AC 2011-1540: INTEGRATING A NONTRADITIONAL HANDS-ON LEARNING COMPONENT INTO ELECTRICAL AND ELECTRONICS COURSES FOR MECHANICAL ENGINEERING STUDENTS

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Integrating a nontraditional hands-on learning component into an electrical theory course for Mechanical Engineering students

Introduction

The use of highly integrated sensor suites and control systems integrated with microprocessors and interfaced to a computer, is fundamental to many designs. The ability to view and manipulate digitized inputs and outputs of these systems using commercial software packages, has changed the field of mechanical engineering (ME) as well as altered the technical skills ME students need as they enter the workforce. Today, ME students not only have to gain an exposure to electrical and computer engineering (ECE) so that they can function on multidisciplinary teams, they must also obtain a solid understanding of electrical and computer engineering principles so that they are able to apply these principles themselves as they work within their own discipline. To address this need, faculty from Departments of Mechanical Engineering and Electrical and Computer Engineering at Virginia Tech initiated discussions in Spring 2009 to revise the two service ECE courses that are required in the ME undergraduate curriculum with the goal to increase the depth and breadth of the theoretical and practical learning outcomes. As a result of these discussions, it was decided to replace the current lecture course on electrical theory with a combined lecture and laboratory course on electrical theory with an emphasis on ac circuits, which facilitates the application of theory into practice while enabling more advanced material to be incorporated into the second course.

The design of the laboratory portion in the course on electrical theory is an application of a pedagogical approach that was implemented, and has proven to be highly successfully, in the undergraduate Electrical and Computer Engineering curricula – hands-on experiments that are performed outside of a traditional classroom using a student-owned analog/digital trainer, parts kit, digital multimeter, and USB oscilloscope (collectively known on campus as Lab-in-a-Box or LiaB).[1] In addition, ME students simulate circuit operation and analyze the data collected and stored on their tablet computers using commercial software packages. The electronics course, which already had a laboratory component, was also revised to incorporate more material on digital electronics and microprocessors into the syllabus. Furthermore, the pedagogical approach to experimentation has been extended into the electronics laboratory portion of the course.

A description of the circuits and electronics experiments that have been written to focus on the needs and interests of the ME students will be provided. The authors will discuss the organization of the laboratory portion of the course to manage the volume of students, totaling upwards of 600 students per semester, as the ME students join the ECE majors to obtain assistance as they debug their circuits and to demonstrate their operation for a fraction of their lab grade in an open lab environment. The fact that all ME sophomores will have their own Lab-in-a-Box, will been taught basic measurement techniques, and can perform basic circuit simulation has led to discussions on modifications to the core courses and technical electives taught within the Department of Mechanical Engineering. The impact that the inclusion of LiaB in the ECE service courses on the Mechanical Engineering curriculum will be described.

Background on Lab-in-a-Box

In 2004, the Bradley Department of Electrical and Computer Engineering (ECE) began to offer a d.c. circuits laboratory course to accompany the d.c. circuits lecture course to provide an opportunity earlier in the Electrical Engineering (EE) and Computer Engineering (CpE) curricula for students to apply the concepts taught in the circuits lecture courses. The motivation that drove the development of the d.c. laboratory course was the recognition by the faculty members that students were not learning the basic concepts in electric circuit theory. After collecting input from students during focus groups and exit surveys as well as discussions among the faculty members, it became clear that the level of abstraction with limited real-life applications during the lectures was extremely high in the introductory circuits course, which made learning the material difficult for those who are visual learners. An additional factor that was handicapping our visual learners was the fact that a number of informal learning opportunities outside of academia had vanished. For example, the push in the high technology consumer electronics has moved towards a plug-and-play or discard-and-buy-new approach, rather than customize-it-yourself approach to computer upgrades, which has been the one of the last area where our students were 'tinkering' with electronics at home. We determined that we needed to have a significant active "hands-on" learning component to help achieve the learning outcomes for the circuits course by reinforcing the theory described in the lectures with hands-on demonstrations in the experiments.

The LiaB kit contains an analog/digital trainer (ANDY board), shown in Figure 1, a digital multimeter (DMM), electrical components that include a set of 5% resistors, capacitors, inductors, light emitting diodes, several operational amplifiers and a few 555 timers. A recent addition to this set of equipment is a USB-powered oscilloscope, which was replaced a software oscilloscope and sound card interface. A two channel oscilloscope with arbitrary function generator (Velleman PCSGU250) was adopted in Spring 2009. The laboratory manual, now in its 3rd edition, contains background information on the operation of the powered ANDY board and the components and the experimental procedures with circuit schematics and step-by-step instructions on the analysis, simulations, and measurements that the students are to perform.

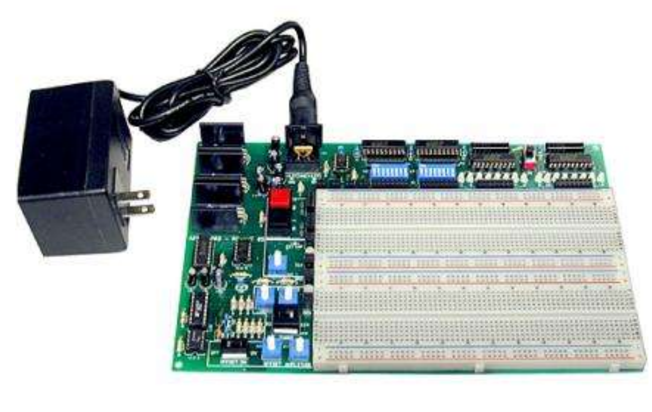

Figure 1: The RSR/VT A and D trainer.

The goals when developing each of the assigned experiments are to provide a demonstration of one-to-two theoretical concepts in practice, to provide an increasing level of experimentation and design content in the exercises, and to develop a sense of self-confidence and motivation for the students to complete the experiments with minimum guidance from graduate teaching assistants (GTAs), the laboratory staff, and course instructor. A unique feature of this laboratory course is that the students conduct much of their work using set of equipment, known as Lab-in-a-Box (LiaB), outside of a traditional classroom environment.[1] The GTAs staff an open lab where they are available to answer questions about measurement techniques and provide guidance on how to debug circuits. They also grade students on their ability to perform certain measurements and to explain the operation of the circuit in each experiment. To support the independent learning, particularly since we expected most of this to occur at times when the course instructors and GTAs were not available even via e-mail, we developed a large set of instructional materials that include a laboratory manual,[2] online lectures about each experiment,[3] and online tutorials on PSpice, MatLAB, and use of the measurement equipment.[3,4] This pedagogical approach of integrating concrete and abstract learning received overwhelmingly positive feedback from students enrolled in the d.c. circuits course and was adopted as an instructional component during the development of the a.c. circuits course in the following year.

Rationale for LiaB Course for ME Undergraduates

Mechanical systems today employ at least one electronic sensor or electronic control system along with a microprocessor. These electronic systems, because of their cost, reliability, and speed, have increased the ability to monitor and control the performance of the mechanical system with the result that the mechanical system can be operated more efficiently, economically and reliably. The automobile is a frequently used as an example of this trend. Electronic ignition and fuel injection systems, oxygen sensors, antilock brake systems, and computer diagnostics systems are commonplace in gas- and diesel-powered cars. More complex systems for collision avoidance and driverless parking have been demonstrated and will likely emerge on the marketplace shortly. Hybrid and all-electric vehicles should be thought of as electronic systems with mechanical parts. A similar degree of integration of electronic systems is occurring in all other areas of mechanical engineering.

Rather than simply learning sufficient material on circuits and electronics to pass the Fundamentals of Engineering exam, ME undergraduate students must understand concepts in electrical and computer engineering at a much deeper level so that they can participate fully in the design, construction, and testing of mechanical systems. This is forcing changes in the undergraduate ME curriculum. Starting in the 1970's,[5,6] microprocessors have been incorporated into ME courses, usually in a senior technical elective or laboratory course at a number of schools. Coursework on mechatronics, a discipline form at the overlap between mechanical, electrical, and computer engineering, exist in almost all engineering schools with minors and degree programs available at some institutions.

While a two-course sequence in mechatronics is routinely offered to seniors at Virginia Tech and a Minor in Mechatronics is under consideration, the introductory circuits and electronics courses offered by the ECE department and taken by all ME undergraduate students had remained unchanged. The circuits course was a three-credit lecture course, covering topics ranging from Ohm's law, RL and RC circuits, to operational amplifiers. The electronics course was a two-hour lecture, one-hour laboratory course that covers motors, transistor amplifiers and operational amplifier circuits with little coverage of digital logic, digital electronics, or microprocessor systems. In Spring 2009, faculty members in Virginia Tech ME department approached the ECE department with a request that we modify the course content of the circuits and electronics courses so that the ME students would obtain a stronger background in electrical and computer engineering theory and practice before they enrolled in the two-semester senior ME laboratory course sequence and the mechatronics and robotics technical electives. In addition, the ME faculty members asked that more in-depth instruction on digital circuits with practical applications be added to the electronics course, which would support the ME capstone design projects and several of the senior technical elective courses.

Traditional laboratory classroom experiments can also demonstrate how concepts in circuits and electronics are applied. In practice, there was a growing constraint that was hampering our ability to engage all of the ME students in hands-on experiments in the lab associated with the electronics course. The ME undergraduate population at Virginia Tech has exploded; the number of students enrolled in the circuits and electronics courses has almost tripled in the past decade. Laboratory classroom space has not changed during this time. An additional complication when determining the number of laboratory classes to offer is the fact that there has been a reduction in the number of GTAs in the ECE department. Thus, the only feasible option was to increase the number of students per experimental station from two students to at least three if the students continued to work on the experiments in the classroom. Aside from the fact that there wasn't enough space at each experimental station to accommodate three or more students, it was clear that 3^+ students per lab bench would not result in the increased practical hands-on learning desired by the ME faculty members. The introduction of the LiaB approach in the courses for ME students insures that every student has ample experience with the construction and measurement of electrical and electronic circuits without the allocation of additional classroom space. The pedagogical approach used in the LiaB courses also provides a strong connection between theory and practice, which has been shown to assist visual learners to develop a deeper understanding of abstract theoretical concepts. Furthermore, the availability of online tutorials and other instructional materials has reduced the demand for GTA support. Therefore, the application of the LiaB pedagogical approach to the circuits and electronics courses for the ME students appeared to address the education and resource issues that arose as the ECE department considered how to respond to the request from the ME department.

Course Modifications

Given the success of the LiaB courses in reinforcing the learning of the fundamental concepts in circuit theory and in establishing practical circuit construction and debugging skills in our students early in their academic careers, we proposed a modification to the circuits and electronics courses for the ME students that incorporated the LiaB pedagogical approach. After a review by the ME undergraduate curriculum committee, it was agreed that the circuits and electronics courses would be modified to be two-hour lecture/one-hour laboratory courses where the content of the lectures would be altered to include an introduction to digital electronics and microprocessors and the labs would be experiments performed with the same LiaB kit used in the d.c. and a.c. circuits courses for the ECE students. It was also agreed that the ME students would purchase the ANDY board and USB-powered oscilloscope and that the ME department would revise several of their junior and senior level courses so that the equipment would be used by the ME students in future courses. This has two advantages in terms of student acceptance – first, the cost of the ANDY board and USB-powered oscilloscope (a total cost of $215) would be amortized over five courses taken by the ME students once the equipment has been adopted in all of the ME laboratory and technical electives identified by the ME curriculum committee and, secondly, the use of the equipment in ‘traditional’ ME courses would demonstrate that the students are expected to apply the practical knowledge from the circuits and electronics courses in their own discipline.

Significant alterations have been made to the syllabi to accommodate the LiaB laboratory experiments in the circuits course and the new material on digital circuits and microprocessors in the electronics courses. The format of the experiments employs a similar format as the experiments assigned in the LiaB courses for the ECE students. The experiments are performed outside of a traditional laboratory classroom. The ability to use the digital multimeter and USB-powered oscilloscope to obtain current and voltage measurement are a major learning outcome of both courses as is the ability to simulate the operation of the circuits using standard industrial software packages (e.g., OrCAD PSpice). There is limited circuit design, but more emphasis is placed on identifying the operating limits of the circuits and understanding the effect of the resolution of the equipments on the measurement accuracy when comparing the experiments to the LiaB experiments assigned to our EE and CpE students.

Circuits Course: The circuits course, which always had a two-semester physics course (classical mechanics and electricity and magnetism) as pre-requisites, has been redesigned to build directly on the material covered in these courses. Instead of covering resistor networks, which is taught in the second semester physics course, the lectures in the circuits course begins with an analysis of circuits containing components with impedances rather than simply with resistors. First order RC and RL circuits are reviewed with an emphasis on their use as low pass and high pass filters. The concept of resonance frequency is discussed in terms of RLC circuits. The ideal and nonideal models of an operational amplifier and the application of the ideal op amp model in simple operational amplifier circuits, including inverting, noninverting, summing, and difference amplifiers, are taught. Lastly, the piecewise model of a p-n diode is introduced.

For the first half of the semester, the experiments that have been introduced into the ME circuits course are almost identical to the initial experiments assigned in the circuits course taken by the EE and CpE students. These experiments serve as an introduction to the LiaB kit – what a breadboard is and how components should be connected using it, how to perform voltage, current, resistance, and capacitance measurements using the digital multimeter, how to operate the oscilloscope to collect time-varying voltage measurements. The circuits constructed are simple, designed to demonstrate one concept from the lecture; for example, the equivalent impedance of series and parallel components. PSpice simulations are included in the experimental procedure, in part to provide students with a means to verify that their measurements on the circuits that they have constructed are correct. As students become more familiar with the LiaB kit, the complexity of the circuits in each experiment increases. However, the emphasis continues to be the practical application of the theory presented in the lecture and there is minimum design included in the experiments. As an example, students determine the Thevenin equivalent resistances of the function generator and oscilloscope and investigate how these resistances affect the accuracy of measurements in one of the last experiments assigned in the semester. No formal lab reports are required at the end of each experiment; instead, students complete a worksheet as they perform the PSpice simulations and measurements on the circuit constructed. The worksheets are turned in for a grade when the students demonstrate the operation of their circuit to one of the course GTAs.

Electronics Course: The two major modifications to the course content in the electronics course are the decreased emphasis on transistor circuits and the inclusion of lectures on digital electronics and microprocessors. In the original course, approximately 15% of the course was devoted to the piecewise and small signal ac model of the transistor and their application in analog transistor amplifier circuits. This has been halved by eliminating most of the instruction on the small signal ac model, only introducing the model to explain why there are limitations to the switching speed and the cause of switching losses. In addition, the instruction concentrates on the analysis of circuits where the transistor acts as a switch. The time in lecture spent on digital logic, digital circuits, and microprocessors has now more than doubled in comparison.

While there were considerable changes made to the material taught in the lectures, the more significant modifications have been in the electronics experiments. With the inclusion of the LiaB experiments in the circuits course, students enter the electronics course with experience with the LiaB kit, PSpice, and measurement techniques. They also have performed experiments on simple resistor, RC, and RLC networks. Therefore, a quarter of the experiments in the old electronics course have been replaced with experiments involving digital circuits. For example, an experiment in which students construct a night light using a CdS photocell, light-emitting diode, and a transistor switch has replaced the n-p-n transistor amplifier experiment.

Informal Assessment

Informal conversations with one of the members of the ME curriculum committee indicates that the students do not have any serious complaints about the modifications to the courses. Antidotal comments made by students participating on the extracurricular teams in the college suggests that the ME students who have taken the revised course are better able to function on interdisciplinary teams and apply their knowledge from the LiaB experiments on the projects. We are preparing to initiate an assessment of the course using surveys of the students to collect data on the students' perception of the value of the hands-on experiments to their learning and to their professional careers. We meet with the ECE faculty members who teach the circuits and electronics courses to seek their input on the coordination of lectures and lab experiments. We are also soliciting the opinions of the faculty members who teach the senior mechanical engineering laboratory courses and those who teach the mechatronics and robotics technical electives to gain feedback on the changes made to the circuits and electronics courses, in particular, whether there has been a positive long-term impact of the hands-on LiaB experiments on the ME students' performance in these courses. Unfortunately, we do not have sufficient data collected at this time to draw any formal conclusions.

Conclusions

The first cadre of students completed the revised circuits and electronics courses that now include a laboratory with LiaB experiments in December 2010. Twenty laboratory experiments have been developed and used in these courses. The ME department uses the circuits and electronics classes as examples of the hands-on learning opportunities available to students at presentations to high school students and their parents during the Virginia Tech College of Engineering Open House. Some of the parents have commented positively on the level of sophistication of the equipment. They are also pleased to see the degree with which the Tablet PC, used to power the oscilloscope and to display the measurements from the scope as well as to run the simulation software, has enabled students to engage in the LiaB experiments. Refinement of the course syllabi as well as improvements on the experimental procedures continues.

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Bibliographic Information

1. Hendricks, R.W., K-M. Lai, and J.B. Web (2005). "Lab-in-a-Box: Experiments in Electronic Circuits That Support Introductory Courses for Electrical and Computer Engineers." Proc. ASEE Annual Meeting, June 12–15, 2005, Portland OR. (available online at www.asee.org)
2. Hendricks, R.W. and K. Meehan (2009). Lab-in-a-Box: Introductory Experiments in Electric Circuits (3/E), Hoboken, NJ: John Wiley and Sons.
3. K. Meehan, R.W. Hendricks, P.E. Doolittle, R.L. Clark, Jr., and C. Shek, "Lab in a Box: The development of materials to support independent experimentation on concepts from circuits", Proc. ASEE Annual Meeting, Austin, TX, June 14-17, 2009. (available online at www.asee.org)
4. C. Shek, K. Meehan, and R.W. Hendricks, "Podcast Tutorials on PSpice and Lab-in-a-Box", Proc. ASEE Annual Meeting, June 14-17, 2009Austin, TX. (available online at www.asee.org)
5. Mehta, D.P. and M.A. Wessler, "Microprocessors in an undergraduate laboratory in mechanical engineering", Proc. 1983 Frontiers Education Conf., Oct. 17-19, 1983, Worcester, MA, pp. 115-19.
6. Johnson, G.R., "Algorithmic control [microprocessor based controls course]", 1980 Joint Automatic Control Conference, Aug. 13-15, 1980, San Francisco, CA, FP4-B/4.