AC 2012-4141: UNDERGRADUATE ELECTRONICS STUDENTS' USE OF HOME EXPERIMENT KITS FOR DISTANCE EDUCATION

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Undergraduate Electronics Students Use of Home Experiment Kits for Distance Education

Abstract

Laboratory practicals form an essential component in any electronics or electrical-engineering course. Many students choose to study engineering by means of distance education. Providing such students with effective and manageable practical experience has always been a significant challenge for those involved in providing distance education. Our university has employed an experimental electronics kit for teaching laboratory skills to distance-education students over the past several years. The chief limitation of the early kit was the inability to use it for performing AC experiments without an additional AC signal generator and an oscilloscope. We now supply distance-education students with the original components pack, and an additional "HELP" kit which contains the signal generator, PC-oscilloscope, a basic multimeter, logic probe, software and documentation. The combined kits allow these students to perform basic DC and AC electronics experiments at home in both freshman and sophomore electronics courses. A more recent development is introducing a small robot platform intended to enhance the student experience and interest in electronics and mechatronics, while still covering the basic skills necessary for the engineer-in-training. Distance-education students receive an updated experimental kit containing the robot, other equipment and components to allow them to complete a fuller suite of practical exercises in electronics in their first two years of study. Within this paper, we present these developments in our HELP kit and also make comparisons between on-campus and off-campus performance.

Introduction

Laboratory practice is an indispensible part of any engineering course. In most cases, the practical components are of equal importance to the theoretical and mathematical components. In electrical engineering and in electronics, this is particularly true. Students in electronics and in electrical engineering must learn how to build, test, trouble-shoot, and design discrete circuits, systems, and sub-systems. A typical electronics course contains a number of hands-on exercises that the student performs while under the supervision of a lab instructor. More often than not the practical exercises are performed on-campus in a teaching laboratory.[1]

Distance education or off-campus delivery was an important innovation in teaching in the late 20th century.[2-5] Students are now able to complete whole university courses at home without the need to attend on-campus classes. This arrangement suits many students who due to family or work commitments, or through physical isolation, are unable to attend on-campus classes. Distance learning has become more common in recent years with the rise of the Internet, multi-media technology, and on-line learning. Since 1991, Deakin University in Australia has offered a complete undergraduate engineering major by means of distance education.[6] While many of our off-campus students live within 100 km of the home campus, a significant number live interstate, and a few live overseas.

One of the greatest challenges in distance education is providing training in practical skills, especially in engineering.[7-9] There have been many approaches to address this problem.[10,11] The first solution is to offer on-campus lab classes, generally in the evening or on weekends, which off-campus students attend. On-campus lab classes have the disadvantage in that students who live very far away from the campus (interstate, for instance) would be unable to attend. In any case, those who can attend lab classes running for one to three days still have a time limitation in the lab. Learning practical electronics requires a great deal of time learning practical skills and building confidence.

Another common solution has been to use computer-based simulations for specific electronic circuits and systems, which the student can perform at home.[12,13] Indeed there are a large number of excellent software packages available for electrical and electronics simulation, such as PSPICE, Proteus, or NI-Multisim. While software packages have many advantages (flexibility, low cost, ability to simulate complex circuits quickly, ability to determine trends from changing inputs or components), they do not teach practical skills, such as assembling circuits on a breadboard, soldering, component handling, safety, and operation of test equipment.

A third solution employed in many universities is to offer real-time practical exercises that can be performed by remote control.[14-18] This approach became popular as the Internet and its applications grew. Internet control of specific laboratory practicals has developed in many areas of engineering education, including both electrical engineering and mechanical engineering.[19-22] (Some universities use remotely controlled exercises as means to reduce congestion in crowded on-campus lab classes.[23]) Remote control of specific lab exercises is usually limited to very specific circuits in very controlled conditions. It also requires a technician to operate the host equipment and perform troubleshooting operations.

Since 1996, the Deakin University School of Engineering has issued off-campus electronics students with a components kit.[24] The students originally used this kit to perform a series of basic digital experiments and a limited set of analog experiments. On-campus students completed the same experiments in the lab with the assistance of an instructor. This arrangement worked well with one key disadvantage. Experiments requiring an AC signal generator and oscilloscope could not be completed in a student's home because the necessary test equipment was beyond the means of the average student. Thus off-campus students still used computer simulations to perform such classic experiments as the full-wave rectifier, transistor amplifiers, and the op-amp integrator. The kit has gone through a number of stages to continuously improve its effectiveness as a teaching tool. Off-campus students receive this kit free-of-charge as part of their study pack. A typical kit contains about $30 in components, including a breadboard and pack of jumper wires.

In the absence of low-cost signal generators and oscilloscopes, we developed a prototype test package that included a battery-powered AC signal generator and PC-based oscilloscope (PC-CRO) package.[25] Both battery-powered, hand-held signal generators and PC-CRO's became commercially available a few years later. With this development, our experimental package delivered to off-campus students was expanded to include the original components pack plus an additional "HELP" kit.[26] The HELP kit (figure 1) contained essential, but low-cost test equipment required in any electronics workshop:

- A battery-powered audio signal generator (Digitech QT-2302).[27]
- A two-channel PC-USB oscilloscope and accessories (PoScope).[28]
- A logic probe.
- A digital multimeter.
- Documentation and a CD that contains manuals and software.
- Probes and test leads.

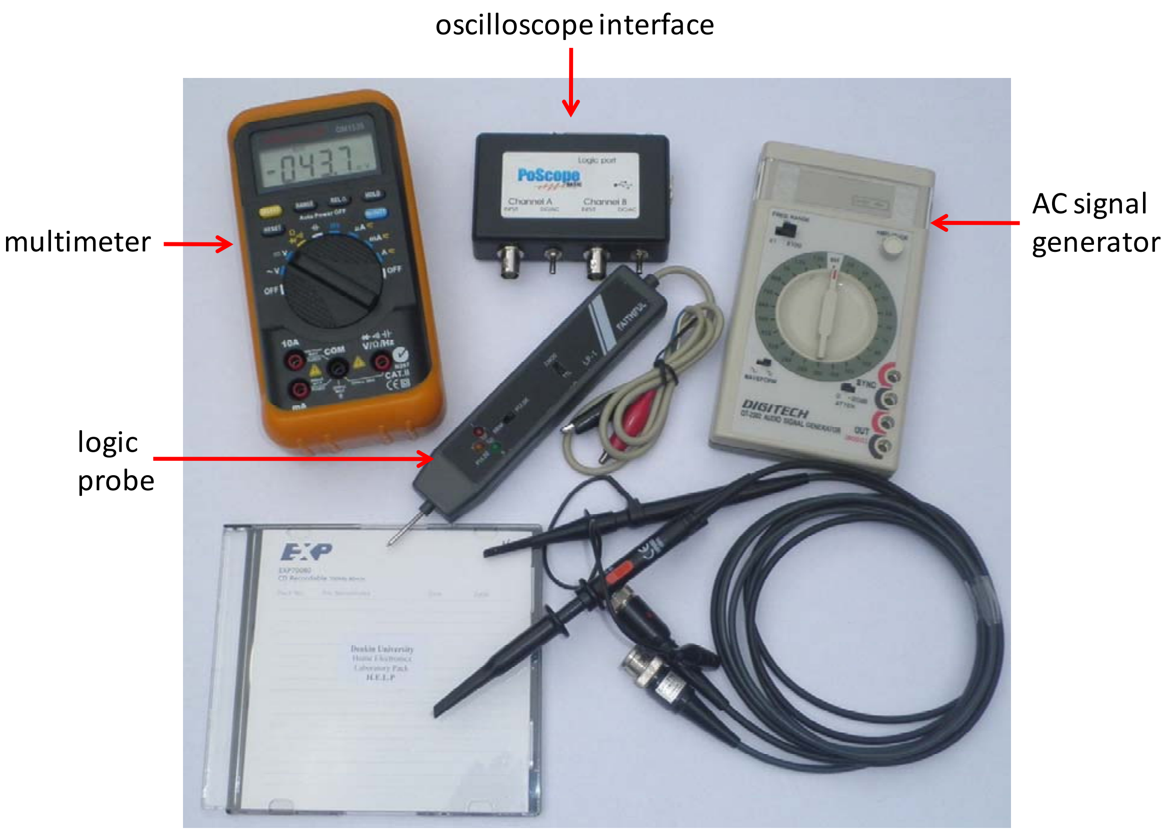

Figure 1: The Deakin University H.E.L.P. kit.

The significant costs in this kit are the signal generator ($85 each) and the PoScope ($220 each). Students were loaned this kit for the semester, with the option to purchase it. The key components are the signal generator, and the oscilloscope interface and software. The remaining items make the package more complete. We used the HELP kits for the first time in 2008.

The final development in our HELP kits is the inclusion of a small robot platform. The robots were used within in the experimental program in 2009 and 2010. This paper reports on the use of and development of the HELP kit to facilitate off-campus practicals. We present our work for the three years 2008-2010.

The Lab Course

The lab experiments ran in the context of a first-year electronics course. The pre-requisite was introductory physics (which covered the basics of DC electric circuits, but not AC circuits). Delivered July-October, over 13 weeks, the course was divided into three parts:

- Digital systems – four weeks
- DC network theorems and AC circuits – three weeks
- Analog electronics and devices – six weeks.

The student breakdown was typically 75% on-campus, 25% off-campus, with a total enrolment of around 90 students. The laboratory experiments were divided into digital exercises and analog exercises.

Experiments for 2008

The 2008 lab program was divided onto two parts: digital (part A) and analog (part B). Table 1 shows the activities associated with each part. The experiments were modified from our earlier program to include more AC measurements. The introduction of the HELP kit allowed us to eliminate the need for computer simulations in the analog experiments.

Exercise	Activity
A1	Introduction to the breadboard and the transistor
A2	Basics of logic gates
A3	Universality of NAND and NOR gates
A4	Equivalence of Boolean expressions
A5	Combinational logic circuits
A6	Flip flops
B1	Voltage dividers and multimeters
B2	The oscilloscope
B3	Diodes and rectifiers
B4	Introduction to bipolar transistors
B5	Op amps – open-loop operation
B6	Op amps – closed-loop operation

Table 1: 2008 lab exercises assigned in first-year electronics.

The Robot Platform

Over the years, when speaking to students enrolled in this unit, the comment was repeatedly raised that the lab exercises, while necessary, were neither exciting nor interesting enough.

Students claimed to find it difficult to see immediately the practical application of the circuits they build and test.

To this end, in 2009, to make the lab exercises more interesting for the student, and to demonstrate some immediate practical applications of the experiments, we introduced a robot platform with which the students perform their practical exercises (figure 2). The robot platform gave students a base on which to build the experiments, and demonstrate practical application of electronic circuits, while still covering the required course content and teaching the skills necessary for students to become proficient in electronics. The detailed integration and analysis of the robot practicals into the electronics experiments is the focus of on-going research work, and are not presented here. Rather, we discuss the inclusion of the robots as a component to the off-campus kits.

The output signals from the various experimental circuits, both digital and analog, were used as control inputs for the robot. Thus in addition to observing how, for instance, a combinational logic circuit performed various operations, the students could see how the logical operation being performed affected the operation of the robot. And they could see how changing an original input, or changing the control circuitry, affects the robot's motion.

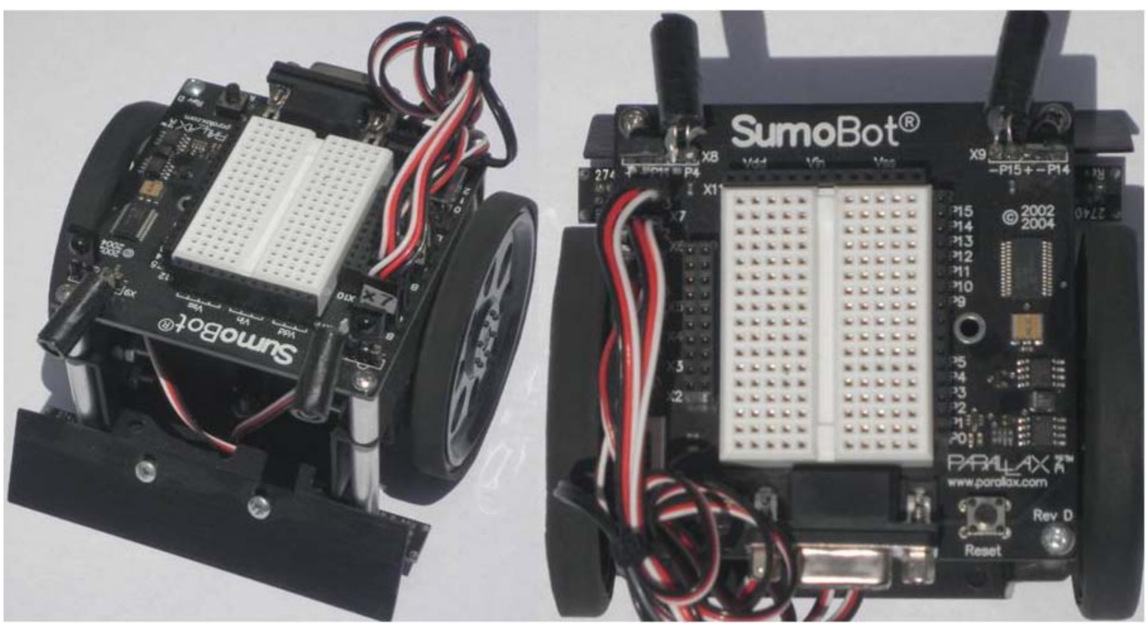

Figure 2: The Parallax Sumo-Bot.

The robots were from Parallax.[29] We obtained a number of "SumoBot" robot competition kits (cost: $200 each). Each kit comes with two robots and a competition ring. The SumoBot provides a battery power source (or DC input), a breadboard for developing circuits and an interface allowing the outputs of the electronic circuits to move the SumoBot around. The robot has mounted on it two sensors for detecting obstacles and two sensors on the bottom for detecting white and black lines. The drive is provided by separate servo motors connected to each wheel. Control on the robot is via a Microchip 8-bit PIC16F57 microcontroller. Instructions written in BASIC are downloaded to the microcontroller. The robots can be used either as a stand-alone breadboard or as a complete, mobile robot. We used both settings in our experiments because some exercises were unsuitable for driving the robot around. The robots also come with a dedicated text on applied robotics.[30]

Each off-campus student or on-campus student group received a pre-assembled robot with a pre-programmed set of instructions. The robots were only programmed to drive forward, stop, or turn for specific control inputs. The original experiments were revised to work with the robot, maintaining a total of 12 exercises. We maintained the basic flavor and goals of most experiments from the earlier years. The experiments were developed specifically to interface with the robot, but again included both digital and analog exercises. One of the new experiments applied the skills learned earlier in the new series to drive the robot around obstacles.

Evaluation of the Kits and the Lab Program

Student reporting of their lab work and results has not changed over the years. The student assessment is essentially the same as was previously reported. All students write basic reports on all experiments in a lab notebook. Lab instructors grade all the students' reports on a scale from one to ten, ten being the top score. The student reports were checked for completeness of the experimental work, the structure of the reports, the results, and grammar. In 2008 separate grades were recorded under the two headings Digital and Analog. In 2009-2010 the grades were separated into experiments 1-6 and experiments 7-12. Table 2 shows the average scores on each type of report for the past six years. We also list summary scores for 1999-2003.

Year	Total on-campus assessed	Total off-campus assessed	Average on-campus Digital score	Average off-campus Digital score	Average on-campus Analog score	Average off-campus Analog score
1999-2003	73*	24*	7.0	7.1	6.1	5.6
2008	66	11	8.2	8.9	8.0	8.3
			Scores exps. 1-6		**Scores exps. 7-12**	
2009	83	12	8.9	8.9	8.5	8.9
2010	89	16	8.1	7.9	8.2	7.8

* average

Table 2: Average lab-report grades for on-campus and off-campus students over the years 1998-2003. The maximum possible score is ten.

From 1999-2003 to 2008-2010, the average number of on-campus students assessed has increased by 8%, whereas the corresponding number of off-campus students has decreased by 46%. While both on-campus and off-campus scores increased in 2008 compared with 1999-2003, this increase is more marked for the off-campus students. Also, in 2008, with the introduction of the HELP kit and a small number of off-campus students, the off-campus scores are higher than the on-campus scores for both digital and analog experiments. These results are consistent with trends seen across the whole Engineering School. A detailed study completed in 2002 showed that the overall Engineering grades are higher for off-campus students than for on-campus students.[31] Thus we suggest that eliminating AC computer simulations and introducing the HELP kit had a positive overall affect on the off-campus learning outcomes.

The results for 2009-2010 are more mixed. On and off-campus students obtained the same or higher scores in 2009 compared with 2008, but lower for both in 2010. However, the student grades for 2009 were the same or better than in 2008, and the experiments in these two years were identical. The robots were used in both years. This suggests that further work is needed to assist off-campus students with their experiments.

The response from students on the use of the HELP kits has been very positive. At the end of 2008 the students who used the HELP kits for the first time were given a basic questionnaire to determine how they received the new kits and experimental procedures. It posed six questions:

1. Did you have any problems during the installation of the PoScope oscilloscope package?
2. Did you have any difficulties learning how to use the signal generator and PoScope?
3. Was the documentation found on the CD satisfactory?
4. Was the equipment supplied in the HELP kit satisfactory to successfully complete the requirements of the practical experiments?
5. Would you have preferred to complete the practical experiments on campus during a weekend?
6. Would you like to see the HELP kits offered in other practical units?

Not surprisingly, the number of returned surveys was small. However, feedback from this survey and further correspondence with off-campus students by email and telephone in 2008 and 2009 revealed that the students were generally happy with the new kits. They found the POScope software installation straightforward, the signal generator easy to use, and the documentation satisfactory. They all said that the analog pracs were especially difficult, but only a few students indicated their preference to perform the experiments on-campus. All students intended to use the kits in further electronics courses. (We later designed the experiments in second-year analog electronics, to also make use of the HELP kits.)

The students' response to the inclusion of the robot platform was overwhelmingly positive. All students, on-campus and off-campus, enjoyed the practical exercises much more with the robot kits than without them. Many students reported that the lab exercises became fun when they used the robots, and they could see very practical outcomes from their lab work.

One key shortcoming of the robot kits was that the breadboard on top of the robot was too small to fit some of the more complicated circuits. An experienced technician could get by, but students new to electronics need more breadboard space to build their circuits. Extra space was also needed to follow wires and connections for trouble-shooting. The solution was to use a larger breadboard for the main circuit, then run long jumper leads to the robot power sources and control inputs. This limited the mobility of the robot somewhat, but the compromise was worthwhile. The robots also required maintenance each year after the students returned them. In particular the trim pots controlling the balance to the drive motors needed to be readjusted each year. In a few cases non-balanced motors caused a robot to drive in a curve when it was supposed to travel in a straight line, which confused those students using them. Queries from off-campus students were usually answered by telephone and email.

In our previous work, we suggested the need for a dedicated companion website for first-year electronics. We suggested that such a website "…contain photographs of all the components in the kit, further instructions on reading data sheets and color codes, and photographs of select circuits to help the student get started."[24] We took this idea a step further by producing a short video series on the first-year experiments (figure 3) to accompany the HELP kit. Each video contains a short multi-media presentation on the experiment, its theory, aims, and hints. This was followed by video footage and commentary of the instructor actually performing the experiment. The videos were then made available to all students via the course website.

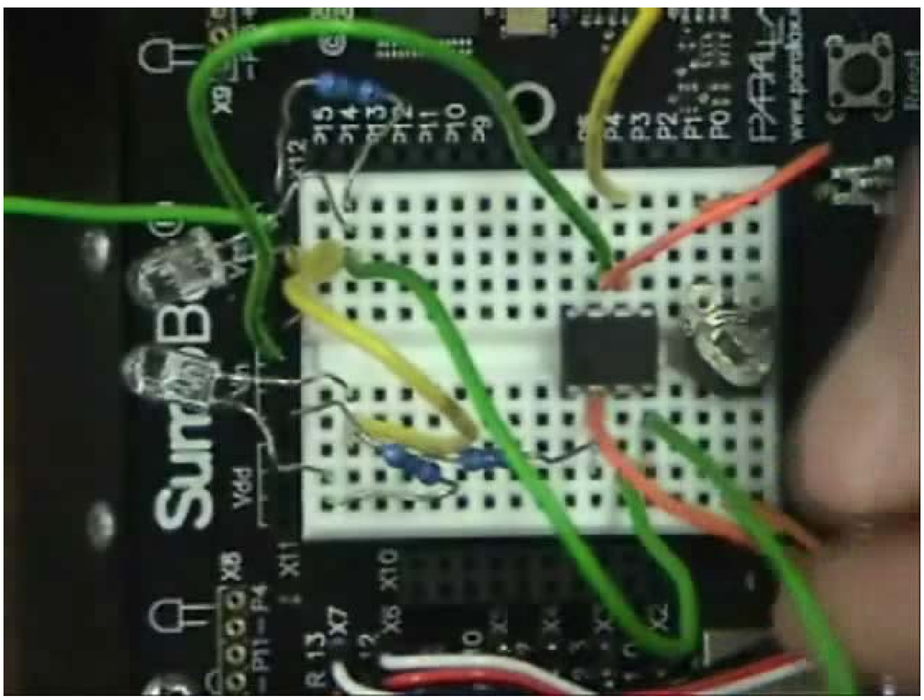

Figure 3: Screen-shot from a video showing students how to perform experiments 11 and 12, operational amplifiers.

Discussion

For many students who later become electrical or electronic engineers, developing a home electronics workshop often starts with a beginner's electric/electronics kit. These kits are widely available from toy stores and hobby shops. Such a kit often has components to build flashers, alarms, sensors, radios, and simple amplifiers. More advanced kits offer challenging projects such as building power supplies, sound synthesizers, and power amplifiers. A very popular modern kit is Lego Mindstorms, where one can build and program simple robots. These hobby kits do assist in teaching electronics, but in general, not in the systematic and mathematical way that is taught in a typical university course. Very often a typical introductory electronics experiment consists in building a specific circuit, then testing that circuit while varying some key parameter, such as an input signal or DC bias. Recreational kits and experiments in a university electronics course have very different purposes. The former is designed for building specific devices (often for entertainment) and the latter is for teaching more systematic skills such as circuit analysis, testing, and especially design. For example, a recreational electronics kit may teach one how to build a working transistor amplifier that may drive a small speaker. The corresponding components in a university laboratory course would be used to investigate load lines and the effect of DC bias on the performance of the amplifier. Bias resistors could be changed to put the amplifier into saturation or cutoff. Then through a speaker, the student could hear what happens when the amplifier circuit is not designed correctly. The same components together with an AC signal generator and oscilloscope would allow the student to investigate frequency response and bandwidth in electronics.

We believe that one of the best ways for students to learn basic electronics is to encourage them (even on-campus students) to develop their own electronics workshop at home. Our kits are designed to replicate the components and test equipment found in the on-campus laboratory as much as possible, and to give off-campus students a similar practical experience to that of the on-campus students. Until recently, the main stumbling blocks for any student trying to put his home workshop together are the cost of the oscilloscope (around $1000 for a good one) and the signal generator ($300+). While cost of test equipment has come down over the years, these two key pieces of equipment are often beyond the reach of most beginning students. The hand-held signal generator and oscilloscope we use are much more affordable for the average student and have the functionality required for most experiments and home projects. Our students borrow the HELP kit and the robot with the option to purchase them outright. The small size and weight of the kit also helps us to keep shipping costs down. The overall costs to the School are absorbed into the yearly budget for off-campus teaching.

In recent years a number of other engineering schools have developed teaching kits of their own for teaching electronics and electrical engineering. The Mobile Studio was introduced in 2007 with similar aims to ours.[32,33] This kit contains hardware and software for producing and measuring DC and AC signals. The kit is employed in studio-based lab teaching for conventional on-campus students. In 2009 the Virginia-Tech Lab-in-a-Box kit was introduced.[34] Again, this kit contains similar components and sub-systems to ours. It interestingly uses a computer’s sound card for the oscilloscope input, similar to that in our first attempt at designing a PC-based oscilloscope.[25] The developers of this kit aim to have students complete some lab exercises at home in addition to performing their on-campus experiments. To help ease overcrowding and scheduling problems in large electrical-engineering courses, Kansas State University and East Carolina University developed the “Rapid Analysis and Signal Conditioning Laboratory” (RASCL) in 2010.[35,36] The single integrated unit is a tool for analog and digital prototyping and is controlled by LabVIEW. These kits and associated practical exercises are employed in a similar manner and with similar practical goals as those we have developed with one very important difference.

The Mobile-Studio, Lab-in-a-Box, and RASCL kits are employed for conventional on-campus students to enhance at-home activities, reduce overcrowding in labs, or allow students to work in smaller studio groups. The experiments are still conducted at the host university and the students attend on-campus classes each week. In contrast, the off-campus students that use Deakin's kits for their experiments do not come on campus at all for the duration of the course. They perform their experiments completely at home, and their only contact with the lecturer is by telephone, email, or via the course's website. Again, many of these students live more than a day's drive from the home campus. Some of the students live in very remote parts of Australia. Thus for them, on-campus attendance is impractical. Deakin University's program delivers practical instruction to many students who otherwise would not be able to complete a conventional on-campus course in electronics.

Future Developments

In 2011 the first year of the Deakin Engineering major was extensively revised to accommodate the introduction of new programs in civil and electrical engineering. The course was changed from electronics into a new course on fundamentals of electrical engineering. The analog component of the course was partly retained, with the digital component transferred into second year. The practical exercises were rewritten to include more exercises on basic circuit theory. The original components kit and the HELP kit were used by some off-campus students, and the remaining students attended on-campus practical sessions. Our next step is to rework the off-campus practical program to fit in better with the new course structure. The components kit and the original HELP kit will remain integral. Given the significant changes to first-year, the robot was removed for 2011. However, the HELP kit will allow off-campus students in particular to begin developing their personal electronics workshop. The students will also find kit quite useful in later-year electronics and mechatronics courses.

The number of first-year off-campus students has increased from 16 in 2010 to 33 in 2011. In semester-two 2012 we expect over 50 students to complete this course. Delivering an off-campus practical program to them will be a challenge. The new techniques employing more modern computer, instrumentation, and Internet technology will be a key component of the new lab exercises we develop. And the off-campus students we serve will make a superb testing ground for the new ways of teaching electrical engineering outside of the traditional on-campus lab setting.[37]

Conclusion

A key component of any electronics or electrical-engineering program is practical work. Providing workable practical exercises to distance-education students in electronics is a tremendous challenge. For over 15 years we have employed an electronics kit issued to off-campus students so that they can complete some or all of their lab experiments at home. To our knowledge, we were the first, and now are one of the few engineering schools that employs kits in off-campus teaching of electronics. While the DC and digital experiments worked well with the kits alone, the off-campus students were unable to perform AC experiments at home due to their lack of AC signal generators and oscilloscopes. We have now rectified this problem by introducing a new HELP kit that contains a battery-powered signal generator and an interface that allows a home computer to be used as an oscilloscope. Trials of the new kit have resulted in enhanced student learning, greater convenience for off-campus students, and a better learning experience. The new kits also help students to complete their electronics workshop, which any student in electronics needs to develop. We also introduced a small robot as a new platform on which all students complete their experimental work. This robot was well received by the students as making the practical exercises more interesting and enjoyable. The results given here indicate that in spite of increasing complexity over the years, the use of experimental kits remains an effective means for teaching electronics to first-year undergraduates.

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