AC 2009-784: A PROJECT-BASED LABORATORY FOR A COMMON FIRST-YEAR ENGINEERING COURSE

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Project Based Laboratory for a Common 1st Year Engineering Course

Abstract

Engineering disciplines at the University of South Australia have a reputation of offering programs with a strong emphasis on developing hands-on skills highly valued by the engineering profession. These skills are developed gradually over four years of engineering programs. Traditionally all technical courses include laboratory component in the form of a number of set experiments where each experiment aims to verify one or more theoretical concepts. Through these sessions students also learn how to wire circuits, use instruments, interpret measurement results and develop appreciation for errors and imperfections present in real measurement data.

However, our experience shows that students are not very motivated by this type of experiments often resulting in missed learning opportunities. Final year projects have proved to be much more motivating and thus a more effective way of learning. Yet, the majority of first year students have very limited practical skills and technical knowledge which makes this type of design projects very difficult to run, particularly for large classes. They demand extensive resources especially extra academic staff time to help students to successfully complete the projects.

In 2006 a traditional set of five independent laboratory experiments was replaced by a project-based laboratory in a 1st year electrical engineering course. During six 2-hour sessions students build a fully functional pre-designed power supply, which they keep and use in follow-up courses. This development was supported by a University of South Australia Teaching and Learning grant and was very well received by students.

In this paper we present how the power supply project is successfully complemented by two additional projects that are more suitable for civil and mechanical engineering students, when the electrical engineering course became common for all engineering disciplines in 2008. The approach is likely to be suitable for engineering programs elsewhere.

Introduction

Practical skills are highly valued in engineering graduates by professional engineering accreditation body as well as by industry employers. At the University of South Australia (UniSA) the development of these skills starts from the very beginning of all engineering programs and is closely monitored, gradually developed and nurtured throughout the duration of each program. Over the years this approach has earned Unisa a reputation of being a university which offers programs with a strong emphasis on developing hands-on skills.

Over the past decades the interest in studying engineering disciplines among local students has been rapidly decreasing. On the other hand the competition among universities to attract students has increased. Consequently, the senior management team made a strategic decision to capitalize on the reputation of being a hands-on university by further advancing the practical component of student experience in all programs and courses. As a result, all courses have been reviewed with an aim to expand and to improve quality of the practical component in courses where it has already existed and to introduce experiential learning in courses which did not have it.

As part of this process, the practical component of the first year course *Introduction to Electrical Engineering* was reviewed and a Teaching and Learning Grants were obtained in 2005 and 2006 to develop a project based laboratory that would replace the set of five independent laboratory experiments in the course. It was envisaged that students would gain the same practical skills in wiring circuits, using laboratory instruments and performing measurements, but it was anticipated that working on a project would be more motivational for students than independent experiments which reinforce theory covered in the course curriculum.

The project based laboratory has been developed and successfully implemented since 2006 in the previously mentioned first year course taken by students enrolled in electrical engineering disciplines. The laboratory was based on a small project where students assemble and test an electronic power supply over six 2-hour laboratory sessions. Student feedback was sought and the surveys showed a large majority of students (>88%) agreed or strongly agreed the project motivated them to learn more and they were highly satisfied with the quality of project-based laboratory[1].

However, in 2008 engineering programs of all disciplines, including civil and mechanical engineering have been restructured with the aim to introduce more commonalities between programs. This resulted in a common first year for all three engineering disciplines, with the course Electrical and Energy Systems becoming a common 1st year course that covers fundamentals of electrical engineering relevant to electrical, mechanical and civil engineering professionals. This prompted introduction of two additional projects considered to be more relevant and motivational to mechanical and civil engineering students. Consequently three different projects have been developed for each discipline, namely:

- Power supply for electrical engineering
- Racing car for mechanical engineering
- Moisture probe for civil engineering.

The racing car and the moisture probe projects have been developed by Mr Derek Fuller as part of the Australian School Innovation in Science, Technology and Mathematics (ASISTM) project supported by Australian Government (http://asistm.gotdns.org/~asistm/) aiming to improve the ways in which science, technology and mathematics are taught in schools.

Although each of the three projects is recommended for one discipline, there are no hard constraints in the choice of the project: students are encouraged to select the project allocated for their discipline, but they are allowed to select different projects. The reason for this is twofold: firstly, it is envisaged that some students may change the selected discipline at the end of the first year so they may like to taste the work flavor of another discipline during the common first year; secondly, students work in groups of 2-3 not necessarily from the same discipline or working on the same project. Students from one group can choose to assemble only one electronic device or two or one each, i.e. the group collaboration is not limited to the production of a common device.

The collaboration is rather in helping each other by sharing knowledge, skills and experiences. The only constraint for the group work is in the domain of writing a joint report. Students working on different projects are not able to collaborate on the same report.

Projects

In the project based laboratory we implement projects designed to suit first year engineering students with no assumed prerequisite knowledge in electrical engineering and no practical laboratory skills. The course has three hours of lectures per week. Two hours per week are spent on basic electrical engineering (EE) principles and one on discussing the projects. During these sessions students learn about components, their functions and performance when interfaced with other components. Also, basic EE principles are reinforced in these sessions on examples of simple circuits implemented in the projects. The sessions gradually cover project topics and modules as students are progressing through their projects.

It is important to clarify that here we use term project in its broadest meaning, acknowledging that most education researchers would not regard what we describe here as a project because it does not involve problem-based learning[2]. However, Kolmos usefully differentiates between three types of project work based on a different level of freedom that students have [3]:

1. *Assignment project* where the problem, the tools (methods) and outcomes are all well known in advance and the supervisor can fully control these.
2. *Subject project* where the subject is well known and students have freedom to choose either a problem within the subject or methods for a pre-defined problem.
3. *Problem project* where even the problem itself may not be well defined. Thus, students need to first fully specify their own interpretation of the problem and the outcomes of the project, and then select or develop suitable methods for its implementation.

We selected the assignment project as the most suitable type of project for the students enrolled in this common first year course because of their very limited technical background in the subject matter. In this course students have six 2-hour designated practical sessions in the electrical engineering laboratory over the 13-week study period. In this short period it is unrealistic to expect students to do more than become familiar with some common components, learn to operate common measuring instruments and follow a given testing procedure through to the drawing of appropriate inferences and to develop practical skills in soldering, circuit wiring, and, where necessary, fault-finding and rectification.

Power supply

The project requires students to build and test a simple electrical/electronic power supply. The schematic diagram of the whole project is shown in Figure 1. For safety reasons the project does not include the mains transformer which is normally part of a standard power supply[4, 5]. Instead, an external 230V/10V AC/AC adapter is used to connect the circuit to the 230V, 50Hz power supply. On the other hand the project includes some additional electronic circuitry to make it immediately useful in practical work for a follow up course. Figure 2 shows the completed power supply.

In the course of the project students not only gain knowledge about components and diagrams, but they also have to make a cognitive connection between the diagram and the actual product they eventually build. For a novice to electrical engineering there is certainly a big difference between the physical product shown in Figure 2 and its schematic diagram shown in Figure 1.

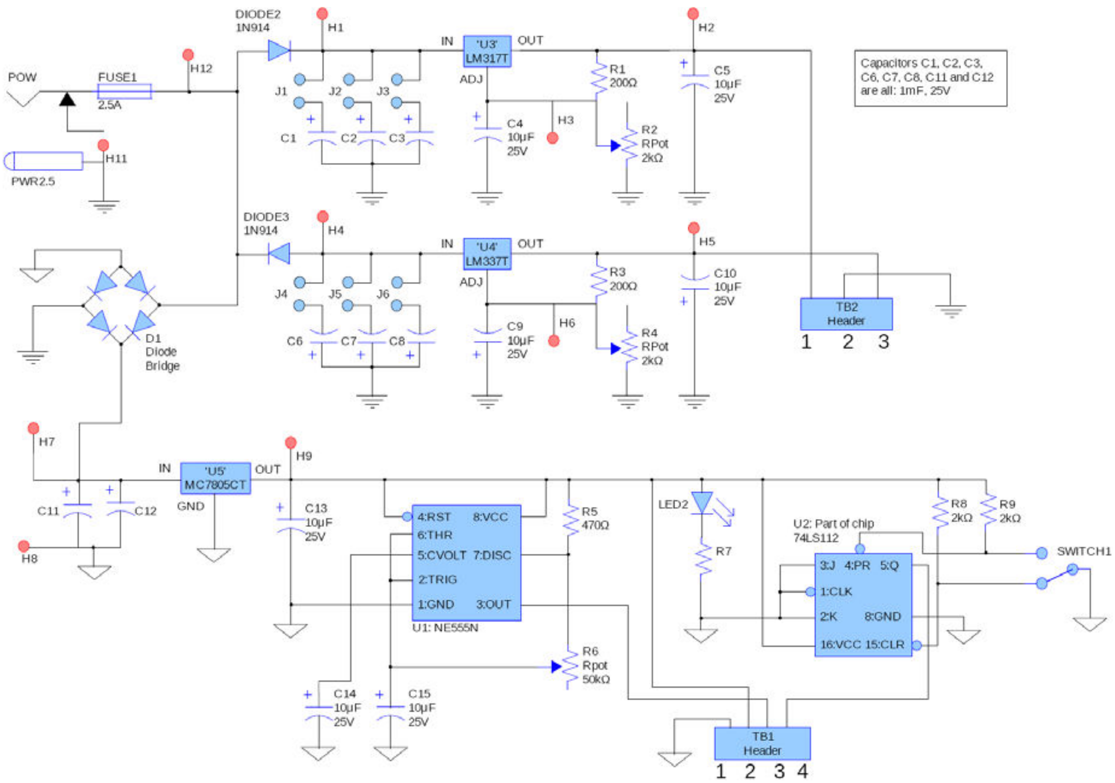


Figure 1. Project schematic diagram

Figure 2. Completed power supply

The power supply has three modules:

1. Fixed +5V regulated power supply including:
    Full-wave bridge rectifier
    Filter
    Regulator
    +5V LED indicator

2. Two regulated variable power supplies including:
    Two half wave rectifiers
    Filters
    Two regulators
    +1.5V to +12V adjustment subcircuit
    -1.5V to -12V adjustment subcircuit

3. Auxiliary TTL logic circuitry including:
    Variable clock generator with 555 timer/oscillator
    ON-OFF logic output with JK Flip-Flop

Each module is completed in steps. After each soldering step students perform a set of measurements on the completed part of the circuit. This way, students learn in detail functionality of the components and how they operate when interfaced with other components. This approach not only enhances student learning but also provides sequential troubleshooting procedure which maximises the successful outcome of the project as each fault is imediately detected before more complex circuit is completed.

In each practical session students complete one of these modules. In addition to these three sessions there are two introductory sessions covering soldering practice and circuit simulation using NI Multisim® simulation software. The final session is allocated for overall product testing including load tests. During this last session students demonstrate their product to the practical supervisor for assessment.

Racing car

Students enrolled in mechanical engineering disciplines are encouraged to select the racing car project. A final product is shown in Figure 3.

Students are supplied with both electronic and mechanical components together with a printed circuit board (PCB). The block diagram of the project is shown in Figure 4 and includes microcontroller PIC12F675, of Microchip Technology Inc. As microcontroller programming is beyond the scope of this first year course, students are provided with a ready-made program which they download to the microcontroller using Microchip PICkit™ 2 Development Programmer/Debugger and MPLAB IDE software. However, students get to keep the car at the end and may wish to learn programming later in their program. The car has two motors that can be controlled and a number of sensors like light dependent resistor (LDR) that can be used to program the car to perform different functions such as line following, object avoidance, etc.

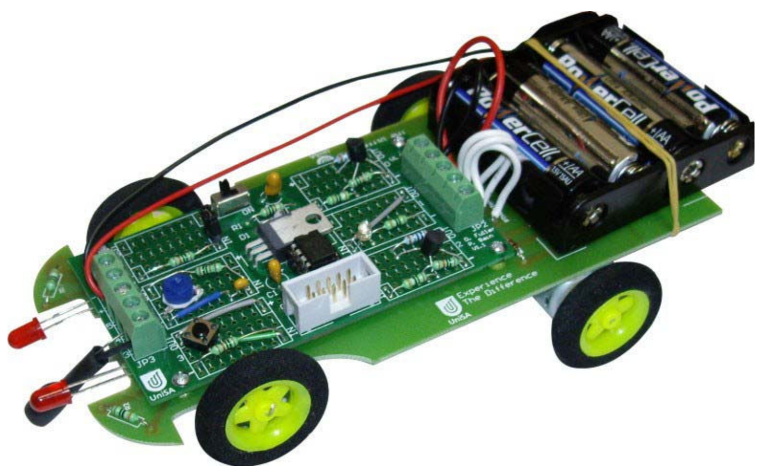


Figure 3. Completed racing car project.[6]

The work on this project is also modular. During each session students complete one of the assigned modules including soldering components and testing the completed module. This way students are in a better control of the progress of the project then if the testing was done after the completion of the whole product. It also helps laboratory supervisors to teach first year students troubleshooting rather than doing it for the students.

A schematic diagram of the first module and its implementation are shown in Figures 5 and 6 respectively. This module is the central part of the project and includes the microcontroller and a regulated power supply.

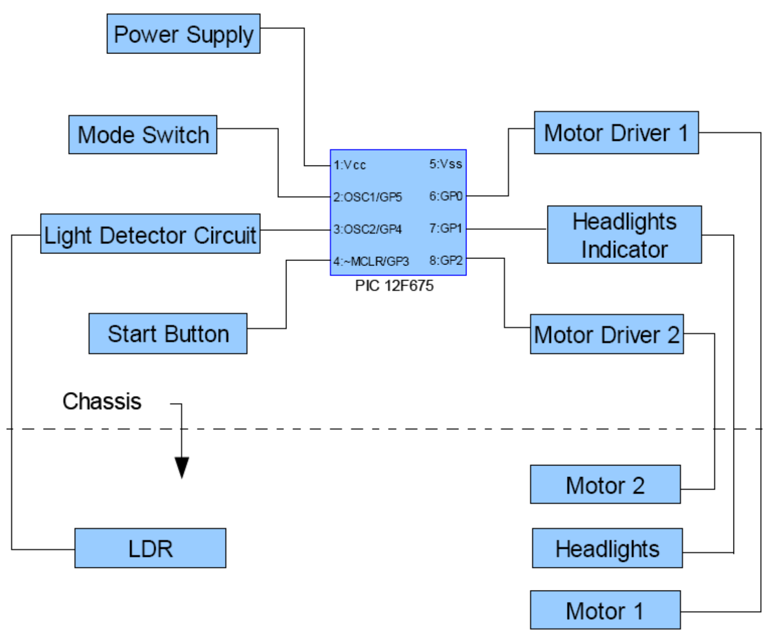


Figure 4. Block diagram of the racing car project.[6]

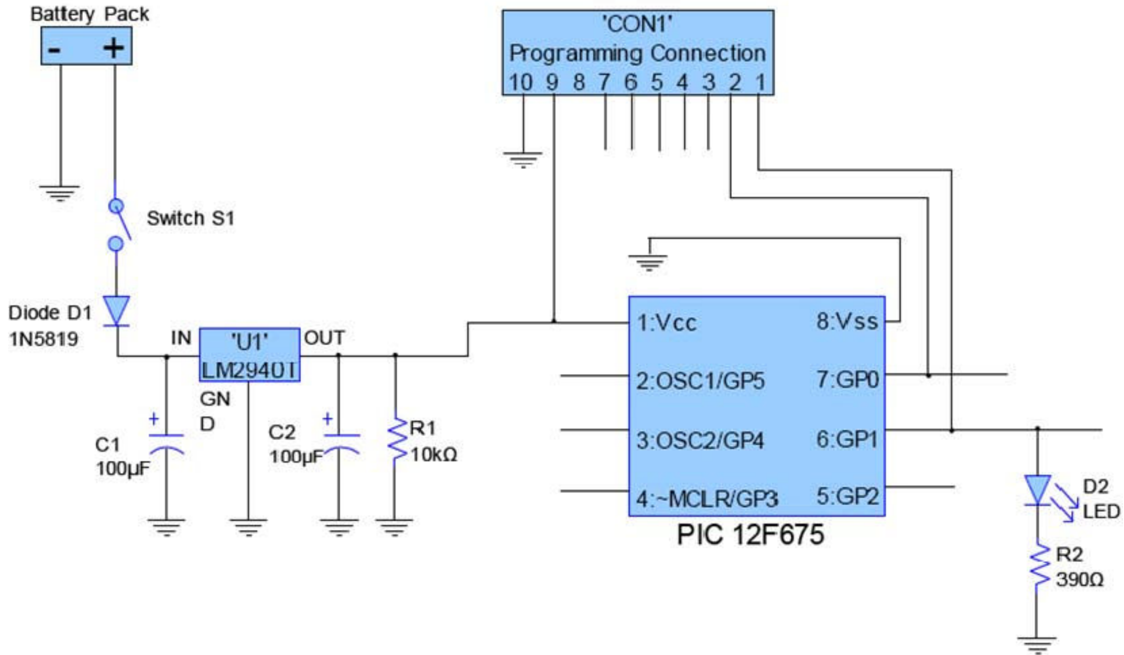


Figure 5. Schematic diagram of Module 1.[6]

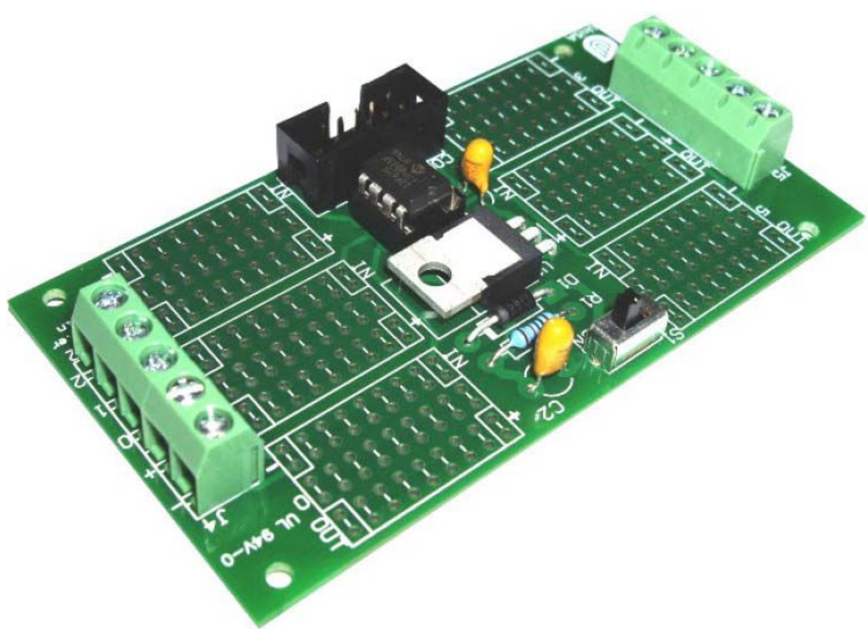


Figure 6. Module 1 with the microcontroller and the regulated power supply.[6]

Moisture probe

Students enrolled in civil engineering discipline are encouraged to select the moisture probe project depicted in Figure 7. This is an electronic device with the purpose of indicating by an alarm sound when the soil moisture level falls below a certain threshold. The project is relatively simple, but is an excellent platform for teaching electrical engineering concepts and practical skills needed by students.

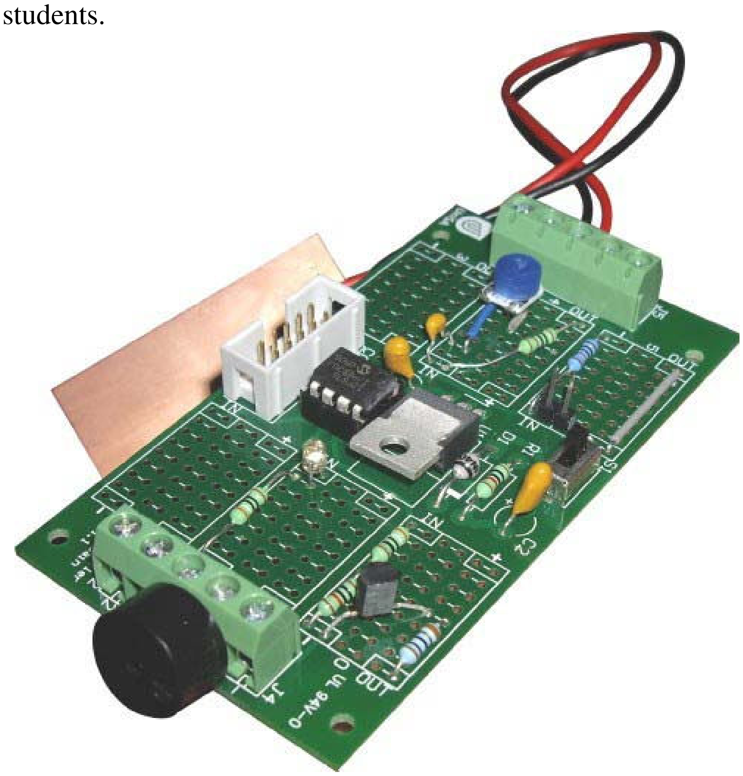


Figure 7 Completed moisture probe project.[7]

This project utilizes the same PIC microcontroller board used for the racing car project. Input and output circuitry is different, but concepts of sensor inputs and actuator outputs are similar and can be easily covered in lectures with students doing different projects. As indicated in Figure 7, here students also do some minor design tasks in prototyping areas in order to interface sensors and indicators with the microcontroller chip. Again, a ready-made program is provided for students to download it into the microcontroller using the PICkit™ 2 programmer. After assembling and testing the device students calibrate the probe to a desired moisture level. The moisture sensor is simply a piece of a double sided copper plated board (normally used for production of PCBs) able to detect the variation in soil resistance with the moisture.

As in the case of the other two projects, students work on this project over six 2-hour sessions. During the final session students demonstrate the project to the supervisor for assessment.

Not just a soldering exercise

For all three projects detailed guides have been developed and are available on the course web page (http://www.unisanet.unisa.edu.au/courses/course.asp?Course=eeet+1025). The guides also include questions and exercises that support deep understanding of theoretical concepts and learning of practical skills. This also ensures that students understand functionality of each part of the project rather than just blindly following the procedure.

One such exercise is the measurement of the equivalent capacitance between test points H2 and H3 shown in Figure 8. For many 1st year students it is not obvious that capacitors C4 and C5 are connected in series between these two test points. On the other hand, some students skip this measurement when scheduled and try to perform it when they already solder resistors R1 and R2 and find out they are not able to measure the equivalent capacitance. Naturally, they want to know why, which leads to a very interesting and an advanced question about how an instrument (digital multimeter) measures a capacitance; answer not known even by many experienced engineers.

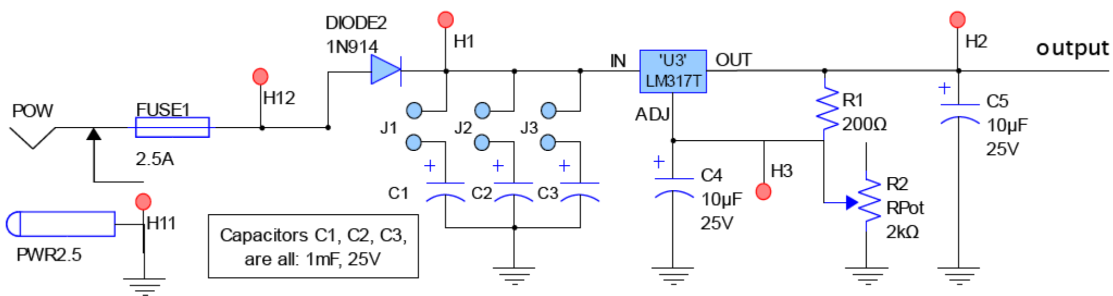


Figure 8. Example of an exercise for deep learning.

Another example is a small design task where students need to determine the resistance value to limit the current through the LED of the headlight indicator in the racing car project. The part of the relevant circuit is shown in Figure 9. Students are supplied with the data sheets for different LEDs; yellow, red, green and blue. They choose the LED which they like and then from the data sheets they determine LED current and the voltage drop across the LED. Then they calculate resistance value and the power rating of the resistor R2. After checking their calculation with the supervisor they take the resistor from the workshop.

The next stage in this exercise is to determine how to implement this little circuit in one of the six “prototyping” areas. Surprisingly many students find this not as easy task as we would assume. Students are asked to first draw connection on the paper template of the prototyping area shown in Figure 10(a) and check their solution with the supervisor before soldering components on the board. Students are warned that there is no unique solution; one of the many solutions is shown in Figure 10(b).

Hee we presented only two examples to demonstrate that even an assignment project if used properly can be a reach platform for students learning and not just “soldering exercise”.

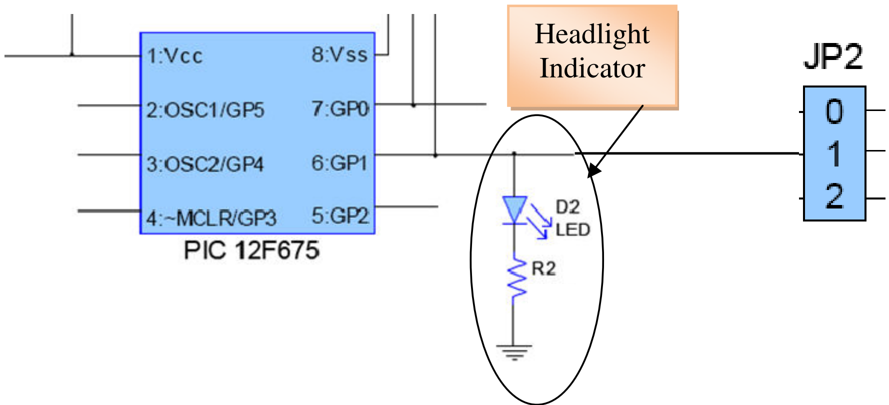
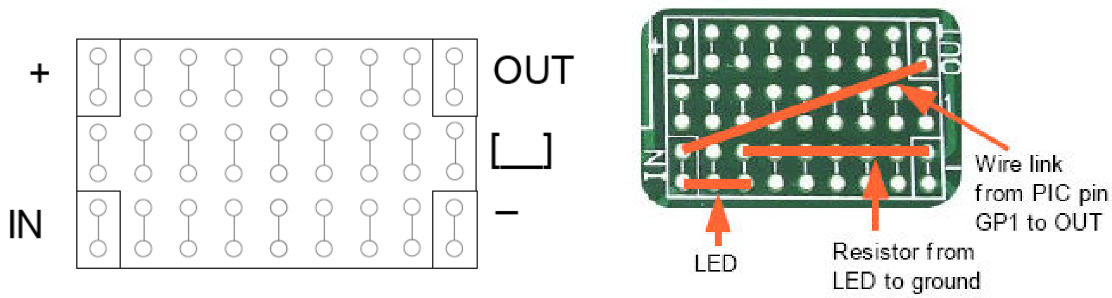


Figure 9. Headlight Indicator for car project.[6]



(a) (b)

Figure 10. Implementing headlight indicator (a) prototyping area template; (b) one possible solution.[6]

Student feedback

The project based laboratory was implemented in the second half of the first year engineering programs in 2008 with 200 students enrolled in the course. We sought student feedback on their experience. A ten question survey was used; nine Likert scale questions (with answers: strongly agree (SA), Agree (A), neutral (N), disagree (D) and strongly disagree (SD)) and one question for text comments.

Of the 200 students, 75 (37.5%) responded to survey. Of these 75 students, 20 did power supply project, 25 did racing car, 15 did moisture probe with 15 did not declaring which project they did.

The survey results presented in Table 1 and chart in Figure 11 show that the satisfaction of electrical engineering students (doing the power supply project) remains at the similar level as in previous years (2006 and 2007). A large majority of students (95%) agreed or strongly agreed the project motivated them to learn more and 80% of them were highly satisfied with the project-based laboratory.

The chart presented in Figure 12 shows that mechanical engineering students and particularly civil engineering students are significantly less satisfied than the electrical engineering students. All students are supervised by the same supervisors and taught by the same lecturers. Responses to questions 4,5,7 and 8 reflect student perception of students-staff relationship. Interestingly, students from mechanical and civil disciplines perceive staff to be less helpful than electrical discipline students. This can be explained either that nonmajor students need more help, despite working on less complex projects, or that their interest in the subject material is lower and therefore they seek more help instead of investing more effort in working out solutions themselves. To improve the satisfaction, it has been decided to introduce more projects so students can choose projects they may perceive more relevant to their profession and more appealing to their interest.

All comments supported the concept of the project based laboratory. Students liked the hands-on work, while suggesting improvements such as more tools, more time to complete the project, more detailed instructions etc. None of the students stated that they did not like the project based laboratory; most testified that they enjoyed it, stating that it was the best part of the course.

Table 1: Student Feedback; (SA) = Strongly Agree, (A) = Agree.

Question		(SA) + (A) [%]			
		2006	2007	2008	
		Elec.	Elec.	Elec.	All
1	The laboratory project has motivated me to learn more about electrical engineering	91	80	95	73
2	The laboratory project enabled me to develop and/or strengthen a number of the qualities of a University of South Australia graduate	87	84	70	64
3	The laboratory developed my understanding of concepts and principles in electrical engineering	84	72	85	80
4	Laboratory supervisors motivated me to do my best	82	64	80	57
5	Staff involved were genuinely interested in my progress	84	84	75	57
6	I am satisfied that I acquired useful knowledge and skills in electrical engineering	82	80	85	67
7	I have received feedback that was constructive and helpful	73	48	65	55
8	The staff teaching in this course showed a genuine interest in my learning	80	76	65	52
9	Overall I was satisfied with the quality of the project-based laboratory	87	88	80	63
10	What did you like most about the project-based laboratory, and what can be improved?	-	-	-	-

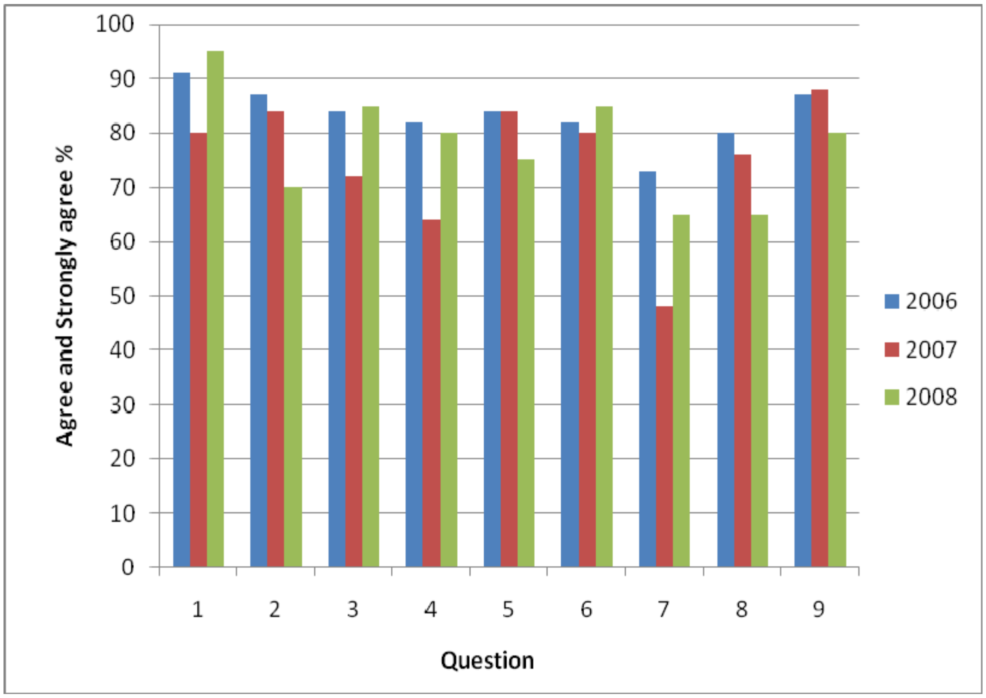


Figure 11. Comparison of responses with response in previous years (electrical engineering discipline only)

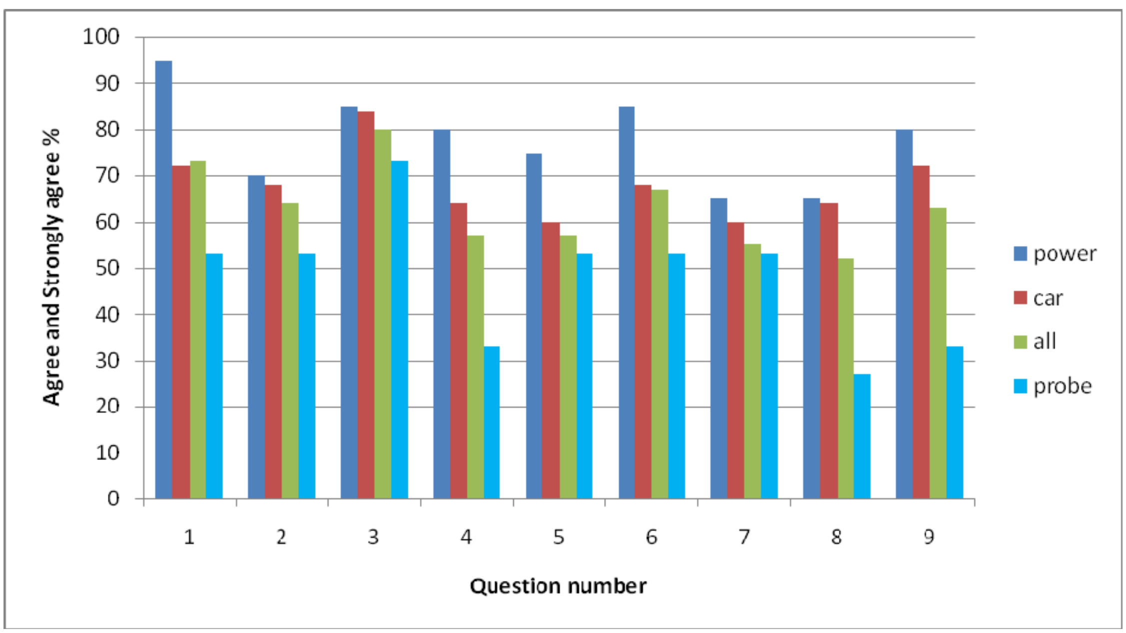


Figure 12. Comparison of responses in respect to project type (discipline)

Reflection on the projects

Most engineering students love building things and making them work properly. Consequently, the project base laboratory is expected to be more motivational than a set of independent laboratory experiments, unconnected with utility, dedicated mainly to validate some of the theoretical concepts covered in the course. As educators we welcome every opportunity to capitalize on student motivation as increasing student motivation certainly is a proven indicator of increased ability to learn.

The three projects developed for the project based laboratory are learning driven[8] rather than result driven[9] in the sense that outcomes of each of the three projects are known and the objectives are to focus on the learning process and acquiring knowledge and skills rather than developing an optimal design. In each session, knowledge and skills acquired in all previous sessions are consciously used to reinforce them. Although the final session is designated as being for the overall testing of the device, during each session students perform a number of small tests. These aim not only to teach students troubleshooting of the device, but also to reinforce the theory covered in the course. These tests include: measurement of equivalent resistance or equivalent capacitance between two points in the circuit, monitoring how the resistance and voltage vary with adjustment of a potentiometer, etc. By testing each module as it is completed, students learn a modular approach to building systems.

Good teaching practice requires a shift from teacher-centered to student-centered education. An assignment project[2] being a closed project, does not necessarily transfer much control over project activities to students. However, we do believe that in every project there is space for inclusion of activities which encourage students to take the initiative and the responsibility for their own learning. The objectives we are seeking include, but are not limited to:

- The use of discipline specific equipment, methods and tools;
- Familiarity with the modular concept of system development and implementation;
- An elementary understanding of concepts of manufacturability and testability;
- Safe working practices and conditions;
- Correlating electrical/electronic engineering theory with practice;
- Development of technical information literacy and communication;
- Collaboration.

The three projects described above are relatively simple. However, for the first year engineering students they constitute a fertile ground for learning practical skills, essential for engineering practice. Because students are strongly motivated to build an artifact with a clearly defined useful purpose, and because they want to build it well, they want to learn how it works and the reasons why the task is carried out in the sequence and manner prescribed. Consequently, they ask numerous questions. These are not always answered directly. Academic staff of the School strives to embody approaches which encourage student reflection and deeper understanding of new knowledge and skills.

Conclusions

It has been demonstrated that having students build a simple, modular, testable artifact with a definite useful purpose, which they own at the end of the process is an effective motivator compared to the conventional run of stand-alone first year experiments. Although an assignment project lacks the potential educational richness, and indeed the relevance for fully-formed professionals of true problem-based projects, it has proven to be an adequate vehicle for stimulating student curiosity, thinking and problem solving skills within a fixed context, as well as the development of practical, social and technical literacy skills.

References

1. A. Nafalski and Z. Nedic, "First Year Project-based Laboratory in Electrical Engineering Program," in *Research Symposium on Problem Based Learning*, Aalborg, Denmark, 2008, 8 pages.
2. D. Woods, *Problem-based learning: how to gain the most from PBL.* Hamilton ON: McMaster University, 1994.
3. A. Kolmos, "Reflections on project work and problem-based learning," *European Journal of Engineering Education,* vol. 21, pp. 141-148, 1996.
4. K. V. Cartwright, "Further results related to power supply design and analysis in the undergraduate curriculum," *Education, IEEE Transactions on,* vol. 44, pp. 262-267, 2001.
5. B. W. Sherman and K. A. Hamacher, "Power supply design in the undergraduate curriculum," *Education, IEEE Transactions on,* vol. 40, pp. 278-282, 1997.
6. T. Everingham, "EEET 1025 Electrical and Energy Systems - Practical Guide – Racing Car," School of Electrical and Information Engineering, University of South Australia, 2008, 51 pages.
7. T. Everingham, "EEET 1025 Electrical and Energy Systems - Practical Guide – Moisture Probe," School of Electrical and Information Engineering, University of South Australia, 2008, 50 pages.
8. B. Raucent, "Introducing problem-based learning in a machine design curriculum: result of an experiment," *Journal of Engineering Design,* vol. 12, pp. 293-308, 2001.
9. Ö. Göl, A. Nafalski, and K. McDermott, "The role of industry-inspired projects in engineering education," in *31st ASEE/IEEE Frontiers in Education Conference*, Reno, USA, 2001, pp. F3E-1-4 vol.2.