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Laboratory focussed learning of core electronic engineering concepts in the first year of an honours degree programme

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Abstract: *In common with most universities teaching electronic engineering in the UK, Aston University has seen a shift in the profile of its incoming students in recent years. The educational background of students has moved away from traditional A'level maths and science and if anything this variation is set to increase with the introduction of engineering diplomas. Another major change to the circumstances of undergraduate students relates to the introduction of tuition fees in 1998 which has resulted in an increased likelihood of them working during term time. This may have resulted in students tending to concentrate on elements of the course that directly provide marks contributing to the degree classification. In the light of these factors a root and branch rethink of the electronic engineering degree programme structures at Aston was required. The factors taken into account during the course revision were:*

- *Changes to the qualifications of incoming students*
- *Changes to the background and experience of incoming students*
- *Increase in overseas students, some with very limited practical experience*
- *Student focus on work directly leading to marks*
- *Modular compartmentalisation of knowledge*
- *The need for provision of continuous feedback on performance*

We discuss these issues with specific reference to a 40 credit first year electronic engineering course and detail the new course structure and evaluate the effectiveness of the changes. The new approach appears to have been successful both educationally and with regards to student satisfaction. The first cohort of students from the new course will graduate in 2010 and results from student surveys relating particularly to project and design work will be presented at the conference.

Introduction

Engineering is an applied discipline that requires not just the accumulation of knowledge but the ability to widely apply this knowledge in the design, construction and maintenance of real systems. The world has experienced an explosion in technological development since the first demonstration of a silicon transistor in 1954 and in recent decades electronic engineering has experienced greater growth than most other subject areas. This gives us a problem since it is not now possible in an undergraduate degree to comprehensively teach students everything in electronic engineering that is required to prepare them for their future roles as engineers. Instead we have to strive to give them the skills to research knowledge and apply what they find to the task at hand.

Institutionally this need has been embraced by the promotion of design skills and the belief that if students understand the design process and have enough background knowledge they will be able to operate effectively outside of their areas of direct expertise. Electronic Engineering programmes in the UK are generally accredited by the Institute of Engineering and Technology (the IET), which sets out the following broad aims for accredited programme. Such a programme should:

- "Motivate students towards the practice of engineering and technology

- Stimulate their learning providing a foundation for a wide range of subsequent study and promotion of lifelong learning
- Contribute to the personal and professional development of students
- Be taught in the context of design, so that design provides an integrating theme that exposes students to a blend of analysis and synthesis
- Present an intellectual challenge, integrating theory with current industrial practice in the context of real engineering applications
- Provide an awareness of the environmental, social, legal, economic, ethical and regulatory contexts within which engineers operate
- Include a strong and effective industrial input" [The Institution of Engineering and Technology]

Most of these points can be addressed by a well rounded, interesting and engaging engineering course. However, it is the point '…Be taught in the context of design, so that design provides an integrating theme that exposes students to a blend of analysis and synthesis' that has become crucially important in the modern work environment and that presents a number of challenges for any course and in particular modular based programmes.

In 2001 the CDIO Syllabus was published [Crawley E. F.] which describes a statement of goals for undergraduate engineering students. The CDIO initiative sets engineering in the context of Conceiving – Designing – Implementing- and Operating real-world systems and products [Berggren K-F. *et al.*]. The CDIO Initiative proposed 12 standards for engineering programmes that act '...as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement'. These 12 standards are (from [CDIO]):

1. 'CDIO as Context - Adoption of the principle that product and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education
2. CDIO Syllabus Outcomes - Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders
3. Integrated Curriculum - A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills
4. Introduction to Engineering - An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills
5. Design-Build Experiences - A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level
6. CDIO Workspaces - Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning
7. Integrated Learning Experiences* - Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills
8. Active Learning - Teaching and learning based on active experiential learning methods
9. Enhancement of Faculty CDIO Skills - Actions that enhance faculty competence in personal, interpersonal, and product and system building skills
10. Enhancement of Faculty Teaching Skills - Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning
11. CDIO Skills Assessment - Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge
12. CDIO Program Evaluation - A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.'

These aims and ideas have been developed and incorporated into teaching programmes in a number of educational institutions around the globe [for example Moore D. J. *et al*, Montero E. *et al*., Rehman H. U. *et al*., and Xiong G. et al.] some under the CDIO banner and others described as integrated learning approach or similar. In this paper we discuss our restructuring of our electronic engineering programmes to be broadly in line with the aims and ideas set out by the IET and CDIO initiative and evaluate the effectiveness of the changes. Whilst CDIO is well covered in the literature in terms of curriculum development [for example Crawley E.F. *et al* and Svensson T. *et al*] there is not a great deal of work published looking at the effectiveness of such changes. This is perhaps because of the length of time it takes for large scale curriculum changes to be implemented.

Background and Programme Structure

Prior to our 2006 programme review, the course structure for a typical student was as illustrated in figure 1. For simplicity here we will concentrate only on the electronic and electrical engineering course, although much of this structure is also shared between programmes in electronic engineering and computer science, internet systems and communications engineering. A number of issues caused concern. The programme was made up overwhelmingly of 10 credit modules that were possibly failing to give a coherent picture of electronic engineering – the subject base was too wide and students often appeared to be unable to see how everything was related. There was not a sufficient focus on design and in a 10 credit module there was not enough time to address this issue in sufficient depth.

Year 1 - 1st Semester		Year 1 - 2nd Semester	
Java Programming Foundations	20	Internet Computing	10
Foundation in Digital Electronics	10	Analogue Electronics 1	10
		Principles of Electronic Engineering	10
Electrical Circuit Theory	10	Waves & Electromagnetic Fields	10
Transition Mathematics	10	Engineering Mathematics	10
Practical & Communication Skills	10	Introduction to Business Management	10
Year 2 - 1st Semester		**Year 2 - 2nd Semester**	
Digital Logic Design	10	Analogue Electronics 2	10
Signals and Systems	10	Telecommunications Systems	10
Java Program Construction	10	Programmable Electronic Systems	10
Engineering Maths 2	10	Hardware Description Languages	10
Numerical Method/ Statistics	10	Control Systems	10
Value Based Management	10	Electronics Team Project	10
Optional Placement Year			
Year F - 1st Semester		**Year F - 2nd Semester**	
Digital Systems Design	10	Digital Systems Architecture	10
Internetworking	10	Electroheat	10
Optical Communication Systems	10	Optoelectronics	10
Radio Systems and Personal Communications Systems	10	Project Management 2	10
Individual Final Year Project			40
Key			
Design based		Theory based	
Maths		Business	

Figure 1: Initial structure showing typical modules on the Electronic Engineering programme and their credit value. The type of course has been indicated by colour.

Modular based courses can be problematic because the learning units tend to be quite small (equating to 100 hours of student effort per 10 credit module at Aston) and in our experience students often fail to make connections between related material in separate modules. Often modules are taught by different staff and the staff can also fail to make these links since they are not always aware of the details of what is being taught elsewhere. Furthermore, all courses have a habit of growing organically over the years so that although a programme might have a logical structure on day one, the chances are things will evolve over time and potentially move towards a less coherent structure.

In addition to our desire to introduce a shift in focus from fact based to problem based scenarios, we also had to deal with a change in the student cohort. In the past electronic engineering students would traditionally have come to university with a background in hobby electronics and with science A'levels and reasonable mathematical skills. They would generally have had good financial support either from families or, earlier, from grants, and of course, prior to the 1998 Teaching and Higher Education Act, students would also not have had to pay tuition fees either. The governmental policy changes that affect student finances are summarised by Callender [Callender, C] and it was found that students from low income families, mature students and those will dependants to support were more likely to work a higher number of hours per week during term time. Increasingly the students we are teaching have very diverse educational and socio-economic backgrounds; some have very limited practical experience and little or no prior knowledge of electronics and many need to juggle work and study due to financial pressures.

The bottom line was that within electronic engineering we had relatively high attrition rates and whilst the majority of students were producing high standard work by the end of the programme, a significant minority had either fallen along the way or seemed to have only marginally acceptable engineering skills, as seen in particular in their achievements in the final year projects. In 2006, with these issues in mind, we undertook a complete review of our electronic engineering programmes. The aim was to design a more integrated structure that developed the skills that our students required in a more efficient and effective way. The first intake to the redesigned programme was in the autumn of 2007 and the majority of these students are currently in their final year. The CDIO standards were used as the broad basis for our revised programmes and provided a coherent way of delivering the design agenda required by the IET.

The new structure is illustrated in Figure 2 where the four main course types are identified – design, theory, mathematical and business – and colour coded. The new programme is made up predominantly of 20 credit modules which give more flexibility in course design, assessment and also greater continuity. Another major change was to move the final year project so that is dominates the final semester rather than being spread across two semesters. We believe this will increase the hours students dedicate to their project.

<table>
<tr><th colspan="2">Year 1 - 1st Semester</th><th colspan="2">Year 1 - 2nd Semester</th></tr>
<tr><td colspan="3">Computing for Electronic Engineering</td><td>20</td></tr>
<tr><td colspan="3">Principles and Circuits</td><td>20</td></tr>
<tr><td colspan="3">Electrical Systems Engineering</td><td>20</td></tr>
<tr><td colspan="3">Digital and Analogue Electronics</td><td>20</td></tr>
<tr><td>Transition Mathematics</td><td>10</td><td>Engineering Mathematics</td><td>10</td></tr>
<tr><td>IT& Communication Skills</td><td>10</td><td>Introduction to Business Management</td><td>10</td></tr>
<tr><th colspan="2">Year 2 - 1st Semester</th><th colspan="2">Year 2 - 2nd Semester</th></tr>
<tr><td colspan="3">Digital and Programmable Systems</td><td>20</td></tr>
<tr><td colspan="3">Communications Engineering</td><td>20</td></tr>
<tr><td colspan="3">Electronic Systems Analysis</td><td>20</td></tr>
<tr><td colspan="3">Electrical Systems Engineering</td><td>20</td></tr>
<tr><td colspan="3">Themed Design Project</td><td>20</td></tr>
<tr><td>Value Based Strategy</td><td>10</td><td>Professional Studies</td><td>10</td></tr>
<tr><td colspan="3">Optional Placement Year</td><td></td></tr>
<tr><th colspan="2">Year F - 1st Semester</th><th colspan="2">Year F - 2nd Semester</th></tr>
<tr><td>Digital Systems Design</td><td>10</td><td>Coursework assessed electives</td><td>20</td></tr>
<tr><td>Examined electives</td><td>40</td><td rowspan="2">Individual Final Year Project</td><td rowspan="2">40</td></tr>
<tr><td>Project Management</td><td>10</td></tr>
<tr><th colspan="4">Key</th></tr>
<tr><td>Design based</td><td>Theory based</td><td>Maths</td><td>Business</td></tr>
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Figure 2: New course structure showing typical modules on the Electronic Engineering programme and there credit value.

Module level restructuring

Having simplified the overall programme structure and increased the average module size we then looked at the individual modules. A key part of the programme redesign was the pairing of some modules to make even larger, integrated learning units. Looking now specifically at an example from the first year, this resulted in a 40 credit learning unit formed by the combination of Electronic Systems Engineering and Digital and Analogue Electronics. This combined block is known as EECORE. By teaching this course as a single unit we could ensure continuity, focus and a sense of building knowledge from a common base. It is team taught by two academics, two technicians and two PhD demonstrators. The lead academic swaps depending on the focus of the session.

The course is timetabled to cover two four hour block sessions per week and the year is broken down into shorter units that typically last a few weeks, as shown in Figure 3. Each unit contains just 1 or 2 introductory lectures each week, with learning primarily taking place during related practical and simulation exercises, normally undertaken by the students in pairs. We change the lab partners at regular intervals taking into account attendance and marks to try to match students of similar abilities. We use the “threat” of regular practical lab tests to encourage all students to participate rather than being a passenger to a more motivated student.

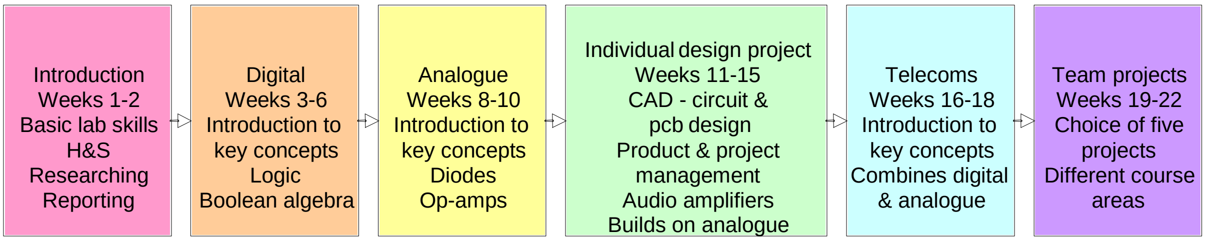

Figure 3: Breakdown of EECORE

The first semester predominantly covers an introduction to the basics of digital and analogue electronics. This is a fairly traditional approach, except perhaps for the emphasis on learning through practical work. However, towards the end of the first semester the students start an individual design project – currently the design of a dual stage amplifier taking an input from an MP3 player and amplifying the signal to drive a speaker. This exercise brings together and reinforces various concepts from the analogue electronics unit and is also used to teach PCB design and soldering. More able students have the freedom to extend this work (and gain extra marks) as they see fit. To date, we have seen designs for stereo amplifiers, the inclusion of tone controls and the provision of a signal level monitoring display.

After the individual design project students follow a section on telecommunications which introduces key concepts in signals and systems and is focussed on the construction of an optical fibre link transmitting pulse-width-modulated signals. This topic provides an excellent example of a system that combines both analogue and digital techniques.

The individual sessions are structured with experiential learning in mind – new information is presented to the students, they use the information to complete a task, and are then asked to do something related but less well defined using what they have learnt. Most labs are structured such that the work for 80% of the marks is compulsory and the final 20% of the marks are for optional extension exercises. These extensions have proven useful in challenging the more knowledgeable students but also, unexpectedly, seem to have raised the ambitions of most of the other students in the class.

Every piece of work the students do is marked and returned to them with feedback. Three class tests (open notes) are given during the year; these cover the main concepts, general understanding of principles, practical skills and the ability to use CAD for design and simulation. The students are discouraged from compartmentalising the knowledge because knowledge gained in earlier units is reused later on (for example operational amplifiers are used in the analogue introduction, the individual design project, telecommunications and possibly in the team project). In addition, although the class tests predominantly cover the material from the previous few weeks the students know there will also be a few questions from the previous units.

Everything the students do contributes towards the final mark. High fidelity individual work (reports, presentations, class tests etc) carry the greatest percentage of marks, while joint laboratory work, other collaborative work and on-line tests carry a much lower percentage of the total mark. Work is predominantly staff assessed although we also use some peer assessment (for group wikis, individual recorded presentations and some aspects of the team project). We do not allow course work to be submitted once and tests cannot be retaken if the student fails to achieve a high mark. This is partly to do with efficiency but also to do with encouraging the students to learn that deadlines are important and that sometimes there is only one opportunity to get things right. Since we have a large number of assessments this policy will not result in a student failing the course from one poor performance. We also have internal mechanisms for making allowances due to extenuating circumstances affecting the student.

Facilities

In the first year that we ran the course, the lectures and simulation work had to take place in a different location to the laboratory work, preventing direct comparison of simulated and constructed circuits and severely constraining the flexibility of the timetabling of classes. In the summer of 2008 we were very fortunate in being able to completely refurbish our main undergraduate electronics teaching laboratory. This allowed us to replace the benches so that all of the students faced forwards, install AV equipment to enable lectures to be given in the room, and install one computer for each pair of students. This allowed us complete flexibility over what activities were occurring in the room at a particular time. We were a little nervous that having access to the internet during laboratory classes might distract the students but there has been virtually no abuse of this arrangement. Very encouragingly, having the ability to view their circuit simulation as they construct the hardware implementation has significantly increased the speed with which students get through the practical tasks, allowing us to increase the volume of material covered in the practical exercises by about 20%.

In all we have 30 workstations set up with a computer, bench top power supply, function generator, oscilloscope and digital multimeter. This allows us to accommodate a maximum of 60 students in a single class although in the past three years the number of students has typically been around 45. Each student is provided with a breadboard and a wire set at the start of the year. The computers have Proteus PCB Design Software [Labcenter Electronics] installed for circuit and PCB design, alongside Labview [National Instruments] to control the oscilloscopes. The students are given a student licence for the Proteus software which allows them to use it at home.

An advantage of teaching electronic engineering is that, once capital equipment has been purchased, it is relatively low cost, at least in the early stages. In addition, everything is small enough to fit on a single bench. Beyond the capital expenditure our costs are primarily for electronics consumables and consequently fairly low (£10s per student). This enables us to run a lab where all of the students are doing the same thing at the same time which is extremely beneficial in providing good coherence between the lectures and the labs.

Figure 4: Changes to laboratory: before (left) and after (right). During lectures, video projected on the front screen is also fed to each PC screen.

Evaluation of EECORE

Evaluation of course changes is notoriously difficult since it is likely to be coupled with increased staff engagement and additionally the profile of the student cohort can vary by quite large amounts from year to year. There were three ways in which we gauged the level of success of the course: (a) end of year marks; (b) student feedback via module questionnaires, (c) student feedback from focus groups and student-staff meetings.

Looking at the end of year marks the graphs in figures 5 and 6 show the percentage pass rate and mean percentage marks at first attempt for the analogue and systems engineering courses before and after the restructuring in 2006/07, when they were effectively absorbed into EECORE. Both courses show an increase in mean mark of around 10% and an increase in pass rate of 5-10% after the change. It should be noted here that the courses were taught by the same lecturers pre- and post-changes so variations between staff marking styles (i.e. whether they are considered a ‘high’ or ‘low’ marker) can be discounted. We were somewhat surprised to note that the variations in the percentage pass rate and mean percentage mark between years either side of the change were actually relatively small indicating that the step change is real.

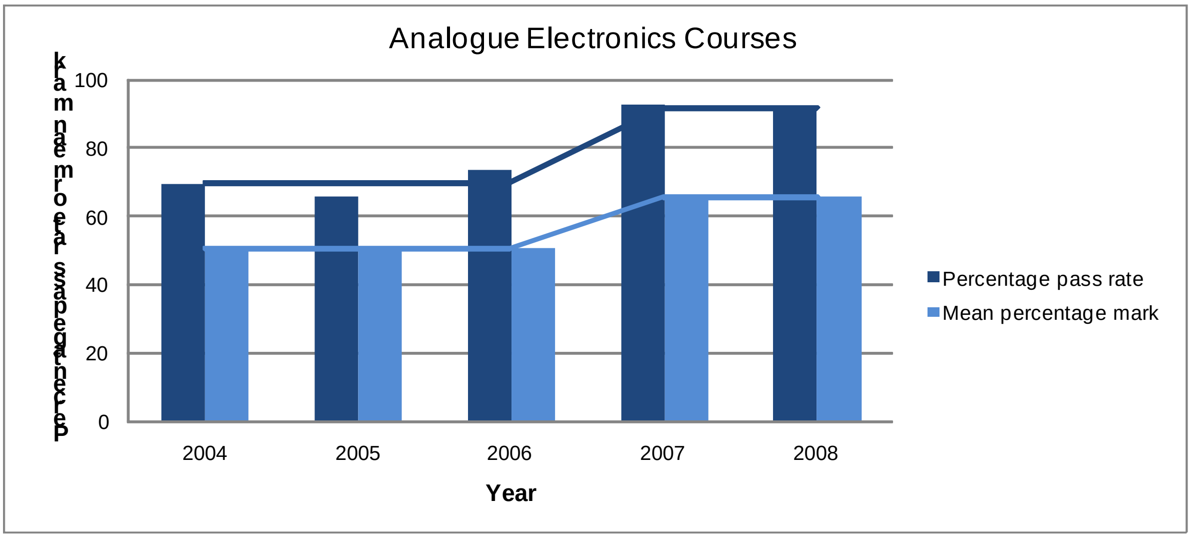

Figure 5: Percentage pass rate and mean percentage mark for analogue modules before and after the redesigned programme was launched in 2007

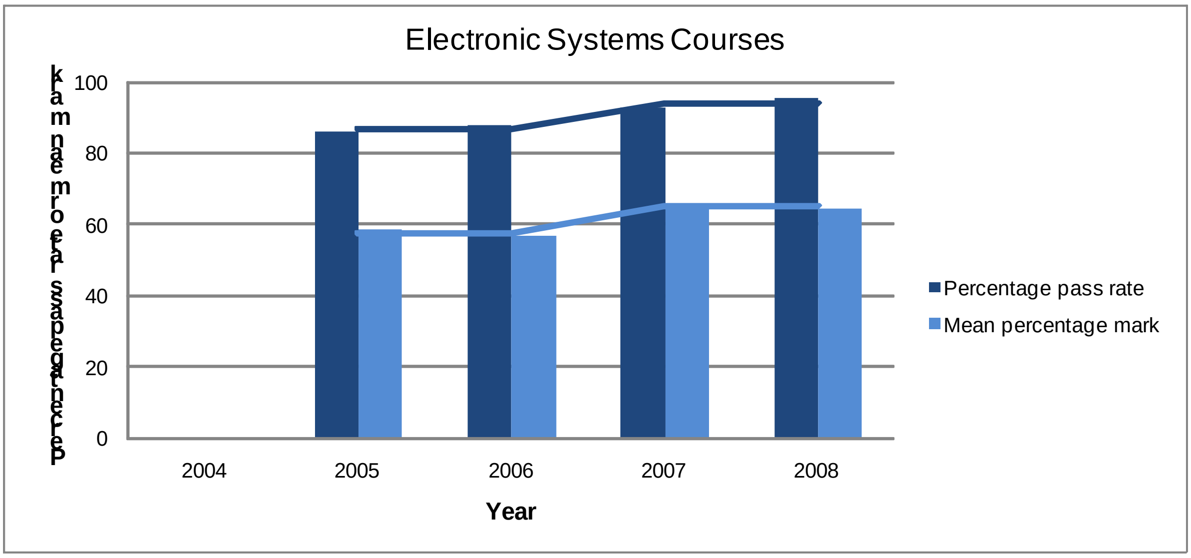

Figure 6: Percentage pass rate and mean percentage mark for systems engineering courses before and after the redesigned programme was launched in 2007

So, what might be the cause of the increased grades? We do not believe the increase in the marks is due to making the course easier. In moving to a largely practical based learning experience, we were forced to decrease the breadth of the material covered but we believe that this is more than balanced by an increase in the depth of learning that is required in the new course. The students have an increased amount of staff contact due to the time spent in the laboratory and the high staff to student ratio: in the class room there are usually at least 3 staff members (one academic, one technician and one PhD demonstrator) to 45 students at any one time. This may lead the students to be more highly motivated and give them more opportunity to clarify problem areas. Also, because everything contributes towards the final mark the level of student engagement tends to be high and typically the attendance is over 90% for all classes (as contrasted with attendance rates of 50-70% for the lecture courses in the previous system). Additionally and importantly, because the students follow the accumulation of marks throughout the year they have the opportunity to take corrective action during the year rather than finding out after the summer exams that there is an issue. The increase in the mean marks and pass rates for these 40 credits was of course good news, indicating we had achieved one of our primary objectives plus it also increased the overall pass rate for the year.

The second thing we looked at was student feedback via a focus group of 10 students, which took place at the end of the first year the course ran. This feedback was very positive.

The focus group came up with the following specific comments (direct quotations):

- We feel comfortable with practical work – it has given confidence and is a good platform to progress from.
- The feedback we got was useful
- Can’t wait until next year - if it is taught in a similar way.
- Good flow – good connections between different parts, continuous, good links, forces you to keep up since everything builds on the previous work.
- Is important not to miss one of the building blocks but it is ok to have some weaker sections and not struggle with the rest.
- Like the lecture + lab format
- Like the final project even though there were problems
- Lab support good
- Weekly brief useful

Understandably for a new course there were some suggestions that the students had to improve things:

- Add extension exercises for stronger students
- Textbooks – be more specific about what we should read – test students on info in the books as well as notes
- More opportunities to present things
- Raise the pass mark – make certain things compulsory – so it harder for people to just get by and then bring team marks down
- Projects – more taxing projects for better people
- Lesson on how teams work – strengthen understanding of process
- More numerical examples
- Would like the lectures recorded so don’t have to write and listen at the same time

Interestingly most students were asking for more rather than less work (although this might have been because the more motivated students came along to the focus group). Most of these suggestions were incorporated in the following year.

The third thing we looked at was student feedback via module questionnaires. This probably gives a more balanced view since they include responses from the less motivated students. One issue that has been raised by a small number of students in the questionnaires is that once someone starts to fall behind it is quite difficult to catch up. However, this is probably better than the previous case where the first sign of problems would often be when they failed the end of year exams.

The module questionnaires asked the students for opinions on a wide range of things. In figure 7 we summarise the feedback for the years either side of the changes on four specific things – whether the module was interesting, intellectually challenging, if the feedback was helpful and timely.

In 2007/08 figure 7 also shows the average response value obtained for all undergraduate modules across the School of Engineering and Applied Science and across the subject group of Electronic Engineering. It is clear that the changes received a favourable reception from the students when compared to the previous year and to other modules.

	2006/07		2007/08		
	EE1PPE	EE1AE1	SEAS Avg.	EE Avg.	EECORE
The module was intellectually challenging	4.0	4.1	4.1	4.5	4.7
The module as interesting	4.2	4.2	3.9	4.2	4.7
Helpful feedback was given on coursework	3.8	4.3	3.8	4.2	4.5
Timely feedback was given on coursework	3.8	3.7	3.8	4.2	4.4
Overall	82%	84%	79%	82%	93%

Figure 7: Results from module questionnaires (average 40 student responses), giving average response for the School of Engineering and Applied Science (SEAS), Electronic Engineering (EE), Principles of Electronic Engineering (EE1PEE), Analogue Electronics (EE1AE1) and EECORE. Marks range from 1 (I completely disagree) to 5 (I completely agree), except for the final percentage approval score.

Conclusions

Overall, the changes that we made on a programme and module level have been very successful. The mean mark for the EECORE module has increased compared to the modules it replaced, as has the percentage pass rate. This has had a knock-on effect in terms of reducing the first year attrition rates. The level of student satisfaction has also increased and we have had very positive feedback.

We believe that there has been an overall increase in standards and the increase in marks is due to the increase in contact time, increase in student motivation and the increase in feedback so students can measure their progress effectively. In addition, the staff involved have found delivering this type of course more satisfying than the traditional chalk-and-talk (or Powerpoint-and-talk) plus labs approach. This success is aligned with current thinking on the role of practical and design based work in engineering education [Edward N. S.].

There are some disadvantages however, the main one being the extra demands placed on staff time. In its previous lecture focussed format, the course would have consisted of an average of 4 hours of lectures and 2 hours of laboratory per week. In the current format this is increased to 8 contact hours, at least 6 of which are intensively laboratory based. There is also an additional marking load. However, we have reduced this partially by marking sections of the labs as we go along and not allowing the students to progress to the next section until they have completed the work to our satisfaction. Some worksheets we give to tutors to mark and hand back to students in small group tutorials. The increased student engagement also increases workload since they are more likely outside of class to ask questions.

The current arrangement also requires block timetabling, which can be problematic and some of the students find 4 hours a long time to have to concentrate. However, we feel that the gain in terms of flexibility and contact time makes this block timetabling extremely valuable.

Overall it is difficult to set the course level so that it meets the needs of those that have no electronics experience as well as those that already have A'level electronics, or have studied electronics in our Foundation Year. This year for the first time we have set non-compulsory extension exercises. The weaker students can opt to complete only the compulsory 80% and the stronger students can aim for the final 20% which stretches their abilities with more open ended tasks. This appears to be working well.

A major measure of success for the new course structure will be the performance of the current final year students in their projects, which are just starting at the time of writing. Information on this will be available by the time of the conference.

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