Developing pre-service primary teachers' understanding of engineering through engineering habits of mind and engagement with engineers

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Accepted: 13 March 2021 / Published online: 13 May 2021
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Abstract

This paper explores how primary teachers might be prepared through their pre-service training to feel more confident to include engineering in their teaching. Prompted by concerns about young people's lack of interest in STEM subjects and careers, engineering is gradually gaining visibility in the primary curriculum in several forms, particularly through integrated STEM programmes. However, the status of engineering relative to science, technology and mathematics remains contested in schools and engineering has low visibility in pre-service preparation programmes for primary teachers. Therefore, this case-study investigated how two strategies might give students learning to be primary technology, computing and science teachers greater confidence to introduce the concept of engineering into their teaching. By reframing engineering as engineering habits of mind and by giving students experience of engaging with practising engineers, the study found that it was possible to enhance primary trainee teachers' understanding of the world of engineering and increase their confidence to introduce engineering habits of mind in lessons with primary children. The paper concludes with some implications for practice of this approach.

Keywords Engineering habits of mind · Pre-service teachers · Initial teacher education (ITE) · Engineering education

Introduction

Education for engineering is mostly absent in schools but the global demand for science, technology, engineering and mathematics (STEM) skills remains high despite numerous initiatives to encourage more young people to progress into STEM careers (Blackley and Howell, 2015; Department for Business, Innovation & Skills 2013). This has led to calls for engineering to be addressed more visibly in schools, particularly at primary level (Finegold et al. 2018; Katehi et al. 2009). By introducing young children to engineering, it is possible that some of the influences which appear to constrain the development of their

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interest in STEM, such as lack of self-identification with STEM subjects (Archer Ker et al. 2013), may be ameliorated.

Although some countries do now refer to engineering within the formal curriculum, different models exist and rather than being taught as a discrete subject, engineering often appears as the context or the problem through which science and mathematics content is taught (Blackley and Howell, 2015). Some models focus on integration between STEM subjects but the position of engineering with reference to the other three subjects is often contested in the operationalisation of this approach. For example, it is often claimed that science and mathematics are prioritised over technology and engineering (Aydeniz and Cakmakci, 2017) or that the differences between technology and engineering are eroded (Margot and Kettler, 2019).

However, new ways of practising engineering require interdisciplinary thinking and complex problem-solving skills to address global societal, economic and technological challenges (Lloyds Register Foundation 2018). In response to these new demands on engineers, the narrative of engineering education has changed from being one of addressing specific skills shortages to being about a way of thinking and behaving that improves people's lives (Chalmers et al. 2017; Finegold, 2016). One of the ideas underpinning this new narrative is to reframe engineering education through the ways of thinking, or habits of mind that professional engineers use in practice.

A combination of emphasising when children are using engineering habits of mind (EHoM) in lessons and introducing children and primary teachers to practising engineers who exemplify real-world engineering thinking has proved to be a powerful combination for changing perceptions about engineering in the United Kingdom (UK) (Lucas et al. 2017), in a context where engineering in primary education is mainly reliant on the interest of individual teachers (Clark and Andrews, 2010).

However, teachers need confidence to introduce engineering-related topics into their teaching (Avsec and Sajdera, 2019; Coppola, 2019) and to instigate contacts with engineers and draw on their practical experience (Gibson, 2013). Professional development programmes for teachers, both in-service and pre-service, are addressing these challenges in innovative and creative ways (Mesutoglu and Baran, 2020). Nevertheless, it has been suggested that more attention should be paid to researching the experiences of pre-service primary teachers (Clark and Andrews, 2010; Rinke et al. 2016; Shernoff et al. 2017; Wendell et al. 2019). Consequently, the overall aim of this case study was to explore, in the context of the new narrative for engineering education noted above, how a specific approach to understanding engineering as engineering habits of mind (EHoM), reinforced through authentic engagement with engineers, might support primary pre-service teachers (PST) to develop greater confidence to embed engineering themes into their teaching. This paper starts by briefly describing the position of engineering in primary education and then discusses factors influencing primary teachers' confidence to teach engineering. After examining how some pre-service teacher development programmes have attempted to address the challenge, the potential for building teachers' confidence by emphasising EHoM and by experiencing contact with engineers during their preparation programmes is discussed. This leads into an account of the research undertaken with pre-service students learning to teach technology, computing and science on a primary teacher preparation programme at a university in England.

A lack of clarity in teachers' minds over the boundaries between STEM subjects may contribute to their reluctance to address them so for this study, technology is understood as "any modification of the natural world done to fulfil human needs or desires" and engineering is "a systematic and often iterative approach to designing objects, processes, and

systems to meet human needs and wants" (National Assessment Governing Board, 2018, pp. xv–xvi). Although sharing practices with both, science is a distinct discipline whose goal is "the construction of theories that can provide explanatory accounts of features of the world" (National Academies of Sciences, Engineering, and Medicine 2020, p. 40).

Pre-service primary teachers' preparation for engineering education

Engineering as a concept could be introduced into primary education through almost any subject but is approached mainly through science or technology. In the US engineering is included in science educational standards as one of the disciplinary core ideas, so both engineering thinking and scientific inquiry are taught (NGSS Lead States, 2013). In other countries, for example Australia, engineering is located within the technology curriculum (Thompson, 2016). In England, engineering is not a subject within the national curriculum but computing, mathematics and science are compulsory subjects from age 5–16 and technology, referred to as design and technology (D&T) is compulsory to age 14. Teachers are encouraged to incorporate iterative design and engineering as a focus for learning in D&T (Department for Education (DfE) 2013), but there is limited application of engineering within other subjects in the primary curriculum (Hanson et al. 2018).

In England, primary teachers usually study a three-year undergraduate Bachelor of Education (BEd) to obtain a university degree and qualified teacher status. Those already holding an undergraduate degree can join a one-year Postgraduate Certificate in Education (PGCE) offered by universities or partnerships between universities and schools designated as training hubs. Through either route students train to teach a broad range of subjects since primary teachers are normally expected teach across most subjects in the curriculum to their class, although within the training programme they would normally would have the opportunity to specialise. On all routes, student teachers spend a minimum of 24 weeks in school (DfE, n.d.).

Although primary teachers would appear to be in a strong position to teach integrated engineering projects because they normally teach across all areas of the curriculum (Pope, 2019) a frequently cited barrier to doing this is PSTs' lack of content knowledge, not only in engineering but in the actual STEM subjects they are training to teach, such as technology (Avsec and Sajdera, 2019; Bencze, 2010; Lee et al. 2020; McRobbie et al. 2000), science (Radloff and Capobianco, 2019) and computing (Bell et al. 2016). This leaves them feeling unprepared to teach engineering (Bir et al. 2017; Coppola, 2019), despite their awareness of its importance (Bir et al. 2017; Kurup et al. 2019; Margot and Kettler, 2019). They are also hampered by their stereotypical or erroneous views of engineers (Bir et al. 2017); a lack of insight into the nature of engineering (Pleasants and Olson, 2019); and their inexperience of authentic contexts in which science and technology knowledge is used (Bencze, 2010).

The widespread response of teacher educators to these challenges is to introduce PSTs to the engineering design process (EDP) as the vehicle for learning to teach engineering projects (Aydeniz and Bilican, 2018; Coppola, 2019; Lin and Williams, 2017; Mativo and Park, 2012; Radloff and Capobianco, 2019; Wendell et al. 2019; Winarno et al. 2020). However, most students starting primary teacher-training are unlikely to have had much exposure to engineering design at school (Dalvi et al. 2020). Science students may struggle to understand the difference between science and engineering (Pleasants and Olson, 2019) and their ways of thinking (Dalvi et al. 2020), not being able to distinguish between

the controlled experimentation of scientific inquiry and the iterative nature of engineering design (Radloff and Capobianco, 2019). This can lead to them misrepresenting engineering in the classroom and downplaying the importance of problem-solving and creativity (Aydeniz and Cakmakci, 2017).

Technology students may have a narrow conception of the design process, not perceiving it to be an iterative process that encourages reflection on failure and learning from mistakes (McRobbie et al. 2000), so they skip the re-design stage or simply frame the project as building a product rather than being a process (Coppola, 2019; Wendell et al. 2019).

There is growing interest in incorporating computational thinking (CT) into primary education to foster children's digital literacy skills (Hacker, 2018). CT includes thought processes such as abstraction, algorithms, troubleshooting and debugging, pattern recognition, problem decomposition and simulations and it has been suggested that engineering design and CT can be complementary (Ehsan et al. 2020). But again, many primary teachers will lack relevant expertise to teach the subject confidently (Bell et al. 2016) or equate computing with technology (Lee et al. 2020).

Teacher educators can use several strategies to overcome these challenges. An incomplete understanding of the EDP might arise from experienced design teachers underestimating the skills involved in the design process, which can be ameliorated by discussing design skills with students and enabling them to develop a more sophisticated conceptualisation of the process before they begin a project (van Dooren et al. 2020) or by using real-world problems and engineering-based projects, strategies which increase PSTs' sense of self-efficacy and enhance their creativity (Avsec and Sajdera, 2019).

Many PSTs hold entrenched views about how subjects should be taught, based on their own educational experience in which posing problems and habits of mind were most likely missing (Dalvi et al. 2020), and they are hard to change (McRobbie et al. 2000) but active learning pedagogies modelled by their lecturers can modify their attitude and develop their confidence and ability to use design-based and student-centred learning approaches themselves (Bencze, 2010; Coppola, 2019; Radloff and Capobianco, 2019). Furthermore, students reported that their confidence to be more innovative and creative in lesson planning was increased when they actually taught their lessons to children rather than just planning them or completing design projects (Aston and Jackson, 2009; Coppola, 2019).

Some educators foster links between PSTs and engineers or engineering students to support content development (Fogg-Rogers et al. 2017; Williams and Mangan, 2016) or to undertake design projects in industry (Gibson, 2013; MacGregor and White, 2016) to expand PSTs understanding of engineering. However, many primary PSTs still report that their training programme lacks opportunities to experience integrated STEM or pedagogical approaches that emphasise real-world learning (Kurup et al. 2019). Therefore, if the foundations for good practice in engineering education can be established through pre-service teacher preparation programmes, greater familiarity with engineering thinking and engineering contexts can be established early in teachers' careers.

Principles for adapting programmes to prepare primary teachers to engage with engineering have been identified, either by interviewing teachers (Shernoff et al. 2017) or by undertaking a systematic literature review of professional development programmes (Mesutoglu and Baran, 2020). From these sources, it appears that effective interventions for PSTs should provide real-world examples that develop understanding of engineering, promote interaction between teachers and professional engineers, emphasise student-centred pedagogies that focus on asking questions not providing information, give teachers hands-on experience of designing lessons, and finally have them teach a lesson in class to children. However, two principles that are less frequently included are explicitly

emphasising engineering thinking through engineering habits of mind and foregrounding the value of engaging with engineers to demonstrate how these habits are enacted in practice. The potential of these factors is explored in the next two sections.

Engineering habits of mind

Habits of mind (HoM) are dispositions and effective patterns of thinking that intelligent individuals draw on when confronted by problems, and like habits, they are internalised practices guiding decisions and actions (Costa and Kallick, 2002). It has been suggested that STEM disciplines' HoM and ways of thinking should constitute an important element in STEM education because they help students understand the 'nature and discourse of STEM and thus be able to legitimately engage in STEM' (Chalmers et al. 2017, p.S28). There is some evidence that the need to enhance HoM is being addressed during the preparation of mathematics primary PSTs (Jacobbe and Millman, 2010) and in science (Çalik et al. 2014). Engineering habits of mind (EHoM) appear less often in the context of teacher preparation, despite their inclusion in the US Next Generation Science Standards (NGSS Lead States, 2013). In the UK, a variation on the US model of EHoM was conceived and validated in collaboration with engineers (Lucas et al. 2014) and includes systems thinking, problem-finding, creative problem-solving, visualising, adapting, and improving. EHoM are not fixed traits, they can be intentionally cultivated by teachers using a combination of four principles; developing understanding of the habit, creating the climate for the habit to flourish, choosing teaching methods that facilitate the practice and transfer of the habit, and building learner engagement and commitment to the habit (Lucas et al. 2017). Understanding EHoM can add clarity for teachers to the learning required to successfully engage with engineering and to select the most appropriate pedagogies when teaching it, for example real-world projects (Williams, 2011). Furthermore, it can be shown that EHoM complement the design process, for example, by aligning improving with testing and evaluating design specifications, and so may present an alternative or complementary approach to integrating science and mathematics with engineering (Asunda and Weitlauf, 2018). Design processes and scientific inquiry describe disciplinary practices aimed at developing a product or revealing knowledge whereas habits of mind reflect the values and culture of a discipline and give it meaning; both practice and habit are important in understanding the similarities and differences between STEM subjects, but habits are often under-emphasised (Pleasants and Olson, 2019).

Building teacher confidence through contact with engineers

Uncertainty about what engineering is can result in negative perceptions of engineers and what they do (Bir et al. 2017; Pleasants and Olson, 2019), so even brief contact with engineers can expand primary teachers' awareness of the impact of engineering on the world around them and increase their understanding of engineering thinking (Duncan et al. 2011; Gibson, 2013). Furthermore, engineers can help to make STEM classroom activities appear relevant to the real-world, build teachers' confidence to discuss engineering themes with pupils and highlight the importance of problem-solving, collaboration and communication skills (Bowen and Shume, 2018; MacGregor and White, 2016).

However, there are many reasons why primary teachers may not be able to make the most of engineers' support, including lack of time or confidence to establish meaningful contact with industry, so by increasing PSTs' experience with the engineering environment, they may use that experience to sustain their confidence in making contact beyond their training (Gibson, 2013; MacGregor and White, 2016).

A framework for exploring pre-service teachers' confidence to engage with engineering and developing the research questions

EHoM resonate with teachers and in conjunction with support from engineers have proved to be useful points of access to engineering for in-service teachers (Lucas et al. 2017) so it seemed appropriate to investigate their value for developing PSTs' confidence to teach engineering. The principles for designing effective programmes to introduce PSTs to engineering (Mesutoglu and Baran, 2020; Shernoff et al. 2017) were aligned with four principles for cultivating habits of mind (Lucas et al. 2017) to create a framework (Table 1) which underpinned our exploration of primary PSTs' engagement with engineering in this study.

With the overall aim of seeking to understand how primary PSTs might be encouraged to engage with engineering through EHoM and contact with engineers the following research questions guided our study:

1. How can pre-service primary teachers develop the confidence to plan, design and teach activities that encourage children to think like an engineer?
2. To what extent can pre-service primary teachers identify engineering habits of mind through D&T, computing and science?
3. What are the opportunities and challenges within a pre-service teacher-training context for student teachers and their tutors to develop an awareness of engineering habits of mind?

Space does not permit us to address the third question in this paper, but it has been addressed elsewhere (Hanson et al. 2018).

Table 1 Cultivating habits of mind and understanding engineering

Cultivating habits of mind	Cultivating pre-service teachers' understanding of engineering
Develop understanding of the habit	Provide real-world context to establish relevance of engineering; promote interaction between teachers and engineers
Create a climate for the habit to flourish	Emphasise student-centred pedagogies that focus on asking questions not providing information
Choose pedagogies that encourage practice of the habit	Give teachers hands-on experience of designing lessons
Build learner engagement and commitment to the habit	Teach lesson in class to pupils; observe and reflect on learners' reactions

Research design

Setting

Two elements, EHoM and contact with engineers, were embedded through a small-scale qualitative intervention within an initial teacher education programme. The programme, offered by an English university, was a three-year undergraduate Bachelor of Education (BEd). The research team (authors) comprised education tutors (module leaders) in the Education Department and researchers from an education research centre at the same university. The tutors were responsible for education modules in D&T, computing and science and aimed to use the lens of EHoM to foster cross-disciplinary thinking between their students studying these subject specialisms and in so doing, enhance the students' creative approaches to teaching. It is worth noting that the university does not include an engineering department.

The study took place over one semester (12 weeks). Ethical permission was given by the university's ethics committee and informed consent was gained from the tutors, students, engineers and the headteachers in the two schools where the students undertook their teaching activity. The school children and their teachers were not the primary focus for the research so data were not collected from them directly.

Research approach

A single-case study was adopted as the methodology since the investigation took place in a real-life context (Yin, 2014). Our intention was to develop understanding of the impact of an intervention that took place over a defined time-period within specific pre-service programme modules, making it a clearly identifiable bounded system (Creswell, 2013). The case was approached through a holistic design with a single unit of analysis, the intervention (Yin, 2014).

Participants

Three modules that ran concurrently in the same semester were purposefully selected. One was a third-year science specialism which prepared students for their future role as primary science subject leaders; one was a third-year computing specialism in which students examined issues surrounding the management and teaching of computing; and one was a second-year D&T option module. Voluntary participation by students was sought in advance of the semester in which the research took place. They had the option not to participate, but all consented to do so. Twenty-nine undergraduate students (22 female and seven male) were recruited in total, nine for D&T, seven for computing and 12 for science.

Engineers were recruited from the UK's STEM Ambassador network. This is a national network of volunteers from a wide variety of STEM jobs and disciplines across the UK. They offer their time and enthusiasm to bring STEM to life by undertaking activities in schools, including supporting after-school clubs, giving careers talks to pupils and helping teachers to introduce engineering topics into the curriculum (STEM Learning n.d.). Four

engineers (three males and one female) volunteered to participate. They each demonstrated a different career path into engineering and reflected a range of engineering jobs, including civil and chemical engineering and avionics. They contributed to the research by attending two sessions with the students, one at the start of the intervention and one at the end.

Finally, school partnerships were essential for the teaching element of the project to be realised. The head teachers of two local primary schools, who were willing to allow the students to teach their EHoM lessons to selected classes, were recruited. School A hosted a combined group of D&T/computing students and School B hosted the science students. These were both schools which had an established relationship with the Education Department.

Process

An introductory session was facilitated by the tutors and researchers, in which the students discussed EHoM and met the engineers. The students were then divided into small groups to plan their teaching sessions. D&T and computing students worked collaboratively on a common project in groups of 3–4 students while the science students worked in small groups but each group worked on a separate project. For the first six weeks of the semester the students met with their tutors each week to discuss progress in planning their lessons. During weeks seven and eight they were in school, and weeks ten to twelve were spent on reflecting on their teaching experience and completing their assignment. An evaluation session, bringing together the engineers and students for the final time, was held at the end of the semester.

Instrument

The instrument adopted for facilitating understanding of EHoM was the model (Table 2) shown as series of concentric circles. At the core of the model is the driving force of engineering; making ‘things that work’ and making ‘things’ work better’ surrounded by six specific EHoM, which in turn are surrounded by seven more generic learning habits. The model and the descriptors for each EHoM were developed in collaboration with engineers and piloted with teachers in the UK (Lucas et al. 2014, 2017). A template was created using the model to help the students both to plan their lessons and to reflect on how they had observed children using EHoM in their lessons.

Table 2 Engineering habits of mind (Lucas et al. 2014)

EHoM	Description	EHoM	Description
Improving	Making things better by designing and experimenting	Systems thinking	Seeing connections between things, seeking out patterns
Visualising	Seeing the end-product, being able to move from abstract ideas to concrete	Adapting	Making something designed for one purpose suitable for another purpose
Creative problem-solving	Generating ideas and creative solutions to problems	Problem-finding	Deciding what the actual question is, finding out if solutions already exist by clarifying needs

Data collection and analysis

Qualitative data were collected through multiple sources at several points during the intervention to provide an in-depth picture of the case (Creswell, 2013) and to foster greater validity of findings through triangulation from different sources (Yin, 2014). They included artefacts, observations, group discussions and a survey. A full description of the sources and their contribution to answering each question is provided (Table 3).

Since our intervention took place in modules which contributed to the students' final award, ethical approval was given on the understanding that there was minimal risk of harm to participants' academic progression. This limited our ability to use some data sources as we could not include students' module assignments or their formal module evaluations.

Data not already in an electronic format and audio recordings were transcribed. As most resulting documents were short in length the analysis was done by hand rather than using a QDA tool. Pseudonyms were allocated to students at this stage to protect anonymity. Tutors are referred to as TutorD&T, C, or S and STEM Ambassadors are SA1-4.

A theoretical orientation guided the data analysis (Yin, 2014) shaped by the literature on pre-service teacher preparation and our previous research. Prefigured codes (Creswell, 2013) drawn from our framework in Table 1 were used to interrogate data sources and

Table 3 Data sources

Category	Data source	Research question
Artefacts	Lesson plans (group) Completed EHoM templates (group)	RQ1 students' confidence RQ2 students' identification of EHoM
Observations	Unstructured observations by tutors of students while planning lessons and teaching them in schools Tutors' field notes and reflective journals	RQ1 students' confidence RQ2 students' identification of EHoM
Group discussions	Audio-recorded discussions (×3) between tutors and researchers in weeks 4, 7 and 12 Notes from group discussions between tutors, students, STEM Ambassadors and researchers (×2) (notes made by tutors & researchers)	RQ1 students' confidence RQ2 students' identification of EHoM
Survey	Written reflections collected from each student at the end of the semester with questions prompting them to describe their reactions to incorporating engineering habits of mind into their teaching	RQ1 students' confidence RQ2 students' identification of EHoM

identify themes in support of answering research question one and prefigured codes from the EHoM descriptions in Table 2 were used similarly for research question two. The findings from this process are reported below in relation to the research questions.

Findings

RQ#1: Can pre-service teachers develop the confidence to plan, design and teach activities that encourage children to think like an engineer?

D&T/Computing students

The D&T/computing students collaborated on planning and teaching an integrated topic for year 5 (age 9), culminating in teaching a combined class of 65 pupils across two classrooms for 90 min in School A. Working with the topics of control in D&T and coding in computing, the real-world context for the activity was ‘Through the window on Bonfire Night’,¹ which engaged pupils in a design task and problem-solving involving sequencing instructions linked to programming. They had to use block coding with the Crumble programmable controller (<https://redfernelectronics.co.uk/crumble/>) to control Sparkles (LEDs) that can be programmed to change colour, for example, to represent a firework display, something pupils could imagine from personal experience.

After providing input about the task, the students engaged pupils in analysing the requirements of the design task, with the aim of encouraging them to “learn to work as a team on a STEM project” (Beth/Ethan). They cultivated pupils’ collaboration skills by allocating them to different team activities, some coding and some designing a blackboard representing the night sky to house the Sparkles. Pupils changed activities during the lesson so they all experienced both coding and designing. Students developed pupils’ problem-solving skills by asking questions of the coding teams “to prompt the children to use self-enquiry and de-bugging techniques” (Emelia/Camilla/Mia). With the design teams, they planned to “Encourage the group to design and make their firework night sky, using the resources provided” (Emelia/Camilla/Mia). They continued this positive climate-building to the end of the lesson by incorporating time for evaluating and encouraged children to improve and adapt their work by asking questions such as “What improvements could be made? What else could you use Crumble to do?” (Amber/Chloe).

The students concluded that their active learning strategies successfully engaged the children with EHoM. They noticed them “collaborating” (Sophia, Isla) or “working well” in groups (Camilla, Amber, Ethan, Adam). They observed children “problem-solving” (Adam, Ethan). Beth expanded on this by noting that the children “discussed how to rectify errors and problem solved, created a plan but adapted it as necessary”. Other students described this type of behaviour as “debugging” (Emelia, Florence, Chloe) or “improved on their work” (Adam). Some were pleased that “Children had an end-product by the end of the lesson” (Ethan) but others recognised that this focus on the end-product might have come at the expense of allowing pupils time to arrive at deeper understanding of EHoM, as one suggested “not sure children had time to focus on their EHoM of adapting and

¹ This refers to the annual commemoration of a foiled plot to blow up Parliament on November 5th 1605, when it is a tradition in England to light bonfires and set off firework displays.

improving and problem-solving; there was obvious evidence of systems thinking in the Crumble kit, but this was given to them rather than the child choice” (Amber).

Each student group took a different approach to managing the activity. Computing students in charge of one classroom “spent a lot more time getting the children to plan on paper and ... labelling the designs where the lights would go... before they actually started the project” (TutorC). Whereas in the D&T students’ class “there was a lot more movement and activity and a lot more making” (TutorD&T) perhaps because they were confident enough to “step back and let them [pupils] get on with it” (TutorD&T). The tutors observed pupils using EHOM including adapting and problem-solving in both classes but felt that the students did not always see this until they reflected at the end of the lesson when “the engineering suddenly became more apparent because ...they were having to integrate all this electronics into the picture” (TutorC).

Science students

The science students were divided into four groups, each teaching a separate topic to a class of 25–30 pupils. Of their own volition the students selected four science topics from the English national curriculum (DfE 2013) that were appropriate for the ages they would be teaching. The four topics were the properties and uses of everyday materials, using making teabags as an activity (Teabags) (with Year 2/age 6); comparing and grouping different kinds of rocks (Rocks) (with Year 3/age 7); comparing properties of human and animal teeth (Teeth) (with Year 4/age 8) and deciding how mixtures of materials might be separated through filtering (Filters) (with Year 5/age 9). The structure of their module enabled them to have two sessions in School B, so each group used their first lesson to elicit pupil knowledge on their topics, which allowed them to focus the second session on engaging the pupils in scientific inquiry and problem-solving activities because “it was felt that this would provide opportunities for the children to demonstrate aspects of EHOM” (TutorS). The lesson plans for all four groups suggested that their intention during both lessons was mainly the acquisition of scientific knowledge, with learning outcomes such as “Expand and strengthen knowledge of rocks” (Ada/Carol/Eloise) and “Use of knowledge of solids, liquids and gases to decide how mixtures might be separated through sieving and filtering” (Rita/Zara/Sam). Only one group (Filters) referred to the EHOM, where creative problem-solving, problem-finding, adapting and systems thinking were listed in their assessment criteria for the lesson without further explanation (Rita/Zara/Sam) but this group also planned to allocate roles to pupils based on EHOM so they could emphasise when the children were using them.

All groups planned active pupil-centred teaching, although topics chosen by two of the groups were less likely to contain opportunities to practise EHOM. For example, the Rocks group planned a realistic scenario where pupils role-played detectives solving the mystery of which rock was used to break a window, using tests such as sink/float to identify the properties of different rocks provided. So, the students’ focus of attention illustrated their greater concern for the scientific enquiry process as they planned to notice children’s behaviours such as “Making accurate observations” and “Use[ing] their findings to support and justify their conclusions” (Ada/Carol/Eloise).

Many of their post-lesson reflections also focused on the children’s knowledge acquisition “Children were able to use previous knowledge to problem-solve an investigation, they mostly came to the correct solution” (Carol). Some attempted to link these observations to

EHoM, “Children recalled what we did and used that knowledge to complete a problem using various EHoM” (Ada). In a more specific example, Sam noted that “children adapted constantly throughout their investigations, choosing different equipment which was more efficient and effective”. Members of the Filters group that gave children EHoM roles felt that this was a successful strategy “through incorporating EHoM into our classroom practice we were able to give children roles which then gave children ownership over their work and motivated them to engage with the lesson” (Zara). Other groups also noted how engaged the children were by the activities. The Teabags group provided some of the closest examples of EHoM, due to their making activity, “Engineering=making things work, they were able to make teabags out of all materials” (Ivy).

Risk-taking exhibited by the science students was demonstrated as they not only selected topics to teach “that they hadn’t taught before and were keen to develop their own knowledge of” (TutorS), and also by giving the children an opportunity to engage in the inquiry process, or ‘working scientifically’ (DfE 2013) by teaching a problem-solving activity. This meant that they had to respond quickly when they realised that some children lacked inquiry skills and “found it hard to reason” (Maeve) or when they “had to change a clue halfway through the second session because we realised it would confuse the outcome of the investigation” (Eloise).

An inherent tension between the focus of the scientific inquiry process to uncover knowledge and that of EHoM as part of the engineering process to develop a solution to a problem or meet an expressed need became apparent. This factor could have been responsible for the lack of overt attention to EHoM in their plans and lessons. During the lessons, their tutor could see that they were cultivating some of these habits in the children “but it wasn’t explicit” (TutorS). Furthermore, “Some students need more time grappling with the subject [science] before thinking about wider issues [ie: EHoM]” (TutorS). On reflection, the topics may not have been the most appropriate for embedding EHoM and giving further thought to the context of each problem-solving challenge, with a more overt focus on client need, might have ameliorated this shortcoming. Some ideas were suggested by the students, such as locating the Rocks activity outdoors because “children tend to be more open to dialogue, this may have encouraged more systems-thinking and more space to explore physically and mentally” (Carol). Other ideas were offered by the tutors on reflection, such as asking children to design a toothbrush as the context for learning about teeth or developing a filtering system for providing clean drinking water to a community. So, as TutorS noted, “Given more time I think the students would have benefitted in exploring EHoM further at their own level—undertaking practical activities and then reflecting on how they themselves were using EHoM”.

The contribution of engineers in developing students’ confidence

Meeting the engineers at the start of the intervention was a valuable experience for the students since the discussion helped them move from an abstract to a more concrete understanding of EHoM. When talking with the engineers, the students “were picking up the particular EHoM and trying to unpick what does it mean, what would it look like; they were instantly engaged with it” (TutorS). The engineers in turn told the students how they would use the EHoM in practice “...he (SA1) was telling the students, ‘often I am just going through a process and then realising I have to change something or alter it’” (TutorD&T). The students’ confidence grew as the conversations became a mutual exchange of information, as they “explained to him (SA2) about what they were doing in schools...they had to

think through the process a bit more, because they were having to explain it to someone who was outside the norm, so that was useful” (TutorS). The SAs drew on their experience of working with pupils and urged the students “don’t make it [the task] straightforward, bring in problem-solving and resilience” (SA2). In the following weeks the tutors reminded the students about including EHoM, noting that “they seemed confident in reflecting on how aspects of EHoM were evident in their activities” (TutorS) particularly problem-solving, which they wanted to focus on in their lessons as well as working scientifically. However, as we have noted above, not all science students’ challenges fully afforded opportunities to develop EHoM, so further contact with the engineers during the planning might have resulted in some changes to contexts which favoured engineering.

At the end of the intervention the engineers confirmed that the students’ use of active learning tasks with a real-world focus was consistent with cultivating children’s problem-solving and other EHoM. They advised the students to build time into their lessons for reflection and improving, recognising that it was perfectly acceptable to fail and then think how you can adapt to the new situation “an engineer can always find ways to improve something” (SA3). They endorsed the importance of introducing primary children to engineering, since they became engineers more by chance than design “I never had any careers advice ...and never understood what engineering was, but I always had a passion for how things worked and building things, so a better understanding would have helped” (SA4). The engineers also played a particularly valuable role in validating the tutors’ aspiration to introduce their students to engineering through EHoM as “they added something very significant, very special, because if it had been just us, it would have been more everyday but because they were coming from the outside world and they did add a very special element” (TutorS).

RQ#2: To what extent can pre-service primary teachers identify EHoM through D&T, computing and science?

Each group of students was asked to record on the EHoM template children’s behaviours observed during the lessons that they believed correlated with each EHoM. Drawing from this data enabled us to analyse the students’ understanding of EHoM against the descriptions in Table 2. Our findings are explained below with indicative examples of the variation from weaker to stronger levels of students’ understanding provided in Table 4. So quotes in Table 4 represent the students’ own words according to their interpretation of EHoM, while the exemplification of these being weak to strong interpretations is researcher-selected.

Systems thinking: the strongest examples came mainly from the D&T/computing students who noted when children realised the interdependency between the actions of the coding and design groups to achieve their desired end-product. Science students were more likely to present evidence of ST as a reflection on the inquiry process, for example, interpreting it as children seeing connections between the properties of materials. In several cases they left the template blank for this EHoM, indicating they could not observe any relevant behaviour.

Adapting: this was often explained by students in both D&T/computing and science groups as being a characteristic of the children being adaptable or willing to change their minds in response to new evidence, rather than the action of changing something made for one purpose to be suitable for another. Students showed evidence of moving towards this level of understanding, but often in the context of making improvements to existing

Table 4 Examples of weaker to stronger levels of students' understanding of EHoM

EHoM	Stronger		
	Weaker	Medium	Stronger
Systems thinking	“[Seeing] similarities and differences between the different rocks” (Science-Ada/Carol/Eloise)	“Making predictions on the size of the filter or sieve and making connections after the experiment. Able to relate to why results reflected actions, exploring through explanations and reasoning to evidence answers” (Science-Rita/Zara/Sam)	“The children were beginning to predict what the sequence for programming the lights would be and also began to work out themselves what it would be for flashing lights... because they began to understand the system” (D&T/C-Emelia/Camilla/Mia)
Adapting	They adapted very well when the DT group added new elements, and the Coding team decided to change the colour of the lights (D&T-W Beth/Ethan)	“Making a prototype for teabag and then adapting this by using a different material each time and testing its effectiveness” (Science-Ivy/Luna/Maeve)	“Making their teeth good for sharks” (Science-Crispin/Willow)
Problem-finding	“Check solution, methodically and effectively. Questioning, curious and sceptical. Finding that solutions already exist” (Science-Rita/Zara/Sam)	“Were able to investigate and decide which material worked best for their tea bag” (Science-Ivy/Luna/Maeve)	“They visualised the end product with the DT [group] 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” (D&T/C-Beth/Ethan)
Creative problem-solving	“Generating ideas and solutions (ideas of using other equipment, not necessarily available) ...working as a team” (Science-Rita/Zara/Sam)	“Children came up with suggestions as to how they would test their teabag” (Science-Ivy/Luna/Maeve)	“When the children needed to put holes in the backing board for the baton I asked them how they would know how the lights and holes would line up, one child replied ‘we can measure it by putting it on the board and making dots where the lights will go’” (D&T/C-Amanda/Sophia)

Table 4 (continued)

EHoM	Weaker	Medium	Stronger
Visualising	“Water test sink/float. Children were visualising what was going to happen to the rocks based on their appearance” (Science-Ada/Carol/Eloise)	“They were able to draw diagrams of their prototype onto paper; labelled the materials, the purpose of the materials” (Science-Ivy/Luna/Maeve)	“...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. The coding team quickly changed the colour of the light to represent this. They then thought about it more, and 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” (D&T/C-Beth/Ethan)
Improving	“...the children did a water test before a scratch test and discussed the effect this had on the scratch test” (Science-Ada/Carol/Eloise)	“Experimenting, making small tests with tea bags/materials; sketching drafting, predicting” (Science-Ivy/Luna/Maeve)	“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’” (D&T/C-Amber/Chloe) “Consistently improving the efficiency of their experiments through trialling different types of equipment (changing their method and strategies)” (Science-Rita/Zara/Sam)

practices. The science students provided one of the stronger examples as they noted children suggesting how human teeth could be adapted to fit the needs of sharks.

Problem-finding: the ability to notice children re-framing an original problem came more easily to D&T/computing students. The science students, several of whom did not offer evidence for this EHoM, more frequently noticed children seeking solutions to the given problem rather than posing a different problem, as some of the D&T students were beginning to frame this EHoM.

Creative problem-solving: all student groups believed they were successful in getting the children to collaborate. They recognized this as a necessary precursor for CPS and was something that they all included in their plans. D&T/computing students gave extended examples of CPS, but while some science students were able to offer appropriate evidence of CPS, others did not fully understand the concept as an EHoM and struggled to identify examples of children generating creative ideas.

Visualising: some students, mostly science, evidenced visualising in a more colloquial sense by describing what children might be imagining when undertaking a scientific process or as labelling a diagram. It was the D&T/computing students who came closer to providing evidence of children using visualising as a form of communication between the coding and design groups, as they mentally rehearsed changes needed to ensure that the end-product was achieved more or less as planned.

Improving: D&T/computing students identified conversations between children that demonstrated their ability to make deliberate changes leading to improved designs, suggesting that they saw improving as an iterative process related to the overall product design, and as indicated in their evidence for problem-finding and visualising, one in which making mistakes was seen as an opportunity for learning. Some science students evidenced improving in terms undertaking a different process or using different equipment during the experiments. Others were able to cite examples of children not only making changes but noting that these led to improvements in the efficacy of their research process.

Overall, the D&T/computing student groups most consistently offered the strongest examples of EHoM descriptions, with the computing sub-groups showing somewhat lesser alignment. The science students' examples mainly related more to scientific inquiry than EHoM but as suggested, the topics selected for lesson activities could have contributed to this outcome.

Discussion

Our aim was to encourage primary PSTs to engage with engineering and introduce it into their teaching of D&T, computing, and science. To do this we offered a route to understanding engineering through its habits of mind, or EHoM, and through meeting engineers who exemplified these ways of thinking in their professional practice. The student teachers were asked to plan and teach a lesson using EHoM with primary children. The findings are now explored with reference to four points of the framework we identified in Table 1, particularly developing understanding of EHoM, followed by reflection on how EHoM may have facilitated these outcomes.

Developing understanding of EHoM

Strategies used by teacher educators to expand PSTs' understanding of engineering often include facilitating contact between PSTs and engineers and introducing design projects using the EDP but several challenges in implementing these approaches were revealed in the literature. We found, like other studies (for example, Bir et al. 2017; Coppola, 2019; Dalvi et al. 2020), that our PSTs lacked experience of the world of engineering but that even relatively short contact with practising engineers with different roles and career trajectories deepened their understanding of the nature of engineering and the ways in which EHoM are used to underpin engineering thinking in the real-world. This will hopefully increase PSTs' confidence to invite engineers into their classrooms after they graduate to model engineering practices to children (MacGregor and White, 2016). Other methods of facilitating this interaction, such as industry placements (Gibson, 2013) would take considerable organisation for education departments that are normally oriented towards school contacts. Pairing education and engineering students to co-develop outreach activities with schools (Fogg-Rogers et al. 2017) would not be feasible for education departments in universities without engineering, as in our case. However, as we found, STEM Ambassador networks, as in the UK (STEM Learning n.d.) and New Zealand (Williams and Mangan, 2016), offered an excellent alternative for promoting interaction between PSTs and engineers, but careful planning is required to reinforce insights into EHoM that it potentially offers.

When it came to planning teaching for EHoM and recognising when children when using them, D&T students, perhaps unsurprisingly, were more likely than computing or science students to understand that children were using EHoM when they were collaborating, problem-solving, improving and adapting within the designing, making and evaluating stages of their activity. D&T students used a realistic context in which to locate their teaching activity, focused on the EHoM of improving and adapting to reinforce the iterative nature of the design process and engineering thinking, which technology PSTs have not always grasped so clearly (Mativo and Park, 2012; McRobbie et al. 2000).

Computing students benefited from collaborating with D&T students in a joint teaching activity in which computing was used in resolving a realistic design challenge. So using EHoM may have expanded their perception of engineering design and problem-solving as an iterative process and helped them appreciate the contribution of computing to technology/engineering rather than seeing the computer merely as a tool for accessing subject content to solve problems (Dalvi et al. 2020). Our computing students emphasised the importance of algorithms in beginning to design and identified children engaging in debugging during the lesson, but did not provide further instances of CT. However, Ehsan et al. (2020, p.20/24) suggest that CT can be "synergistic" with engineering design so it would be worth STEM primary teacher educators continuing to explore this relationship with their students.

Our science students found it more challenging to include EHoM within their lessons. Several factors could have contributed to this, including their lack of experience in selecting appropriate topics for the task and the level of preparedness of their children for independent inquiry. As a result, they appeared to prioritise scientific inquiry and science content over EHoM. This is not unusual according to others (Coppola, 2019; Dalvi et al. 2020). It may be more challenging to incorporate engineering within science than technology or computing partly because there is a considerable body of literature on the nature of science and scientific inquiry which significantly influences science education,

whereas there is far less about the nature of engineering thinking (Pleasants and Olson, 2019). Nevertheless, our science students realised that they needed to plan pupil-centred activities that included some real-world characteristics to incorporate EHoM, rather than sticking to teacher-directed investigations (Dalvi et al. 2020). They encouraged children's collaboration and problem-solving, unlike some studies where science PSTs failed to recognise the importance of working collaboratively in engineering (Lin and Williams, 2017). Furthermore, they could recall instances of EHoM behaviours after the lessons, so it is possible that given more time, they would be able to promote engineering thinking, using EHoM language, through science inquiries (Johnston et al. 2019). They could have been guided by tutors to select more open-ended challenges with a client focus and through discussion appreciate the differences between science and engineering ways of approaching problem-solving (van Dooren et al. 2020) but even experienced elementary teachers struggle to move between the controlled experimentation of science inquiry and the development of multiple possible solutions to a design problem (Radloff and Capobianco, 2019). Since their choice of topic did not initially accommodate the iterative nature of the design process, in a repetition of this exercise it would be advisable to engage in topics with a clearer engineering context and client focus.

Create the climate for EHoM to flourish

Even when teachers do understand the meaning of dispositions such as EHoM, cultivating them in children can be undermined by a classroom climate which is not conducive to learning them. Studies suggest that PSTs struggle to create the right climate for design projects when using the EDP as the focus for their lessons by being unwilling to shift from a teacher-directed mode of learning to a student-centred approach (Dalvi et al., 2020) or failing to see the importance of getting children to work collaboratively (Lin and Williams, 2017). However, our students talked with engineers about how they worked in teams in the real world and they understood that problem-solving was an EHoM. Since problem-solving features in all three subject curriculum statements, the tutors encouraged their students to design their own problem-solving activities for their lessons which potentially provided opportunities for creating the climate for EHoM to flourish (Bencze, 2010; Coppola, 2019).

While the project topic chosen by D&T/computing students may have afforded more opportunities for developing and discussing EHoM, most students approached their lesson planning task with the aim of creating an appropriate climate. They planned problem-solving scenarios in which they tried to keep direct instruction to a minimum, although this was sometimes undermined by the children's abilities. They posed questions, welcomed children's suggestions and praised their resilience in working through problems when things did not turn out as expected. This can be challenging for novice teachers (Radloff and Capobianco, 2019) but demonstrated that they understood the importance of asking questions of children rather than always giving them instructions. The students also took appropriate action to deal with unexpected events, for example, adapting an activity to suit children's needs. This required them to model flexibility, suggesting to the children that they would reward similar behaviour from them.

Choose pedagogies that encourage practice of EHoM

PSTs have reported that they valued experiencing active learning strategies such as independent projects when they were learning about implementing engineering in science and technology (Mativo and Park, 2012; McRobbie et al. 2000). Within the constraints of our module requirements, students were given considerable autonomy to select topics and design their own lessons. The outcomes suggest, as others have found, that enabling PSTs to experience self-directed projects themselves may increase their confidence to facilitate collaborative pupil-led learning in their own teaching (Bencze, 2010; Radloff and Capobianco, 2019).

Building engagement and commitment to EHoM

Engaging with schools to enable our students to teach their EHoM lessons to primary children was a time-consuming activity for the tutors to organise, however the benefits for students' engagement was significant, as noted in other teacher development programmes (Mesutoglu and Baran, 2020). It enhanced their understanding of engineering thinking and their willingness to teach it through pupil-centred activities and encouraged them to reflect on what they would do differently next time, such as giving more control to the children. These findings confirmed the value of having PSTs teach a lesson. Even if they sometimes focussed on product at the expense of process, prioritised knowledge-giving over inquiry or did not give enough time to failure analysis and improving, their post-lesson reflections indicated that they recognised how they might change their future practice and how pupils' outcomes might improve as a result (Wendell et al. 2019). Tasks such as critiquing engineering lesson plans without putting them into practice were not so valuable in facilitating PSTs commitment to asking open-ended questions or giving children the chance to ask questions during engineering designs (Dalvi et al. 2020).

The value of using EHoM to develop understanding of engineering

In considering how EHoM rather than other approaches such as the EDP might have contributed to these outcomes, we note first that we had relatively few instances where students were too teacher-directed, or too product- rather than process-focused. They may not have had time to use a full design cycle with the children, but they did recognise which EHoM they did not have time to emphasise. This might be because EHoM are expressed as 'action words' and as dispositions they reflect language and attitudes habitually displayed by members of the engineering community; they express how engineers go about their work. Pleasants and Olson (2019) suggest that not enough attention is given to explaining the culture of engineering and its characteristic way of thinking, and they argue that although design is important in engineering, students are unlikely to fully understand engineering solely through design projects.

Winarno et al. (2020) noted that no single model of EDP is used in science education and that few ideas are forthcoming about how to improve linkages between engineering and science. However, Asunda and Weitlauf (2018) have suggested that EHoM can be mapped on to design processes. Wendell et al. (2019) stress the important role of teacher educators in preventing the EDP from being reduced to a simple algorithm or a physical building activity. Even design students can be helped to better understand the design process by

having explicit discussion with their tutors about the nature of design skills or ‘designerly thinking’ rather than just focusing on the design product (van Dooren et al. 2020). Discussions about professional thinking processes might enable PSTs to move from a layperson conception of design towards more sophisticated conceptions of the design process where “disciplinary habits of mind become an interpretive lens” through which practitioner perspectives and actions can be understood (Asunda and Weitlauf, 2018, p.35).

Science students are immersed in an inquiry process which has a different purpose to that of engineering (Pleasants and Olson, 2019), particularly in England since the increased emphasis on ‘working scientifically’ in the national curriculum (DfE 2013). They therefore need support to understand the differences between science and engineering problem-solving (Radloff and Capobianco, 2019) which might be aided by discussing EHoM and science habits of mind with their tutors and professionals from engineering and scientific communities. If we had taken more time at the beginning of the intervention to explore the EHoM language with the students, to compare it with science inquiry language and reflect on differences between the two professional cultures, they may have moved further in their understanding.

EHoM did enable our students to recognise two essential characteristics of engineering, its team-based nature and its solution orientation, which are sometimes missed (Antink-Meyer and Brown, 2019). This is helpful in contexts where science is the predominant vehicle for introducing children to engineering and it is important that the interdependent relationship between science and engineering is understood, rather than seeing engineering merely as a sub-domain of science (Antink-Meyer and Brown, 2019).

A further advantage in using EHoM in England is the interest expressed in the model by schools (Lucas et al. 2017). We found that EHoM encouraged our schools to engage with us because the model was already a good fit with their school ethos. Their vision for learning already encompassed habits of mind and it is unlikely that a focus on the design process would have had quite the same capacity to engage them. Given the call for stronger links to be made with local schools to provide space for PSTs to try out their engineering lesson plans (Rinke et al. 2016), EHoM may support teacher educators to achieve this.

Limitations

This was a small-scale research study incorporated into the normal work and study routines of pre-service students and tutors during a busy semester at one university in England, so the outcomes are inevitably limited in their scope and generalizability. There is a wide variety of models for pre-service teacher preparation so factors affecting the implementation of the study in our context may differ elsewhere. The varied interpretations of engineering and its position within the curriculum could also moderate the findings in other contexts. The nature of our intervention was to some extent influenced by the characteristics of the three modules selected for the study. For the quality of the students’ experience it was important to ensure the integrity of each module was maintained and that required standards were adhered to, which meant that it was not possible to organise a fully cross-curricular experience for the science students. The engineers could have played a more active role in the intervention but this was the first time of using the STEM Ambassador Network and lessons were learnt for future iterations, including making time for them to talk with students during their lesson planning period. Nevertheless, the findings should be relevant to teacher-educators seeking to enhance the visibility of engineering in schools

and to develop the confidence of pre-service primary teachers to contribute to this aim, particularly in education systems where engineering is not yet included within the formal curriculum.

Implications

Incorporating an introduction to engineering concepts and providing opportunities for embedding them into the curriculum may increase the confidence of primary PSTs to embed engineering into their teaching of STEM disciplines such as technology, computing or science as already acknowledged (Mativo and Park, 2012). However, this study demonstrates the possibility of using EHoM as another vehicle for raising the visibility of engineering that complements the use of the traditional vehicle, the EDP, in two ways. There are many, possibly confusing, variations of the EDP in use in science education (Winarno et al. 2020) but there are fewer iterations of EHoM. The UK model used in this study (Lucas et al. 2014) was developed from the US model (Katehi et al. 2009) and is promoted in the UK by the Royal Academy of Engineering. Furthermore, organising teaching to cultivate habits of mind and learning dispositions involves active learning pedagogies more familiar to primary teachers (Pope, 2019). This study also demonstrated that PSTs are interested in exploring STEM disciplinary practices through EHoM, potentially gaining insights into opportunities for cross-disciplinary teaching in the future.

The value of using engineers to assist with the interpretation of EHoM has added to other findings that contact with engineers in various ways enhances pre-service teachers' perceptions of engineering (Gibson, 2013; MacGregor and White, 2016). We found that it also enhanced teacher educators' confidence to consider designing a cross-disciplinary engineering experience for their students.

The inclusion of teaching practice in a school, for which PSTs plan and teach lessons incorporating EHoM, is confirmed as a critical element in increasing their understanding of and building their engagement with EHoM (Bir et al. 2017; Mesutoglu and Baran, 2020). However, the organisation to make this happen, particularly as it involved students preparing to teach three different subjects, does require significant determination from education tutors, since the dispersed nature of university departments can make this sort of cross-subject collaboration challenging (Mativo and Park, 2012; Shernoff et al. 2017).

Conclusion

In order to raise young people's awareness of engineering and to increase their aspiration to pursue STEM careers, many consider it necessary to introduce children to engineering during their primary education. This study investigated a professional development intervention that might improve pre-service primary teachers' understanding of the nature of engineering, with a view to encouraging them to address this challenge once they start teaching professionally. The study built on factors previously shown to enhance pre-service teachers' confidence to include engineering in their teaching, such as elements of cross-curricular learning, active learning pedagogies and teaching practice. These factors also align with the principles for cultivating habits of mind and we contributed to the understanding of methods of preparing the teacher workforce to embed engineering by arguing that if trainee-teachers became familiar with engineering through the lens of engineering

ways of thinking or engineering habits of mind, and by exploring these with practising engineers, they may have the resources to incorporate engineering into their teaching of technology, computing and science in the future. Further research in the form of a longitudinal study would be valuable to determine if pre-service teachers introduced to engineering through these means incorporate it in their future teaching. The EHoM template used in this research proved to be a useful instrument for gathering data from students and further refinement of this to show progression in EHoM understanding would be worth developing to support teachers in the classroom.

Acknowledgement This material is based on work supported by the Royal Academy of Engineering (<https://www.raeng.org.uk/>) published in Hanson, J., Hardman, S., Luke, S., Maunders, P., & Lucas, B. (2018). *Engineering the future: training today's teachers to develop tomorrow's engineers*. London: Royal Academy of Engineering.

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