

Engineering – young people want to be informed

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Abstract: *Young people in developed nations recognise the contribution that science and technology make to society and acknowledge their importance now and in the future, yet few view their study as leading to interesting careers. Some countries are taking action to raise interest in science, technologies, engineering and mathematics and increase the number of students studying these subjects. One of the barriers to young people pursuing engineering is their limited or distorted perception of it - they associate it only with building and fixing things. Young people rarely encounter engineers, unlike other professionals, engineering has little or no advocacy in the media and there are few opportunities to experience engineering. Many of the pupils surveyed at the start of Engineering the Future, a three year EPSRC-funded project, wrote “don’t know what engineering is” and/or “would like more information”. This paper reports on work with researchers, policy makers and practitioners in Scotland to develop a sustainable model of activities and interactions that develops pupils’ understanding of the nature of engineering, embeds experiences of engineering within the school classroom and curriculum and promotes engineering as a career. After learning about engineering through the activities the pupils’ perceptions had improved. Almost all considered it important that young people know about engineering, because it is an essential part of everyday life and, in the words of one pupil - “If we know more about it, our minds wouldn’t stay closed to it. We would maybe take it up.”*

Introduction

Engineering the Future (EtF), funded by the Engineering and Physical Sciences Research Council, sought to explore and address some of the major challenges facing engineering in education. Researchers, policy makers and practitioners worked together to enhance young people's understanding of, commitment to and participation in engineering. Research shows that young people in developed nations recognise the contribution that science and technology make to society and acknowledge their importance now and in the future. Yet few view their study as leading to interesting careers (Schreiner and Sjøberg, 2007; OECD, 2007; Canavan et al., 2002).

One of the barriers to young people pursuing engineering is their limited or distorted perception of it - they associate it only with building and fixing things (Marshall et al., 2007). Young people rarely encounter engineers, unlike other professionals, engineering has little or no advocacy in the media and there are few opportunities to experience it. Therefore most remain ignorant of the nature of engineering and the diverse career paths it offers.

Between the academic years 2005/06 and 2006/07 the number of full-time engineering and technology undergraduates in Higher Education in the United Kingdom (Higher Education Statistics Agency, 2005-2006) increased by 2%. However, in the decade 1996/97 to 2006/07 the number fell by 15%, while the overall number of students entering full-time education increased by 28 %. Unless action is taken there is likely to be a shortfall of engineers in disciplines such as electronic and

electrical engineering (where the number of applicants has declined by 29 % between 2002/03 and 2007/08 (Engineering UK, 2009)) to meet the requirement for the recruitment of substantial numbers of people by 2017 in the engineering and manufacturing sectors (Engineering UK, 2009), who will play key roles in meeting the needs of society today and for the future. In the UK engineering outreach initiatives such as residential courses, engineering clubs, challenges and projects aim to encourage young people to study engineering. However, there is no guarantee that young people will experience one of them, because not all UK schools engage in them (STEMNET, 2008). EtF believes that the key to ensuring **all** young people are informed about engineering lies within schools. This paper reports on work with researchers, policy makers and practitioners in Scotland to develop a sustainable model of activities and interactions that develops pupils' understanding of the nature of engineering, embeds experiences of engineering within the school classroom and curriculum and promotes engineering as a career.

Engineering the Future

The EtF project focused on Electronic and Electrical Engineering (EEE) in Scotland and aimed to develop an innovative, sustainable and transferable model of activities which encourage young people to study engineering and support them as they make the transition from school to university.

The objectives were to:

- embed engineering within national curriculum, assessment and qualifications policies and practice
- provide experience and understanding of engineering activities within school classrooms
- identify and make young people aware of key skills, mind-sets and dispositions needed by engineers to face changing demands through their working life (in the light of information emerging in the project, this aim is being pursued through careers guidance, as well as school engineering experiences)
- support students' motivation and learning across the school-university transition and into engineering at university
- develop pedagogy in university engineering which challenges and supports students to extend their prior knowledge, skills and dispositions.

The project is thus complex, incorporating several strands, each with multiple aims and activities. The complex nature of the Engineering the Future project derives from research evidence (Hayward et al., 2004, 2005) that significant and sustainable educational change requires the collaborative partnership in pursuit of a common aim of **all** the key players in the educational system. The design, implementation and evaluation of the EtF project are described by MacBride *et al.* (2008, 2010).

School-University Partnerships

The project set up school-university partnerships to identify engineering-related topics in national curricular guidance and examination syllabuses in Scotland and across the UK in subjects related to science and engineering, with a view to developing collaboratively innovative EEE activities for pupils. Engineering was not embedded in the science curriculum, but the partnerships gave participating schools a chance to enrich both their technology and science curricula. They also provided opportunities to interact and collaborate with science and technology teachers in other schools and engineers in the real world. Such collaboration enables sharing of knowledge, experience and expertise which does not normally happen.

Schools were assigned EEE lecturers on a random basis. The three-year school-university partnerships typically involved one or two teachers from the school Physics or Technology departments and up to three EEE lecturers. Different models of collaboration emerged, but particular factors characterised successful interactions:

- face-to-face meeting early in the relationship
- well defined task
- agreed way of contacting each other (usually email)
- planned face-to-face meetings to keep the momentum going.

Reciprocal school/university visits were also very beneficial in fostering successful collaborations. These gave participants an opportunity to update their knowledge of learning and teaching in the other sector.

Lecturers' reasons for getting involved

Although various justifications were advanced for the importance of the school-university partnerships, the recurring theme was enabling pupils to make informed decisions regarding their university study and enthusing some of them for engineering. As one lecturer pointed out, "We're here as researchers but also as educators. And one of the things that can be quite difficult is the school and university interface for pupils. Anything that can be done to improve that is useful."

"...a lot of ... negative images [that] are associated with engineering and I think trying to get across to school pupils the positive sides of engineering and what engineers do for the betterment of society is more important." (Lecturer interviewed at the end of the project).

The lecturers recognised that giving pupils more in-depth knowledge of engineering *might* work against engineering recruitment. Nevertheless, they felt that the pupils would be making a reasonable and well-informed decision that a different career was, in fact, more appropriate.

"...hopefully it could help students to make wiser decisions about the university degree that they choose. And that could work both ways in the context of engineering, I suppose. It could make some decide that they don't want to do it, but, hopefully, it would also persuade some that they may be capable and would be good at doing it, but haven't really got a clear idea of what it's about." (Lecturer interviewed at the end of the project).

Teachers' reasons for getting involved

The teachers had different reasons for developing the engineering activities, such as creating something valuable for the pupils, wishing to develop a more interactive teaching/learning approach, enhancing their existing syllabus, re-framing scientific tasks by giving pupils problems to solve and incorporating skills that are important for both engineers and scientists. Several mentioned the advantage of access to additional resources and equipment as a benefit of taking part in the project.

"Although it's been a lot of work, we have got an insert now that can be used - and that can only be valuable for the children. They have a better experience and things. I think that's a major advantage that we have this thing. There's also the money as well: we have got a bit of money, so that's an advantage as well. It is nice to be involved with the universities and other schools and things like that. It's certainly an advantage to have outside contact... many teachers would not have any contact with researchers, so that would be a valuable thing." (School Teacher interviewed during the project).

Building links with the universities and working with the university lecturers, who provided an external stimulus and support for developing new ideas, were also seen as important. Another benefit of participation was sharing experiences and practices with the other teachers in the project and finding out how other schools approach things. A major challenge to participation was time, because of pressures from the normal pattern of the school year and workload priorities. One teacher commented on what they perceived to be the difference between EtF and many other projects.

"It seems to me that you can get all sorts of money for all sorts of things, apart from when it actually comes to direct delivery into the curriculum and the classroom, and that's what the positive thing about this project has been, it's been about direct-delivery in the classroom. Teaching. And that's why we like it. And that's why we're involved in it and that's why we enjoy it. There's so many things that go on in a parallel universe and they never actually make an impact at all. Then they produce all sorts of glossy documents, and we're struggling to photocopy in black and white on our budget." (School Teacher interviewed during the project).

Awareness and understanding of engineering

At the start of the project EtF obtained questionnaire information from school pupils (in classes selected by teachers participating in the project) and 1st year students taking EEE in the Universities of Glasgow and Strathclyde about factors influencing their ideas about engineering and their choice of it for university study.

- 7 schools (5 state-funded, 2 private)
 - 869 pupils (389 females, 480 males) (approximately 20% of pupils in years S3-S6 in these schools)
 - S3 (age 14/15) – 418
 - S4 (age 15/16) – 193

- S5 (age 16/17) – 185
- S6 (age 17/18) – 75
- 1st Year University students – 177 (9 females, 168 males) (approximately 80/90%)

Many of the pupils surveyed had no or limited awareness of engineering and 65% had never considered a career in engineering. It was evident from the pupil questionnaires that much careers and subject choice advice came from family and friends and that careers advisers and school staff did not feature prominently. The Royal Academy of Engineering (RAE) and the Engineering and Technology Board (ETB) study 'Public Attitudes to and Perceptions of Engineering and Engineers 2007' (Marshall et al., 2007) found that it is not only pupils who have a limited awareness and understanding of engineering. Almost eight out of ten respondents, aged from 16 to over 75, agreed that "there are so many types of engineers that it makes engineering confusing to the average person to understand", but "overall, engineers fix things". Practical action in this study suggested that "providing people with information about engineering improves and clarifies understanding of the scope and breadth of engineering and importantly, generates interest in the profession".

77% of the 1st year EEE students identified family links as the main factor in encouraging them to study engineering - 56% mentioned family or friends involved in engineering. Another key factor for some (61%) was engineering experiences in the school classroom. The student survey demonstrates that school-based educational experiences *can* influence pupils' decision-making about their further study and career. However, awareness of the nature of professional engineering and engineering experience related to science and technology courses are currently absent from nearly all pupils' school work. This situation leaves most young people uninformed about the nature of engineering and ignorant of the career options open to them. In response to a final invitation to make additional points, a lot of the pupils wrote "don't know what engineering is" and/or "would like more information". EtF sought to redress the situation by developing classroom engineering experiences, providing resources for active careers advice and working to embed engineering formally in the curriculum.

Investigating engineering careers provision in the project schools

Prompted by pupils' poor awareness of the nature of engineering and associated careers and by the apparent lack of influence of school careers guidance staff on the university students' choice of engineering, the project investigated careers guidance materials and provision. Seven project schools (five state-funded and two private) were visited to establish the careers guidance pattern and the availability of careers materials. Teachers identified by the schools as having a careers guidance role (the number varied from one to ten) were invited, in discussion with researchers, to describe guidance practice in each school. The initial findings of this investigation are described by Ekevall *et al.* (2009). In almost all cases the pattern of guidance was entirely responsive. Engineering might occasionally be mentioned to pupils who were very good at science or mathematics, but in most cases it came up only when pupils asked for information about it. The large numbers of pupils ignorant of engineering and associated career options were thus in a 'Catch 22' situation.

A study by the project team of the available engineering careers material revealed a wide range of resources in multiple locations. Only a few explained the duties and professional practice of engineers. The project produced a leaflet 'Engineering – is it for you?', which explained the nature of engineering, the skills required, different types of engineering and the benefits of an engineering career. This was read and discussed in either their guidance or their science class by pupils in S2, aged 13-14 (n=472), and S4, aged 15-16 (n=643), in the seven schools.

An on-line survey showed that overall the use of the leaflet was successful. Before reading it 70% (n=377) of the S4 pupils and 80% (n=379) of the S2 pupils had not considered a career in engineering. Just under half (S4 – 44%, n=237; S2 – 45%, n=212) were interested in the leaflet when they were first given it. 68% (n=338) of the S4 pupils and 46% (n=216) of the S2 thought that it made engineering seem an interesting career. 43% (n=234) of the S4 pupils and 51% (n=239) in S2 changed their ideas about engineering after reading it. Most (S4 – 78%, n=412; S2 – 79%, n=371) indicated that the leaflet helped them to understand engineering.

(Responses to a second leaflet, 'Electrical Engineering: is it for you?', discussed by S4 pupils only, are not reported here.)

Integrating practical engineering experiences in secondary schools

Physics teachers in ten Scottish schools (8 state-funded, 2 private), working in partnership with Electronic and Electrical Engineering (EEE) lecturers from the Universities of Glasgow and

Strathclyde, developed contemporary engineering experiences that were built into science or physics courses for classes ranging from S1 to S6. The engineering activities were based on

- (a) a set of key ideas that pupils should understand about the nature of engineering and its motivating power;
- (b) essential characteristics of high quality engineering learning experiences identified by the participating teachers and lecturers at the start of the project (MacBride et al., 2010).

Qualitative research methods were used to investigate the views of the teachers and university lecturers who developed the activities and to explore the experiences and views of the pupils after engaging in the activities:

- interviews with all the teachers and university lecturers;
- focus groups with up to eight pupils who had experienced an engineering activity;
- classroom observation in the classes during the engineering activities.

Despite the teachers having initial concerns about finding space or time to fit engineering in to the physics curriculum in examination stages – S3-S6 - they did succeed in doing so: twelve of the nineteen engineering experiences produced during the project were for S3-S6. Table 1 provides a brief description of the whole set.

Table 1: Engineering experiences established within the existing science and physics curricula

Year	Title	Description
S6	Advanced Higher Investigations in School	Practical Investigations into the Speed of Light and the Mobility of Charge Carriers.
S6	Advanced Higher Investigations at University	Physics staff in the school, working with electronic and electrical engineering colleagues and doctoral researchers, developed six advanced investigations, ranging from ultrasonic characterisation of viscoelastic materials to electrical sterilization of liquids.
S1/2	Bat Monitoring	Using bat monitors to listen to sounds inaudible to humans and learning about ultrasound and its uses.
S1	Building a Lighthouse	Planning and building a simple model of a functioning lighthouse with a fully operational circuit and appropriate supporting structure.
S1/2	Carnoustie Wind Project	Optimising a wind turbine to produce the maximum power/energy and consideration of the benefits and problems associated with wind turbines, including issues of planning and positioning within the local environment.
S1	Fun with Bridges	An engineering challenge with an enterprise link, involving the construction and testing of bridges.
S2/3	Hot Potato	Calibrating a thermistor and using it to monitor the differences in temperature of a heated potato as it cools; exploring the relationship between temperature and resistance.
S3	LEDs and Photodiodes	Using commercially available light emitters and receivers to investigate how the application of the principle of sending signals through optical fibre could be improved
S2/3	Light and Dark	Investigating how a light sensor (LDR) reacts to light brightness; working through a staged process illustrating how automatic street lights work.
S1/2	Mars Rover	Planning a Mars mission (balancing scientific benefit against budget and other practical considerations) and specific aspects of electronic engineering relating to robotics.
S4	Nuclear Debate	Learning about engineering applications related to radioactivity and nuclear physics, including building a radiation detector and managing a nuclear plant simulator.

S3/4	PETS Course	An integrated Physics, Economics and Technological Studies course newly designed by the school specifically for school students who are interested in an engineering career.
S3/4	Pimp My Trolley Engineering	Designing, building and testing a crumple zone for a lab trolley (as a model for a motor vehicle).
S3	Radio Project	Building a radio with easily sourced materials such as toilet roll tubes, crystal earphones, diodes, terminal blocks, aerials and capacitors.
S1/2	Security Unit	Designing and building electronic security systems.
S3/4	Ultrasound	Using ultrasound to measure distance in a Health Physics unit and learning about other engineering applications such as sonar, weld testing and car reversing indicators.
S5/6	Wheatstone Bridge	Building and modelling a realistic engineering scenario involving Wheatstone Bridges.
S5/6	Wii Sports Unit	Introducing some of the ideas of mechanics at the level of Scottish Qualifications Authority Higher Physics by considering the physics which a software engineer would need to implement to make the Nintendo Wii-Sports game realistic.
S1	Wind Turbines	Developing an engineering-based unit of work related to wind turbines in the context of studying renewable energy sources. The challenge is to find a design configuration to produce maximum power.

Schools involved in EtF and some previously uninvolved were invited to trial these engineering activities. The trialling schools were provided with the teacher guides written by the original developer(s) and the key principles for high quality learning experiences in science and engineering. All of them found the engineering activities manageable and suitable for all their pupils. They plan to use them in years to come.

Overall, participants were very positive about the collaborations and about developing experiences that could be very helpful to other schools for promoting engineering within the existing curriculum.

Lecturers' views of developing the engineering curriculum inserts

After developing the engineering experiences the lecturers believed they had a greater understanding of what is required for pupils to make a successful transition from school to university. The school-university partnerships were viewed as a good way of "keeping up with the curriculum", in the (usual) absence of other school-university links. Prior to the project, lecturers had been making assumptions about pupils' knowledge based on either their own experiences at school or previous awareness of a now outdated curriculum. Their involvement gave them the opportunity to explore why certain areas were not taught or were taught differently from the way they had expected and helped them to understand their students and the school system better. The lecturers discovered the limitations and constraints that teachers are under: a "packed curriculum" that is 'restrictive' and 'prescriptive'; an apparent lack of resources, modern facilities and equipment – "It was older than me"; and assessment processes that impact on pedagogy.

Knowing the current school curriculum and how schools operate was seen as the first step for a successful school-university transition. Those involved in first year teaching, who were concerned to link school and university learning and to help students with the transition, benefited particularly from better understanding of the school curriculum and "the way the subject is taught". This group of lecturers indicated that their new understanding of the students' previous learning experience made them think about the course content and their own teaching methods and they sought to take account of the kinds of learning/teaching that students had previously experienced.

Lecturers also mentioned other practical advantages of being in a working partnership with schools. These included:

- increased knowledge and confidence on "how to pitch" a talk to promote engineering;
- feeling positive and encouraged, knowing that they were "contributing in some way";

- possible value to their academic career, adding a form of 'outreach' to research and teaching.

Teachers' views of developing and trialling the engineering curriculum activities

Almost unanimously the teachers perceived the engineering curricular activities to be very interesting and motivating for pupils. Reasons offered for this included practical problems, more interactive teaching and learning approaches and relevance to everyday life. Some of the engineering experiences had engaged pupils with a challenge and/or competitive element with an achievable goal, stimulating healthy competition.

Teachers noted that they themselves had been highly motivated by the activities, too: one said they had encouraged more interactive teaching/learning and opened up creative possibilities in keeping with his original motivations for becoming a physics teacher. They frequently mentioned the higher than usual degree of interaction (pupil-pupil and pupil-teacher) and reflected on the nature of pupils' learning. They believed the pupils benefited from more ownership - "They learn for themselves and remember better in this type of work" - from "having fun, but learning at the same time" and from having to be creative and active learners, using their knowledge and, often, imagination to solve a problem.

Teachers also spoke very positively about the general skills the pupils were learning - teamwork, collaboration, social skills, planning, reasoning and information handling. Two teachers who had implemented the Mars Rover project commented that working to constraints and the iterative process of designing something, finding out that it costs too much and having to go back and re-think, possibly sacrificing some things to make everything fit, brought into focus for the pupils the idea that this is what people actually do in their jobs - people have to think and problem-solve in this way every day.

There were some concerns about possible resourcing issues for some of the activities. Sharing equipment across schools with the support of education authority staff was suggested. Schools involved in trialling overcame possible resourcing problems by substituting and borrowing equipment. Some teachers predicted that biology and/or chemistry teachers might find it difficult to run the engineering experiences in the common S1-2 science course, especially if equipment failed: "What to do when an electronic board goes wrong is a main issue". However, in the schools where the engineering activities were trialled by the whole science department the other staff members enjoyed teaching them, although some found it a bit daunting at first to deal with class management issues and new resources. Notably, it was not the engineering content that was new or daunting.

Pupils' views of the engineering curriculum inserts

The pupils in the focus groups were aware of the science/physics and the basic mathematics within the engineering experiences, such as telecommunications in the Radio Project, sensors and outputs in the Mars Rover activity, forces, energy and design in the Pimp My Trolley activity and calculations, formulas and graphs in various activities.

A variety of reasons for engagement and motivation were given by the pupils, but one of the most frequent was fun - "Good, fun, but hard work"; "More fun and better learning"; "More fun - you can talk about what you're doing"; and "More fun, when all working together". One pupil even commented "It's more fun - so you want to know more about physics". The pupils were also motivated and engaged by the challenges: "If you work hard at it, the benefits are good"; "It was a challenge, but not too easy or too hard - achievable but not easy"; "Challenging, but you've accomplished something - it 'clicks' and you remember it"; and "It was more challenging because you had to find out for yourself, but this makes you learn it well".

The practical activities within the engineering experiences provided opportunities to be independent and creative and to make choices. Most pupils reflected that the practical work made it easier to understand and remember the physics: "There should be more projects like this - helps you to learn better. A practical activity is easier to remember than notes". The practical work was often perceived as different from 'normal' practical work, because the pupils weren't demonstrating something that has just been explained, already knowing what will happen, or following instructions. One pupil focus group summed it up: "Lessons different - more active and more freedom... make your own choices". The majority of the pupils enjoyed working in teams. They said they could work together, help one another to understand and share ideas.

After taking part in the engineering activities a number of pupils in the focus groups had changed their views of engineering now they "knew more about it" and, as a result, some were more interested in it. Most realised that engineering covers a wider range of things than they had thought: for example, "[I

used to think engineers fixed bridges, ships. Now I know they design and plan them..." Others recognised it was "not just a male job".

All the pupils in the focus groups thought young people should have some general knowledge of engineering, even those who were not interested in it: "There's a need to understand what it really is – not a stereotype – and not just for boys, and that it pays well. It's not just the guy that fixes the washing machine, it's always developing, changing, and society needs engineers." Other reasons why young people should know about engineering included: "It's a big part of everyday life and the economy"; "You have to know about the world you live in"; "It helps you to understand the science"; "It justifies science – it shows how science is used"; "The knowledge would be useful in later life - people should know how things are made/fixed"; "They might want to do it when they're older and not know about it"; and "If it was in the curriculum more people would try it. Some who don't like physics/ maths might be motivated by an engineering applications treatment of these subjects."

Engineering in the Curriculum

After learning about engineering through the engineering activities the pupils' perceptions of engineering had improved. Almost all the pupils in the focus groups considered it important that young people know about engineering, because it is an essential part of everyday life – "We would like to find out more about engineering"; "If we knew more about it, our minds wouldn't stay closed to it. We would maybe take it up"; and "The world will need engineers in the future, so if people learn about it some will want to go on and do it, You'd enjoy it, too." The importance of engineering, both for learning and for economic development, is mentioned within curriculum documents (Scottish Executive and Learning Teaching Scotland, 2006) and government documents (Scottish Executive, 2001, Robert, 2002, HM Treasury, 2004, Sainsbury, 2007) but without strong emphasis. To create circumstances where engineering really can contribute strongly to individual pupils' learning and to economic development requires an explicit and detailed strategy which builds engineering and the associated skills into the learning of *all* pupils. Engineering courses in UK schools –Engineering Skills for Work in Scotland and the Engineering Diploma in England - are restricted to the upper secondary phase after pupils have made their subject choices. Engineering the Future argued for the formal inclusion of engineering in the emerging reformed curriculum in Scotland, Curriculum for Excellence, in both the sciences and technologies throughout primary and secondary school. In the Curriculum for Excellence science and technology outcomes and experiences (Learning Teaching Scotland, 2009c, 2009a) and the principles and practice documents (Learning Teaching Scotland, 2009d, 2009b) engineering now features more prominently than in the previous curriculum documents. The project team are now interacting with policy makers on the implementation of strategies that would ensure that the concepts and activities central to engineering *do* form part of pupils' school experiences. Embedding engineering in schools requires teachers who are informed about engineering. School-university partnerships are a valuable way of sharing knowledge that can benefit both sectors and provide improved, more integrated and coherent experiences for both pupils and university students.

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