Large-scale Laboratory Teaching for 1st Year EEE Undergraduates

ABSTRACT

This paper details lessons learned from the implementation of a new approach to first year Electronic and Electrical Engineering (EEE) undergraduate laboratory teaching at the University of Sheffield (UoS), UK. Having moved from traditional small group laboratory teaching to much larger group teaching, a number of issues have been identified.

With the construction of a new faculty-wide engineering building came a new undergraduate practical teaching paradigm. In this paper, the rationale behind the new model is introduced. Details of the laboratory teaching materials and exercises are also given. An analysis is presented of the experience gained during the first academic year's delivery. Finally, suggested improvements are discussed.

INTRODUCTION

Having grown and developed separately, each of the engineering departments in the Faculty of Engineering at the UoS occupied its own laboratory space, with overlap of facilities in some cases. A projected increase in student recruitment required expansion of the available laboratory provision[1]. Hence, the UoS made a strategic decision to move engineering undergraduate practical teaching from existing department-based laboratories to a centrally located set of specialised laboratory facilities.

The building housing the facilities, known as "The Diamond"[2], provides 19 engineering teaching laboratories, including an Aerospace Simulation Laboratory, Fluids Engineering Laboratory, and the Electronics and Control Laboratory (E&C) These laboratories are based around "themes", not on the traditional departmental structure.

The publically stated, official vision[3] for the new multidisciplinary approach was:

- The Diamond to be the best integrated engineering teaching space in the UK if not the world
- To equip our 1st and 2nd year students with the necessary fundamental experimental skills and technical competencies, which will feed into their 3rd and 4th year learning and research/industry led projects, and which will help them to develop the academic and technical skills that industry is seeking from top graduates.

A new teaching group, known as "Multidisciplinary Engineering Education"[3] (MEE) was set up in order to coordinate academic and technical efforts from all engineering departments.

In many cases, staff from existing departments transferred to MEE (some on temporary secondment). In others, including EEE, new staff were recruited to design and deliver the laboratory exercises.

LABORATORY LEARNING

Feisel and Rosa[4] note that engineers manipulate materials, energy, and information, and that to do so successfully, the student engineer needs to augment his / her theoretical understanding with good practical experience. Historically, such experience was gained in university educational laboratories. However, the authors noted the changing form of such practical teaching activities, and discussed thirteen "Fundamental Objectives of Engineering Instructional Laboratories".

Previous work by Ernst[5] identified three objectives for undergraduate engineering laboratory exercises:

- Students should learn how to be an experimenter.
- The laboratory can be a place for the student to learn new and developing subject matter.
- Laboratory courses help the student to gain insight and understanding of the real world.

With this in mind, the first year EEE dedicated laboratory course (EEE160) had the following aims[6]:

- To provide experience in the use of instruments for the analysis of Electronic and Electrical systems, including an appreciation of the accuracy and applicability of these instruments; develop skills in the carrying out of experimental work, making an intelligent choice of data measured, understanding of measurement accuracy, and the ability to critically evaluate the data.
- To reinforce technical concepts introduced in other courses through exposure to these in a practical setting.
- To provide opportunities to apply basic electronic concepts to the design of circuits and other systems.
- To develop skills in reporting technical results in a variety of formats, including graphical and other presentation of experimental data, technical reports and oral presentations.
- To develop an appreciation of good computer programming style including an introduction to programming in the C language.
- To develop personal organisational and project management skills.
- To engender and encourage an enthusiasm for the subject by introducing practical applications of scientific and engineering concepts.

In addition to the aims, the EEE160 course objectives[6] are that the student should be able to:

- Carry out experiments to a prescribed set of instructions.
- Make appropriate use of equipment available and make sensible choices in the measurements made.
- Critically analyse results and estimate measurement uncertainties.

- Use the C computer language to produce structured programmes.
- Report their results in a variety of forms, both oral and written, in a concise and clear manner.
- Work effectively in a group to produce a design under identified constraints.
- Plan their study time effectively.

Although this paper does not discuss the details of any particular experiment, the following list (Table 1) gives an indication of the range of technical subject areas covered by the EEE160 practical laboratory course. It should be noted that the EEE department does not synchronise delivery of laboratory exercises with the lecture series for the first year course.

TABLE 1 *EEE160 Coursework Module Content*

Experiment Title	Assessment Method	% of EEE160 course grade
Bipolar Junction Transistor	Short Report	10%
Computer Aided Design Project	Continuous	2%
Computing	Software Exercises	30%
Coupled Circuits & Transformers	Continuous	2%
Digital Logic Circuits	Formal Report	10%
Direct Current Machines	Continuous	2%

Group Project	Continuous	2%
Individual Project	Formal Report & Oral Presentation	10% & 4%
Light Emitting Diode (clean room)	Short Report	5%
Passive Networks	Formal Report	10%
Personal Tutorial Attendance	Tutor Assessment	5%
Professional Skills	Tutor Assessment	2%
Spectrum Analyser	Continuous	2%
Workstation Familiarisation 1	Continuous	2%
Workstation Familiarisation 2	Continuous	2%

Source: *University of Sheffield EEE 1st Year Student Handbook*[7].

The technical content of the experiments listed in Table 1 remained largely unaltered in the move to large-lab teaching. However, the organisational ethos under which these were delivered changed greatly.

The following section discusses this change, in terms of teaching methods and materials, physical and human resources, and organisational administration. Reflections on, and conclusions drawn from, the experience gained in the first year of operation are also presented.

TEACHING METHOD AND MATERIALS

The previous method of delivering the EEE lab exercises generally involved the student:

- Receiving a printed lab sheet upon arrival at the lab session.
- Reading a substantial amount of background (theory) material in the lab.
- Becoming familiar with, often exercise-specific, equipment.
- Following a tightly defined set of instructions to perform a lab exercise procedure.
- Carrying out observations and / or measurements, and recording data.
- Being informally assessed in-lab and / or subsequently submitting a formal assessment.

Utilising elements of both flipped learning and blended learning, the new teaching approach uses the following template for each lab exercise:

- Pre-lab:
  - Health & Safety (H&S) Background and Test
  - Technical Background and Experiment Induction Test
- In-lab:
  - Experiment
- Post-lab:
  - Test / Reflective activity
  - Survey

Whilst a small number of the legacy lab sheets recommended that the student read the material before attending the session, this relied on the student having access to the sheet, and reading it, prior to the lab, something that did not happen consistently.

The new approach builds-in the Pre-lab phase, with this material made available via the UoS Virtual Learning Environment (VLE), called My Online Learning Environment (MOLE). MOLE is based on Blackboard[8] (BB). Much of the MOLE Pre-lab work uses video and audio materials, with some requiring student interaction and active participation.

The students were made aware of the format of the laboratory course in the week before the start of lectures and labs (induction week), and the full set of (In-lab) laboratory exercises was bound in hard copy and given to the students before the course started.

In order to firmly embed H&S in the course, students are required to pass the Pre-lab H&S test (for every exercise). Failure to do so means the student cannot gain access to the laboratory.

Likewise, students are required to read the necessary background theory and become familiar with the details of the experiment procedure / exercise before attending the session. Assessment of student understanding of this material is via a test on MOLE. Again, failure to pass means the student cannot gain access to the laboratory.

In some cases, for example the Spectrum Analyser exercise, students are required to carry out a series of complex calculations, record these in the bound lab book, and then use these during the In-lab part of the exercise. Whilst this is part of the Pre-lab work, it is checked within the laboratory as part of the ongoing formative assessment process.

Primed with the knowledge gained from the Pre-lab material, the student is much better prepared for the In-lab exercise. Consequently, the In-lab exercises could be streamlined, with many re-written or reformatted in order to provide a sharper focus on the learning outcomes of the individual exercise.

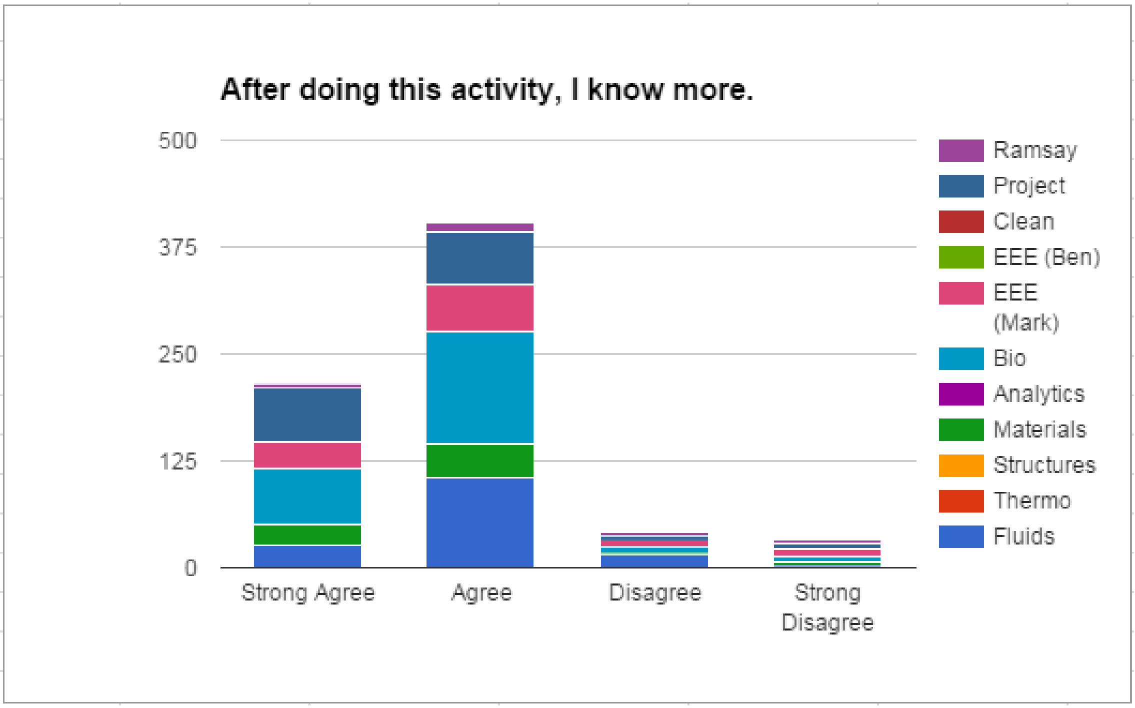
Further, apart from a very short “housekeeping” introduction and welcome message, no oral introduction to the theory or procedure for the lab exercise was given. In most cases, this meant that the laboratory exercise could be performed much faster and in a more efficient manner.

The exercise reformatting also provided an opportunity to make use of spiral learning techniques, thereby guiding students to progressively develop laboratory skills throughout the course.

Referring again to TABLE 1, for exercises requiring a formal report submission, full guidance was provided in the exercise’s Post-lab area of MOLE. For those lab exercises with no formal report submission, a reflective follow up Post-lab exercise was required, together with a requirement to complete a questionnaire.

Whilst it is not possible to provide a quantitative comparison of the new approach to the previous one, results (Figures 1 and 2) gathered from the Post -lab questionnaires show the effectiveness of the laboratory practical teaching model in general across all multi-disciplinary areas, including EEE.

FIGURE 1 *MEE Post-lab survey results ("know more").*



An additional feature of the multidisciplinary approach was the (re)use of faculty-wide "induction" lab exercises. These (three) exercises were scheduled at the start of the semester, with the requirement that every engineering student in the faculty complete each one before being given access to the laboratories to start their course-specific lab programme. The induction lab exercises were:

- The Project Space Induction Lab Exercise: a guided introduction to the facilities available for manufacturing (laser cutters, 3D printers, lathes, etc.). Also, a consideration of the risks associated with the use of tools of all kinds.
- The Danger Lab Exercise: design of an experimental protocol to measure the impact fracture toughness of chocolate at room temperature and at cryogenic temperatures.

- The Measurement Lab: the use of different types of measuring instrumentation in order to appreciate the impact of test equipment on a system being tested.

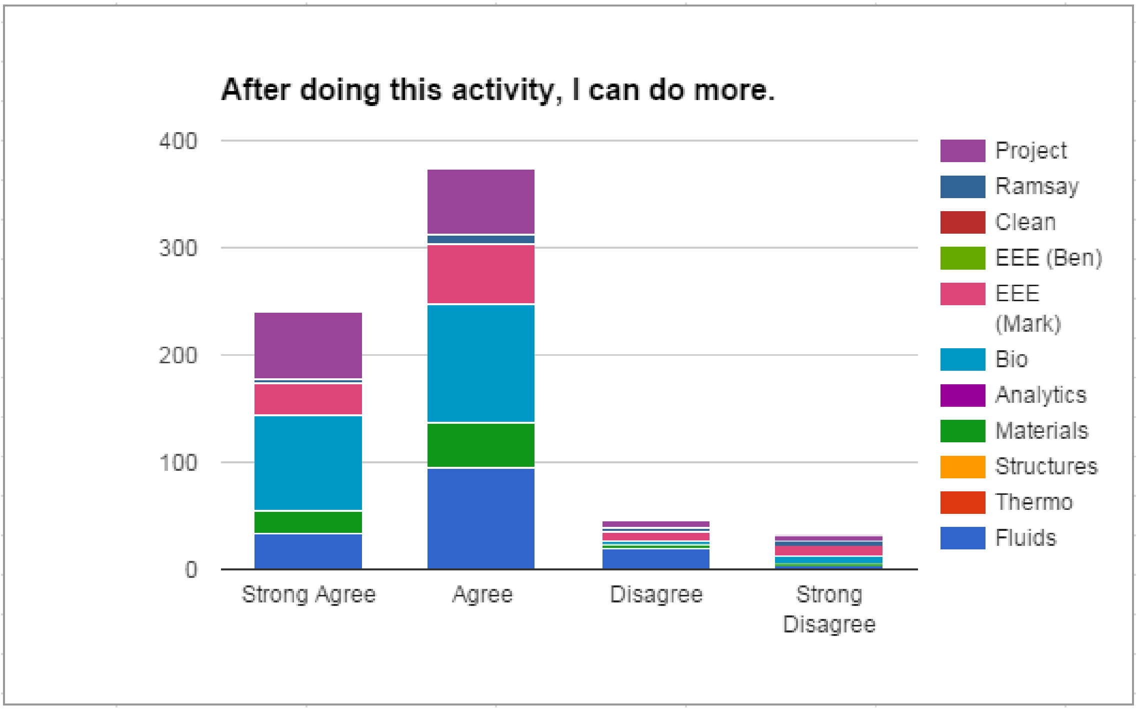
The first two of these were common to all students, with the last having two variants; one with a mechanical bias, the other with an electrical focus. For EEE students, the Measurement Lab consisted of:

- Carrying out basic measurements in an electrical circuit using various instruments, and considering the sources of error and inaccuracy in such readings. The different test instruments were:

    - Digital multimeter (DMM).
    - Mixed signal oscilloscope (MSO).
    - Analogue multimeter (AMM).

The last major change noted in this section is the means by which the lab exercises were assessed. Before the move to the multidisciplinary approach, the EEE department had responsibility for assessing students' lab performance and post-lab submissions. This was usually carried out by lab session supervisors (post-graduate students) or occasionally by the member of the academic staff responsible for the particular laboratory exercise. Following the move, MEE assumed responsibility for all assessment marking. Some of the consequences of this shift are discussed in the Analysis and Conclusions section. However, it is worth noting that a faculty-wide marking schema was used in order to provide a standardised student experience across all themes, since students often carried out experiments in other theme's laboratories.

FIGURE 2 *MEE Post-lab survey results ("do more").*



HUMAN RESOURCES: ACADEMIC AND TECHNICAL STAFF, AND TEACHING ASSISTANTS

In the traditional EEE approach, each laboratory session would require two post-graduate teaching assistants / PhD students, usually subject experts whose PhD topics aligned with the subject being studied in the laboratory session. In addition, one experienced technician and, generally, a member of the EEE academic staff would be present for most, if not all, of the session. Depending on the particular experiment / staffing, this gave a student to staff ratio of approximately 10:1. For most experiments, those for which there were no equipment limitations, students worked in groups of two.

Remembering that MEE is a “service” department providing practical laboratory teaching, and not a traditional subject-specific department, a new formal staffing arrangement was implemented. Each theme (within MEE), and hence laboratory, was staffed by:

- One or more academic
- Teaching Technicians
- Graduate Teaching Assistants (GTAs)

As noted, new academic (and technical) staff were recruited by MEE to design and deliver the EEE laboratory exercises. This differed from all other departments / themes, since in those, existing members of staff were seconded or recruited directly from the existing departments to work in MEE.

A consequence of this was that one person was now responsible for all lab exercises, ranging from Digital Logic Circuits to Direct Current Machines, whereas previously a subject expert would have been responsible for a single lab exercise associated with her / his specialism.

Technicians in the past had provided some, albeit limited, guidance to students in the lab. The MEE approach was to employ “Teaching Technicians”. These members of staff were recruited / seconded not only for their technical know-how, but also for their ability to impart their extensive practical knowledge and skills. Hence, their remit ranged from equipment design, commissioning, and testing; through to lab session “delivery” and assessment of student work.

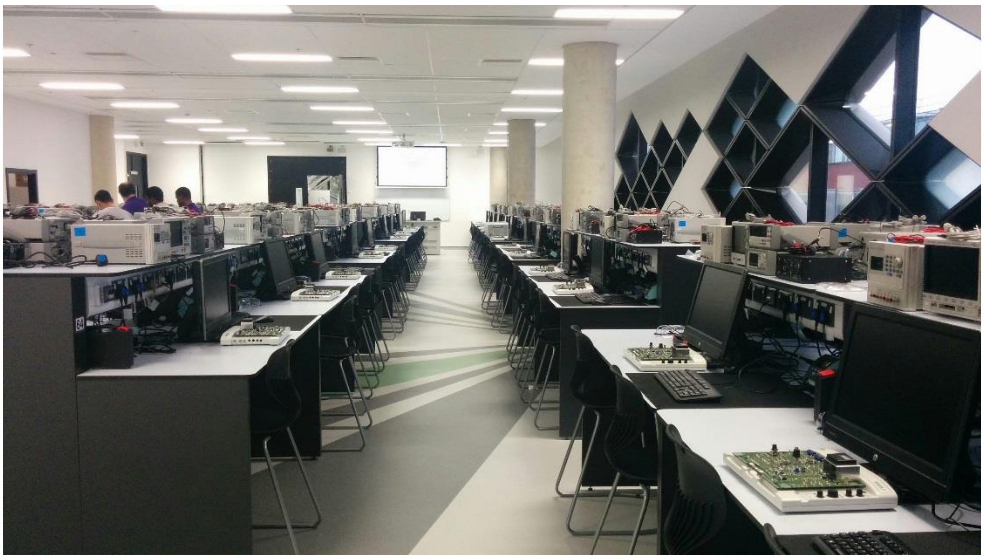
The employment, training, and administration of GTAs was professionalised with the move to the new model of teaching. GTAs were considered to be staff members, and had a wider range of responsibility than under the previous approach. For example, they were required to attend various induction and training courses, lab-specific preparation and assessment events, and were considered to be “trainee academics”, rather than casual workers.

A number of staffing issues were encountered during the first year’s delivery under the new model, with some of these discussed in the Analysis and Conclusions section below.

PHYSICAL RESOURCES: THE EEE LABORATORY PHYSICAL LEARNING ENVIRONMENT

In the past, due to limitations both in the size of EEE departmental undergraduate laboratories and on the amount of laboratory equipment available, EEE laboratory exercises have been limited to a maximum of approximately forty students per session, and for some experiments to fourteen students per session (e.g. DC machines in the machines / drives room and LED construction in the clean room). This meant that most laboratory exercises would be delivered three or more times, in order to accommodate the full cohort.

FIGURE 3 *UoS E&C lab.*



The new E&C lab (Figure 3) seats 144 students. Therefore, for standard EEE year groups, which are generally between 120 and 140, an entire cohort can be accommodated. The main anticipated benefits were:

- Single, standardised delivery of each laboratory exercise.
- Practical exercises scheduled at the same point in the course for all students.
- More equitable approach since all students have the same opportunities in terms of consolidation of course theory through practical work.
- Much reduced (repeated) set up, take down, movement, and storage of equipment.
- Reduced staff workload since lab exercises are not delivered multiple times.
- Greater throughput, resulting in better use of resources.

For EEE students, the first three advantages were realised. However, since the lab is also used for service teaching of EEE courses, larger cohorts (e.g. mechanical, aerospace, etc.) still had to be managed in multiple sessions, leading to some unforeseen problems, such as increased staff workload resulting from repeated set up and take down of 144 sets of equipment.

Although useful, the advantage of having practical exercises scheduled at the same point in the course for all students is not as important as it might seem since, as noted above, the EEE department hitherto had not aligned the practical sessions with the taught theoretical material delivered in the lecture series (the rationale behind this was that it would require students to independently research the topics for which the theory had not yet been taught). However, the large lab did ensure that all students were treated fairly, in that all students attended a given lab exercise at the same point in the semester, and hence all were at the same point in the lecture series.

A number of unintended consequences were encountered as a result of the use of such a large teaching space, with these discussed in the Analysis and Conclusions section below.

ADMINISTRATION SUPPORT / ADDITIONAL RESOURCES

Although not part of the technical delivery of the laboratory exercises, the administrative support function in MEE had an important role, and hence some aspects should be briefly mentioned. It was necessary to have in place an administrative team in order to support the academic and technical staff.

Whilst most staff were recruited or seconded from within the UoS, additional new members of staff were recruited from outside the organisation. Considering some of the staff that directly interfaced with both the academic / technical staff and students, the following played an important part in supporting the delivery of the teaching service:

- Timetable manager
- Office support manager / staff
- Academic administrative support
- Project manager and support staff

Additional resources were provided by equipment manufacturers, suppliers, and training organisations, including National Instruments, Shimadzu, Quanser, and Keysight.

ANALYSIS AND CONCLUSIONS

This section considers the experience gained from the first year's delivery of practical laboratory sessions under the new model introduced above.

Following the transfer of responsibility for delivery of the 1st (and 2nd) year undergraduate EEE laboratory practical exercises from the home department to the MEE group in The Diamond, there were identified a number of problems.

Whilst some teething problems were to be expected when undertaking such a large structural change in the provision of practical teaching, other problems identified were more fundamental in nature. Among those occurring as a direct result of the move to large scale teaching were the following:

- Students failing to complete all of the Pre-lab reading and preparatory work: many EEE students were found to have not satisfactorily completed the Pre-lab work prior to attending the laboratory session. Although initially a cause for concern, it was noted that students attending service courses (e.g. 2nd year Bio-Engineering students) had, almost universally, completed the Pre-lab work. On further investigation, it was found that their home department had previously introduced this in the 1st year. Hence, these students had experience with this model. As the semester progressed, completion rates among EEE students improved significantly (probably since penalties were more rigorously applied).
- Insufficient number of knowledgeable Graduate Teaching Assistants (GTAs): whereas in the previous model, only two or three GTAs would be required per lab session, in the new large-scale model, many more were required simultaneously. Thus, one of the problems identified during semester 1 (2016) was a limitation on the number of experienced GTAs. One possible solution to this problem is to schedule parallel sessions. That is, continue having large numbers of students in the laboratory for each scheduled session, but have many different laboratory

activities operating simultaneously. This way, a much smaller number of GTAs is required for each laboratory activity, but they are all required at that same time in the same session. The total number of GTAs per session would remain the same.

- Marking of large numbers of laboratory reports, and the timely provision of student feedback: with large numbers of students carrying out practical work at the same time comes the submission of a large number of Post-lab reports. Obviously, one approach is to spread the load by allocating some marking to the GTAs. This is not without problems. Among these are issues of consistency, although this can be addressed by using a detailed rubric / marking scheme. The above recommendation regarding "parallel sessions" would also help address this, in that the different exercises can be marked by a wider range of specialist GTAs, although rubrics / marking schemes would again be required. Automated testing and / or marking is also possible, but is of limited value when marking written reports.
- Logistical problems associated with increased amounts of equipment: although anticipated, the problems associated with large quantities of equipment were considerable. Both the movement and storage of large and small components created a heavy workload for technical staff. This was exacerbated by the following issue.
- Laboratory session duration and timetabling problems: miscommunication between departments, and inexperience on the part of timetabling staff, resulted in laboratory activities being scheduled in incorrect slots, and these being placed contiguously in the timetable. Hence, there was often no time for set up / take down of experiments. In such a large lab, this created a considerable delay, and often resulted in staff having no breaks. This, in turn, led to staff frustration and burn out.

- Facilities and physical resource problems resulting from large numbers of students: simply moving large numbers of students in, out, and around a large laboratory space proved difficult and time consuming. In order to maintain a safe working environment, strict safety, storage, and movement rules had to be put in place. Poor room design, including narrow aisles, increased problems in this area.
- Room design: the overall room configuration meant that there was not line-of-sight to all parts of the room, resulting in visual and audio "dead zones". Also, this issue resulted in physical access problems.
- Room size, the "critical mass" problem, and the loss of "intimacy" in the lab: it was noted that, although the room capacity was 144, when the occupancy rate was above approximately 70, there was a loss of "intimacy". This meant that communication was difficult, and that it was necessary to shout and / or move around repeating instructions. This is a considerable problem since one of the perceived benefits of laboratory work is the more intimate atmosphere[3], allowing better interaction between students, and between students and staff.

Whilst not necessarily related to the move to large-lab teaching, this transition has highlighted an existing area of concern:

- Lectures not aligned with laboratory sessions: under the previous model, the fact that lab exercises and lectures were not linked was a problem, but was one that was "averaged out" over the semester. That is, as the semester progressed, students worked through the lecture course while they, in much smaller groups, worked through the lab practical sessions. By the time many students performed the experiments, they had covered the theoretical background in the lectures. Having much larger lab sessions meant that the entire cohort were often faced with lab exercises for which they had not studied in depth the necessary theoretical background.

Other, process-related and more “political” problems noted, but not dealt with in this paper, include:

1. Communication with departments in general, and with subject experts in particular.
2. Departmental “buy-in” to the large-lab approach.
3. Responsibility / ownership for each lab exercise.
4. Inter-departmental administrative support.

Considering some of the above concerns, those that can be improved by changing approach (i.e. not physical space restrictions etc.), the author suggests that laboratory activities should be, at least loosely, linked to the lecture material. Further, it is recommended that individual laboratory exercises should be linked to each other. That is, there should be a technical narrative that carries the student through a series of linked laboratory exercises.

It is the author's view that no laboratory exercise should be scheduled as a 4 hour activity (as they were). The duration of an activity should not exceed 2 or 3 hours. In addition to student fatigue after 4 hours, the academic and technical staff require time to set up and take down laboratory equipment between laboratory activities. Whilst this may appear to be common sense, it is worth restating, since it is easy to avoid accidentally demotivating students in the lab.

It would be also be useful to incorporate at least some form of real-world, problem-based and perhaps also research-led learning into the EEE160 module. If done properly, this could stimulate students who are struggling with the theoretical aspects of the subject. It could also pique the interest of all students and (re-)engender their enthusiasm for the subject more generally.

In conclusion, the following comments from the Post-lab questionnaires provide a useful summary of student opinion following the first delivery of the new laboratory model:

“Lab schedule needs to be checked so as to avoid a lab subject before lecture coverage”.

“The lab practical was good to help understand what we were learning about”.

“Would be more useful if theory behind lab activities was first taught in lectures”.

“The laboratory sessions were better than when I was in first year” (from a 2nd year student).

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