Motivating Students in a Hands-On Environment

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***Abstract**: For the last five years, less than 5% of students entering Electrical Engineering at the University of Adelaide claim to have had any significant exposure to electronics as a hobby or school subject. A full year practical program, loosely coupled to electronics engineering theory, but also related to professional practice, has therefore been introduced, taking students from no experience to competent hobbyist and rudimentary engineer in 24 weeks. By comparing the performance of student cohorts with and without the program, the benefits of such experience are dramatically illustrated. The practical program, its objectives and linkages are described in detail, and students' reactions are also presented.*

Introduction

There is a great deal of anecdotal support for the conjecture that students entering Electrical Engineering degree programs today do not have the level of hobbyist experience seen in the past. Engineers who graduated in the 1960s and 1970s claim by-and-large to have been hobbyists in electronics, amateur radio or related fields. By the 1990s, however, many would claim that there was a marked dilution of hobby experience amongst student cohorts, an observation supported by the commercial failure of three of the four major Australian hobbyist magazines and the decline in the availability of kits and retail component suppliers. Informal surveys of students starting their degrees since 2005 suggest that the hobbyist rate is now in the order of 3%. In a class of 330 students, typically twenty will acknowledge having previously seen a resistor, and perhaps ten will be able to name the component, despite learning Ohm's Law in high school physics. Three students (typically) will be familiar with the NE555 timer IC and around five will have access to a soldering at home.

Such a situation poses real challenges for the development of an effective learning environment for electrical engineering students, because the lack of exposure means that the contextual paradigm is fundamentally missing. Course materials based on the implicit assumption that students have some practical understanding of electronics concepts are doomed to fail. Today's students are surrounded by electronic devices but few have explored the electronics behind mobile phones, digital cameras, laptop computers, pocket calculators, television or radio receivers.

Rather than lament the circumstances or "dumb down" the curriculum, a practical approach was implemented in 2005 at the University of Adelaide to compliment the traditional lecture-based theory, based in part on the life experience of the author but also on the identifiable expectations of the students and gaps in their understanding. In the first semester, students use a prototyping breadboard to build and explore self-contained modules – a power supply, an oscillator, some experiments with logic gates and some exploration of flip-flop-based registers and counters. Finally, students synthesise their understanding by designing and building an electronic die, integrating the previous modules together in a systematic design-build-test approach as shown in Figure 1. In 2009, 87% of students in evaluation feedback agreed that the practicals are helpful in understanding the course material, and 65% identified the practicals in open answers as one of the best things about the overall course (which was itself well received overall). Importantly, this class includes not only students studying electronics-centric engineering, but is dominated by students in other areas of engineering (notably mechanical engineering) by nearly 3:1.

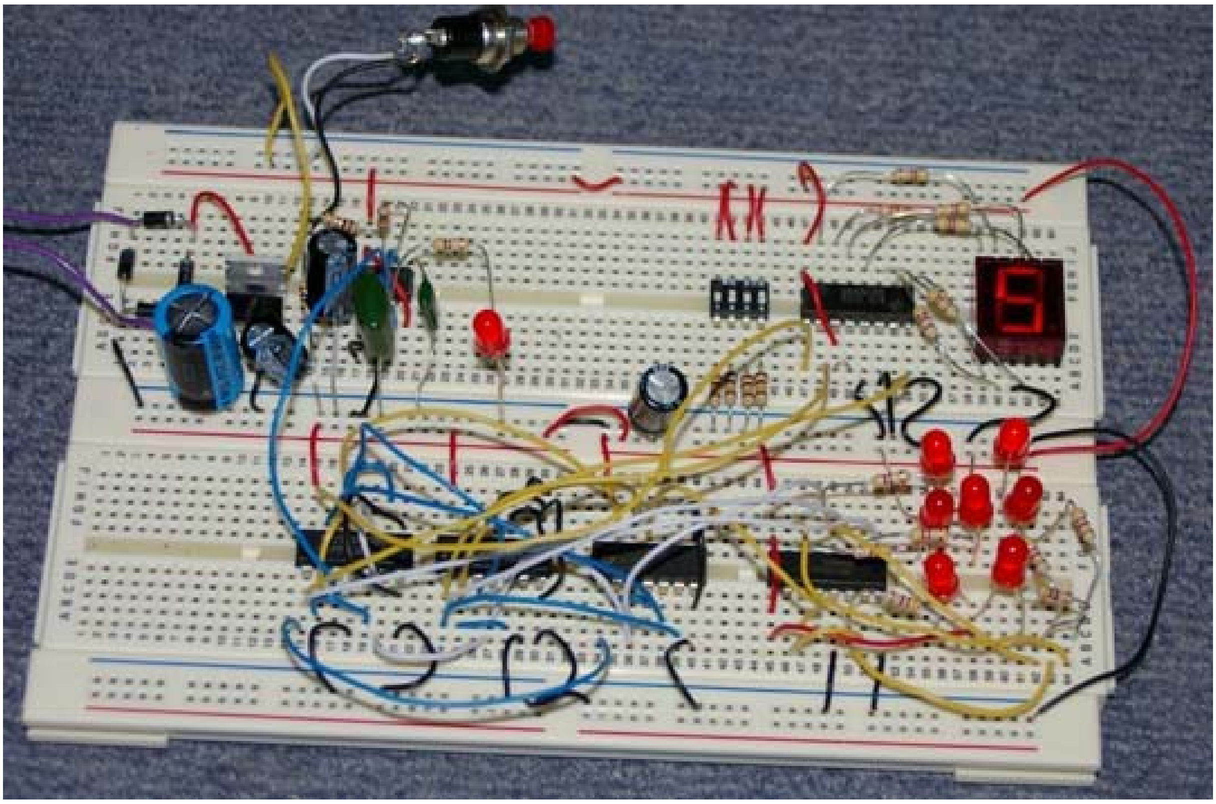

Figure 1: An example of the completed Semester 1 project. Each module is apparent in the final integrated design – Power Supply, Oscillator (upper left), Logic Gates (upper right), and Flip Flop-based Counter (lower section)

In the second semester, electronics engineering students explore concepts in steady-state sinusoidal network analysis by the systematic modular design, building and testing of an AM radio receiver, based around an amplified envelope detector (crystal set) which is constructed on a printed circuit board as in Figure 2. In 2008 and 2009, all students agreed that the practicals were helpful in understanding the course materials, and the practicals were universally acknowledged as one of the best things about the overall course.

The practicals serve multiple objectives, including:

- familiarity with electronics concepts,
- seeing theory put into practice,
- a sense of motivation and pride in designing and building working systems,
- an appreciation for the systematic design approach in engineering, and
- experience in the documentation of one's work.

The practical program differs from typical arrangements, especially at this level, in that there is an explicit scaffolded narrative in which concepts are introduced and integrated to create an overall project. The conventional approach, in contrast, usually consists of a series of mutually unrelated exercises, each of which is tied to a particular lecture, or group of lectures, without the opportunity to see the bigger picture of how the engineering process comes together.

The importance of real-world understanding is well documented in the literature. Berryman (1991) notes the importance of context in an effective learning environment, including the benefits of exposure to "tricks of the trade" and to the development of cognitive management strategies and learning strategies. Ericsson (2002) has stirred up some controversy by claiming that no-one is naturally gifted, only that sustained and directed practice in a field of endeavour will lead to outstanding performance. Whether one accepts this extreme view or not, what is clear is providing the students with a practical, contextual, rich and sustained learning environment provides significant motivation for students to understand many of the complex principles of electronics engineering. Analysis presented later in this paper demonstrates that as a consequence, the performance of the students in terms of progression rates is very much improved.

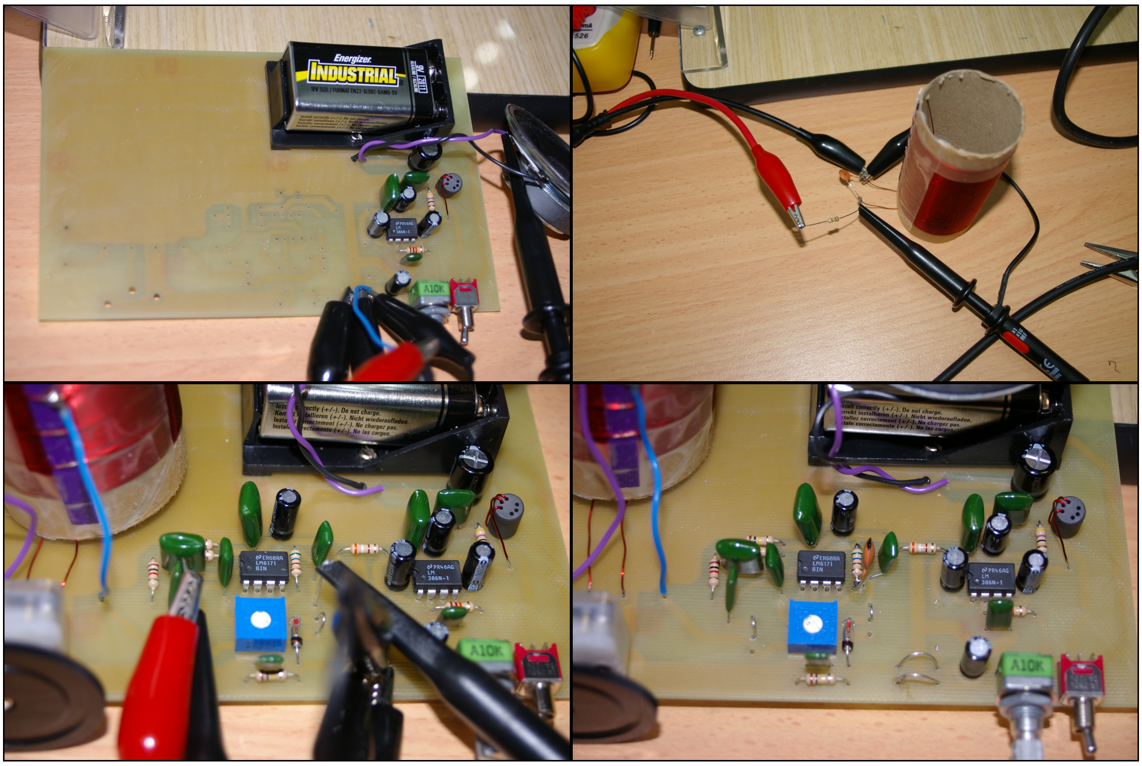

Figure 2: The Semester 2 Project under construction.

- **Upper left: the Audio Amplifier and Audio Bandpass Filter under test.**
- **Upper right: having wound the coil, it is necessary to measure and verify its inductance.**
- **Lower left: the Radio-Frequency preamplifier under test.**
- **Lower Right: the completed radio receiver.**

Students have contributed to the design by selecting and justifying components at each stage, verifying the operation of each module, and taking responsibility for construction and integration.

Loose Coupling

A conventional practical exercise is tightly coupled to the relevant concept in lectures. The elementary study of operational amplifier circuits, for example, is usually enhanced by building and testing the same inverting and non-inverting feedback amplifiers under near-ideal conditions. Whilst valuable, the experiential context is narrow and the practicalities of *how* and *why* such an amplifier would be used in a real design are missing. Simply put, by focussing attention on demonstrating a single concept to the exclusion of all other phenomena, the opportunity for students to learn more about engineering is lost.

Our contrasting approach introduces the practical aspects of theory through an independent, integrated engineering project. Of course, this is a ubiquitous approach in the final year of the degree, but we are not aware of a first-year project-based approach of this nature in any other Electrical/Electronic Engineering program, in which students with no experience build up a level of competency to be able to design, test and build their project in such a short period of time. Many concepts are mutually and explicitly reinforced between lecture material and the practical, but just as some theoretical derivation has no explicit place in the laboratory, there are many practical skills which are never discussed in lectures. Exposure to both the exclusively theoretical and the exclusively practical reinforce the overall learning environment, even if the links are not explicit.

Such loose coupling also ties in the third fundamental foundation of professional practice, particularly the skill of effective communication. The first *Professional Practice* class exercise in the second semester course illustrates this point:

> Students are divided into groups of four. Each group is given a simple circuit on a prototype breadboard based on the first-semester practical and containing about ten components. Each group has one sheet of paper to document sufficient information to reconstruct the circuit. At the following class each group is handed a box of components. However, the documentation is now handed to a different group...

The exercise (and there are a range of variations) is used in the Professional Practice stream to highlight the importance of effective documentation, using previously established practical skills to provide a relevant context. The importance of clarity, conciseness and accuracy is immediately established, and students appreciate that actually learning some communication skills is to their benefit as future professional engineers. The exercise is followed up by an introduction to the *Engineer's Log Book*, and how a professional engineer uses such a book to document the design process, complete with dating, signing and numbering each page, keeping all pages intact, and so on.

The Log Book now becomes the students' only form of acceptable documentation in the laboratory. A filter design might begin with the calculation of a capacitor value. From such a calculation a standard value, available to the student, is chosen. The student must then record, in the Log Book, the variation in performance due to the use of the real, rather than ideal, value. After construction, the filter is tested and the Log Book documents not only the measured performance of the filter, but provides a comparison with both the theory and with the initial design requirements. Theory, experiment and professional practice are thus brought together.

In practice, of course, most students struggle to deliver the ideal documentation. Well trained demonstrators in a low student to teacher ratio (15:1) reinforce the message until, by the end of the semester, the documentation reaches an acceptable standard.

Similarly, students see theoretical concepts in action. Sometimes this occurs in lectures first, and sometimes in practicals. Describing how a diode acts as a sort of electronic valve, or deriving its exponential current-voltage relationship, leads at best to some on-paper understanding of why a diode is useful. In the laboratory, configuring first one diode, then four, to convert alternating current to direct current as part of a regulated power supply, on the other hand, brings the concepts to life.

The abstraction of a circuit diagram is another challenge. Initially, schematic diagrams better resemble a literal wiring diagram with component and wire placement closely resembling the physical circuit. The functional blocks of each integrated circuit are then introduced within the confines of the device, separating the concept of the wiring diagram from the internal functionality. In the next stage, logic gates and flip flops are drawn independently and it is up to the student to identify which integrated circuit to use and how to connect it, usually with reference to supplied data sheets. Finally, logic circuits are shown without support circuitry such as current-limited light-emitting diodes to display the output logic level of a gate. At this stage, students are expected to be able to work out such details for themselves.

Finally, there are many lessons which can only be learned in practice but which are an essential part of an engineer's education. These include the supposedly obvious, such as the need to apply power to every sub-circuit, but there are also the spectacular lessons which can only happen in a real environment. What happens when an electrolytic capacitor is wired in backwards? Theory describes the chemical breakdown of the electrolyte; a book might make passing reference to the potential explosion and a sufficiently well-constructed computer simulation might (but never does!) introduce some spectacular graphics. But having a capacitor explode in front of one's face, with the stench of smouldering electrolyte, reinforces for the entire class the importance of understanding polarity labelling, the use of safety glasses and the need to check one's work. There is also, of course, the slight humiliation and the laughter which creates a stronger bond between members of the student community. Once experienced, no one forgets this valuable lesson.

Evaluation

The performance of two cohorts have been tracked since 2003, which are nominally the *Electrical* and the *Mechanical* groups. The Electrical cohort includes students studying Electrical and Electronic, Computer Systems, Telecommunications, Software, Avionics, and Sustainable Energy Engineering and a handful of other programs, representing the classes which from 2005-2007 participated in the practical program described here. The Mechanical cohort includes students studying programs from the School of Mechanical Engineering, who did not have access to the practical program until 2008, and in addition the mixture of topics within their subject was slightly different. In 2004, both cohorts studied the same course without practicals, and from 2008 the two cohorts study a unified practical-enhanced introductory course. It should also be noted that the changes in 2005 also introduced significant new lecture material at a more difficult standard compared to previous courses.

Analysis of the student performance suggests that the most compelling metric is the completion rate for each cohort, as shown in Figure 3. The completion rate is defined as the number of students who received a Conceded Pass or better, after supplementary examinations, as a proportion of the total number of students receiving a grade for the course. The university audits courses with a failure rate exceeding 20% (ie a completion rate below 80%), and for this reason the 80% completion rate guideline is used as an indicator of student performance.

The dip in overall performance in 2005 can be attributed in large part to the level of difficulty of the new courses, but it should be noted that the completion rate for the Electrical cohort is 6.8% higher than the Mechanical cohort, a consistent trend in performance in 2006 (2.6%) and 2007 (10.8%). In 2008, the performance of each cohort in the common course was indistinguishable, with completion rates for both cohorts at 91.3%, and a high completion rate has continued in 2009.

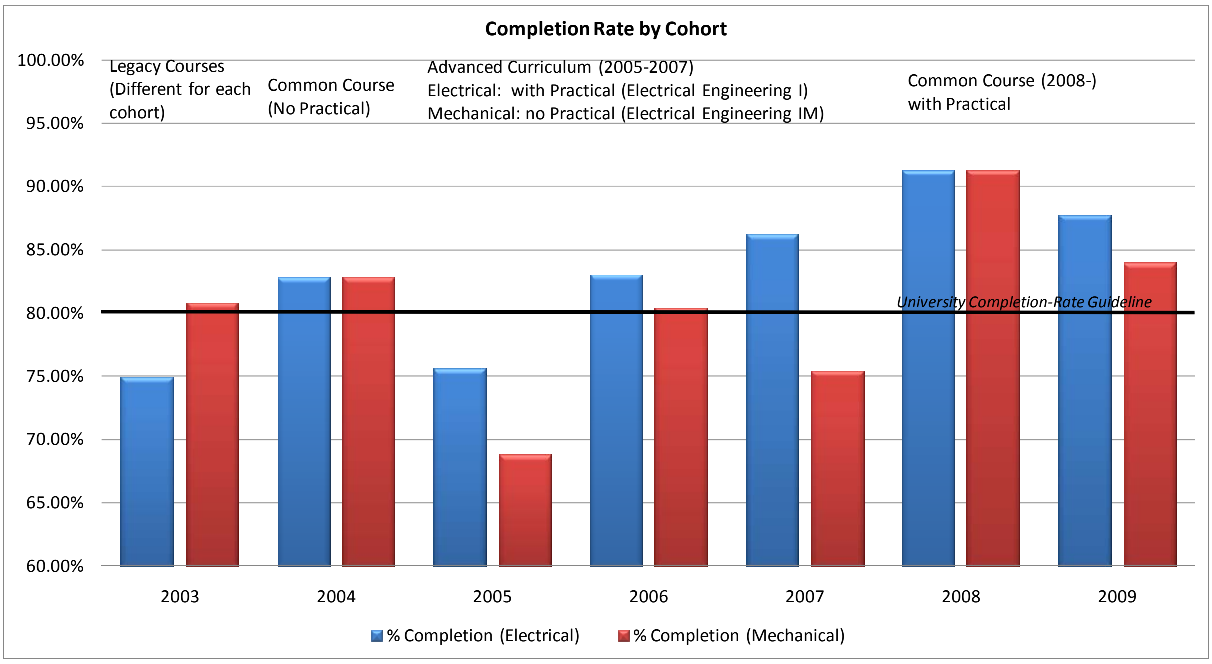

Figure 3: Completion Rates for the Electrical versus the Mechanical Engineering Cohorts.

The explanation for the difference in the cohorts' performance is not straightforward. The argument that the practical mark itself contributes positively to the total weighted mark might be valid, but it is also the case that with some other differences in the curriculum the Electrical cohort was subjected to an overall harder program. Some advanced topics (Sinusoidal Analysis) were shifted from Electrical

Engineering 1A in 2008 to be covered in Electrical Engineering 1B – the resultant course material is harder than the Electrical Engineering 1M course of 2007 and slightly easier than Electrical Engineering 1, and yet the completion rate is higher than ever in both cases. Even with these secondary considerations, however, it is impossible to escape the conclusion that immersion in the coherent practical program contributes positively to the students' overall understanding, motivation and successful course completion, especially in the light of such feedback from students as:

- *They allow me to put the theory into practice which helps me to understand the theory much more.*
- *It is much more interesting and effective to learn by building the circuits*
- *Applied concepts give sound understanding of basic principles. Problem solving challenges demonstrate the sort of challenges faced by electrical engineers.*
- *They make the theory make so much more sense. Without the practicals I would have no idea how most of the theory works.*

Conclusion

Richard Feynman (1985), after a semester teaching a course in electricity and magnetism in Brazil, gave a very critical review of the educational background of his students. His most scathing observation of his students was that they were very good at memorising definitions, but had never been exposed to real experience or real data. Using a local textbook as an example, he noted:

> There are no experimental results mentioned anywhere in this book, except in one place where there is a ball, rolling down an inclined plane, ... The trouble is, when you calculate the value of the acceleration constant from these values, you get the right answer. But a ball rolling down an inclined plane, *if it is actually done*, has an inertia to turn, and will, *if you do the experiment*, produce five-sevenths of the right answer... [T]his single example of experimental 'results' is obtained from a *fake* experiment.

The practical course described here, at its heart, recognises the folly of theory in the absence of practice. By immersing the students in a practical environment, the experience goes well beyond theoretical knowledge (and potentially some understanding), to a real and quite complex appreciation of the behaviour of electronic circuits in the context of the engineering design process. In Feynmanese, the students *know something*, not just the *definition of something*. More than this, they have fun, bond as a community, and take pride in what they have managed to achieve.

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