AC 2012-3442: LAB-IN-A-BOX: TECHNIQUES AND TECHNOLOGIES TO MANAGE LARGE AND NOT SO LARGE LABORATORY COURSES

Ms. Justeen Olinger
Michael Hutton
Mr. Christopher Gretsch Covington
Dr. Kathleen Meehan, Virginia Tech

Kathleen Meehan is an Associate Professor in the Bradley Department of Electrical and Computer Engineering at Virginia Tech. She joined Virginia Tech in 2002 after having taught at the University of Denver (1997-1999) and West Virginia University (1999-2002). Her areas of research include optoelectronic materials and devices, optical spectroscopy, packaging for power electronic applications, and electrical engineering pedagogy.

Dr. Richard Lee Clark Jr., Virginia Western Community College
Mr. Branden McKagen, Virginia Tech
Mr. John Harris, Virginia Tech

Lab-in-a-Box: Techniques and Technologies to Manage Large and Not so Large Laboratory Courses

A project known as Lab-in-a-Box (LiaB) was developed in 2004 by faculty members in the Virginia Tech (VT) Electrical and Computer Engineering (ECE) Department to improve student learning by allowing students to make their own observations on concrete examples of fundamental concepts in electrical engineering.[1] LiaB is a set of hands-on exercises in which students design, build, and test at home circuits using an inexpensive electronics kit, digital multimeter, and a USB oscilloscope and, thus, does not require the same resources as a traditional experimental lab class to implement. The d.c. and a.c. circuits LiaB-based courses were introduced into the VT BSEE and BSCpE curricula six years ago. In 2009, the circuits and electronics courses taken by our mechanical engineering undergraduate students were revised to include LiaB experiments instead of the traditional classroom laboratory component.[2] The average enrollments in the introductory d.c. circuits laboratory per year are approximately 300 ECE and 375 ME undergraduate students. The enrollment of ME undergraduates per year in the electronics laboratory course is similar to that in the circuits laboratory course while the number of students in the a.c. circuits laboratory course is 110 per year as only electrical engineering undergraduates are required to take this course.

The LiaB pedagogical approach has allowed the VT ECE department to reconfigure some of its laboratory classrooms into open space for senior design projects and extracurricular design competitions. More recently, the mechanical engineering (ME) faculty members have begun to use the LiaB kit in their senior technical elective on Mechatronics and to prototype electronic circuits in several ME senior design projects. The inclusion of LiaB in the ECE and ME curriculum has received very positive comments from students and faculty members as well as from parents and visitors to the ECE and ME departments.

The LiaB project has generated significant interest outside of Virginia Tech. The pedagogical approach with some modifications has been adopted by Virginia Western Community College (VWCC) in 2007 and two other community colleges within the Commonwealth of Virginia.[3] Enrollment in the laboratory courses at the community colleges is considerable smaller than at Virginia Tech, averaging between 5-15 students per year at each institution. We expect that the list of schools incorporating this pedagogical approach will expand as University of Virginia and several 2- and 4-year institutions of higher learning outside of the state are considering adopting the LiaB kit and the instructional methodology.

A number of enhancements to improve student learning has been developed over the years with the support obtained from the National Science Foundation Curriculum, and Laboratory Improvement Phase II grant, awarded in 2008. These include the institution of laboratory lectures, which are delivered face-to-face in the first laboratory course and then offered online in the second course; the creation of Excel report templates; generation of supplemental learning materials for each experiment, which are posted on the course Scholar site; and development of multimedia tutorials on measurement techniques, PSpice simulations, and calculations using MATLAB, which are posted online and are embedded as hotlinks in the appropriate report templates.[4] Scholar is the name given to Virginia Tech's deployment of Sakai CLE.

Several issues pertaining to course management have persisted since the inception of LiaB. Two trends in higher education have aggravated the situation. First, the budget reductions experienced by our institutions over the past decade has lead to a decrease in available resources to support these courses, as well as the other courses in the departments. Secondly, the increased enrollment in engineering at the undergraduate level has meant that we are teaching significantly more students with considerably less resources. These issues must be addressed to achieve a higher level of student satisfaction with the LiaB courses[5] and to reduce the resources required for the current LiaB courses so that personnel is available to apply the hands-on learning pedagogical approach into other courses in our curricula. We have developed several strategies and implemented certain technologies to continue to deliver the same level of instruction, require the same level of effort – and learning – by the students while reducing the workload on the course graders, graduate teaching assistants, and instructors. A summary of the course management issues that are shared between VT and VWCC as well as the ones that are specific to each institution will be described. The automated course management tools have been written in-house using Visual Basic, MATLAB, Cameyo, and bash script will be discussed. The improvements in course management observed when these tools were adopted at Virginia Tech and VWCC will be detailed.

Common Lab-in-a-Box Course Management Issues

One objective of the LiaB courses is to train students to follow the steps in a typical design process where they analyze, simulate, and construct a circuit, take measurements, verify the results, debug the circuit if necessary, and summarize the results. To encourage this, students are required to write two reports for each experiment: a pre-lab report where they document the results of their calculations and circuit simulations and a post-lab report where students document the measurements on their circuits and state their conclusions about the practical execution of the theoretical concept covered in the experiment. These reports trigger the primary course management issue at Virginia Tech and VWCC, which is the effort associated with grading the two sets of reports each week.

Report Templates: The first challenge to grading the reports as the lack of conformity associated with the submitted reports when a format was not specified. Many students could not determine what data were critical and should be included in the report, which negatively impacted their ability to draw the desired conclusions and detracted from the learning objectives of the experiments. Furthermore, a significant number of students did not understand how to present information in an organized manner. Even when properly written reports were submitted, the location within the report where specific results were compiled varied from report to report. As a result, the person grading the report had to spend time searching through each individual report to determine whether all of the required information was included and to determine the depth of understanding demonstrated by the students' conclusions. This was challenging when faced with grading a small number of reports during a semester, but was an impossible task when grading two reports per student per week. To support student learning and to reduce the complexity of grading, standardized Word report templates were instituted in 2007 at Virginia Tech. Excel report templates for the introductory d.c. circuits course were developed by Dr. Clark and his students at in Fall 2010 with worksheets dedicated for each of the steps in the design process. The VWCC Excel templates were adopted for the introductory d.c. circuits course at Virginia

Tech in the following semester. MATLAB report templates have recently been developed for use at Virginia Western Community College for use in both the A.S. and A.A.S. curricula. However, the Word templates continued to be used in the a.c. circuits course to provide the third-year students with examples of a format for formal reports.

Simplification of Reporting: Over the years, various attempts to reduce the number of lab reports that need to be graded have been tried – and have generally failed. As an example, we decided to eliminate the submission of a pre-lab report one semester. We found that students did not perform the circuit analysis and simulation at the preferred step in the design process, before constructing a circuit, unless there is a timely deadline and a grade associated with the work. Instead, more than half of the class performed the analyses and simulations as they were completing their post-lab report. As a result, these students did not have a prior knowledge about the expected values for the currents and voltages when they were taking measurements at various points in the circuit. Thus, they rarely knew if their circuits were functioning properly. For those that did recognize that their measurements were not correct, the approach to debugging the circuit was inappropriate – usually a process that involves swapping components until the measurement of the output of the circuit is close to what the students had heard that it should be. The students became extremely frustrated and the volume of questions about each experiment was overwhelming. Needless to say, submission of pre-lab reports has been reinstituted and the graduate teaching assistants (GTAs) and course instructors routinely ask to see the pre-lab reports before answering questions about the experiments. Similarly, an attempt to remove the duplication of information in the pre-lab and post-lab reports, which was done in another semester, was not successful as students did not connect the results of the analyses and simulations with their measurements when writing their conclusions on the experiment when the information from the pre-lab was not in the same report. It is now clear that the lab reports are a crucial element to guide students through the design process.

Automated Report Grading: There is continued pressure to reduce the cost of the courses, particularly the number of GTAs and graders associated with the LiaB courses. Other ideas to reduce the volume of lab report grading in the LiaB courses have been discussed including grading a randomly selected set of reports, either by student or by experiment, during the semester. Each idea has advantages, but all hamper our ability to achieve the entire set of course learning objectives. Another concern with grading is that students are irritated when there are delays between the time that they submit a report and when it is graded since errors in the pre-lab report will likely impact the correctness of the conclusions that the students made in the post-lab report as well as variability in the grading of the individual reports that result when several people grade a single assignment or a single person grades the assignment over the course of several days. Hence, the implementation of automated grading will address one of the frequently raised issues identified during our project assessment.[5]

Two approaches to address this problem have been pursued. At VWCC, Dr. Clark and his students are developing MATLAB report templates. Each m-file completed by the student is compiled into a batch job that is run by a MATLAB program to automatically grade the values entered into the report template. In the second approach, a Visual Basic program is called by a custom macro in Excel, which opens each Excel template and grades the numerical entries and graders can tab to worksheet entries that contain derivations, graphs and written conclusions to hand grade these items.

Automated Grading Using MATLAB: This approach gives the student experience and a greater comfort level in the MATLAB program while also addressing the problem of timely grading. There are three MATLAB files that are important in this grading process - the m-file given to the student, the mat-file generated by the student, and the m-file which the grader runs. The first file is the m-file given to students as a means of entering data. This serves in lieu of the Excel template so as to increase the time-efficiency of the grading program. When students run the m-file they are able to input numeric, textual, and pictorial data. The entered data is assigned to specific variables which exist whether the students have entered data or not. This makes it easy to see where steps have been omitted. After a student has entered all the data, the variables are saved to a in a format called a mat-file. This is the second file which plays a key part in the MATLAB grading process. Since the mat-file holds the student's individual results, it is the file that gets submitted for grading. When each student has submitted a mat-file, the third and most important file comes into play. It is the m-file which the grader runs. When this last program commences, it asks for the location of the student files. Upon processing this information it is able to go through the list of student mat-files automatically opening each one, checking the various types of data, calculating a grade, and providing a feedback file. Numeric data grading involves checking significant figures, measurement ranges, and calculation answers in view of past inputs. It is done automatically without any input from the person running the program. Textual data must be graded by hand, since the answers to an open-ended lab questions may vary considerably. The program organizes all textual answers in a table and displays it to the instructor or GTA. Images, such as graphs, screenshots, and lengthy derivations, are also put on view as individual figures. Before a student's final grade is calculated, the grader is asked to enter a separate grade for both the textual and pictorial data. These are then weighted and taken into account when calculating the final grade. Finally, all the student grades are written to an Excel file from which they can be easily transferred to the required place. This summarizes the MATLAB approach designed to give familiarity with a crucial program to students and to simplify and speed up the grading process for instructors.

Grading with Excel and Visual Basic Application: In the second approach, an Excel worksheet is used to describe the expected contents of a report as well as the weighting associated with each graded element. Supporting software, written in Visual Basic for Applications (VBA), can then grade each student submission according to the master worksheet in a fully or semi-automated fashion. Our primary motivation for developing a grading system in Excel is the hope that it will make the system instantly familiar to the widest possible audience. Expected values can be entered into cells in absolute terms, such as "3.5 mA", or they can be calculated from a student's measurements. For example, power could be calculated from a voltage and current that the student measured and then compared with the student's own calculated value. Creating worksheet formulas for such calculations is facilitated by a set of User Defined Functions that handle issues like the recognition of units and prefixes. Feedback is handled in a similarly flexible fashion; awarded points can be based on fixed or calculated weightings, functions are provided for color-coding graded results, and the system can generate comments for items that received partial or no credit. There is also a mechanism that allows the grader to run the grading process in a semi-automated fashion. The software will present the specified portions of each report after grading, but before recording the final grade, so that the reviewer can see color-coded, commented results and perform manual overrides if necessary. The same mechanism is used to call out portions of a report that must be graded by hand, such as plots and hand-written calculations. All of the supporting software is written in VBA and is directly editable from within Excel without the need for additional tools.

Course Management Issues Specific for Large Enrollment Courses

Another of the objectives of the LiaB project is to provide students with a set of tools that they own along with sufficient components so that they are empowered to design and construct analog and digital circuits independently. To minimize the cost of ownership, a sound card oscilloscope with a freeware software interface was initially used.[1] The specifications of the inexpensive sound cards that we selected presented several constraints – they had a maximum frequency of operation, the inputs to the sound cards were ac coupled, and the maximum voltage that can be applied to the input was 1 V. Nevertheless, they were sufficient for experiments that were designed to demonstrate concepts from our introductory circuits courses. However, the performance of the sound card oscilloscopes was such that few students were interested in experimenting with circuits after they had completed the two required laboratory courses. Furthermore, other faculty members in the department did not consider incorporating hands-on experiments into their courses as the capabilities of the sound card oscilloscopes severely restricted the scope of the experiments. There was also considerable manpower required almost every semester to update the laboratory instructions as the selected sound cards were discontinued by the manufacturer or there were compatibility issues with the specified sound cards and the new versions of computer operating systems. Thus, the faculty at Virginia Tech endorsed the adoption of USB-powered oscilloscopes when relatively low-cost equipment became commercially available with the caveat that the overall cost to students be held as low as possible.

Standalone Executable Programs: To minimizing cost of ownership for the students, we have elected to use the free version of Cadence OrCAD PSpice. We have found that the learning curve is fastest for Schematics, which was last available as a stand-alone program in version 9.1. While Virginia Tech does require students to purchase their own tablet personal computers and officially sanctioned specific operating systems, there are conflicts during the installation and running of OrCAD PSpice approximately 20% of the time. A growing number of students, approximately 10% last semester, encounter issues when installing and running the oscilloscope software program. The percentage of students that encounter issues with one or both programs is highest during semesters in which new versions of the sanctioned operating systems are released. Once the nuances of each operating system are understood and directions for installation and running the programs have been modified appropriately, a majority of the remaining issues are com port errors. However, there is a reasonable percentage where the source(s) of the error have not been identified, but appear to be related to specific computer and operating system combinations. The error(s) are not resolved when we have tried installing more recent versions of OrCAD PSpice on these computers. Given that our student population in the courses that use Lab-in-a-Box ranges is roughly 550 students per semester, this presents significant demand for technical support at the beginning of each semester. The ECE department information technology group created a standalone executable application of both software programs to address these issues using Cameyo, a free application virtualization product. The standalone executable does not require students to install PSpice or the oscilloscope software programs, but instead launches an application that functions exactly as the installed versions of the programs. The standalone executable files have functioned properly on all of the allowed computer platforms since its development in Spring 2011.

Bash Scripts: Another issue that we faced in these courses was grading the students during circuit validation, a procedure where the students come to an open classroom and demonstrate to GTAs that the circuits that they constructed function, that they understand how to perform the required measurements, and that they know the fundamental concepts that are demonstrated experimentally. When the laboratory courses were first instituted, students would print out the validation instructions. The GTAs would ask each student to perform the measurements and answer the questions on the validation sheet. The GTA would assign a grade that was written on the sheet and then signed the sheet. The sheets were then collected and one of the GTAs would enter the student names and grades into an Excel spreadsheet, which would be uploaded to the course management system – at the time, this was Blackboard. As the initial years that the LiaB lab courses were offered, only two LiaB courses were offered and the student population taking the courses numbered around 150 per semester. Data entry was time consuming and the usual problems of lost paperwork and incorrect entry of grades existed. The situation rapidly grew out of control as the number of full- and part-time GTAs staffing the open classroom increased to 10, the number of LiaB lab courses expanded to 4, and the student population swelled to 550 per semester.

To reduce time and effort associated with the grading activity, we have developed a bash script grading program, which interfaces to optical and magnetic card readers. At the beginning of each semester, class lists for each of the LiaB courses are downloaded from Banner and compiled into one master list. Upon entering the open classroom, the student checks in electronically. When it is his or her turn to validate the circuit, the student provides the GTA with his or her student ID card, which is read by one of the two readers. While we would prefer to only use the optical reader, severe scratches on some of the student ID cards has caused read errors and, thus, the magnetic card reader is used as a back-up. The GTA then scans the appropriate validation sheet, of which there are four as each course has a different experiment assigned each week, and then enters a grade for the student. The bash script correlates the number from the student ID to the student name, PID, and course from the master list. The experiment number and course are recorded when the GTA scans the validation sheet. The course from the validation sheet is compared with the course determined from the master list. An error message is displayed to the GTA, should the information on the courses not match. The GTA is then prompted to enter a grade for the student, which is written along with the student name, PID, and experiment number to an Excel spreadsheet. A new Excel spreadsheet is created for each laboratory experiment and is saved in separate folders for each course in a format that allows the Excel spreadsheet to be uploaded directly to grade book of the course management system – now Scholar. An cryptographically signed email is generated at the end of the bash script that sends a validation receipt to the student along with a blind copy to the course instructor. This receipt provides the student with evidence that a grade for the validation was entered for a specific laboratory experiment along with the date and time of the validation.

This program has been extremely helpful in managing the validation process. Since instituted, less than 10 students per semester contact the course instructor about possible missing validation grades and the cause has almost always been an error in memory by the students. The exception was an invalid entry of the student PID in the master list. Tracking the grade for a student who validates an experiment after the deadline because of an excused absence from school is straightforward. The course instructor no longer has to communicate to the all of the GTAs that a particular student may be coming to the lab to validate an experiment late. The GTAs are instructed to allow any student to validate a circuit at any time and the course Excel spreadsheet is updated automatically with the student name, PID, and grade when the late validation is performed. A simplified version of the bash script has also been written to take class attendance at the lectures for the d.c. circuits laboratory course for ECE students.

Conclusions

Several course management tools have been created at Virginia Tech and VWCC to address needs associated with the delivery of the Lab-in-a-Box courses. The development of many of the tools was driven by the growing gap in the budget for instructional resources and the increasing student populations in the Lab-in-a-Box courses. Other tools were required to overcome incompatibilities between computer programs used in the courses and the expanding number of computer platforms that students are allowed to purchase.

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