically and design-make-evaluate. At this stage, this is work in progress showing just two examples, for improving and problem finding. Further consideration of these connections could be taken forward by subject associations or curriculum planning groups.

4.7 Summary

Within the length of a semester the authors demonstrated how it might be possible for university ITE departments to introduce trainee primary teachers to ways of thinking about engineering that they might incorporate into their teaching of STEM subjects. Using the concept of EHoM and ways of 'thinking like an engineer', and with support of their education lecturers and the professional engineers, trainee teachers were confidently able to prepare, plan and teach activities to primary children. However, the short duration of the available planning time and the teaching periods meant that there was limited opportunity for them to emphasise the engineering focus. Nevertheless, as the teachers reflected on their activities, they were clearly able to identify occasions when children might be using EHoM.

5. Conclusions and recommendations

5.1. Summary of the project outcomes

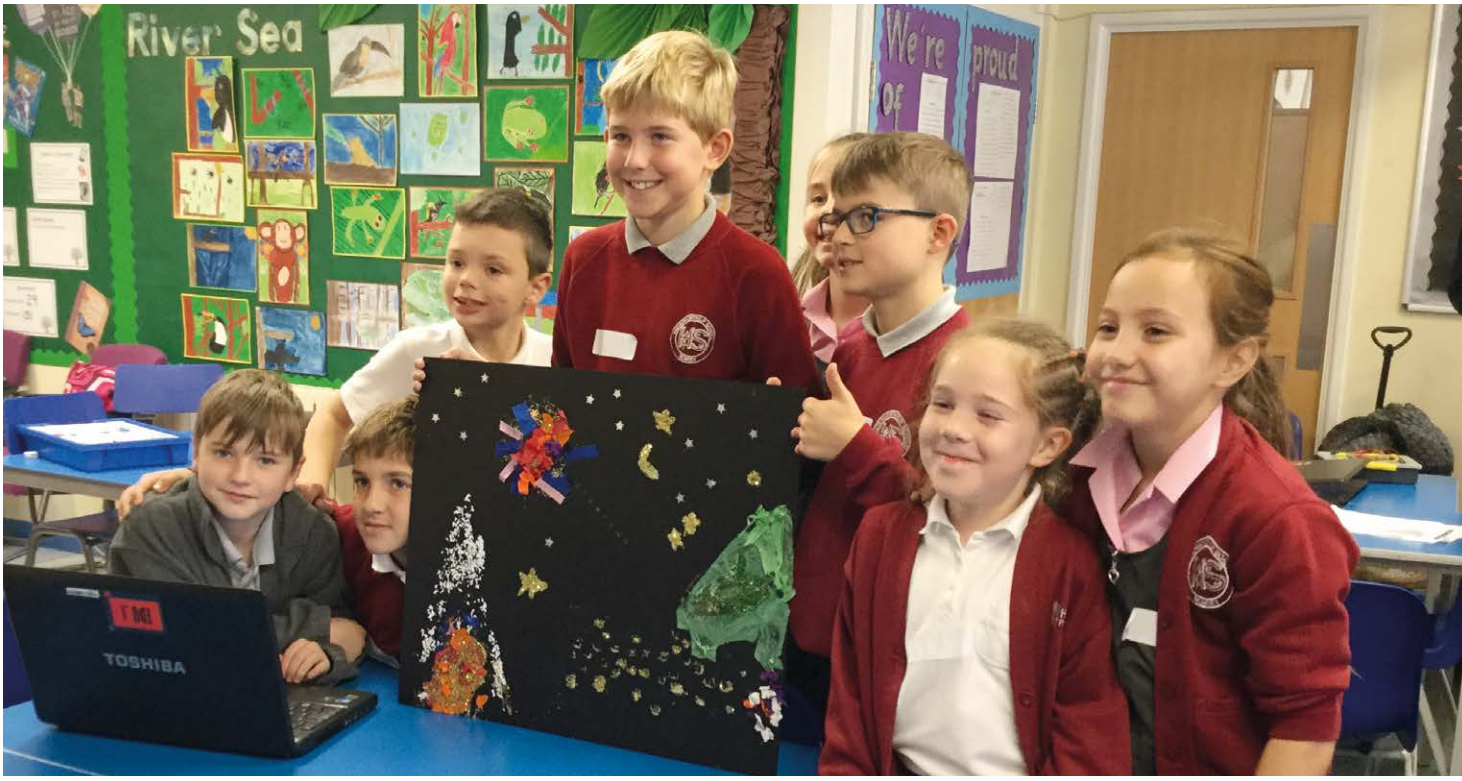
Although this was a very small-scale intervention it demonstrated that within a university ITE department it was possible for education lecturers to introduce EHoM to primary trainee teachers through cross-curricular learning. These students then demonstrated that they understood the process through which EHoM might be incorporated into their lesson planning, that they could confidently teach activities to cultivate EHoM together with subject content, and that it was possible for them to recognise when the children were using EHoM.

University ITE departments are busy places and there are many demands on education lecturers' time. Nevertheless, three lecturers from three different disciplines worked collaboratively, with some external research support, on this activity. This enhanced their own understanding of EHoM and demonstrated how ITE structures and processes could be adapted to foster cross-curricular learning within STEM subjects. They also gained insight into how EHoM might be used within their subject specialisms to develop a cross-curricular approach to STEM learning for a future module that might be developed for the BEd programme.

The lecturers became more aware of the requirements, opportunities and challenges for primary student teachers to develop awareness of EHoM within an ITE context, which included the following:

- A good understanding of EHoM and how they align with each subject is necessary, including understanding that EHoM should be embedded within teaching rather than being seen as an 'add-on'.
- Module plans and learning intentions should be flexible enough to accommodate projects such as this when they arise.

Pupils at Halterworth Primary School proudly display their interactive fireworks scene



Close up of pupils' interactive fireworks scene

- ITE department workloads should be sufficiently flexible to accommodate lecturers' engagement with planned action research activity.
- A school context is required in which to undertake a teaching activity designed to develop EHoM; preferably a school that has STEM and/or relevant learning dispositions within its improvement plan.
- A whole-school approach to developing EHoM is desirable.
- Working with STEM Ambassadors is very useful, but it should be on an extended basis rather than a single visit, preferably through establishing links at the company level as well as at the individual level.
- Time is needed for the students to build up their understanding of EHoM, plan their activities, teach the lesson and then reflect on the outcomes; a single semester was probably too short a period to allow for the activity and consolidation of learning.
- An action research approach, in which lecturers reflected on their activities with an external researcher, facilitated data collection and modelled a reflective stance to their students.

Over the course of one semester the students training to be primary teachers grew in confidence, not just in their understanding of EHoM, but also in their ability to prepare, plan and teach activities that encouraged children to begin to think like an engineer. They recognised several important factors that contributed to their success, in addition to aspects that could have enhanced the outcomes, as follows:

- It was necessary to allow children to lead the activity, with the trainee teacher as facilitator, but this needs confidence and risk-taking on the part of both teacher and child.
- The students accepted that there were no right or wrong answers, as long as the pupils could justify their solutions, they had to step back and encourage the children learn from their mistakes.

- The children were keen to critique and improve their outcomes, but the classroom environment is time-poor and did not allow for this to occur to any great depth, which limited the amount of learning and reflection that could take place.
- All the activities planned by the trainee teachers would have been even more effective if more time had been devoted to them, taking perhaps a whole day or having shorter sessions over a more extended period.
- Classroom roles and responsibilities can be associated with each EHoM and allocating the roles to different pupils in group work can be used to engage children in the activity.
- EHoM do align with the subjects the students were teaching but embedding them into lessons initially required increased planning and subject knowledge to support the child and EHoM.
- The role of the teacher has to include scaffolding learning through asking questions to support understanding and to provide opportunities for EHoM to occur; teachers should not simply provide answers to pupils' questions.
- It would have been helpful to have prior knowledge of the children's abilities, they were very good at some aspects of programming, and their problem-solving was evident.
- Need to consider the resources used to support pupils when problem-solving.
- The students recognised that they were using EHoM themselves, they always had to be flexible to adapt their teaching, for example thinking on their feet to reboot the laptops, or to use different materials if planned resources were not available.

The project also demonstrated that primary student teachers are able to identify EHoM within computing, D&T and science, and that the students developed a more favourable attitude towards engineering as a result of being involved in the project activity.

The students clearly developed understanding of EHoM and showed willingness to identify ways in which they could incorporate them into the teaching of D&T, computing and science. It appeared to be easier for the D&T and computing students to achieve this for two reasons. It seemed to be easier for them to quickly make links between their subject and the EHoM, and they were probably more confident in their subject knowledge. The science students began their planning with the science content they wanted to cover and then considered the teaching methods they might use. In doing this, they were more attuned to the principles of working scientifically before they addressed the EHoM.

The two schools that hosted the students' teaching activities were very pleased with the outcomes and valued the students' input. The class teachers were very impressed with the students and they admitted to being prompted to think about challenging the children more frequently themselves. Despite the great pressures on schools, and the need for very tight organisation of teaching practice, it was possible to make a small amount of time available for this kind of reflective project. One factor that would have enhanced the situation for the students would have been to have greater prior knowledge of the children's abilities.

The STEM Ambassadors valued the opportunity to become engaged with the project and it was a novelty for them to be involved with students training to become primary teachers. Working with the Ambassadors was also a very positive experience for the student teachers and the lecturers, although the restricted timetabling of the project activity meant that it was not possible for the STEM Ambassadors to attend the schools when the students taught their lessons. The students found this engagement with engineers so memorable that they nominated their lecturers for a university teaching award for this aspect of their learning experience in the project.

Student teacher invites Halterworth pupils to evaluate their final interactive fireworks scenes

Finally, this project provided an opportunity to view the EHoM and their alignment with STEM disciplinary thinking through the eyes of a new group of stakeholders. This led to a revision of the descriptors associated with the original six EHoM and their 12 sub-habits. These amendments remain to be further validated in due course by teachers and engineers.

5.2 Recommendations

To university providers of ITE

- Give it a go! You just need enthusiasm for helping students look at their teaching creatively through a different lens to open their eyes to the possibilities of engineering.
- Look at your own curriculum subject specialisms through the lens of EHoM, which offer an approachable way of introducing engineering to ITE students, schools and children through almost any subject in the curriculum.
- Provide an introductory lecture on EHoM and introduce the concept to students early in the module in which you plan to incorporate an intervention such as the one described in this report.
- Provide examples of possible projects, but consider giving the students something that is a work in progress so that they can explore it for themselves and plan how to teach it.
- Use STEM Ambassadors to support your EHoM initiatives and enthuse teachers and children about the real world of engineering.
- Seek the involvement, where possible, of your university's engineering department.

To schools and providers of school-centred initial teacher training

- Encourage subject leaders and mentors to support new teachers to have the confidence to suggest innovations in their teaching practice such as those illustrated in this report.
- Use STEM Ambassadors strategically as part of the school's careers strategy and within teachers' professional development or initial training.
- Designate a lead teacher for employer contacts.

To engineering employers and professional bodies

- Engage with primary schools, they are keen to have your support.
- Promote ways in which engineers can engage with trainee teachers and newly qualified teachers.
- Reach out to ITE providers, whether university or school based, to engage them in the idea of using engineers, for example STEM Ambassadors, to support EHoM initiatives and increase understanding about engineering.

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