Providing a Practical Education for Off-Campus Engineering Students

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Abstract: This paper considers the provision of laboratory-practicals for distance-education students in engineering degree programmes. The authors discuss the role of laboratory-practical work in the curriculum and reflect on five methods that can be used to ensure off-campus students have an equivalent practical experience as the traditional on-campus cohort. On-campus sessions, videotapes (or 'on-line' movie-clips), computer simulations, home experiment kits and laboratories controlled over the internet are covered. Some examples are given to show how these can be incorporated into the curriculum. A case study then discusses the problem of (and an exemplar solution to) delivering the laboratory-practical components of two microcontroller units offered at Deakin University – a leading provider of distance-education in Australia. In doing so, it leads the reader through the solution process and cites some constraints that drive the choice of model - for example, cost considerations and the need for relevant didactic materials.

Introduction

In recent years, many universities world-wide have started to introduce distance-education into their engineering programmes and hence a significant number of students now elect to undertake their studies in off-campus mode. In order to ensure that off-campus students are not disadvantaged by their isolation a number of critical issues must be addressed. These issues include:

- Student access to course teaching and learning materials;
- Student access to general course-related information;
- Student access to university teaching staff;
- Student access to university facilities (library resources etc);
- The educational benefits of peer support; and
- Student involvement in laboratory-practical components of the curriculum.

Most universities have developed simple strategies to manage student access and peer support, and in doing so have engaged the first five of these issues. Well thought-out course materials are distributed in hard copy and/or via the World-Wide-Web (WWW). Lecturers are accessible by
telephone, fax and e-mail as well as via specially developed conferencing and discussion facilities. Books may be reserved in the library by telephone or on-line through the WWW to be despatched via the mail service, and peer support has been addressed by the distribution of lists comprising contact details of all consenting students enrolled in each unit. Conference facilities and 'chat rooms' have also been provided through specific unit web pages.

The provision of laboratory-practical components for distance-education students has proven to be more problematic [Walkington et al., 1994; Alexander and Smelser, 2003]. There is therefore a temptation to simply waive their requirement but this means placing different requirements for on- and off-campus students, which is difficult to justify in educational terms and raises some very real equity problems.

About Deakin University

Deakin University is a leader in distance-education in Australia [Briggs, 1995]. The School of Engineering and Technology offers a four-year Bachelor of Engineering (BE) degree which is accredited by the Institution of Engineers, Australia (IEAust). Three specialist majors are currently offered:

- Mechanical Engineering;
- Electronic Engineering; and
- Mechatronics/Robotics Engineering.

All three programmes are available in on- and off-campus study modes. Conventional entry students usually undertake their studies on-campus, full-time; but some do elect to take part or all of their studies part-time and/or off-campus in later years to better suit their employment or other personal circumstances. Mature age students can study on-campus, full-time, but often elect to study off-campus and/or part-time because of employment or family commitments. International students can enrol on-campus or with Deakin’s overseas partner institutions in Malaysia and Singapore. Hence, distance-education students form a significant proportion of the total student population.

Laboratory-practical work has an important role in the three programmes (reasons for this are discussed in Section 3) and the School has therefore needed to address the provision of practicals for off-campus students. This paper comments on five methods that can be used to provide off-campus students with an equivalent practical education to their on-campus counterparts. A case study considers the problem of (and an exemplar solution to) delivering laboratory-practicals to distance-education students in two microcomputer/microcontroller units.

The role of laboratory-practical work

There is no general agreement on the role of laboratory-practical work in an engineering degree programme. There is not even agreement about which parts of the curriculum require laboratory-practical work [Jinks, 1994]. A number of educators have asserted that many aspects of an engineering curriculum could be assayed without the use of practical work at all - this argument has found favour with institute administrators as it promises a reduction in the expenditure inherent in the delivery of laboratory-practical components of an engineering degree course. But is it realistic?

Historically, engineering courses have been designed to incorporate laboratory-practical work within the framework of academic tuition. Practical work was considered to be a support or supplement to the concepts and theories presented in the lecture theatres and tutorial rooms. The hypothesis being that teaching and learning of engineering concepts and theories are reinforced by way of experimentation or demonstration. The other perceived function of practical work is in the development of specific, discipline-related skills. This has been the main function of laboratory-practical classes in some of the traditional engineering sciences (for example, materials science) and to a greater extent in disciplines such as analytical chemistry where, strict and complex procedures must be mastered before being put into practice in the field.

Developments in competency-based approaches to tertiary education [Bowden and Masters, 1993] have reinforced these older, more traditional ideas by advancing the concept that competency is a function of three core components: Attitude (or behaviour), Skills and Knowledge (ASK). It is accepted that a student who excels in one
component of a competency but not in the other
two components cannot be deemed to have
satisfied that competence. In an engineering
education context, knowledge, and to some extent
attitude can be promulgated and developed in the
lecture theatre and tutorial rooms (or off-campus
equivalents) but skills are acquired and polished in
the laboratories and workshops. Laboratory-
practicals are therefore an essential component of
an engineering degree course and they must not
be cast-aside on a whim.

Delivery of off-campus laboratory-
practicals
Providing laboratory-practicals for distance-
education students is a difficult task. Off-campus
students must gain an equivalent practical
experience as their on-campus counterparts.
There are five methods that can be used to ensure
this occurs: on-campus sessions; videotapes;
computer-based simulations; home experiments;
and laboratories controlled over the internet.
These models, however, are not mutually
exclusive and therefore two or more models can
be used to satisfy the teaching and learning
outcomes of a unit.

On-campus sessions
One common solution is to require off-campus
students to attend for one or two weekends per
semester (or a ‘residential school’) for intensive
laboratory-practical sessions for every subject
under study. This approach is dogged by two
separate sets of problems; firstly, the logistical
problems of travel for the student and provision of
time slots by the university, and secondly, the
problem of equity in the learning-experience for
on- and off-campus students. Typically on-
campus students are time-tabled with a fixed
laboratory period every week of the semester; two
to four hours slots being typical. Over ten or
twenty weeks of a semester this amounts to at least
twenty hours. To replicate this for off-campus
students would require around three full days of
attendance at the university, plus any travel time,
which in Australia may be considerable. This
problem is multiplied where students are taking a
number of units that each requires laboratory-
practical attendance and must visit the university
for each of them.

In some circumstances it is possible to organise
laboratory facilities near a student’s locale. This is
often the case for students who study through
educational partners, but there is still the
consideration of timeliness of presentation if
students are required to attend only a single two-
or three-day block of intensive laboratory practice
per semester [Giannetti, 1998]. If the practical is
meant to reinforce some particular concept or
theory then the ideal time-slot for it is
immediately following its introduction in the
lecture programme. If it is assayed too early the
students will lack the knowledge required for its
proper understanding. If introduced after too long
a time period, its relevance may no longer be
obvious. For small on-campus groups with weekly
time-tabled laboratory classes a carefully planned
time-table can mean that this does not present too
much of a problem but the distance-education
cohort is often not so fortunate.

Videotapes
Sending videotapes (or using internet-based
digital movie-clips) is a simple and economical
method to show laboratories to off-campus
students. Videos have been used by the Open
University in the United Kingdom [Alhalabi,
1998]. An assessment of whether a student has
understood the concept is made by an on-line
examiner who asks a sequence of searching
questions to determine a student’s
comprehension. There is not therefore a focus on
the practical skills. Thus, whilst movies can be a
useful tool for demonstrating some simple
experimental procedures they cannot be a
substitute for laboratory-based practical work.
Their principal role should therefore be in the
support of teaching and learning, i.e. to ensure
that the limited time available for actual ‘hands-
on’ practical sessions is used most effectively.

Computer-based simulations
Some units provide computer simulations [Llamas
et al., 2001] for some, or all, of the practical
classes. However, when using Computer Aided
Learning (CAL) programs great care must be
take to ensure that the simulation measures the
same knowledge and skills as its laboratory-based
counterpart [Rabinowitz and Brandt, 2002].
Simulations may provide an adequate solution for
some subjects but in general should not be a replacement for laboratory-practicals. Control theory and digital-signal processing [Stewart et al., 2000] are two examples where software such as Matlab® can provide a more-than-adequate experimental tool. Digital and analogue circuit simulators have been used in some units but these have limited scope. Although students learn the skills of part selection and circuit design using simulations, they do not gain proficiency in the skills of measurement and diagnostic tools such as signal generators, multi-meters, oscilloscopes etc. that they will require in the workplace. Other simulations (and/or hands-on experience) are needed for this purpose.

The Deakin CAL program METROLOG [Ferguson and Wong, 1995] is a simulator which introduces students to the operation of precision measurement equipment. It introduces students to micrometers, verniers and callipers, and demonstrates the principles involved in their use — see Figure 1. The program is not used as a replacement for hands-on practical experience (nor should it be) but rather to simply familiarise the students with the equipment. Skills in the use of micrometers and verniers are needed near the start of an on-campus ‘workshop practices’ programme. To tutor students on the use of these instruments involves a considerable amount of one-to-one teaching — METROLOG considerably reduces the time involved in this instruction.

Figure 1. METROLOG CAL Program: (a) micrometer simulation; (b) vernier simulation.

Home experimentation kits

Home experiment kits can offer educational benefits when hands-on experience is essential to the teaching and learning outcomes of a unit. They are used by a number of universities (including the Open University) in their engineering distance-education programmes. Deakin University uses them in several of its units — for example, in first-year electronics (see Figure 2) [Long et al., 2004a] and in two microcontroller units [Jones and Hall, 2005]. Deakin are leading the way with the use of home kits in microcontroller courses — in the literature it has been argued that home experiments are not possible in hi-tech courses such as “Advanced Logic Design and Microprocessors” [Alabahi, 1998].

Figure 2. Home experimentation kit for first-year electronics [Long et al. 2004a].
A simple home kit and relevant instructions are sent to the students who work at their own pace to solve practical problems. Students are free to iterate through possible solutions free of the constraints of fixed length time-tabled slots at a time that is convenient to them. The home kit concept does not simply take the laboratory to the students instead of the students to the laboratory; rather it bestows both freedoms and responsibilities on them. It gives the students the freedom to assay laboratory-practicals at their own pace while also making them responsible for their own time and resource management. The freedom of home experiments mean they are well received by the students - evidence of this is found in Deakin's formal student evaluation of teaching and learning exercise [Jones and Hall, 2005]. Feedback often points out the feeling of accomplishment gained when they, eventually, complete the laboratory-practical component of the course. Success in this way appears to raise their self-esteem.

**Remotely controlled practicals**

Many universities are now exploring the possibilities of real-time, remotely controlled laboratory-practicals [Trevelyan, 2003] - Deakin University was one of the first. The WWW has been used at Deakin to deliver a laboratory-based fluids exercise [Lemcckert and Florence, 1996; Florence et al., 1997] and to program Computer Numerically Controlled (CNC) machine operations [Ferguson and Florence, 1999]. These exercises are controlled by off-campus students from their home or workplace using a Personal Computer (PC) and internet connection. The laboratory-practical is therefore undertaken at a time and place that is convenient to each student, and at a time that supports or supplements the theoretical component of their studies. The downside is "you often do not get the feeling of being in the lab or of working real devices. It is hard to tell if the experiment is being performed in reality or just faked by prerecorded pictures and videos generated by simulation" [Boehne et al., 2002].

The remotely controlled fluids experiment (FLOW) developed at Deakin University considers the flow of water over a weir, as shown see Figure 3 [Long et al., 2004b]. The experiment has been used as a laboratory-practical for 'Fluid Mechanics' - a compulsory second-level unit for mechanical students. The aim of the experiment is to determine the relationship between the height of the waterfall and the mean water velocity. A computer-controlled water pump is used to regulate the flow rate of water in the channel (Figure 3(a)) and a digital camera takes still images of the weir (Figure 3(b)). The experiment is operated in real-time by students and a reservation program is in operation to ensure that only one student runs the experiment at a time.

Figure 3. The FLOW experiment: (a) experimental arrangement [Long et al 2004b]; (b) the operating page [Lemcckert and Florence, 1996].

5. **A case study – microcontroller practicals**

The mechatronics/robotics and electronic engineering courses offered at Deakin University include two microcontroller units as core subjects. Each of these contribute a one credit-point load
from a thirty-two credit-point degree requirement. Initially, when the units were offered in on-campus mode only, students attended a three-hour per week laboratory session for ten weeks of the thirteen-week semester. During these timetabled sessions the students worked on Z80 microprocessor-based development sets. Their exercises included direct data entry of simple programs via a built-in monitor program on the sets, they also used a Z80 cross-compiler on a PC to write and compile more complex programs. In all cases, the exercises were closely specified and required very little creative thought on the student's part. It would have been preferable to set the students problem-based tasks in which students develop their own solutions to open-ended questions or tasks [Rhem, 1998; Savery and Duffy, 2001] However, this is very difficult to implement when delivery is through traditional, formal laboratory-practical sessions.

When the two units were later offered to distance-education students, the team members responsible for course development took the chance to revisit how the laboratory-practical components were delivered. The constraint was that those students graduating from the revised courses must still satisfy the learning outcomes as defined in the unit outlines. Three critical objectives of the laboratory-practicals were, to:

- Write, develop and debug programs for microcontrollers;
- Design and construct electronic circuits that interface with a microcontroller; and
- Integrate simple, computer controlled electronic and electro-mechanical systems.

Hence, simply waiving laboratory-practical components was not an option as program writing and debugging, circuit design, systems integration and trouble-shooting skills cannot be developed in the lecture theatre or tutorial rooms. The use of videotapes and CAL simulators for off-campus students, though freely available, were also discounted as these methods did not allow assessment of the students' hands-on practical skills - for example, in the construction of electrical circuits. Remotely controlled experiments could offer an equivalent experience as the traditional on-campus laboratory-practicals but this would mean the closely specified exercises that the team members wanted to move away from would have to remain. The decision was therefore made to create a home experiment kit. The kits would be supplied to both on- and off-campus students, and thus, would ensure equity in the practical assessment of the two cohorts. Traditional on-campus laboratory-practical sessions would cease.

It was initially proposed that the university would buy sufficient of the then-used Z-80 development boards along with associated software to provide one set for each student. However, with the cost for one set at over AU$400 and a combined intake of about 200 students this would involve an initial outlay of AU$80,000 to which must be added the yearly on-going costs for distribution, collection and testing prior to being despatched in following years. This was considered to be too great an expense and a daunting logistics problem. After some investigation, it was concluded that a designed-in-house, simple, self-contained development board (referred to as the DUET board) could be commercially made for less than AU$50 (in 1997) - Figure 4. By judicious choice of the microcontroller used the kit could have adequate memory and could be programmed using any PC that was equipped with a serial port.
A Motorola 68HC711E9 [Motorola Inc., 1991a] microcontroller was chosen for the DUET board - a survey of available hardware and software showed the Motorola 68HC11 [Motorola Inc., 1991b] family of microcontroller to be very well supported by a wide range of freeware cross-assemblers, excellent text books and many other didactic materials. Moreover, a board based on the 68HC11 could be used to satisfy the learning objectives for both of the microcontroller units and could also be possibly incorporated into two more capstone units - 'Mechatronics Design' and 'Autonomous Systems' in the mechatronics/robotics stream. Since the cost for the home kit was less than that for a prescribed text book (typically AU$90) it was therefore not beyond the pocket of the vast majority of students. To reduce the cost further, however, it was also proposed that students who purchased the boards from the university could opt to sell them back to the university or to succeeding students.

The total hardware and software requirements for the laboratory-practical components of the two microcontroller units are:

- A home experimentation kit, i.e. a DUET board complete with a serial-connection and power cables;
- A PC and serial-terminal program. Many

• terminal programs are freely available, either bundled with the PC's operating system or as freeware;
• A power-source (a PP9, 9v battery is sufficient); and
• Various low-cost electronics components such as resistors, Light Emitting Diodes (LEDs), pushbuttons etc.

The students are now presented with a problem and required to iterate towards their own solution. For example, in the first of the two microcontroller units, students are required to develop their own software solutions to what are reasonably complex programming problems for absolute beginners. Examples of these have ranged from simple calculator programs with a user choice of output in either binary, hexadecimal or decimal, to simulations of the traditional Australian ANZAC day game of chance called 'Two-Up' - a game based on the face combinations obtained from tossing two coins. In the second unit, students design and construct simple hardware projects and write the associated software to control the hardware. Typical examples are a LED display reaction-tester and the control of speed and direction of a small d. c. motor. These problems seem to challenge the students who in-turn assume a greater responsibility for their own learning.
This could not be achieved in the restrictive framework of traditional laboratory-practical slots.

Conclusions

This paper has considered the provision of laboratory-practicals for off-campus engineering students. The authors point to two main reasons why practical work is an essential part of the curriculum:

- It supports or supplement the concepts and theories presented in the lecture theatres and tutorial rooms, and
- It is essential to develop and polish practical skills.

Moreover, the pros and cons of five methods that can be used to ensure distance-education students receive an equivalent practical experience as the traditional on-campus cohort have been discussed. The five methods were: on-campus sessions; videotapes (or on-line movie-clips); computer simulations; home experimentation kits and remote controlled practicals. Some examples have been used to show how these methods have been incorporated into Deakin’s engineering degree courses. A case study has also considered (in detail) the issue of delivering the laboratory-practicals for two microcontroller units. It discussed the rationale behind the choice of a home kit. These kits are now used for on- and off-campus students instead of traditional laboratory-based practicals – their use in the area of microcontrollers is a recent advancement.

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References


