Engineering futures - a proposal for a new curriculum,

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Summary.
A proposal for an integrated engineering first year based around state of the art technology and a radical, problem-based teaching approach to exploring fundamental engineering concepts in a modern engineering context. The principle educational philosophy is to develop core mathematical skills alongside generic engineering courses which demonstrate the basic principles of the subject in a multi-disciplinary, computer-based teaching environment. Alongside the formal modules there will be weekly small group tutorials that will reinforce the mathematical foundations by incorporating group-based engineering modelling activities, information searching and the presentation and communication of interesting engineering case studies and issues together with a business game which will involve a monthly exercise in the running of a virtual engineering business set against the context of a dynamic, global economic framework.

$1. The need for change.
Not only is the world becoming more connected and interdependent but traditional industries are also moving into new directions rapidly or succumbing to market pressures and declining. The role of Information and Communications Technology (ICT) is becoming all pervasive but at the same time this is such a dynamic technological area that new opportunities are opening up continuously. Many aspects of engineering are changing, particularly at the interfaces between what were traditionally different disciplines. The developments in ICT are also providing new opportunities for supporting teaching and learning. Our curriculum and teaching philosophy should recognise these fundamental truths.

Our current provision also has some areas where we could improve. The way that mathematics is integrated into the curriculum could be greatly improved, especially if there were clear links between mathematical concepts and solving mathematical problems and the modelling and understanding of engineering situations. Sometimes students are taught techniques either well in advance of or even after they are needed in the engineering course. Some laboratory exercises are similarly remote from the occasion when the issues are discussed in class.

In terms of the Faculty’s position in the engineering education market place we offer a set of what we believe to be high quality research-oriented degrees in specific traditional engineering areas. Alongside these are the Aerospace Engineering degree some interdisciplinary duals (Civil & Architecture; several Control degrees; Mobile Comms and some duals in Materials with Medical Physics etc.) together with Software Engineering. What distinguishes most of these degrees from those in many other engineering faculties and departments, and from many other degrees at Sheffield, is that students enrolling on these degrees have little or no opportunity to change to a different degree in another, related, engineering department. There may be some possibilities for change within a department’s degree schemes but, in general, if a student comes to study a specific type of engineering here then that is what he/she is stuck with unless they repeat their first year - and this is becoming much less likely with the introduction of fees and the mounting student debt (this year’s students are graduating with twice[1] the debt of last year, thanks to fees!)

What this may mean is that prospective students who are not absolutely sure which type of engineering they wish to study would not be advised to come to Sheffield because of its inflexible engineering programme. We are seeing catastrophic drops in applications in some departments, so much so that this, combined with the Taylor’s College closure, will have a major financial effect in the next few years on those departments.

The proposal is for a new integrated curriculum that is based around the development of core mathematical skills in an engineering context, emphasising the generic concepts, principles and theories and their implications for design and manufacture of a full range of engineering artefacts and processes. Thus we propose a carefully designed set of generic engineering courses which demonstrate the basic principles of the subject taught in a multi-disciplinary, computer-based teaching environment.

The teaching load is intended to be resource neutral in terms of the current first year activities for each department. The core modules, described below, will involve several departments working in a co-ordinated way. One

1. Barclays Bank, June 2001.

department will act as module leader and organiser and the other departments will collaborate in providing a proportion of the teaching activities. The distribution of this will be subject to agreement and in line with the nominal loads, they could include giving a proportion of the lectures on appropriate topics, organising lab classes and problems classes, where appropriate.

Each student entering will register for a current, named degree as at present. They will attend all the modules described below. At the end of the 1st year they will then be able to choose to transfer to any other degree program except Computer Science (see below). In the 1st year each student will attend a weekly academic tutorial held in their "home" department (the current tutorial arrangements for the Aerospace students would continue but they would do the integrated core).

The open structure of the programme will encourage departments to provide exciting and well taught elements since students will be able to move to other departments in year 2. This system works well in Arts and the Biological Sciences areas and has resulted in these departments putting some of their best lecturers into the 1st year modules to try to attract students. Each department can restrict entry to year 2 if the resources, labs etc. are insufficient and demand is too strong.

$2. The basic framework.

The principle framework is that of 20 credits of engineering mathematics plus 100 credits of key engineering modules as specified below.

A. Structures and artefacts in the large - static and dynamics forces - 20 credits

B. Materials and processes at the microscopic level - 20 credits

C. Fluids and turbulence: heat and power - 20 credits

D. Electrical and magnetic processes - 20 credits

E. Computers and control - 20 credits

F. Engineering mathematics - 20 credits

Small group tutorials - linking maths, communication and research skills, business game

For those students wishing to take a language option they will have to drop one of the key engineering course which will restrict their options in later years.

Following the 1st year students will be able to choose to specialise in a specific department - some joint options might also be available depending on how the curriculum in years 2, 3 and 4 are developed within departments.
A crude resource model is described below. It is based on the assumption that currently departments teach 100 credits in year 1- the rest being Maths. Assuming that Mech Eng and EEE have a nominal quota of 100 students and Aero, ACSE, Civil, Chem, Materials have 50 then the table gives the changes, assuming the departments contribute as described in $4. Currently ACSE, Aero students attend courses given by other departments I can only approximate to this. The Faculty quota is currently 400 FTEs.

Table 1:

credits × students(FTEs)	ACSE	Civil	Chem	Comp	EEE	Materials	Mech
Current	37	52	36	30	66	33	81
Proposed	50	43	43	33	50	36	63

These figures are very approximate and are based on dividing a department's total ug. load by 4. Aerospace engineering students are subsumed into the departments providing the teaching. The Comp Science load is based on the current 1st year engineering computing courses COM161, 162, 164 etc. from the available evidence I have it seems as though Civil's entries are falling and ACSE's are increasing. There is possibly scope in Mech/EEE providing more teaching in the scheme to balance that of Chem and Civil.

In terms of teaching credits per department for 400 students this comes down to:

Credits	ACSE	Civil	Chem	Comp	EEE	Materials	Mech
Current*	40	80	60	20	90	90	90
Proposed	15	13	13	10	15	11	19

* approximate current number of credits taught by departments on core level 1 degrees.

These figures are slightly misleading since every lecture will have to be given 3 times in order to utilise the technology envisaged. There should still be substantial overall savings in effort through the removal of duplicated teaching and the co-operation of several departments in a module.

$3. Suggested syllabus ideas.

Each module is briefly described below. Associated with part of a module is a design and analysis case study or a simple artefact that will be designed and built in lab classes associated with the module. The purpose of defining a specific application is not only to motivate the theoretical work but also to encourage the students to study more independently. Thus it would be expected that some material needed for an understanding of the problem will be left for the students to read up. The lectures will concentrate on the basic concepts, building models and solving the mathematics, describing the experimental techniques, classifying the materials and artefacts and interacting with the students through the medium of the electronic white boards, computer simulations and computer-based tests. Thus the concept of building models, analysing them, validating and evaluating them will be emphasised throughout. This will be achieved by linking all the modules strongly to the engineering mathematics module and the small group tutorial system. The tables below describe the outlines of the core, inter-disciplinary models with rough existing equivalents stated. A comparative departmental loading in terms of credits for 400 FTEs is given. The Artefacts and Case studies are the focus of the laboratory sessions attached to the module. For each module there is one for each semester. The students' e-lab-book should be oriented around these activities.

It is proposed that assessment is based on several facets. Since practical skills will be important learning outcomes it is *mandatory* that these are assessed in some way.

A possible scheme for each of the core modules, including Engineering mathematics is:

Written examination..70%
Computerised class tests......................................10%
Practical sessions and projects.............................20%

The programme for year 1.

A. Structures and artefacts in the large - static and dynamics forces - 20 credits.

Models of 2-dimensional statics of rigid and connected bodies. Basic equilibrium. Thrusts, shear forces, beams and arches. Use of MATLAB for building and understanding models.
Kinetics in 2-d. Dynamic analysis of rigid bodies.
Work, energy and impulse momentum.
Systems models of simple engineering situations.
Sustainable energy sources.

Artefact A1. Design and build a portable “MEN AT WORK” road sign and test it in a wind tunnel.	*Case study A2*. A wind-farm windmill both design and performance aspects.	MEC101, 106. [10] CIV 100*, 110 [10]

B. Materials and processes at the microscopic level - 20 credits.

Classification of materials. Mechanical behaviour of materials, stress, strain, fracture, deformation.
Basic aspects of the manufacture of metals, ceramics and polymers.
Material balance, energy balance, chemical processes of separation and distillation.
Concretes and soils.
Recycling of materials.

Case study B1. The creation of a simple “expert system” for classifying simple basic materials.	*Artefact B2*. Designing a simple mould for a plastic and a metal widget.	CIV160, 150 [5] MAT121, 131, 122 [5] MEC102, 107 [5] CPE112, 122 [5]

C. Fluids and turbulence - 20 credits.

Modelling of Newtonian and non-Newtonian fluids. Control volume analysis.
Frictionless and laminar flows.
One-dimensional compressible flow.
Thermodynamics of simple substances and gases. Laws of thermodynamics.
Mass continuity analysis.
Liquid/vapour separation by distillation.
Pollution and pollution control.

Case study C1. The basic design and operation of a chemical plant (CPE101)	*Artefact C2*. Design, build and test a simple rocket (cf. proposed Aerospace engineering exercise)	MEC103, 108 CPE106, 123, (101) MAT104,141	[6] [8] [6]

D. Electrical and magnetic processes- 20 credits.

Modelling circuits - analogue and digital.
Signals - their representation and measurement.
Amplifier basics.
Number systems and digital circuits.
Elementary VLSI design.
Measurement, errors and calibration. Instrumentation.
Mobile devices and systems.

Artefact D1. A simple radio built from suitable components and tested to achieve some standard.	*Artefact D2*. A chip to control a simple robot, designed and implemented in a suitable technology - see E2.	EEE103, 101, 104 ACSE103	[15] [5]

E. Computers and control - 20 credits

Problem solving and the design of algorithms and data structures.
Object-oriented programming.
Building software from components (classes). Software integration and testing.
Classical control theory. Objectives, strategies and evaluation.
Laplace and Fourier transforms at work.
Simple robot control strategies.
Artificial intelligence and engineering.

Artefact E1: a simple 2-dimensional drawing package written in Java with a graphical user interface.	*Artefact E2*: a simple autonomous robot with basic sensors and a custom built control chip - see D2.	CS161 [10] ACSE104 [10]

F. Engineering mathematics - 20 credits

Systems engineering principles. The modelling process and modelling packages. MATLAB.
Building and analysing models, validating and interpreting models in engineering.
Essential mathematical techniques, functions, vectors, and matrices, hyperbolic equations, integration.
Solution of differential equations. Partial differential equations.
Numerical solutions of equations.
Basic probability and statistics.
Reliability and safety.

Case study F1. Where to position the headlights on a bicycle, car, bus etc. (cf. an OU modelling exercise)	*Artefact F2*. Building a personal electronic library of engineering models and useful mathematical knowledge.	AMA149, 150 [20]

The personal tutorial system will be built around the sort of activities in CPE101, MEC104, CIV120, together with the business game outlined elsewhere and reinforcing and integrating the mathematical modelling and artefact studies.

$4. A new teaching facility.

A key component of the proposal is a major upgrade of the teaching facilities to enable full use of modern ICT technology to be used in all aspects of teaching, but particularly, in lectures and problems classes. This will be achieved through the deployment of *smartboards* in key lecture rooms, the use of *projection* and *plasma* screen facilities and the widespread availability of laptop computers for students to use in the lectures. If the educational proposals were sufficiently novel it may be possible to obtain grants and support for the purchase of this equipment. A core proposal is the refurbishment of a large lecture theatre to install laptops at every seat. This builds on the experiences of Strathclyde who, in turn, introduced a system from the USA. This has generated such interest from prospective students that they are now experiencing strong growth in applications (in contrast to their traditional rivals, Glasgow). A possible site is Stephenson Lecture Theatre 1 where laptops could be installed in slide out shelves under the current desk tops. They would be secured and networked to the CICS system. This would all be supported by software that allows the lecturer to interact with all students and to control the learning process from the front of the lecture room. The use of smart boards and projection systems would provide an interactive teaching facility. Using *mimio* pens and special software the lecturer can interact directly with one or all the students and to allow them to import prepared notes, simulations, and annotations drawn on the smart board during the lecture.

The educational experience for the student will be based around their development of electronic notes (e-notes) and perhaps e-lab-books which they will be required to keep organised and up to date. This could be a topic of an initial tutorial session. Collecting and organising electronic information, software etc. is the key method of working for the engineer of the 21st C. and we need to encourage students to develop these skills from the beginning. Being able to use intelligent search and information retrieval software will greatly enhance productivity and quality.

At suitable times the students will be asked to undertake computer-based tests or short quizzes which will provide formative assessment. It could also encourage better attendance since it will be possible to record who is present automatically. Such systems are now much more sophisticated and successful. The tests can be carried out during the lecture or during the student's own time on the CICS network.

One alternative idea is to purchase laptops or palmtops with wireless connectivity for loan to students during lectures but this is likely to be problematic in several ways, not least the disruption in trying to set them up at the start.

If Stephenson is converted and we have 400 students then each class will have to be repeated twice, making 3 sessions per lecture. In other universities where this type of teaching is done each student has to sit in the same seat each lecture. This is to help the lecturer know as many students as possible.

$5. *A survey of equipment for supporting the teaching of engineering.*

Apart from the laptops, the key technology is the smartboard which is an interactive whiteboard that allows for the display of computer screen output and the network software that allows the lecturer to control both the lecturer's computer and also the students - being able to display arbitrary screens from the students in the room. The Mimio pen permits the lecturer to write on the smartboard and the students can download this to their laptops and thus their CICS account.

Mimio pens

Smart screen

The costs of refurbishment of the lecture theatre and all the equipment could amount to £300k. Proper plans and quotations are required. There will also be further investment needed to expand the CICS network and to purchase more licences of important design and analysis software.

$6. A timetable for change.

It would be nice to try to target September 2002 as the date for introducing the programme, but this might be difficult in terms of agreeing the principles and details of the change and achieving the refurbishment of the lecture rooms. Also, this means that potential UCAS students will not have information about the new framework. Schools could be circulated at some cost. Probably the more likely date is September 2003. There will be a need for consequential change to all level 2 and 3 modules - possibly level 4 as well in order to accommodate the new level one proposals. This will be an opportunity to redevelop all the degree courses allbeit at some cost in terms of the effort required but it could present us with an opportunity to develop a number of further integrated modules and innovative pathways through the curriculum to new styles of engineering degree.

As a first step we would need to set up a project group representing the more innovative members of each department, including mathematics, to establish the details of the curriculum and the teaching approach. We would also need to address the issue of labs. Traditionally, in some departments, a set of experiments is devised and students go round doing these during the term. This inevitably means that they are often doing them before they have covered any relevant material and surely this cannot be sensible educationally. The redesign of the labs will be a key aspect of the reform. Since cost will be important it is not feasible to have every existing experiment done simultaneously by all the students. Labs will have to be based on a rota system to accommodate all 400 students. Several departments will provide labs for topics that they have the facilities for. A much greater emphasis will have to be placed on computer simulation in order to make the programme cost effective and successful. This will need some planning as well as good will. I envisage that the physical experiments will be restricted to a few key aspects and the facilities extended to match the demand.

The proposed entry grades would be a uniform ABB initially, which is *above* the SARTOR minimum, with hopes to increase this to AAB as the demand increases. The aim, as always, is to achieve our full quota with high quality students. By positioning ourselves as the leading engineering faculty in terms of research, the Newcastle St. building is a good opportunity to emphasise the exciting research developments, and as the leading progressive and technologically developed teaching institution in the field we should be able to create strong demand for our courses.

Accreditation. This is the area which is often used as an excuse for doing nothing. We need to have the confidence that what we are doing will produce much better engineers in all the fields we teach. Opponents need to demonstrate that the proposals are against the published criteria of the Engineering Council or the specialist Institutions. Otherwise we should be resistant to generalised and unsupported claims that accreditation will be a problem. It just needs some imagination and creative thought to overcome these problems.

$7.A less radical approach.

A less radical approach which introduces more flexibility for the student at the end of year 1 is described. It is unlikely to attract financial support from HEFCE or other bodies to the same extent since it is not so distinctive.

Each department runs 40 credits of core modules in their subject. Students choose two blocks of such modules, one in the department that they are registered with and the other from another department. They also do 20 credits of mathematics. Students will also be able to take 20 credits of free choice modules, perhaps a language, further science e.g. chemistry, physics, biology, psychology etc. or subjects from arts and social sciences.

At the end of the first year students can choose to study one of the two core engineering subjects that they have taken. It should be possible to allow for more dual degrees as well, if this could be arranged.

As in the previous scheme departments will need to adapt their curricula in years 2, 3 and 4 to build on the 1st year material. This should be possible without compromising accreditation.

$8. Final thoughts.

One issue that is less than ideal is that the Software Engineering programme would not be available to students from this integrated first year. This is partly because of the existence of the (more or less) identical Computer Science degree and partly because the department could not accommodate any more students without a massive inflow of resources (staff, space and equipment). It is possible for engineering students to take some of the special software engineering modules for engineers. Another reason is that there are already two degrees that combine these modules with engineering modules - Computer Systems Engineering (ACSE) and Mobile Communications Systems (EEE) and we would not want to inhibit these degrees.

If we can put something together like this it might be good to see if we can develop an innovative textbook or series of books. In many subjects there are superb books, mostly American, which provide an integrated introduction to the subject (examples of such are to be found in biology, biochemistry, psychology etc.). It could establish Sheffield as a leading figure in the field.

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