Distance Learning for Laboratory Practical Work in Microcontrollers*

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This paper presents a simple and relatively straightforward solution to the problems of equity in laboratory practical exposure between distance-education students and their traditional, on-campus, fellow cohort. This system has been implemented for the past five years in a university that is amongst the leaders in distance education delivery and has proved to be extremely successful and very well accepted by all students. While the intention was to allow distance education students easy access to the required laboratory practical content of the course, the solution found has proved to have many advantages for the on-campus students. Although this specific implementation is based upon microcontroller technology units in an engineering degree course, the methodology is easily transferable to other disciplines and courses.

THE ROLE OF LABORATORY AND PRACTICAL WORK IN AN ENGINEERING DEGREE PROGRAM

THERE IS ALWAYS an on-going discussion within engineering education relating to the role that laboratory and practical work has to play in engineering courses. These discussions range from concern over the amount of curricular time to be spent on practical work, to which subjects actually require laboratory-practical work [1]. Some teachers of engineering have argued that many aspects of an engineering curriculum could be successfully taught without recourse to laboratory work at all. Institute administrators, searching for means of reducing expenditure, have vociferously supported this attitude.

There are a number of cost factors involved in the development and maintenance of laboratory-practical work programs. One consideration is student-to-staff ratios. The mean student-to-staff ratio for experimental activities is around 12:1 while for lectures the ratio is typically around 30:1 or even 40:1 [2].

The other financial concern is for the resources needed for the maintenance and depreciation costs associated with the laboratory facilities and equipment, as well as the cost of the technicians who run and maintain them.

In the past engineering courses have been designed so as to incorporate laboratory work in with academic scholarship. Practical work was considered to be a support or supplement to the theoretical work of the lecture theatres and tutorial rooms, the hypothesis being that educational value is gained by periodic review of theory by way of exploration or demonstration.

Developments in competency-based approaches to tertiary education [3] 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 but skills are acquired and polished in the laboratories and workshops.

The contribution of each of the core components will vary from discipline to discipline. Some being more knowledge-based—the liberal arts would seem to be a good example of this, while it could be claimed that the social sciences demand a more attitude-based approach. Some of the newer disciplines such as computer programming and other information-technology (IT) based curricula are highly dependent upon the skill component. That is, students must have both knowledge and skills in order to write computer programs or design and build electronic circuits.

Laboratory practicals in distance education
Many Australian universities are introducing distance education into their engineering degree programs, the School of Engineering and Technology at Deakin University in Geelong, Victoria being amongst the leaders in this field [4]. All of their three-year Bachelor of Technology and four-year Bachelor of Engineering courses are offered in both on-campus and off-campus modes [5]. In order that off-campus students are not disadvantaged by their isolation, a number of issues must be addressed. These include:

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

The first four of these issues have been addressed very well [6]. Well thought-out and professionally produced course materials are distributed both in hard copy and on the World-Wide-Web (WWW). Although there is still some debate as to the suitability of the WWW for teaching [7], it has proved to be an ideal medium for courseware distribution and communications.

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 phone or WWW to be despatched via the mail service.

Peer support has been addressed by the distribution of a contact list comprising details of all consenting students enrolled in each unit. There is also the provision of conference facilities or 'chat-rooms' on the WWW.

At present, no satisfactory single solution as been found for the problem of laboratory-practicals for off-campus students.

There is a temptation to waive the laboratory requirement for off-campus students but this means placing different requirements for on- and off-campus students, which is difficult to justify in educational terms and raises real equity problems.

One common solution is to require off-campus students to attend for one weekend per semester for an intensive laboratory-practical session. While this may be practical in, say, the United Kingdom where distances are relatively small, it has obvious shortcomings in Australia where students may be scattered all over all the states and territories, and even south-east Asia. This problem is multiplied where students are taking a number of units that each requires laboratory-practical attendance.

Some units provide computer simulations of some, or all, of the practical classes. These provide an adequate solution for some subjects; control theory and digital signal processing [8] are two examples where software such as Matlab provides more-than-adequate experimental tools. Digital and analogue circuit simulators have been used in some units but, although students learn the skills of part selection and circuit design, they do not gain proficiency in the skills of measurement and diagnostic tools such a multimeters and oscilloscopes.

THE REQUIREMENTS FOR MICROCONTROLLER LABORATORY EQUIPMENT

A number of the courses offered at Deakin, for example mechatronics, electronics and computronics, include two microcomputer/microcontroller units, carrying two credit points from a thirty-two credit-point degree requirement.

Initially, when the units were offered only in on-campus mode, students attended a three-hour laboratory session for ten weeks of the thirteen-week semester. During these time-tabled sessions the students worked on Z80-based development sets. This included direct data entry via a monitor program in the EEPROM on the sets and also the use of Z80 cross-compilers on personal computers (PCs). Although thirty hours of laboratory work per semester is quite normal for an on-campus unit, it represents two or three weekends of attendance per semester for off-campus students which is generally unacceptable.

The team responsible for course development in the area of microcomputers and microcontrollers were determined that the graduating student must display competency skills in such areas as programming and debugging, circuit design, systems integration and trouble shooting. Waiving laboratory practicals could not then be considered. The use of simulations, though freely available, was also discounted as circuit design, systems integration and trouble shooting skills could not be assessed.

The final choice was to provide students, both on and off campus, with a simple 'laboratory kit'—a circuit board carrying a standalone microcomputer or microcontroller that can be programmed via the serial port of a personal computer.

The first version of such a board, the DUET board, was developed and manufactured in-house. It comprises a small circuit board, approximately $65 \, \text{mm} \times 70 \, \text{mm}$ carrying a Motorola 68HC711E9 [9] and all supporting circuitry. A survey of available hard- and software showed the Motorola 68HC11 [10] family of microcontroller to be supported by a wide range of freeware cross-assemblers, text books and other didactic materials.

The microcontroller used has 512 bytes of RAM 512 bytes of EEPROM and 12 kilobytes of ROM which, in our case, is used to contain the Motorola BUFFALO monitor program [11]. Although this may appear to be a meagre amount of memory it is sufficient for quite complex control problems. All input/output (I/O) ports of the device are available to the user via 10-pin headers and a serial port (EIA-232) is implemented to enable the device to communicate with a terminal such as a personal computer. The whole circuitry may be powered by a common 9-V battery and is quite self-contained.

The board design was kept as simple as possible to keep the cost to students down to about the

price of a text book—approximately A\$75. The two units shared the same textbook [12] enabling the cost of the textbook and the DUET board to be spread over the two units. A buy-back scheme was proposed under which the students could sell their boards back to the school but, as will be discussed later, this option has not been taken up by the students.

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

- A DUET board complete with a serial-connection and power cables.
- A personal computer.
- A power source (a PP9, 9-V battery is sufficient).
- AS11 or ASM11 freeware cross-assembler programs.
- A serial terminal program for the PC (Hyperterminal, Teraterm, PCbug, Kermit and many others are freely available, either bundled with the PC's operating system or as freeware).
- Various low-cost electronic components such as resistors, light emitting diodes (LEDs), pushbuttons etc.

The structure of the practical assignments

In the first of the two units in microcontroller technology students are introduced to the concept of the microcontrollers, their architecture and organisation and program development using a cross-assembler. They are set three assignments over the semester. Each assignment comprises a series of programming exercises, based upon the DUET board. These grade from simple understanding of programming and functionality to complex programs that require the students to fully explore the instruction set and data manipulation capabilities of the processor. There is no laboratory or practical timetabled for the on-campus students who, like their off-campus counterparts, work at their own pace, scheduling their own progress within the constraints of assignment due dates. All off-campus students are required to have free access to a personal computer while on-campus students are free to use, should they wish, the computers provided in the university's various computer labs. The unit is supported by its own web page and internal news-group. The web page provides links to related sites on the WWW as well as hints, tips and general advice for students. The student can also download their study guides and software from there. The news group provides a discussion forum for all students with the unit lecturer acting as moderator to the group and adding his own contribution as and when required.

The second of the two units builds on the first unit to introduce students to microcontroller applications—the theory and practice of integrating these devices into real, small-scale systems. As in the first unit, students work at their own pace on three assignments, or projects, over the semester. Each of the projects is based upon one of the

microcontroller's subsystems and requires the student to design and build simple circuitry, devise and write control software, and finally integrate these into a working system with their DUET boards. Some typical, past projects have included:

- An electronic gaming die using a pushbutton start and LED display (Parallel I/O subsystem).
- A programmable timer with push button start and LED display (Parallel I/O subsystem and serial communications interface).
- A three-channel voltmeter (A/D subsystem).
- Reading and writing to serial memory (serial peripheral interface).
- Small DC motor speed and direction control (timer/counter subsystem).
- Small DC motor speed measurement and control (timer/counter subsystem).

The first two projects of the semester are gauged to require around eight to ten hours of the average student's time. The final one, being more complex, requires fifteen to twenty hours of their time.

As previously addressed, the lecturer is available to all students via telephone, electronic-mail system (e-mail) and also by the unit web page on the WWW. On-campus students also have the opportunity to visit the lecturer in his office.

All students submit their assignments in the form of an executable file for the microcontroller plus a schematic diagram of their hardware, a flowchart of their program and a well documented printed listing of their source code.

Educational outcomes for distance education students

This system has now been operating for almost six years. Its initial objectives of providing distance-education students with relevant and attainable laboratory practical experience have been fully met.

Most of the school's off-campus students are in full-time employment and the system described here allows them to work at their own pace and at the times best suited to their own requirements and the demands of their employment. They spend the equivalent of thirty or more hours in traditional laboratory practical activities without having to travel to the university campus and with only a very modest outlay. The school's formal student evaluation of teaching and learning exercise has shown the units are very well received by students across the board. The level of difficulty coupled with achievement are two of the major factors that influence students in their likes and dislikes of a particular subject. In the case of these two units the level of difficulty is considered to be quite high but this is offset by the students achievement in producing small embedded microcontroller systems that they have designed and they have made to work. This latter point is an important attribute of this system. Working outside of formal laboratory setting the students have, to a very large

extent, worked on their own, taking the lecturer out of their 'learning loop'. The criteria for each of their assignments are simple and objective: 'Does the system they have designed and built perform as specified?' This allows students to iterate through the design-construct-test-modify process as many times as required to produce a system that conforms to the criteria and reliably functions to their own satisfaction.

Educational outcomes for traditional, on campus, students

The system was designed to provide distance education students with laboratory practical experience comparable to their fellow students who attend the university. Rather than being disadvantaged or deprived of existing resources, the on-campus students have shared in the benefits granted to the off-campus group. They too are free to work at their own pace and to iterate through possible solutions free of the constraints of fixed-length timetable slots. All staff involved were pleasantly surprised by the students' attitude to this form of learning. With very few exceptions students welcomed being given practical assignments in which they could determine their system's and their own performance against the stated criteria. Feedback from student assessment of teaching and learning has often pointed out the feeling of accomplishment gained when they, eventually, got their systems working to specification. It seemingly raised their self-esteem. Engineers, it would seem, like to be regarded as having the practical, hands-on touch.

DISCUSSION

The system described does not simply take the laboratory to the students instead of taking the students to the laboratory; rather it bestows both freedoms and responsibilities on them. It gives the student the freedom to assay well-defined projects at their own pace and by their own methods while making them responsible for their own time and resource management.

Lecturers are relieved of the onerous tasks of providing laboratory supervision and constantly monitoring and grading the students' progress. They have become a resource for guidance and advice when requested. The school has freed-up laboratory space and been saved the expense of re-investment in aging laboratory equipment.

One further surprising aspect is the number of uses found for the DUET boards after completing their microcontroller units. As was mentioned earlier, the School initially had a buy-back policy for the DUET boards. However, no student to date has taken up this opportunity. They have used their boards in their final-year design-and-make projects as well as in a final year unit in mechatronic design. Students have also constructed home-weather stations, electronic compasses, model train controllers and global positioning systems (GPS) to personal computer links to name only a few of the extracurricular uses found for them.

Following the continuing acceptance of this initiative, other unit coordinators within the school are testing or introducing similar schemes, some with remarkable success.

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