# A case study approach to large-group teaching of first year electronics to engineering students from other disciplines

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# A case study approach to large-group teaching of level 4 electronics to engineering students from other disciplines

## A. Sutton and G. Charles

### School of Mechanical and Manufacturing Engineering

### Loughborough University

## Abstract

This case study describes a project in which we aimed to contextualise the teaching of electronics to a large student group that does not major in in the discipline through a case study design approach developed across the entire module. The target circuit design measures mechanical force or load - important phenomena in the students' core study area. Design ideas and analysis tools are introduced as required to progress the design rather than being grouped towards the front of the teaching as is often the case. A pilot study has been completed and a large group activity is currently underway.

**Keywords:** large-group teaching, cross-disciplinary, electronics

## Background

This project came about as a result of several years spent teaching electronics to both level 4 undergraduate and postgraduate students enrolled on IMechE accredited degree programmes within the School of Mechanical and Manufacturing Engineering at Loughborough University. This project is predominantly aimed at the 220-230 undergraduate students attracted by the School each year across a mix of degree programmes, with typical offers of A*AA at for MEng and ABB for BEng. The Mechanical Engineering course attracts approximately 155 mixed MEng/BEng students, with the remainder spread across the Product Design Engineering, Manufacturing Engineering, Engineering Management, Innovative Manufacturing Engineering and Sports Technology programmes. All students study electronics and electrical power during their degree and typically display little interest as it is perceived to be unimportant to a student specialising in a different discipline. In some cases they are actually hostile to the idea.

## Rationale

Student engagement is widely known to be an issue in HE, with an ever-increasing level of student attrition (Roberts and McNeese, 2010). Many institutions struggle to take student retention seriously (Tinto, 2009) and to translate what they know into actions that improve engagement and retention. Lack of engagement in the study of electronics within our school is a perennial problem that we hope to address with this project.

The problems we face are really twofold: teaching a non-core subject to students who really do not see the need to learn this material and teaching the subject to large number of students (circa 200) with differing backgrounds and entry qualifications. Additionally, the teaching methods need to consider the students' differing preferred learning styles (Kolb, 1971) and offer a broad range of learning opportunities and experiences as well as a demonstrable relevance to what we teach.

Reinforcing mathematically and conceptually complex material to potentially uninterested and unmotivated students presents significant challenges. Contextualising content and developing a clear sense of relevance in real situations (Yilmaz, 1996) through real world case study design and application of theory in a laboratory environment is felt to be key to developing motivation and

engagement. The introduction of open-ended, student-centred simulation exercises also provides a significant opportunity for level 4 students to practice autonomy and time management in their learning. For new students it can be difficult to shed the rote style of learning to which they have become accustomed during A level study and move toward a broader vision of retention and transfer where they are able to both acquire knowledge and apply it to a variety of situations (Mayer, 2002). Students in the school have to complete a project every year, most of which contain some electronics element.

Much of the favoured pedagogy in textbooks is quite unnecessary and is not used by practising engineers, while useful circuits and methods of analysis lie deeply hidden (Horrowitz and Hill, 1989). Our aim was to teach non-subject specific students to be able to 'do electronics' (*ibid.*), a useful skill for their further studies.

## The approach

Initially the project's aim was to develop an innovative teaching strategy for a large group of students. Several factors, including university restructuring, a new management structure within the school itself and a subsequent teaching review across all programmes, resulted in the original target group module being no longer available. The focus then shifted to a different large group electronics module which would not run until semester 2 of 2011/12. A pilot study with a smaller group of students, based around the same teaching philosophy, has been developed and delivered and the large group teaching has also been developed and is currently being delivered.

A significant issue when teaching electronics to non-subject specific undergraduates is the breadth of the subject and the state of the art within the field. Modern electronics systems tend to be developed around microcomputers running programmes and large-scale integrated circuits with design representations downloaded from a PC, abstracting the hardware from the functionality and possibly "hiding" the physical electronics from the student. A significant concern here was that a digital electronics exercise could very easily be seen by students as simply one of writing code.

Several case study ideas were generated, with the promotion and development of student engagement as the defining philosophy. We elected to focus on either an instrumentation system designed to measure some common physical phenomenon or some form of controlled drive system to move a load, both of which are relevant to the students' core areas of study.

Table 1. A selection of the initial ideas for possible adoption as the case study design exercise

| Phenomenon | Discipline bias |
|---|---|
| Measuring shaft rotation/displacement | Digital/processor |
| Measuring weight/force | Predominantly analogue + processing? |
| Measuring temperature | Predominantly analogue + processing? |
| Measuring pressure | Predominantly analogue + processing? |
| DC motor speed positioning of a load | Mixed mode using PWM or DAC + amplifier |
| Stepper motor positioning of a load | Predominantly digital with discrete components |
| Control of mass-spring-damper system | Predominantly digital/processor |

Several case studies were evaluated in terms of educational value, desired discipline bias, relevance to the student's core discipline, engineering depth, health and safety, and ease of development of teaching apparatus. An early outcome was to focus predominantly on analogue electronics and the majority of analogue case study ideas were instrumentation-based. A decision was taken to develop a system to measure some physical phenomenon, but to incorporate flexibility, creating a "universal" instrumentation system which could be easily modified to work with a range of sensors.

Two phenomena were shortlisted: temperature and force or weight. Given the desire to minimise health and safety concerns, a simple weighing system was adopted, based around a low-priced,

600g maximum load, single point load cell (RS Components part number 414-0843 – see Figure 1).



Figure 1. 25 load cells purchased for the project

Sets of kitchen scales weights were purchased and, upon checking against references in our Metrology laboratory, were found to be suitably accurate to within ±0.1g.



Figure 2. A load cell mounted and ready for use with the test weights

An important aspect of the module philosophy was to facilitate as much hands-on application of theory as practicable, while still ensuring adequate time for thinking, experimentation and consolidation of theory. It is all too easy to overload students with too much build-up and connection of the apparatus and leave too little time for actual learning.

National Instruments (NI), a multinational measurement and instrumentation company, strongly supports teaching in universities through their dedicated academic team. NI recently released their latest electronics teaching platform, the ELVIS II (Educational Laboratory Virtual Instrumentation Suite), incorporating removable and low-priced prototyping plugblock boards into which component leads may be inserted to quickly construct simple circuit arrangements. The system also features an integrated suite of 12 commonly used instruments, including an oscilloscope, digital multimeter, function generator, variable power supply and Bode analyser. Based on NI's LabVIEW graphical system design software, NI ELVIS, with USB plug-and-play capabilities, offers the flexibility of virtual instrumentation and allows for quick and easy measurement and display (National Instruments, n.d.).

Virtual instruments provide many benefits for large group teaching, not least of which is the absence of the need to connect a host of long wires to the circuit under test, something which typically accounts for a large proportion of the time spent on a laboratory exercise. The uniform design and appearance of the virtual controls also facilitates rapid familiarity with all instruments.

25 ELVIS II units were purchased in 2011 for use on the large group module, along with an agreement for NI to provide appropriate training, development and assistance in the development of laboratory exercises.
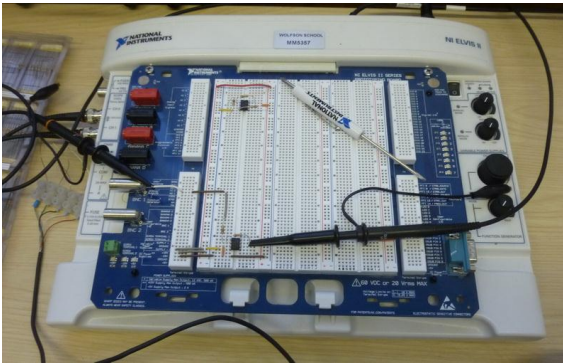


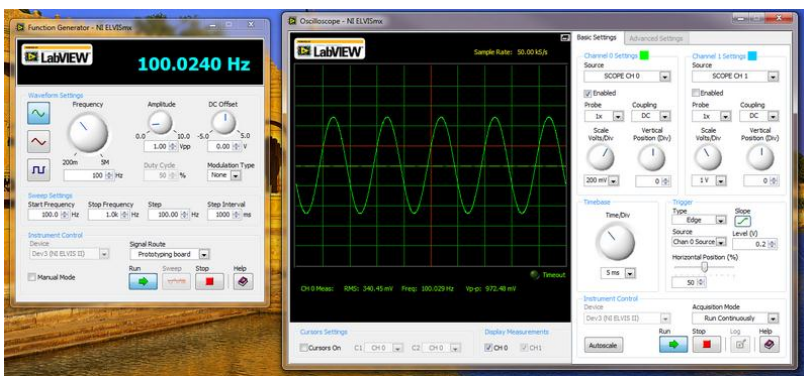Figure 3. NI ELVIS II unit showing simple inverting amplifier circuit



Figure 4. Virtual function generator and oscilloscope

With a case study design in place, a syllabus was developed that started with the traditional introductory subjects and developed ideas and theory towards the final design. Traditionally, textbooks and courses often introduce a range of theory and analysis tools early in the learning before moving on to look at the components and circuit design to which the theory is actually applied, by which time much of it may already be forgotten. With an emphasis on contextualising the learning, it was deemed better to provide the most basic analysis tools early in the learning and introduce more sophisticated and complex methods (such as Thevenin's theory, superposition etc.) only when required to understand the operation of a case study circuit element.

For the small group pilot study module, it was decided to extend and deepen some of the original ideas beyond the large group module plan and use this as a basis for evaluation of what could realistically be included in a module on which 200+ students are enrolled. This additional depth included basic Spice simulation exercises both in the laboratory and as student-centred learning. Simulations were also run during lecture sessions, with students asked to draw predicted output waveforms before the circuit simulation was run over a data projector; a very successful activity, promoting good levels of engagement and interaction. Simulation software licenses were purchased for the laboratory, but students had to use time-limited demonstration copies when working on their own. A second order active filter and a three op-amp instrumentation amplifier were also included in the design, along with discussion of good layout and low noise design principles. Material left out of the large group module has subsequently been integrated into a level 6 instrumentation module where the level 4 case study is revisited and explored, providing deepening across modules.

The final small group case study circuit design is shown in Figure 5 and comprises a load cell connected to an instrumentation amplifier, followed by a second order Sallen and key filter and finally an analogue-to-digital converter (ADC). As the focus of the module is the analogue portion of the system, the ADC was implemented as part of a microcontroller which allowed the raw binary

and converted weight value to be displayed on an alphanumeric display and also sent down an RS232 cable for display in HyperTerminal if desired.
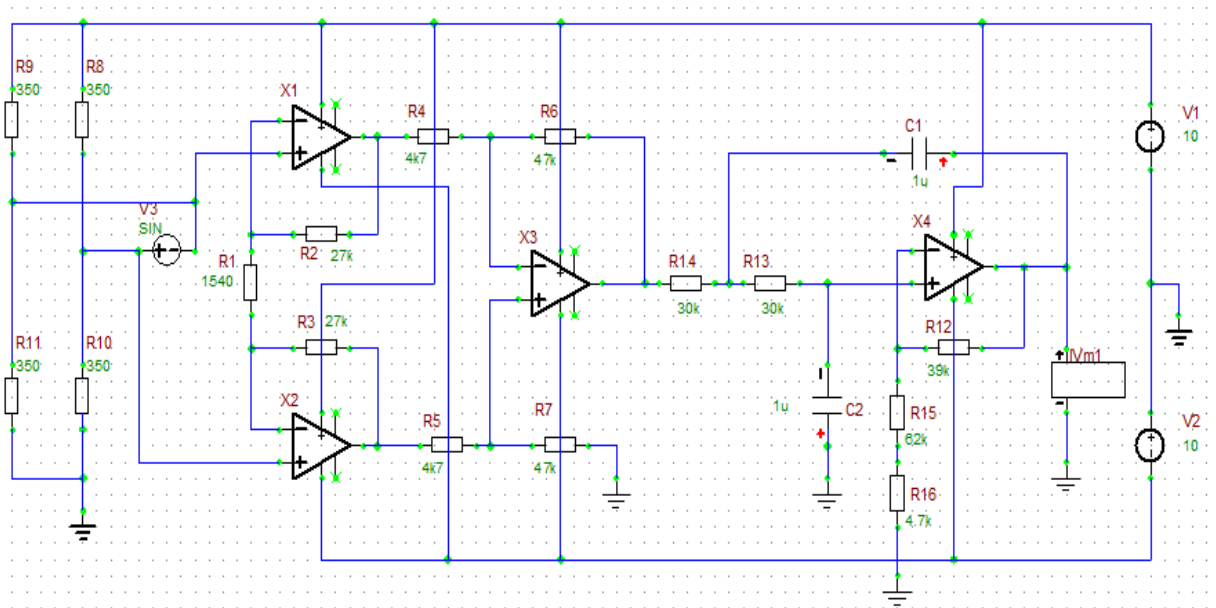


Figure 5. Final case study circuit design used on the small group exercise

With no ELVIS units available for the small group exercise, printed circuit boards (PCBs) with the facility to isolate sections and test points to measure section outputs were produced in-house. Additional circuitry was included to allow students to measure the cut-off frequency of the filter. Laboratory sessions run with these boards were very successful, but it was felt that students didn't get the same "connection" to the circuit as when building it up themselves on ELVIS.

A significant advantage of using the pre-built boards was the facilitation of an additional fault-finding laboratory session. A second set of boards had intentional faults introduced, including unsoldered pins, hairline breaks in tracks, components of incorrect value and a diode inserted the wrong way round (the diode was included in the circuit design solely for this purpose).
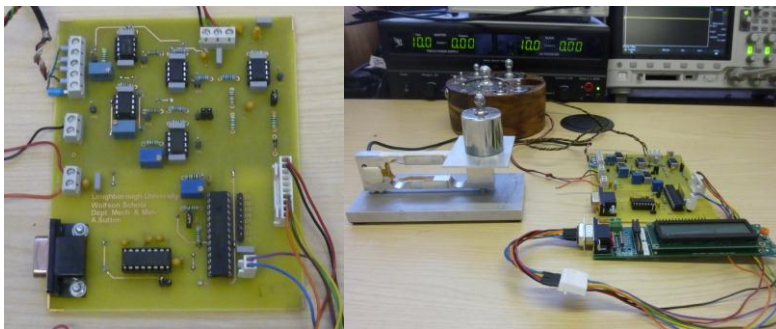


Figure 6. PCB layout for the small group case study and experimental setup

The final syllabus (analogue portion – some digital electronics was also taught) adopted for the small group case study-based teaching is shown in Table 2.

Table 2. Curriculum used when teaching the small group exercise

| 1. Introduction to typical laboratory instruments | 2. Introduction to signals and analogue electronics | 3. Ohms law, power, resistors, capacitors, series, parallel | 4. Nodal and mesh, networks, impedance |
|---|---|---|---|

| 4. Introduction to semiconductors, diodes, bridge circuits | 5. Transistors, switches and common emitter amplifier | 6. Strain gauge, load cell, Wheatstone bridge, Thevenin, impedance matching | 7. Kirchhoff, introduction to amplifiers, inverting, non-inverting, summing, comparator |
|---|---|---|---|
| 9. Filters, Sallen and key, second order low and high pass | 8. Superposition, differential amplifiers, instrumentation amplifiers | 10. Bringing it all together, block diagram and circuit shape | 11. Final design calculations, extension to measuring other phenomena |

N.B. The numbered sections in the table do not necessarily refer to a single lecture/tutorial on the subject, but show the demarcation between sections. Black text signifies both small and large group exercises, blue text small group only.

The overriding issue with the development of the large group teaching exercise is laboratory throughput. Even with the adoption of the ELVIS II, virtual instrumentation and students working in pairs, each laboratory exercise must be repeated five times (with all associated timetabling and staffing issues). For the small group exercise, each laboratory session ran only once.

To reduce the circuit assembly time during large group ELVIS-based laboratory exercises, the signal amplification stage was reduced to a simple differential amplifier with unity gain buffers and the second order active filter was removed. With reduced laboratory time per student, and a limited number of simulation licences, the simulation exercises were also removed.

Table 3. Laboratory exercises undertaken by students on the small group module

| 1. Introduction to B$^2$ Spice simulation software | 2. Spice simulation of resistor and RC circuits | 3. Spice simulation of basic amplifier circuits | 4. Simulation of differential amplifiers |
|---|---|---|---|
| 5. Simulation of final case study design | 6. Measurements on individual stages of physical circuit | 7. Measurements of overall system outputs | 8. Fault-finding exercise |

Table 4. Laboratory exercises undertaken by students on the large group module

| 1. Resistors, series and parallel, networks, Thevenin | 2. Signals, common emitter amplifiers | 3. Basic operational amp circuits | 4. Case study circuit, measurement of system outputs |
|---|---|---|---|

It is hoped that, as experience with the new module format and ELVIS units develops over the next two to three years, the large group exercises may be extended to include additional depth and content to align them closer with the small group pilot study.

## Assessment

The assessment retains a two-hour written examination at the end of the semester which carries 70% of the overall marks. Questions take various forms, including drawing a small circuit diagram, deriving equations (amplifier gains, bridge output, etc.), carrying out typical circuit design calculations, describing the operation of circuit fragments, identifying which of several circuit configurations would give a stated output, determining component values for a given circuit diagram, etc.

Typically, each question follows the format:

a) Show learning from teaching material and reading around the subject

b) Demonstrate depth of understanding of the material

c) Carry out appropriate calculation(s) and/or analyse a circuit fragment.

The first element of the coursework assessment was formative and took place after the initial case study circuit shape was presented without component values. Students were asked to calculate suitable component values for the circuit in their own time. Component values were then derived

during a two-hour lecture slot in a very informal way, with discussion encouraged where students' values varied from those of the lecturing staff. This was very valuable in encouraging the students to understand how design decisions are taken and that there is often not "a" correct value.

The second formative assessment was the addition of a small, relatively informal, *viva voce* style discussion and feedback session in the laboratory at the end of the final laboratory exercise.

The third assessment was carried out summatively during the two-hour fault-finding laboratory exercise and was based around a simple algorithm allocating a non-linear award of marks which correlated to the number of correctly identified faults. The large group exercise does not include this assessment point.

The final coursework deliverable was a ten-page report to demonstrate the students' understanding of the final case study design system and the underpinning theory, making reference to their design calculations, simulation results and actual measurements. Students were also asked to discuss which of these values they would have the most confidence in and possible sources of errors. Worryingly, many had more confidence in simulation than actual measurement!

## Evaluation

The large group study exercise is currently running but the small group exercise has been run and is discussed here.

The examination average of 54.57% was 3% above the average of the preceding four years, with the highest individual score ever seen on this module (88%). The quality of answers was improved over previous years. In this era of student "revision" relying on past papers, the paper format may have caused some confusion. It is also common to see low grades after major changes and we are optimistic that grades will rise significantly as the module matures and past papers become available.

Student feedback on the module was the highest ever received, with questions such as "the module developed my understanding of the subject" and "overall I would rate this module highly" scoring 4.27 out of 5. Individual lecturer scores were 4.76 and 4.78 out of 5, suggesting that students were more engaged with the material than in previous incarnations. Staff involved in the small group module felt that the students demonstrated a better understanding of the material (a view supported anecdotally by several staff who volunteered their agreement). Module staff also found the format more enjoyable to teach, a fact which was reflected in the high individual feedback scores.

A short questionnaire was circulated to students who had previously studied the large group module. Although only 11% responded, some useful insight into the students' view of the school's electronics teaching was gained, much of which supported our own views.

The key points to come out of the questionnaire delivered to the previous group of students are:

- Students gained a better understanding of the digital material than the analogue
- Students would like to revisit lectures through online video
- Students felt that the coursework content of the original module (a class test) was poor and didn't help to develop their understanding of the subject at all
- In response to the question "Do you feel that you could now design your own simple electronic circuits?" the response was very negative, with a typical reply being 'No. I gained very little from the module'
- Students reported that they found the module very difficult to engage with
- Students felt that the module was 'completely useless, with no practical application and not linked to mechanical engineering or any other engineering systems'
- Students felt that 'it was boring - no practical application, no real variation'.

The large group module is currently in its third week of teaching and the questionnaire will be circulated to the current cohort at the end of the module to help gauge its success and feed into future developments.

## Discussion, summary

University and school restructuring caused several issues, resulting in the change to a different large group electronics module. However, significant changes have been made to the way we approach electronics teaching. Several tens of thousands of pounds were spent on new equipment to support this teaching and overall the project is deemed to have been a success, with considerable promise for the future as it grows.

The small group teaching exercise was very successful, with improved student engagement and, significantly, more interest shown in the material. Staff also found the new approach to delivering the material more satisfying and rewarding, seeing students generally developing a better intuitive feel for the subject. A higher level of interaction was achieved between staff and students, particularly during simulation exercises carried out during lecture sessions.

Students didn't get to build up the circuits on the small group exercise, developing less "feel" for the actual components. The large group exercise tackles this with the use of the ELVIS unit, but the trade-off is the loss of the fault-finding exercise and a reduction in the complexity of the case study design. Another drawback to the use of ELVIS is the loss of student interaction with a PCB. It is hoped that, as the large group module matures, it will be possible to develop methods of incorporating these missing elements.

The contextualisation of analytical techniques by their introduction only when necessary to understand a circuit section was also very successful and students were able to answer examination questions using these techniques more knowledgeably and comprehensively than in previous years.

## Further development

Once the results of the large group exercise are known it is hoped that the module can be developed to include some simulation exercises which might possibly form part of the coursework. The key issue here is to identify a simulation package that can be licensed for students to use on their own computers or at least across all of the main campus computing rooms. There is a possibility that this may become computer-assessed, with some form of student feedback automatically generated.

With familiarity with the ELVIS system and the new teaching format, the large group case study design may be extended to include an active filter in the signal path (as used in the small group exercise).

Under discussion is a hybrid approach where small sub-circuits are plugged into the ELVIS unit, facilitating the incorporation of all small group exercises into the large group teaching. An alternative would be to purchase enough plug-in development boards for each student pair to retain one across all laboratory exercises, negating the need to dismantle circuits between exercises.

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