

Engineering the Future*: a sustainable concept?

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*Engineering the Future is the working title for the EPSRC Project 'Promotion of Engineering through the Creation of a Structured School – University Interface', G. Hayward, University of Strathclyde (Principal Investigator) and L. Hayward, N. Hedge & J. Magill, University of Glasgow

Abstract

Engineering the Future (EtF) is a 3 year EPSRC funded Project based in the Universities of Strathclyde and Glasgow which seeks to explore original ways of addressing the challenges posed by the predicted shortfall between the numbers entering university engineering courses and the growing demands for high quality graduate engineers.

Founded on models of transformational change already in practice within Scottish education, EtF is exploring innovative means of developing a 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. EtF is working with researchers, policy makers, practitioners and the industrial community to:

- identify key skills, mind-sets and dispositions needed by engineers to face changing demands through their working life
- provide experience of engineering activities within school classrooms
- support students' motivation and learning across the school-university transition and into studying in university
- develop pedagogy in university which challenges and supports students to extend their prior knowledge, skills and dispositions to become successful engineers
- embed these developments within national curriculum, assessment and qualifications policies and practice.

This work is informed by data derived from questionnaires, interviews, focus groups and observation of participants at work and the expertise of an extended advisory network.

This paper reflects critically on this work and on the theories of transformational change on which ideas of sustainability are grounded.

Background

Policy makers, academia and industry are seriously concerned about the decline in the numbers of young people studying physics in school and entering university to study engineering. While the decline in the proportion of those studying physics in secondary schools has been less noticeable in Scotland than elsewhere in the UK the decline in the number studying technological studies is marked (Scottish Qualifications Authority 2006, 2007). Participation rates in Higher Education are now approaching 50% of school leavers but the number of students applying for engineering courses is generally falling (Scottish Funding Council 2007; Scottish Government 2007c). Retention in the first years of university engineering courses is also an issue. Staff perceive the increasing diversity of attainment and commitment of students on entry to engineering faculties as factors which are difficult to address. There have been several initiatives designed to encourage young people to study engineering but their effects seem limited.

Introduction

Engineering the Future (EtF) is a three year project funded by EPSRC, based in the Department of Electronic and Electrical Engineering of the University of Strathclyde and

in the Departments of Educational Studies and Electronics and Electrical Engineering of the University of Glasgow, which seeks to address these issues and develop a methodology which sustains transformational change in engineering education.

There is extensive literature on likely determinants of successful innovation in education (Kirk & MacDonald 2001; Spillane 1999; Triggs & John 2004, Gardner et al, 2008) including research into practice in Scotland (Hayward et al 2004, Hutchinson & Hayward, 2005, Hayward & Spencer, 2008). Successful change results only when staff in schools and universities can harness system change to their own will and capacity (Condie et al 2005). It also depends on changes in policy to ensure that individual change is supported by collective change, what Hayward & Spencer refer to as systemic integrity (2008 in press). This depends on the sort of collaborative participation of practitioners, researchers and policy-makers (Keys & Bryan 2001) which underpins EtF.

EtF uses Electronic and Electrical Engineering (EEE) in Scotland as the pilot and will share and develop findings with stakeholders in England, Wales and Northern Ireland to promote uptake on a UK basis.

This is an account of work in progress. Engineering the Future became operational in September 2006; this report represents work to March 2008. It is not possible to provide any final summative evaluation of success but it is possible to examine the direction of travel in the light of emerging findings.

Project Structures

Collaboration, dialogue and the explicit sharing of values across research, practice and policy communities are built into the structure of the Project; the project team is interdisciplinary, bringing together staff from two engineering faculties, staff from an education faculty, former members of Her Majesty's Inspectorate of Education, researchers and school teachers. This affords both a model of practice and a space within which principles of collaboration can be explored and tensions identified and addressed.

This team is supported by an Advisory Board which includes high level representation from industry, from the education policy community, from the scientific policy community and from educational research. The Board collectively and individually participate actively in the dialogue among practitioner, research and policy communities.

The team is further supported by an Extended Advisory Network within and outwith Scotland which includes colleagues working in science education, teaching and learning, assessment, careers, economic development and industry who act as critical friends on specific aspects of our work.

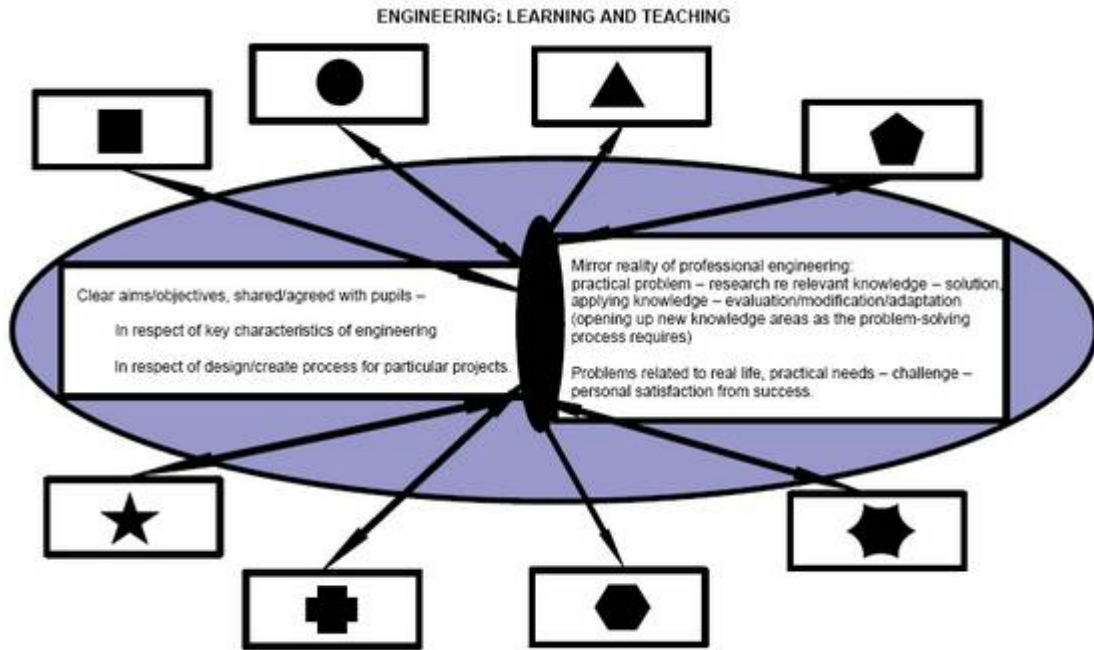
Involving practitioners

EtF has involved staff from both University EEE departments and teachers from seven public schools in five authorities and two independent schools as active participants. All practitioners involved were asked to complete a questionnaire at the start of the project. One aim was to gather their views on the defining characteristics of engineering, on

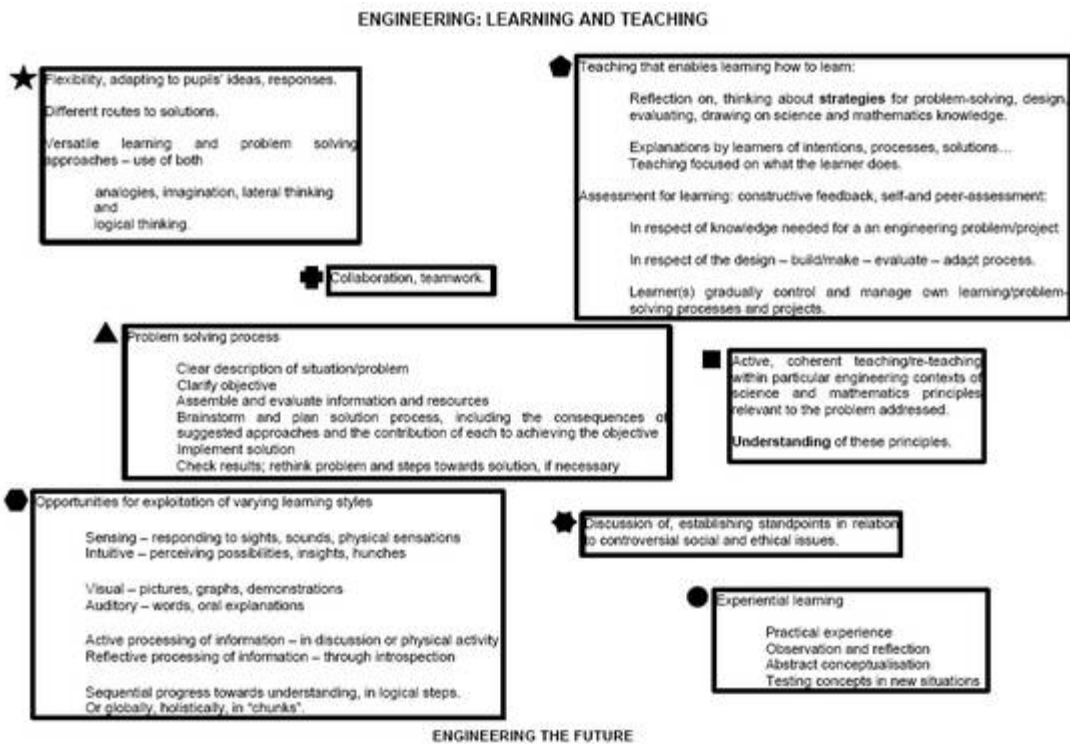
motivating (and demotivating) factors for pupils concerning engineering as a career, and on what makes for effective engineering education. The other focus was the extent of knowledge held by staff in each sector of courses and programmes in the other.

The results from these first areas of the questionnaire were synthesised into a series of diagrams of 'big ideas' relevant to engineering education under three headings: 'characteristics of engineering', 'motivators' and 'principles of learning and teaching' (Fig 1).

Fig 1: Engineering: Teaching and Learning



[please see key on the next page]



These diagrams were shared with participants to validate their contribution to determining the development of the project would and to promote dialogue which moved beyond passing on information to examining principles. These statements act as benchmarks, subject to reflection and review, throughout the Project.

Staff in each sector were largely unaware of the teaching and course demands of the other. This led to a workshop where participants shared their experiences of the curriculum in schools and universities. Partnerships were established which brought together the science staff involved in each school with named member(s) of university EEE departments. University lecturers experienced physics lessons in their collaborating school; teachers attended lectures and toured the labs.

Each school-university partnership undertook to develop engineering related inserts within school science and physics courses; while partnerships were free to choose their school stage and the content of the insert, careful management resulted in all stages of secondary schooling having at least one insert planned. These are currently being trialled both in the 'developing' school and in others within the Project. To test the feasibility of extending these developments beyond the current community of interest, EtF is seeking further schools in which inserts may be trialled.

While changes in curriculum content (relevance to engineering), in pedagogy (problem solving and team work) and in motivation ('real world' issues) are crucial to introducing young people to engineering concepts and mindsets, pupils must receive accurate and attractive information on engineering careers. EtF team members discussed this with teachers in participating schools with specific responsibility for careers education, who illuminated current practice in careers education and advised on steps to improve this.

Involving learners

A research and development project built on the principles of inclusiveness must include the views of pupils and students. In year 1 of EtF these were mainly gathered through questionnaires; in years 2 and 3 there is greater emphasis on exploring ideas through focus groups of pupils and students and through involving school pupils themselves as researchers in schools.

Teaching and learning: teaching and learning across the school-university interface

Addressing the decline in interest in engineering and any discontinuities in learning between school and university requires collaborative action. In the first year of the Project seven school-university partnerships prepared curricular inserts despite participants' initial doubts about the possibility of doing so within curricular constraints. Two further schools (H and J) have agreed to participate in the project from the current session. Table 1 outlines the thrust of each development.

Table 1

Year	School	Insert
S5/6	A	Use of strain gauge/Wheatstone Bridge/amplifier applications in experiments leading to SQA Higher Physics Learning Outcome related to an experimental report.
	B	3 kits and associated activities to be available to S6 pupils as options for the Investigation in SQA Advanced Higher Physics (including activities using a digital oscilloscope).
S3/4	C	Implementation from August 2007 of an S3/4 3-subject programme (Physics, Economics, Technology) with an engineering emphasis, addressing issues associated with global warming.
	D	Several tasks being developed related to Standard Grade Physics (Using Electricity and Electronics topics), with an emphasis on engineering concepts. Initial focus was on S3 but possibilities of extension into S4 have been noted. The school is also considering highlighting in S Grade Physics course materials the sections that are of particular relevance to engineering.
S1/2	E	Two current developments: "Bat Monitoring" (building a device to monitor inaudible sounds made by bats); Renewable Energy (energy generation and storage and design of wind turbines) -- linked to the development in the school of a wind farm as part of its "Eco-school" identity.
	F	An S2 electronics module, enabling pupils to learn about the concepts of input, process and output, devices associated with input and output, and the use of logic gates in creating and using a "Mars Rover" vehicle to explore surfaces at a distance; pedagogy stresses co-operative learning work.
	G	Use of Alpha boards to make practical circuits and micro controllers to design systems that use sensors (heat, motion, etc.) addressing four problems (one per group) in connection with a spy/security systems theme, including modelling before building the system; pedagogy stresses group work and presentation skills.
	H	An expansion of the Energy section of the S1 course book which includes work related to such topics as renewable energy sources has resulted in engineering-based unit of work related to wind turbines.
	J	The focus in 2007-08 is on S2, with some development for S1. The partnership will seek to develop curricular elements based on the existing Engineering Club activities. A key idea will be to have pupils develop their own ideas for projects which would be undertaken by other pupils.

Colleagues were encouraged to employ and develop the 'big ideas' which had been identified from their questionnaire responses and to plan their developments in the context of the principles of a Curriculum for Excellence (CfE) (Scottish Executive 2004a, 2004b). Members of the Extended Advisory Group were asked to provide critiques of the inserts in terms of content, of pedagogy, of resource implications and of the match between these inserts and curricular policies in England, Wales and Northern Ireland.

The majority of the participating university staff had little or no knowledge of the content of school courses relevant to engineering. Likewise most of the school staff did not have a good knowledge of the content of university courses. This has provided one starting point for the consideration of 1st year university courses; another has been Entwistle et al (2005)'s work on pedagogy in EEE; a final starting point was the analysis of relevant pupil and student questionnaire responses.

In addition to discontinuities in content, university and school staff have identified discontinuities in the ways in which subjects are taught at school and university and problems with depth of learning. Noel Entwistle, a member of the Advisory Board, led a discussion at a Project seminar based on his findings on means of developing deep learning. Meetings with EEE staff have started in each University to develop the

dialogue on improving teaching and learning, on supporting students over the transition from school to university and on developing the deep learning required by engineers.

This builds on existing consideration of these issues in the university departments. Among recently implemented changes were: breaking the first year maths syllabus into 4 week blocks, with an hour long examination at the end of each with exemption from the final examination for students who perform well in these; the introduction of small group tutorials with a consolidation week in the middle of the first semester to acclimatise students to the university learning environment. Suggested changes to develop pedagogy in university to challenge and support students include: more project work and application examples/case studies at each learning stage, 'self help' groups in specific subjects; more interactive teaching materials; improved feedback; and refresher courses.

Informing young people

The current model of careers advice in schools stresses the value of young people being empowered to take their own decisions; this approach has resulted in careers guidance being largely responsive to pupils' expressed interests. This can lead to pupils receiving little information on engineering unless they specifically indicate an interest in this career. The pupil questionnaires confirmed the findings of Marshall et al (2007) that most young people have little knowledge of engineering and often depend on their families for information. Science teachers considered that many pupils held stereotypes of engineering as semi-skilled manual labour; this was confirmed by pupil responses. An examination of commonly used careers materials established that this view is often inadvertently reinforced by these materials.

With input from discussions with schools careers staff, EtF has this year developed careers materials to be used proactively and supported these with accompanying advice for staff. Professional engineers acted as critical friends in this exercise. These materials are being trialled and pupil and teacher comment sought through questionnaires and interviews.

Involving the policy community

This project has been designed to involve local and national policy makers throughout because without active policy support any project remains the concern only of enthusiasts.

Through the Advisory Board and the Extended Advisory Group representatives of policy communities play key roles in the project: reflecting on the policy implications from emerging project findings, advising EtF on strategies, and influencing their own policy networks. EtF is building links between itself and the new government's economic and educational priorities (Scottish Government 2007a, 2007b).

Learning and Teaching Scotland (LTS) is the public body which provides advice, support, resources and staff development to enhance the quality of learning and teaching in Scotland's schools. Meetings have been held with members of LTS teams to address such issues central to the sustainability of the project as e-learning, CPD and dissemination.

The timing has been helpful in that a national curriculum renewal programme, Curriculum for Excellence (CfE) (Scottish Executive 2004a, 2004b), was underway and that the initial work of EtF coincided with the development of science experiences and outcomes which will provide a framework for science teaching from 3 to 15 (Learning and Teaching Scotland 2007). EtF and CfE team members within LTS have explored opportunities for providing within the science curriculum space for the inclusion of engineering; the success of this is demonstrated by the invitation to EtF schools to develop their inserts as exemplars for engineering topics to be disseminated to all schools. EtF members have discussed with the LTS team developing the technologies experiences and outcomes ways of grouping these to provide pupils with opportunities to work like engineers using a CDIO – Conceive, Design, Implement and Operate – model (Royal Academy of Engineering 2007). The implementation in School C of a combined Physics- Economics-Technology course exemplifies the interdisciplinary work promoted by CfE.

The location of engineering within the school curriculum is a key issue for EtF. Arguably engineering is more effectively located in science rather than in the technologies because the latter lack a clear identity in pupils' minds and are often perceived as relatively low status. However, Schreiner & Sjøberg (2006) suggest that in fact technology is more attractive than science to boys. This has been the subject of discussion with policy colleagues who have acknowledged that engineering is not reflected in the CfE science structure (Fig 2).

Fig 2: Science Wheel Diagram



The Scottish Qualifications Authority (SQA) is the statutory body responsible for all school qualifications. There is a mismatch between the approaches to learning developed by the school qualifications system and the expectations of university staff; in

particular the model of problem solving which many students have internalised assumes that problems are neatly specified. More generally the pressure of high-stakes summative assessment leads to surface learning. These issues relevant to the school-university transition have been discussed with SQA both at policy level and through the current review of physics qualifications.

Education authority directorates were significant in encouraging the initial involvement of schools and remain central to the longer-term sustainability of the ideas emerging from the project. At the beginning of this year, members of the EtF team contacted education authority officers to discuss possible education authority roles in supporting this innovation. All were supportive and provided additional funds to support school projects and begin the work of dissemination within the authority. On the advice of the directorate member of the Advisory Board discussions have begun with the Association of Directors of Education in Scotland (ADES) on the implications of the Project.

Involving industry

Industry has input to the Project through a number of channels: members of the Advisory Board and of the Extended Advisory Group; questionnaires designed to explore industrialists' views on the qualities required by high quality graduate engineers; dialogue with individual companies; and the Principal Investigator's role as chairman of a spin-off company. This information contributes centrally to the development of teaching to foster these qualities.

Issues arising: Project structures

It is likely that establishing relationships with the school education policy community in Scotland was facilitated by existing relationships between members of the multidisciplinary team and members of that community and by the relatively small size of this system. The question of the conditions for establishing such relationships in other circumstances remains to be addressed.

Issues arising: Involving practitioners

The current model of involving practitioners appears to be working well: most partnerships are ahead of the projected timetable for trialling inserts and participants express positive views of how the collaborations are going.

The school-university partnerships have developed models of collaboration which differ in detail. These findings are being explored as new schools come into the project. EtF evidence suggests strongly that successful collaboration requires participants to have someone to initiate the process, a well defined task to work on, an agreed simple way of contacting each other and planned face to face meetings. Reciprocal visits between the school and university appear to be beneficial through giving participants opportunities to update their knowledge of the other sector. In accord with the conclusions of Hayward et al (2008), the educational integrity of the tasks, their intrinsic educational value, was significant.

The importance of personal relationships to ensuring commitment was evident; this applied to relationships within any grouping of EtF staff, school staff and university staff. Given the pressures on all participants a new project is unlikely to survive if such relationships cannot be not developed. Means of developing and sustaining such relationships require further consideration. It is also important to analyse the nature of relationships to try to discern whether different patterns of relationship (eg good personal relationships as opposed to good professional relationships) had differing outcomes.

Issues arising: Involving learners

Learners through their questionnaire responses have provided the Project with valuable insights into teaching and learning in both schools and universities. EtF is extending our understanding of young people's perceptions. The findings of initial questionnaires have been used to plan input from students in the later years of EEE courses to determine whether initial barriers are perceived as longer lasting and to illuminate learning in the university. School pupils are contributing to the evaluation of school inserts through questionnaires and focus groups.

Learners should become more active participants in our research processes. As a first step to this, building on Brownlie et al (2006) we intend involving pupils through the use of photography to initiate and sustain more active debate about what makes for successful learning.

Issues arising: Teaching and learning: teaching and learning across the school-university interface

Participants are aware of major differences between school and university pedagogy and of discrepancies between what SQA syllabuses and examinations require and what university colleagues regard as contemporary physics and engineering. While we have recognised the difficulty of ensuring deep learning of complex concepts, we have insufficient evidence as yet of the nature of learning (as opposed to explicit content) supported by the school curricular inserts. Initial evaluation suggests that experiencing inserts will not be sufficient; pupils must be made aware of the relationship of these to engineering. Trialling and classroom observation and discussion with pupils and teachers will allow the formation of a sharper view of how much and what sort of classroom experience of engineering is necessary to achieve a real impact.

We need to examine further how to exploit effectively the potential afforded by ICT to enhance learning and teaching in engineering in school and the potential afforded by e-learning for sharing and developing materials and findings with wider educational communities.

It may be worth considering some of the implications of mass education at university level in the light of experience afforded by school systems which have carried out parallel transitions (Esteve 2000).

Issues arising: Informing young people

Questionnaire results demonstrate the extent of the work required to overcome young people's ignorance of and stereotyping of engineering as a career. This is underlined by the finding that the majority of respondents have no recollection of the involvement of careers advisers while parents were the main source of information for many. Research methods used by Marshall et al (2007) may be capable of adaptation to support better informed decision making by pupils.

Issues arising: Involving the policy community

Education authority representatives have played an important part in facilitating links between schools and universities but other factors influence the success of this relationship; indeed there were occasionally difficulties in the school-university relationship despite strong support from the education authority. Extending our conversation through ADES to education authorities across Scotland will further our views of what sustainability requires.

Other issues to be explored in the policy field include some related to school qualifications. The current review of physics qualifications is one step towards the more fundamental need to address the unintended effects of the school examinations system in narrowing the curriculum and encouraging superficial learning. More specifically the case for the creation of SQA qualifications in engineering at Higher and Advanced Higher levels merits exploration.

We need further to consider and develop the possibilities afforded by the increased flexibility of CfE to ensure that all pupils experience contemporary engineering activities within the curriculum. This includes building in opportunities into the experiences and outcomes but goes beyond this to considering the relationship among engineering, science and the technologies. The potential roles of interdisciplinary projects and learning outwith the traditional classroom are being explored by some school partnerships. The potential contribution of the Scottish government's commitment to develop a science baccalaureate is another matter for consideration.

As we consider the UK perspective we have much to do in exploring the channels in England, Wales and Northern Ireland that would facilitate similar conversations and in exploring routes to extend conversations to other universities and engineering organisations.

Issues arising: Sustainability

Sustainability has been a major concern for this project from the outset. The involvement of policy, practice and research communities in the initial project design recognised the importance of leaving more than footprints in the sand. However, issues have begun to emerge as we begin to learn more of what matters in sustainability.

Schools involved have received funding which they have used to buy resources and especially time. This is consistent with research findings on transformational change where time to work through ideas appears to be a crucial factor in developing understanding of and commitment to innovative practice. Multiple demands on teachers and university staff, including their commitment to current classes, limits time for

reflection and raises issues, to be explored at a policy level, of how time can be guaranteed for reflection, cooperation and development of longer term projects.

There are resourcing issues to address if engineering is to achieve a much higher profile in the curriculum. Most of the inserts have involved some element of additional classroom resourcing including digital oscilloscopes in senior classes. We suspect that the impact on both motivation and learning of the provision of up-to-date instrumentation in schools is complex and merits investigation .

In universities, intrinsic motivation and existing relationships among colleagues appear to be key factors leading to ownership of ideas and to staff finding time to commit to the project. However, changing staff remits and pressures to engage in other activities impacted on this commitment; participants have raised the difficulties created by powerful drivers such as research and publication for engagement in this type of activity. Faculty support in building activities into workload planning is crucial for longer term sustainability. We need to consider carefully means of ensuring that recommendations relating to the development of pedagogy, assessment and course structures which recognise prior student knowledge and promote deep understanding can be put into practice in very different contexts across the country.

The implications for projects like this of linking their development and dissemination to national initiatives and priorities require consideration because of the possible tensions between long term planning and the flexibility required to ensure rapid responses to changing priorities.

EtF has used EEE as its pilot. Extending our findings to other engineering fields requires consideration of the role of sciences other than physics in preparing school leavers for the transition to engineering and the nexus of relationships between science, engineering and technology (Schreiner & Sjøberg 2006).

Issues arising: Research, policy and practice

There is a need to consider the perspectives afforded by the project findings on broader issues if we are to ensure sustainability. These relate to the model and methodology adopted by the project from its earliest planning stages.

One such issue concerns the impact of the contexts, immediate and broader, within which participants work and the ways in which contextual catalysts and inhibitors manifest themselves and can be used or countered. While the impact of policy and resources is often recognised, the roles of student expectations, of informal networks among colleagues and of their history, individual and collective, as key contextual factors (Kirk & MacDonald 2001; Yerrick et al 1997) are less often recognised. The need to start from where teachers and lecturers are and the need to recognise how their voices are anchored in their socio-political context pose challenges which require careful consideration.

Above all it is necessary to ensure that the capacity and will of individuals and systems can be developed to sustain transitional change through the provision of impetus and scaffolding at appropriate points (Spillane 1999). The parallels between deep learning by

students and the successful adoption of initiatives by teachers and lecturers are thought-provoking.

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