

UML Laboratory in a box, a new way of teching ECE labs

Prof. Jay Weitzen, University of Massachusetts Lowell

Jay Weitzen has been at University of Massachusetts Lowell for 27 years. He has strong interests in both wireless communication research and in providing students with high quality hands on design experiences. He teaches the first year intro to ECE course and also serves as chair of the College of Engineering First Year Education Committee and serves on the Capstone design committee. Recently he has been working with Analog Devices to beta test their new discovery module which is a complete laboratory module. Dr Weitzen has published over 100 papers in the open literature and is a Senior Member of the IEEE.

Mr. Alan Rux, University of Massachusetts, Lowell

Ms. Erin Isabel Webster, University of Massachusetts Lowell

I am a graduate student in Computer Engineering at UMass Lowell. I am a research student with Prof. Weitzen, and we are developing a hands-on "Lab in a Box" Program for our first year Electrical and Computer Engineering students. The open ended labs are built around the Analog Discovery Kit, and focus on introducing our students to hardware, programming, and test equipment.

The University of Massachusetts Lowell “Laboratory in a Box” a new teaching technique for ECE labs

Abstract

This paper describes how University of Massachusetts Lowell is changing how we teach Electrical and Computer Engineering Labs using our version of the "Laboratory in the Box". The Lab-in-the-Box based on the Analog Devices "Discovery Module" provides students with a low cost, portable electronic test bench in a box. Students can not only work on their labs on their own terms, in their dorm, in the park, in their home, but now have the tools to innovate and create on their own. Students are not dependent on the few hours of access to conventional test equipment or required to invest significant resources to create their own labs. University of Massachusetts Lowell is working to implement a "flipped laboratory" model based on Lab in the Box for year 1 through 4 labs. We believe that this model not only improves the educational experience of the students, but reduces space requirements, equipment costs, and maintenance costs for the institution.

I. Introduction

The University of Massachusetts Lowell “Lab in a box” is more than just a physical set of items. It marks a new way of teaching our Electrical and Computer Engineering laboratories. The paradigm used at most schools is that students report to a lab once or twice a week for a few hours. They work in teams of two or three to a set of test equipment. Unfortunately what often happens is that in these teams one student often does most of the work, while the other students play with their cell phones or just watch. Because of this paradigm, many students do not get adequate hands on experience using test equipment, debugging and just tinkering. The allocated laboratory time is all that they get with this expensive equipment. Students who want to work on their own projects often go to swap fests and purchase used test equipment for their home or dorm laboratory setups. With a mix of residential and commuter students, the commuter students often do not have the time to come to campus to use labs to work on projects.

Conventional teaching laboratories are expensive to equip and maintain and as our enrollment continues to grow at 10% per year, finding enough laboratory timeslots for all the students is becoming a growing problem. With more and more students using existing laboratory test equipment, maintenance costs and equipment availability is also becoming more of an issue for us. At the same time our enrollment is growing placing stress on the teaching laboratory infrastructure, our Industrial Advisory Board is telling us that a general lack of hands on experience is a growing concern of companies wanting to hire new graduating students or co-op students.

We are observing that students are coming to University with less hands on experience than their predecessors and it is hard to close the experience gap between the "haves" with hands on experience and the "have not's" given resource and time limitations. An initial survey of students in the first year ECE course (summarized in Figure 1) at University of Massachusetts Lowell showed that only 35% of the incoming first year ECE class (150 students) had any formal programming experience in High School, less than 30% of the students had ever constructed an electronic project prior to arriving on campus, and less than 18% had ever used an oscilloscope. The students that have this experience are primarily male, and primarily from more affluent suburban High Schools. The students entering our ECE program with both programming and hands on experience are at clear advantage, and this gap only widens as they move into the later years. Based on surveys of students leaving the ECE program without graduating, and with a desire to address the gap in hands on experience, we took a look at ways of providing a hands on laboratory experience to 160 (going on 200) first year students each year and close to 600 ECE students in all years. Unfortunately in past years, resource requirements to run hands-on design program both in terms of lab space, test equipment, and TA support made an individualized hands-on program impractical.

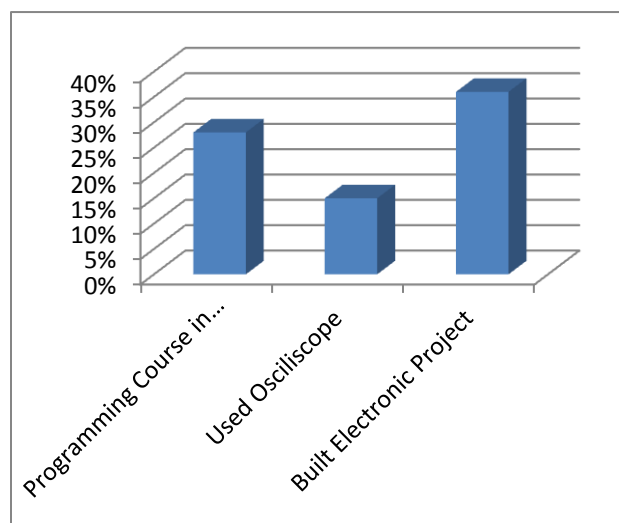


Figure 1. Survey of Electronics Experience of Incoming Freshman Class

II. Goals of Our "Laboratory in the Box" based curriculum

This section describes our top level goals as we undertake the redesign of our laboratory experience for years 1 through 4 in our undergraduate program.

Goal Number 1: Everybody gets Hands-on Experience: Many generations of engineers remember as students working in labs in teams of 2 or 3 students sharing a test setup. Often the

top student of the group did the work; the others either watched or did other things. Today doing other things means checking e-mail, texting, or playing games on cell phones. Only one student gets the real hands on experience, and this is probably the one that least needs it. This observation leads to the first goal of the curriculum design: Everybody needs access to a set of test equipment and needs to do each experiment by themselves. While we encourage students to help each other out by having students work in common areas, making sure that each student does each lab and gets the hands on experience is a critical element of having each student own their own lab. Students are teamed together for the open ended design projects.

Goal Number 2: Scalability and Cost: The electrical engineering class is increasing in size by over 10% per year. We expect to be at about 200 first year ECE students in the next few years and close to 800 total undergraduates students. Our target size for laboratory classes is no more than 19 students per section. For a class of 200 students with 19 students per section (11 sections and 11 Teaching Assistants), and 2 hours formal lab per week, per section, this requires availability of a laboratory with 19 sets of equipment for a minimum of 22 hours per week just for each laboratory class. Working with real test equipment, the classic model for laboratories does not scale if the goal is to have everybody to work by themselves. There is not enough equipment or laboratory space to satisfy goal number 1.

The goal is for the complete laboratory kit to be on the order of about \$200.00, which is approximately the cost of an engineering text book. Students furnish their own computer to work at home or use computers in a generic computer lab on campus. Using the “Lab in a Box” model, instead of a fully functioning lab with 19 equipment stations, we require only a computer room with 19 computer stations. The savings in test equipment is on the order of 50,000 to \$100,000. There is also significant savings on equipment maintenance. Students are responsible for the care and maintenance of their equipment. The Analog Devices Discovery Module is adequate in terms of its performance (100 MHz sampling rate) for almost all year 1 through 3 laboratory work.

Because students can and probably would prefer to work at home, we will change from 2 hours of formal lab with the TA to an open laboratory format in which the students bring in their work to show their TA and get help if they need it. This addresses the space issues and reduces TA cost issues. We are also experimenting with access via Instant Messenger or Skype so students can ask questions of a TA.

Goal Number 3: Enhance Open Ended Design and Innovation Experience: Our industrial advisory board has for years been concerned about both the lack of student exposure to state of the art test equipment and test procedures, and the lack of open ended design experiences prior to their senior capstone project. As the University moves towards a formalized co-op experience as part of the curriculum, getting the students more hands on experience earlier in their studies is increasingly important.

Based on input from our industrial advisory board, the third requirement for the curriculum design is that there are open ended design experiences in each year for students in which we give a set of requirements and have them figure out a solution, rather than classic “wire by number” step by step laboratory approaches. When students have their own electronics workbench they can work at home, they can work on more advanced and individualized projects on their own without having to come up to campus. Currently about 50% of the student are residential and about 50% are commuter students. Since many students work odd hours to pay for their education and find it hard to schedule time when the laboratory is open, this provides incentive for students to innovate and explore.

Goal Number 4: Stress Programming, Test Automation, and Analytical Thinking: Our surveys are telling us that many engineering students find that programming is one of the hardest things to learn, and the low rate of success of engineering students in programming classes requires that students get as much experience as possible and that the programming is reinforced each year of the program. Students learn both classic high level application programming using Matlab or C, and embedded programming using a microcontroller board. The students also learn how to take outputs from test instruments and analyze the data. The design projects in each of the labs should have a programming component.

III. Creating a "Laboratory-in-a-Box" to Meet Our Curriculum Goals

Faced with the need to increase hands on experiential learning in a time of rapid enrollment growth and tight budgets we have been looking to change the standard laboratory model described above. Working with nearby Analog Devices and Digilent we are experimenting with approaches to flip the laboratory model from a fixed lab time model to a "flipped" lab model that allows students to work on both formal labs and open ended design projects on their terms: in their dorms, in the cafeteria, in the student lounge, sitting outside. Our new approach to laboratories is to give all first year students (or transfer students when they arrive on campus) our version of the “Lab in a Box” plus a laptop loaded with required software.

While the “Lab in a Box” concept is not new [1,2,3], our version is different in both the contents and how we are using it. Our goal is to furnish a complete electronics workbench that can be used anywhere there is a computer. One of our key goals is to stress embedded programming and use of sophisticated test equipment early in the curriculum and throughout the curriculum. Our “lab in a box” consists of the following items:

- parts kit (customized for each year)
- wire kit
- proto board
- microcontroller with proto board (to teach programming)
- Digilent/Analog Devices “Discovery Kit

- Software development kits for Discovery Kit and Microcontroller

The curriculum is centered around the Analog Devices Discovery module which consists of a 2 Channel Digital Oscilloscope, Function generator, Digital Logic Analyzer, voltmeter, and power supply. Software development environments for the microcontroller and the “Discovery Kit” are provided to the students. Together these elements represent a complete electronics lab that stresses our priorities in engineering education. The strength of our approach is that students can work on their terms and timeframes. During their formal lab periods, students turn in their work and get help from their TA. We are in essence applying the concepts of the “flipped classroom” to laboratories. Instead of having students report to one of the few laboratories, they report to a classroom with standard tables, further improving the resource management issues for the department. We have already developed a first year curriculum and are currently developing a second year curriculum based on the lab in the box. We have already observed that going to the lab in the box paradigm is providing us significant relief from overcrowding and stress on our existing laboratory resources. Students have responded very favorably to the first year lab curriculum.

IV. Creating a Curriculum For Laboratory-in-a-Box

In this section we describe the curriculum for a 7 week first year ECE module incorporating hardware and software using the “Laboratory in the box” concept. The current format of the class consists of one hour of lecture per week with the entire class and two hours of formal lab time per week led by a Teaching Assistant. Grades are based on the labs and design projects and are given jointly by the TA and the professor. The lectures are video captured and posted for students to view. All laboratory materials are posted on the course website. The curriculum described was designed to be scaled to the entire college first year class and to be run as a blended (online/in class) course. The course requires 2 open ended design project where the students are given a set of design requirements and they work independently to implement them.

Week 1: Learning how to use the digital oscilloscope, and building a digital “Blinker”. In this first laboratory, students learn the function of resistors and light emitting diodes (LED’s). They use the voltmeter function of the Discovery Kit to measure the voltage drop across the LED’s. They write a simple program on the microcontroller to make an LED blink. They use the digital oscilloscope to look at the waveform at the output of the microcontroller. They then make a second LED blink alternatively, and look at both waveforms. They then change the duty cycles and blinking rates and look at the waveforms on the oscilloscope.

Week 2: Reading the status of switches: In the second week they learn how to read the value of a push button switch using the microcontroller and have the light blink when the switch is depressed. They look at switch bounce using the oscilloscope. At the end of week 2, they have to start their first open ended design project which is to design a traffic light controller for a 4 way intersection given a set of specifications.

Week 3: Controlling a servo motor. In this laboratory they learn how to use Pulse Width Modulation to control a servo from the microprocessor. As they do so they observe the waveforms using the digital oscilloscope. We introduce the concept of the capacitor as a filtering or smoothing device.

Week 4: RC time constants: In the fourth week they learn about charging and discharging of capacitors and the filtering of waveforms. They use the oscilloscope to measure



FIGURE 2
Components of the UML First Year “Lab in a Box”

theoretically. They start open ended design project 2: using the servo motor to design a pair of windshield wipers.

Week 5; Sound and frequency: In this laboratory they use the FFT capability of the digital oscilloscope to break down the spectral content of several different waveforms. They use the microcontroller to write a simple ring tone. This also secretly teaches concepts of pointers and memory management.

Week 6: Transistors and Photo Resistors: In week 6 students learn how a transistor and photo resistor works, using the microcontroller to control a transistor and read the values of light sensitive resistors.

Week 7: Operational Amplifiers: In the final week students learn how an operational amplifier works by using the function generator and the oscilloscope to build and measure the gain and frequency response.



FIGURE 3

Lab Setup showing students using the Analog Devices Discovery kit to measure waveforms on the microcontroller

V. Observations from Two Years of Running Program

We have run the Laboratory in the Box curriculum twice for our first year students and are now preparing for the rollout Lab in the Box curriculum for 2nd year students which will hope to begin in fall 2014 and the 3rd year curriculum by the fall of 2015. We have several observations based on the first running of the course.

What Worked:

- 1) It helps retention. In the first semester of the new curriculum, 91% of the students who started the course completed the course, versus 83% when the course was run the previous years. The first year class is prerequisite for several of the sophomore year classes including circuits, logic design and applications programming, and it will be seen whether student performance in the next year improves because of this approach.
- 2) Students had Fun. The end of semester Survey showed that almost all students enjoyed and had fun doing the projects.
- 3) Hands on experience benefits the students. Several Students reported that the hands on experience gained in this class helped them to land internship or summer jobs.
- 4) It saves money and is more scalable. The cost savings in not having to equip and maintain a conventional laboratory have been realized, but how much additional cost savings by reducing TA's still needs to be investigated.
- 5) It addresses a critical space issue: The lab in a box classes are run in standard computer laboratories versus specialized electronics laboratories. This was done by necessity as we

did not have enough laboratory slots to run first, second, and third year labs for so many students.

What Still Needs Improvement:

- 1) Based on observation, we estimate that about 60% of the students are capable of doing the experiments on their own in the "flipped" lab mode. However, about 25% of the students, due to gaps in their backgrounds, require significant TA support to complete their work. As we try to structure how to run the lab in terms of how many TA's, how many hours the lab needs to be staffed this will have to be taken into consideration.
- 2) About 20% of the students need a lot of structure put around them and the "flipped lab" may not work. Without forcing them to come to class each week, they do not do the work on their own.
- 3) The logistics of creating 250 "laboratory in the box" units each year needs to be part of the overall curriculum design. We have looked at using outside contract vendors who will purchase the elements of the lab and create "shrink wrap" packages units that are sold to the bookstore where students can purchase them. An additional benefit of selling through the bookstore is that students can use financial aid money to purchase the lab the same way they would for a textbook.
- 4) The end of semester survey showed that students still find learning to program a challenge. Trying to make learning to program more fun by having them do open ended projects helps, only up to a point.

V. Conclusions

Our conclusion from two years of experimentation with our version of the lab-in-a-box is that this concept is potentially disruptive in terms of changing the model of laboratory experience for undergraduate ECE students. Our observations are that it helps with retention and fosters innovation and open ended design by allowing students to work and innovate on their terms. As we roll out the curriculum to the 2nd, 3rd and 4th year cohorts, we will monitor retention and quality of our graduating students.

References:

- [1] Kathleen Meehan, "Why engineering students need a virtual lab bench", EE Times, 9/10/2012
- [2] Richard L. Clark, George H. Flowers, Peter Doolittle, Kathleen Meehan and Robert W. Hendricks, Work in progress- Transitioning LAB-In-A-Box to the community college setting, Proceedings 2009 Frontiers in Education Conference, Oct 18-21, San Antonio, TX, pp 159
- [3] Jay Weitzen, Erin Webster, Alan Rux, University of Massachusetts Lowell Laboratory-in-a-Box for First Year ECE students. Proceedings 2013 First Year Engineering Education (FYEE) conference, Pittsburgh, Pa, Aug 8-9, 2013