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### Researching primary engineering education: UK perspectives, an exploratory study

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## Researching primary engineering education: UK perspectives, an exploratory study

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This paper draws attention to the findings of an exploratory study that critically identified and analysed relevant perceptions of elementary level engineering education within the UK. Utilising an approach based upon grounded theory methodology, 30 participants including teachers, representatives of government bodies and non-profit providers of primary level engineering initiatives were interviewed. Three main concepts were identified during the analysis of findings, each relevant to primary engineering education. These were pedagogic issues, exposure to engineering within the curriculum and children's interest. The paper concludes that the opportunity to make a real difference to children's education by stimulating their engineering imagination suggests this subject area is of particular value.

**Keywords:** engineering education; primary school; attracting young people; conceptual framework; STEM

### Introduction

Defined by the UK Government as where science meets society and where scientific advances impact on the health, wealth and well-being of individuals (DIUS 2008), engineering is widely acknowledged as being the link between science and society. In the UK, the demand for qualified engineers who are able to bridge the academic/scientific and social divide has never been greater. Indeed, this is a time when engineering is frequently called upon to solve contemporary global, national and local problems (Spinks *et al.* 2006, IMechE 2009). Conversely, whilst the demand for engineers is increasingly reflected in UK Government rhetoric, the demographic nature of the engineering profession is dominated by white middle class males, with a notable shortage of females and individuals from ethnic minorities (Gill *et al.* 2008, NSF 2009). Likewise, engineering education at university level is also manifested by significant gender and ethnicity gaps, with the majority of students being young, white males (RAEng 2009). This situation is augmented by the fact that UK universities experience considerable difficulties maintaining student numbers enrolled on engineering programmes (RAEng 2007). Moreover, from a professional perspective, some evidence exists to suggest that skills shortages (reflected by a lack of appropriately qualified

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graduates) and skills gaps (where there are deficiencies in the skills possessed by engineering graduates) means that many British employers are forced to look overseas to fill engineering vacancies (Spinks *et al.* 2006). Whilst the current state of affairs may appear somewhat dire, current predictions regarding future shortages of engineers mean that the situation looks set to worsen over the forthcoming two to three decades. There is little argument that predicted shortfalls in the numbers of young people entering the engineering profession over the next 10–20 years will represent a serious challenge to future governments—particularly in terms of a lack of suitably qualified talent able to ensure a sustainable infrastructure and global community (Spinks *et al.* 2006).

If engineering education at university level in the UK is to be sustained over the next two decades and beyond, and engineering is to maintain and develop further its status as a key profession within society, then the need to spark the engineering imagination of children as young as five or six years becomes paramount. In order for this to be achieved, it is first necessary for policy makers, engineering professionals, engineering educators and primary school teachers to gain some insight—not only into what is already happening in this area, but also into what needs to be done in the future to ensure the sustainability both of engineering education and engineering itself. It is against this backdrop that the need to conduct empirical investigation, and the possibility of introducing engineering education into the primary school curriculum, is considered. Although the issues presented in this paper are from a UK perspective, the challenges discussed are very much global in nature. Thus, in bringing primary engineering education to the forefront of discussion, this paper makes a contribution to the ongoing debates in both the engineering education and pedagogical fields.

### **Engineering education at the primary level in the UK**

The pivotal role played by engineering in maintaining contemporary society is reflected in the literature (Wilson and Harris 2004, Smith and Monk 2005) with much attention being paid to the need to spark children's engineering imagination early on in their school life. Several UK government and professional association policy documents highlight the value of embedding engineering into the school curriculum, arguing that programmes aimed at inspiring children through a process of real-life learning experiences are vital pedagogical tools in promoting engineering to future generations (see, for example, DIUS 2008, IMechE 2009).

Despite such academic, professional and public policy focused attention, engineering education at primary and high school (pre-14) level in the UK remains sporadic, often reliant on individual engineering champions, teachers or other interested parties, who, through personal interest, get children involved in extra curriculum, time-limited, engineering focused programmes. Moreover, current provision is often based around a 'competition model', whereby children participate in short-term projects and are encouraged to utilise basic engineering skills to develop a working, three-dimensional replica of a vehicle or some other form of exhibit and then compete against other children (for example, see Young Engineers 2009). Whilst such programmes raise the profile of certain aspects of engineering, and do much to elicit interest in the subject, the elitist nature of competitive education inevitably means there are more losers than winners. In addition to this, another concern regarding the 'competition model' of engineering education is that such competitions are frequently built around subjects that are more likely to appeal to boys. This has been shown to have an adverse affect on girls' engagement in many engineering focused initiatives (Kolmos 2009). In sum, the possibility that the vast majority of children will be 'turned off' by participation in engineering competitions represents a real pedagogical dilemma.

Although the 'engineering competition' model may be criticised for its exclusionary nature, the need to spark children's engineering imagination through an innovative and inclusive curriculum is

evident. An important facet of engineering, design and technology has been part of the UK primary school curriculum for several years (Davies 2000, Twyford and Jarvinen 2000). The rationale for this subject is to facilitate pupils' ability to participate in future technological advances and to learn to think in a creative manner in order to improve quality of life (Rasinen 2003). However, as a stand-alone subject, design and technology differs markedly from engineering as a discipline. The latter necessitating the development and application of critical thinking skills in a manner that brings together technology, design, science and maths to identify, understand, analyse and solve a range of socially constructed problems (Brophy *et al.* 2008). Put simply, whilst design and technology constitute important tools used by engineers (Mitcham 2001) the 'art of engineering' involves synthesising and applying knowledge from a much wider theoretical spectrum including science, social science, maths and humanities (for further discussion, see Vlot 2000, Mitcham 2001, Brophy *et al.* 2008). In the UK, much government attention has been paid to the need to enhance the education that children currently receive in the areas of science, technology, engineering and mathematics (STEM). However, whilst STEM education represents a government priority, particularly at the secondary level (NSF 2009), in reality current pedagogic practice is failing to spark children's engineering imagination, with day-to-day classroom effort focusing upon science, technology and maths. Indeed, engineering seems to be the forgotten discipline.

The lack of attention given to engineering as a discipline within the school curriculum is particularly notable in the recent *Independent review of the primary curriculum* (Rose Review 2009), in which science and technology are brought together in the pre-secondary school curriculum. This review does not mention engineering education at all. Likewise, engineering is not mentioned in the more recent independent review of the primary school curriculum undertaken at Cambridge University (Alexander 2010). One explanation for such a lack of focus may be that in some areas, engineering is perceived to be captured within the design and technology curriculum. Alternatively, that engineering does not feature in two such high profile reports may be viewed as indicative of the limited attention given to the discipline at primary level by educationalists and policy makers. Indeed, the government's solution to the dearth in engineering education in schools appears, at present, to focus very much on the introduction of the new engineering diploma. However, the fact that the diploma is targeted at pupils aged 14–19 years means that it does not directly impact primary education in any way (DCSF 2009), apart from through occasional contact between the secondary schools and their feeder primary schools.

### ***Methodological approach: an exploratory study***

Focusing on the research question, 'What barriers exist in the provision of primary level engineering education in the UK?', an exploratory study into primary engineering education within the UK was undertaken during the second half of 2009. The purpose of this study was to enable the researchers to begin to critically identify and analyse relevant perspectives and experiences of current primary level engineering education provision. After much deliberation it was decided that an approach based upon grounded theory methodology was the most appropriate for use within the exploratory study (Strauss and Corbin 1998). Grounded theory provides a useful set of research strategies with which to undertake social investigation into the experiences of primary school-age children (Cummings 1985). Given the somewhat limited amount of previous empirical study in this area, this approach proved particularly useful, in that it allowed the researchers to build theory based upon the emergent data by undertaking a constant comparative analysis of the data.

Having undertaken a literature review in which the pedagogic, political, academic and social influences on, and determinants of, engineering education were analysed, a semi-structured interview schedule was devised. The researchers then utilised theoretical sampling techniques in order

to identify suitable interviewees. This meant that the sample was selected in a theoretically grounded manner based upon the needs of the study and the participants' socio-demographic characteristics. The sample comprised representatives from government bodies responsible for STEM education, individuals working for non-profit organisations that provide one-off engineering education projects for school children aged 6–11 years and teachers with experience at primary and secondary level (responsible for children aged 12 years and under). Questions were grounded in the issues identified in the literature review.

In total, 30 individuals were interviewed. The interviews were recorded contemporaneously and transcribed at a later date. The advantage of utilising qualitative interview techniques was that the approach provided the participants with the opportunity to raise issues that were important to them whilst affording the researchers the flexibility to explore, in depth, the relevant concepts (King 1994). On the negative side, potential difficulties of undertaking qualitative research are discussed in the literature, with particular note being made of problems with sampling, interviewer bias and potential personality clashes being highlighted (Robson 1993). Whilst such difficulties did not arise during the exploratory study, the researchers remained aware of their own perceptions and took into account the impact that they, as educators and professionals, had on the research process. Two university-based researchers were involved in the interview process; one an engineer, the other, a social theorist. Both currently work in learning and teaching research.

The research findings were analysed by an experienced grounded theorist, who following a grounded theory approach used a system of open coding, in which the data were theoretically analysed and the main concepts identified. A further 'micro-analysis' allowed for the identification of sub-concepts. The relationships and linkages between the concepts and sub-concepts were then critiqued and the data thematically categorised accordingly (Strauss and Corbin 1998).

### *Findings*

Three main concepts were identified during the analysis of findings, each relevant to primary engineering education. These were pedagogic issues, exposure to engineering within the curriculum and children's interest. An important part of grounded theory is the use of verbatim quotations. Consequently, these represent a key feature of this study and are intended to give the participants 'voice'.

### *Pedagogic issues*

Half of the participants were involved in providing or facilitating engineering education initiatives within UK schools, either nationally or locally, on either a paid or voluntary basis. All had previously been employed as engineers or teachers. For this particular group of participants, the main pedagogic issue related to teacher training and a perceived lack of confidence amongst teachers in providing practical 'hands-on' engineering experiences:

... teachers get panicked by the thought of engineering... We need to boost teachers' confidence and introduce programmes that fit with what's going on ...

Ex-school teacher: primary

It's difficult to engage teachers... Teacher Training needs addressing. We need to build a critical mass.

Representative: national engineering body

Insufficient training, augmented by a lack of confidence amongst teachers, was manifest by a lack of understanding regarding engineering:

I don't know whether teachers understand what engineering is all about.

Provider: Engineering education initiatives

Teachers in primary schools have little or no training in design and technology. This puts engineering education on the back foot immediately. There's a historic problem about teacher training.

Representative: National STEM education body

For some, the solution seemed relatively simplistic—that is, to embed engineering education into the primary school curriculum:

We need to integrate engineering into what is already being taught. To make teachers aware that engineering brings together all the different disciplines. To bring education to life using engineering concepts.

Director: 'Non-profit' engineering education provider

We've tried to embed engineering across the curriculum. It's not easy though . . . to get them to see that engineering comes into all aspects of life, whether it's History, Maths, English or whatever . . .

Engineering teacher: Specialist secondary school

For others, the issue was not about embedding engineering education, but rather related to the manner in which the curriculum is constructed:

In terms of the curriculum we are constrained. If I don't teach the [ ] curriculum . . . I could go to prison . . . I can't just say, oh we should scrap that and do an engineering based topic.

Chemistry teacher: Secondary

We have such a tight curriculum that sometimes [ ] we're just spoon-feeding rather than encouraging thinking and learning . . .

Design and technology teacher: Secondary

For the teachers amongst the sample, the restraints placed upon them by the national curriculum represent a real barrier to the introduction of engineering education at both primary and secondary level. Such constraints inevitably mean that engineering is a low priority discipline—to which most children receive little or no exposure.

### ***Exposure to engineering education***

All of the participants discussed the lack of access to engineering education within the vast majority of UK schools. Closely linked to insufficient provision of engineering education were concerns that, currently, there is no overall picture regarding what is happening in the discipline in UK schools:

There's a lot of separate groups across the country offering engineering initiatives, but there's no real record of what these are or where they are . . .

Engineering education provider: Local non-profit organisation

. . . we face a lack of awareness regarding what primary schools are doing . . . There's no overall picture.

Regional facilitator: STEM education

The lack of a coherent engineering education strategy means that the vast majority of primary school pupils do not have access to engineering at all. Indeed, the nearest most school pupils are able to get to anything like engineering is the design and technology curriculum, which, as previously argued, represents only one component of engineering. Those that are able to access engineering education do so by means of extra curriculum activities, such as after-school clubs and competitions. An important point about the initiatives that are available and active is that the evaluation of their effectiveness, particularly in sustaining student interest, is essentially non-existent, a point that will be elaborated later. All of the participants felt that, on the whole, the 'competition model' of engineering education is inappropriate:

Competitions don't work as most of the kids are left out. We need to deliver engineering to all children . . . not just the bright ones, or those who attend clubs.

Director: National provider, after-school engineering clubs

. . . whilst competitions might work to switch some children on to engineering, the rest get excluded or are turned off . . .

Engineering teacher: Specialist secondary school

However, on the positive side, clubs and initiatives were praised for encouraging teachers to 'try' engineering. In most cases teachers were expected to engage rather than observe from the sidelines:

Clubs can encourage teachers to put a foot in the water . . . . . a way of getting engineering on the agenda without panicking the teachers.

Ex-school teacher: Primary

Teachers aren't confident with engineering education. That's why we've developed a range of tools and strategies for them to [be able to] offer engineering initiatives.

Director: National provider, after-school engineering clubs

Whilst engineering clubs and non-competitive initiatives were generally perceived to be a good thing, the lack of empirical evidence regarding their long-term value and impact was also discussed:

We have been working with some primary schools for six years . . . The problem is we don't know what impact this has had . . .

Director: National provider, after-school engineering clubs

There's a lot of anecdotal evidence about the success of [after-school clubs] but we have very little scientific evidence about how it works . . .

Local provider: After-school engineering club

The theoretical sampling techniques utilised in the study, reflective of the methodological need to talk to 'expert-practitioners', meant that all of the participants had an interest in the provision of engineering education to schoolchildren under the age of 12 years. For all of them, exposure to engineering was a vital prerequisite to sparking children's engineering imagination—yet all of them were aware that they were merely 'scratching the surface'. The vast majority of schoolchildren in the UK receive no exposure to engineering whatsoever.

### *Children's interest in engineering and science*

In describing current provision around engineering education, the majority of the participants discussed the lack of pupils' awareness:

The problem is raising awareness [of engineering] in schools . . . it's more or less impossible.

Director: National provider, After-school engineering clubs

Engineering just isn't part of the curriculum. Historically it's not part of the vocabulary.

Facilitator: Local STEM education

This lack of attention, resulting in limited, or non-existent, pupil exposure to engineering, was reflected in the fact that most participants discussed engineering education within the wider context of science. For some, the transition between primary and secondary education was manifested by a decline in interest in science education:

There's an issue around transition from primary to secondary. This is seen in a drop off in interest in science amongst children when they get to secondary level.

Local provider: STEM education

Children in primary schools are usually enthusiastic about science. The problem happens when they get here. Something happens between primary and secondary school.

Engineering teacher: Specialist school

Given the perceived drop in interest in science between primary and secondary education, the need to spark children's interest in engineering during primary education was identified as particularly important:

What is needed is a 'hook' to get children interested in engineering. If we can get them early enough then we've got them for the whole of the time they're at school.

Director: National provider, After-school engineering clubs

If you don't get children interested in engineering before the age of 11 then it's too late.

Director: Local after-school engineering club

One of the main barriers to getting children interested in engineering related to misconceptions regarding what engineering actually is:

Most 11 year olds tend to think engineering is about working on cars or fixing engines.

Ex-school teacher: Primary

I'd say most people don't understand what engineering is and think that a mechanic is an engineer.

Director: National provider after-school engineering clubs

For a minority of participants, children's lack of understanding was made worse by gender stereotypes:

It's mostly boys who choose to take part . . . by the time we come to secondary school we've lost the girls.

Engineering teacher: Specialist secondary school

There are still the stereotypical differences between boys and girls. [Girls] are frightened to get hands on . . .

Maths teacher: Secondary

Others pointed to difficulties in developing and then sustaining initiatives, including after-school engineering clubs:

It's difficult to get into hard to reach schools . . . If you don't have buy-in from the Head then there's no chance . . .

Facilitator: Local STEM education

Sustainability is difficult where you only have one teacher involved. If that teacher goes sick or leaves the whole thing stops . . . It's a perennial problem in schools. Teachers move on.

Ex-school teacher: Primary

In developing a response to the primary level education requirement, reinforcement and sustainability of the message must be prime concerns. This will allow for better informed educational decisions by students, parents and teachers at the secondary, further and higher education levels. This can be likened to creating a seamless pipeline through which students can progress, with STEM in general, and engineering education in particular, a constant feature.

## Discussion

The study findings indicate that the main pedagogical issue in respect of primary level engineering education relates to the curriculum and teachers' lack of training and awareness of engineering

as a discipline. This directly impacts on children's learning. Learning may be conceived as a permanent change in behaviour occurring as a result of experiences (Coon 1983, Anderson 1995). Thus, in order to effect a change in children's perceptions of engineering and ultimately influence behaviour, it is important that they are provided with exciting learning opportunities that are flexible enough to take account of individual learning approaches whilst meeting the demands of the wider school curriculum. Such approaches need to provide children with the opportunity to begin to develop an understanding of the main principles of engineering and its role in supporting wider society (RAEng 2007, 2009, IMechE 2009).

One important pedagogic factor shaping children's exposure to engineering education within the primary school curriculum relates to teacher education. This is an issue at all levels of teacher training. For example, at a post-graduate level, out of 1865 teacher training courses currently being offered in the UK aimed specifically at secondary level teaching, only four offer a specialism in engineering (GTTR 2009). With regard to primary level education, the UK Quality Assurance Association Benchmarks for the Bachelors in Education fails to mention engineering (see QAA 2009, for further details). It is therefore not unreasonable to comment that, notable by its absence, the lack of attention given to engineering education by government agencies at pre-university level in general, and at a primary level in particular, does little to reinforce government rhetoric about the importance of engineering as part of the STEM agenda. The National STEM Programme launched in the UK in 2009 may have a positive impact on early education, but as yet the work areas are still being formulated (National HE STEM Programme 2009).

The exploratory study interviews revealed that, in many respects, for children of primary school age, exposure to engineering is dependent on individual school priorities. Such exposure is often reliant on individual teachers with an interest in engineering running 'after-school clubs' or on the buy-in of short-term project-based learning experiences (usually over one day or half a day). Moreover, it would seem that the apparent random nature of primary engineering education across the UK means that the majority of children have little or no exposure to engineering in any form. From a pedagogical perspective, this means that the first time that children come across engineering (if at all) is at secondary level— although it should be noted this is still limited to a very small number of schools.

That the majority of children receive limited exposure to engineering education at primary level means that their interest in this area is likely to be severely restricted or (in the case of the majority who receive no exposure to engineering) non-existent.

The research findings thus far suggest that in order to promote children's interest in this area, engineering needs to be introduced at an early stage in the curriculum. Furthermore, it may be posited that the influential role of wider society in sparking a child's interest is paramount. The study reinforces arguments that social influences and related interactions are central in sparking children's interest and consequently in shaping their development (Howe and Mercer 2010). It may be argued therefore that the introduction of engineering education should be a collaborative and deliberate process in which exposure to engineering is built into the curriculum from the beginning of a child's school life— sparking their interest and engineering imagination from an early age.

### **What next? Current and methodological challenges**

As discussed earlier, with one or two notable exceptions (see, for example, Lewis 2007, Sorby and Schumaker-Chadde 2007, English *et al.* 2009), previous empirical investigation in this area is somewhat scarce. Thus, in considering this issue, the researchers have found themselves on relatively new ground. The lack of previous empirical research in this area, combined with the seemingly random nature of any meaningful activity in the UK, makes the need to clarify the key

conceptual, theoretical and practical phenomena of great importance. Thus, in order to provide such clarity the development of a conceptual framework, upon which the research process may be built, becomes necessary.

Described as ‘the basis of analysis’, Strauss and Corbin (1998) argue that concepts represent the ‘building blocks of analysis’ (p. 202). A conceptual framework brings together the building blocks, articulating and clarifying relationships between them. In this way the framework provides a coherent foundation upon which subsequent empirical investigation may be conducted. This perspective was also discussed by Dewey (1938), who drew attention to the importance of conceptualism arguing that: ‘... The conceptual dimension is held to be logically an objective necessary condition in all determination of knowledge’ (p. 263).

In developing a conceptual framework with which to conduct research into primary engineering education within the UK, three main concepts have been identified: pedagogic issues; exposure to engineering education; children’s interest. Furthermore, three sub-concepts have been identified, each of which is intrinsically linked to the main concepts: teacher education; social influences; school priorities. Figure 1 depicts the relationship between these concepts and sub-concepts in a diagrammatic format and shows how they may impact and influence the future of engineering in the UK and beyond.

The disparate and seemingly random nature of primary level engineering education in the UK means that, prior to conducting further investigation, it is necessary for the researchers to gain a detailed and accurate picture of the current provision of primary engineering education. Thus, the next stage of the research process will be to undertake an in-depth mapping and critical analysis of primary level engineering education. The researchers are aware that the collation of such data needs to be undertaken in an empirical manner; thus, a critical framework with which to record and analyse the data will be developed. The framework will capture the activities undertaken within the various projects and after-school clubs across the UK. It is anticipated that an analysis of the mapping activity will allow the researchers to identify current practice across the country. Additionally, the researchers will also attempt to gain a sense of elementary level engineering provision on a more global basis.

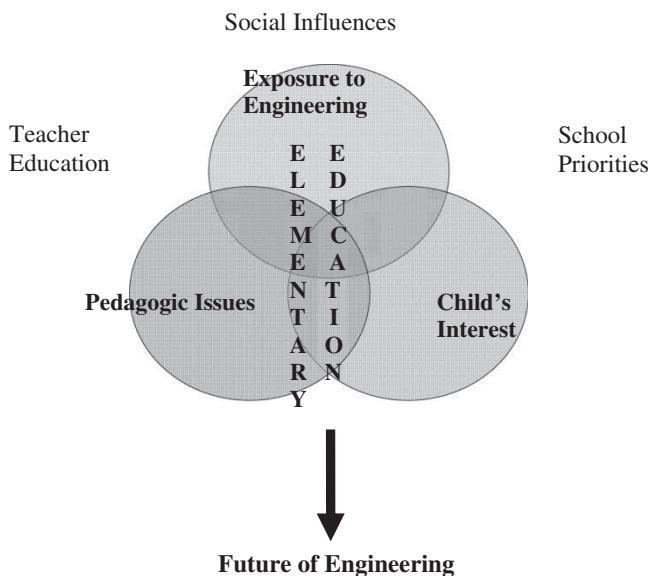


Figure 1. Primary engineering education: A conceptual framework.

The next stage of the study will be to critically analyse current provision in a manner that captures the perspectives and experiences of a wide range of relevant stakeholders. Building upon the approach adopted in the exploratory study, semi-structured interviews will be undertaken, the aim of which will be to consider how engineering may be introduced into the pre-secondary school curriculum in a manner that enhances current teaching across a range of subjects.

## Conclusion

In conclusion, this paper has highlighted some of the current and future challenges associated with conducting research into engineering education at a primary level in the UK. The opportunity to make a real difference to children's education by stimulating their engineering imagination, and in doing so impact the future of engineering in the UK in particular, but also more widely, makes this subject area of particular value. Whilst there is much to learn from research elsewhere (see, for example, Richards *et al.* 2002, Cunningham and Hester 2007) there is much room for further study in this area. Whilst future research areas will undoubtedly be challenging, the potential for such a project to provide the impetus to make empirically grounded, innovative changes in the UK primary level curriculum, by sparking the engineering imagination of children as young as five or six years, makes this a worthwhile and valuable subject for further study and research.

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