Kathleen Meehan, Virginia Tech

Kathleen Meehan is an Associate Professor in the Bradley Department of Electrical and Computer Engineering at Virginia Tech. Prior to joining Virginia Tech, she worked at the University of Denver and West Virginia University as well as having worked twelve years in industry. Her research interests include optoelectronic materials and devices and high heat load packaging in addition to Electrical Engineering pedagogy.

Dr. Robert W. Hendricks, Virginia Tech
Courtney V. Martin, Virginia Tech
Peter Doolittle, Virginia Tech

Director of the Center for Instructional Development and Educational Research, and Associate Professor of Educational Psychology at Virginia Tech

Richard Lee Clark, Virginia Western Community College
Lab-in-a-Box: Assessment of Courses and Materials Developed to Support Independent Experimentation on Concepts from Circuits

Introduction

A project known as Lab-in-a-Box (LiaB) was developed in 2004 as one of the outcomes of a department-level reform within the Bradley Department of Electrical and Computer Engineering (ECE) at Virginia Tech, addressing a need that was identified through student and employer surveys for concrete examples of fundamental concepts in electrical engineering. LiaB is a set of ‘hands-on’ exercises in which students design, build, and test various d.c. and a.c. circuits using an inexpensive electronics kit, digital multimeter, and an oscilloscope. The experiments can be done anywhere and require significantly fewer resources than a traditional electronics lab. LiaB has received overwhelmingly positive comments from the students as well as from faculty members who have used the kits for projects in upper division courses at a four-year college as well as three community colleges, which were formerly lecture-only courses.

A number of the major tasks in the National Science Foundation Course, Curriculum, and Laboratory Improvement Phase II grant, awarded in 2008, have been accomplished. These include the publication of the 3rd edition of the laboratory manual in 2009,\textsuperscript{1} the development of on-line multimedia learning materials to support student experimentation outside of the classroom,\textsuperscript{2,3} vodcasts on measurement techniques used in individual experiments linked directly to the lab report template,\textsuperscript{3} and the development of on-line classes for two circuits laboratory courses.\textsuperscript{4} The first is a d.c. circuits course is designed for off-campus students and the second is a supplement to increase independent learning by students in the a.c. circuits course. The assessment of the learning materials and evaluation of the project has been initiated.

In addition to these activities, the authors have also been engaged in an expansion of the pedagogical approach into the circuits and electronics courses taught to mechanical engineering undergraduate students. A hands-on laboratory component that utilizes the electronic breadboard as a miniature optical table will be introduced into the ECE electromagnetic courses in the near-future. The 4th edition of the lab manual is expected to be published in 2011. The latest edition will incorporate a number of new design lab exercises that have been developed during the NSF CCLI project by our ECE undergraduate students. A laboratory manual for the ECE courses taught to the mechanical engineering students is also expected to be published in 2011. We expect to offer a hands-on tutorial on the LiaB experiments and the learning materials to engineering faculty at Virginia Community College System’s New Horizons Conference in Spring 2011 to initiate the transfer of the pedagogical approach and learning materials to support the instruction at these institutions and to receive feedback and suggestions. A similar workshop was held the Virginia Tech Conference on Higher Education Pedagogy on Feb. 19, 2010, which was well received.

An explanation of our pedagogical approach to the development of the LiaB courses and the associated learning materials, a review of the initial evaluation and assessment results, and a discussion about the methods we have employed to disseminate the results of this project within our institutions and to the other community colleges within the state will be presented.
Pedagogical Approach

It is well-documented that students have a wide range of learning styles.\textsuperscript{5-7} Engineering students are no different from students in other disciplines in this respect. Felder and Smith have developed a taxonomy of their learning styles,\textsuperscript{8} while Felder has compared this taxonomy to three other common descriptions including the Myers-Briggs Type Indicators (MBTI), the Kolb taxonomy, and the Hermann Brain Dominance Instrument (HBDI).\textsuperscript{9} Of particular significance is research on gender and ethnicity differences in learning styles where it has been found that women are generally more visual learners than are men in the sciences, technology, engineering, and mathematics (STEM).\textsuperscript{10,11} Hands-on experience greatly enhances the learning experience for visual learners and, based on learning styles, is generally more important for women than for males. Nonetheless, it is clear that almost all people learn by doing.\textsuperscript{12,13} However, the opportunities for students to engage in experimental informal learning on topics in electrical and computer engineering are disappearing, despite the number of electronics devices that are used daily. Thus, our students were entering our introductory circuits courses without an intuitive understanding of the fundamental concepts that had been developed by students in years past from ‘tinkering’ with electronics kits, ham radio sets, and home-built computers. As the method employed at Virginia Tech when teaching the introductory circuits courses was lecture-based, highly mathematical and abstract in nature, there were no instructional activities for the visual learners that would support their learning of the fundamental concepts in electrical and computer engineering.

To balance the need to introduce hands-on learning early in the curriculum with the practical issues associated with the creation of a laboratory course – cost of equipment, physical space, and staffing, a nontraditional laboratory course was piloted at Virginia Tech in 2004. Experiments were developed that students would conduct outside of a laboratory classroom using set of equipment, known as Lab-in-a-Box (LiaB). The LiaB kit contains an analog/digital trainer, 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.

\textit{LiaB Experimental Design.} The LiaB experiments are constructed based on instructional events:\textsuperscript{14} gain attention, state objectives, activate prior knowledge, present material, provide learning guidance, motivate practice, and provide feedback. A outline based upon these events has been developed and is completed during the design of the experiment so that each event is presented to the students in a systematic manner. The outline, which becomes the written experimental procedure, has the following sections.

(a) Learning Objectives: The expected knowledge that the students will gain from the experiment including a deeper understanding of one-to-two concepts explored in the experiment.
(b) Preparation: The sections of the textbook in which the concepts are discussed are identified.
(c) Background: A brief explanation of the theory is presented along with a short discussion of the practical applications of the theory in day-to-day life, products used commonly by students,
and/or in areas of research that undergraduate students would be aware of. In addition, the experimental set-up is explained. Schematics of the circuits and images of students performing specific measurements are included. Ties between the current experiment and experiments performed previously are also made.

(d) References: Books, other than the course textbook, technical papers, and websites are provided so that interested students can read further on the topics covered in the Background section.

(e) Materials: The components required to perform the experiment are listed.

(f) Experimental Procedure: A step-by-step set of instructions are provided in the following order – (1) Analysis, which are hand calculations and MatLAB programs that are expected to be done before the student start the hands-on section of the experiment, (2) Modeling, which are any simulations that the students are expected to perform using software packages, (3) Measurements, which cover the set of instructions on how the components should be assembled and what measurements are to be made as well as questions interspersed in the instructions that are intended to guide the students as they analyze the results of the measurements and to spur them to consider why differences may exists when the students compare the results from the measurements with those obtained from the steps performed in the Analysis and Modeling.

Lab Reports. Students submit two reports; one is a pre-lab report in which they have performed the steps identified in the Analysis and Modeling sections of the experimental procedure and the second is report is submitted upon the completion of the experiment in which students include their measurements, comparisons made between the results from their analyses, simulations, and measurements, and their conclusions. The format of the report templates, which are Excel workbooks, follows the same format as the outline described above. Each worksheet in the report template corresponds to a heading in the laboratory procedures - Analysis, Modeling, Measurements, etc. The students enter their calculations on the Analysis worksheet either by typing in the equations and the resulting solutions or inserting an image of the calculations that they wrote electronically using their Tablet PC. Per the instructions listed in the laboratory manual and repeated on the appropriate worksheet, students insert images captured from PSpice on the Modeling worksheet and from the oscilloscope display on the Measurements worksheet. They enter the measured voltages, currents, and component values into pre-labeled cells on the Measurements worksheet as well as brief statements on the comparison between the analysis, simulation, and measurements on the Results and Conclusions worksheets.

Instructional Support. Weekly lectures, designed to be no longer than one hour in length, are held to briefly review the concepts that are used in the assigned experiment, demonstrate specific measurement and simulation techniques, and provide some guidance on approached to circuit design and debugging. Graduate teaching assistants (GTAs) also hold office hours in a room outfitted with a number of 6’ tables. Students bring their LiaB kits to the room and set up temporary lab stations on the tables. The GTAs provide guidance to students who have difficulty with some aspect of the circuit design, construction, and measurement. In addition, the GTAs evaluate a student’s ability to demonstrate how specific measurements are performed and the student’s level of understanding on the circuit operation once the student indicates that they have completed the experiment.
In addition to the GTAs, there are hotlinks to vodcasts embedded directly in the report templates since the students are likely to have the templates open on their computers while they perform many of the steps in the experimental procedure. Thus, each of the linked vodcasts is directly related to a particular step in the Measurements section of the laboratory procedure and provides a brief explanation and/or demonstration on how the step should be carried out, providing reinforcement on the experimental techniques that are described during the weekly lab lecture and supplement the longer online tutorials that are posted on the course Scholar website. In the ECE 2074, the d.c. circuits laboratory course, the weekly lecture is a face-to-face presentation by the course instructor with live demonstrations. In the second laboratory course on a.c. circuits, ECE 3074, the lectures are online Adobe Flash presentation composed of powerpoint slides and audio recorded with Adobe Presenter.

Assessment

All students enrolled in ECE 2074, Electric Circuit Analysis Lab, and ECE 3074, AC Circuit Analysis Lab were invited to participate in two online assessment surveys in the Fall 2010 course offerings. The goal of the assessment was to determine if the hands-on exercises were motivating the students’ interest in the field, supporting their learning of the concepts presented in the companion lecture courses, and increasing the students’ self-confidence to design, simulate, construct, and characterize circuits. An initial pre-course survey was conducted in the second week of class and the follow-up post-course survey was conducted after the completion of the final Lab-in-a-Box course project.

Methods

Surveys were made available on the student course management sites. Completion of the surveys was a required component of the course as a self-reflective component of their learning, but students could opt to have their data excluded from the study.

In ECE 2074, of the 121 enrolled students, 106 completed the pre-course survey and 95 permitted their data to be released. A total of 91 students responded to the post-course survey, with 80 students allowing use of their data. Just over half were second-years, a quarter were third-years, and the rest were in their fourth year or beyond. Over two-thirds of the students were EE majors, a quarter were CpE (computer engineering), and the remainder were mechanical engineers (ME) and others. Most students (80%) were concurrently enrolled in the companion lecture course, ECE 2004.

In ECE 3074, of the 61 enrolled students, 59 completed the pre-course survey and 51 allowed their data to be used. A total of 44 students responded to the post-course survey, with 38 students permitting use of their data. About three-quarters of the respondents were third-years and the remainder were fourth-years and above. Over 90% were EE majors (others: EE/CpE, CS, EE/ME). Most students (80%) were concurrently enrolled in the companion lecture course, ECE 3004.
Results

**Prior experience.** Over half the respondents in ECE 2074 (56%) indicated that they had no experience or little experience with hands-on experience building, troubleshooting, or repairing of electrical circuits. Just 29% had above average or extensive experience. By the ECE 3074 course, the numbers improve somewhat with 38% reporting above average or extensive experience, but 28% still responding that they had no or little experience.

**Confidence.** Over the course of the semester, student confidence increased. Table 1 shows the shifts in these perceived capabilities among students in ECE 2074 regarding circuit design, construction, measurement, analysis and modeling. Similar shifts were observed for students in ECE 3074, as shown in Table 2.

The shift over the 12 week interval between the pre-course survey and the post-course is striking for self-reported confidence of many of these skills. Among the ECE 2074 students, just 20% of the respondents had above average confidence in their circuit construction ability. After completing the course, 77% of the students reported above average confidence. Post-course, 91% believed they had above average confidence measuring voltage and current, and 75% had above average understanding of how the circuit functioned.

The findings in ECE 3074 are equally encouraging. Post-course, 97% of students reported above average confidence building a variety of ac and dc circuits and 90% were confident in their ability to “design a circuit by choosing a set of resistors, capacitors, and/or inductors based upon the results of your calculations.”

| Table 1. Frequency of Reported Levels of Confidence Among Students in ECE 2074. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                | 1 = not at all confident | 2 | 3 = average confidence | 4 | 5 = very confident | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| build a variety of ac and dc circuits? | 21 (22%) | 24 (25%) | 31 (33%) | 9 (9%) | 10 (11%) | 21 (26%) | 52 (65%) |
| measure the voltages and currents in these circuits with a multimeter and oscilloscope? | 8 (8%) | 23 (24%) | 29 (31%) | 19 (20%) | 16 (17%) | 21 (26%) | 52 (65%) |
| analyze and model circuit performance using PSpice? | 28 (30%) | 21 (22%) | 25 (27%) | 14 (15%) | 6 (6%) | 21 (26%) | 52 (65%) |
| understand how these circuits function? | 7 (7%) | 18 (19%) | 34 (36%) | 23 (24%) | 13 (14%) | 28 (35%) |
| design a circuit by choosing a set of resistors, capacitors, and/or inductors based upon the results of your calculations? | 15 (16%) | 25 (26%) | 29 (31%) | 13 (14%) | 13 (14%) | 31 (39%) |
**Table 2. Frequency of Reported Levels of Confidence Among Students in ECE 3074.**

<table>
<thead>
<tr>
<th></th>
<th>Pre n=51</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 = not at all confident</td>
<td>2 = average confidence</td>
<td>3 = very confident</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td></td>
<td>2 = average confidence</td>
<td>3 = very confident</td>
<td></td>
<td></td>
</tr>
<tr>
<td>build a variety of ac and dc circuits?</td>
<td>1 (2%)</td>
<td>8 (16%)</td>
<td>21 (41%)</td>
<td>12 (24%)</td>
<td>9 (18%)</td>
</tr>
<tr>
<td>measure the voltages and currents in these circuits with a multimeter and oscilloscope?</td>
<td>0</td>
<td>0</td>
<td>4 (8%)</td>
<td>9 (18%)</td>
<td>20 (39%)</td>
</tr>
<tr>
<td>analyze and model circuit performance using PSpice?</td>
<td>0</td>
<td>0</td>
<td>14 (37%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>understand how these circuits function?</td>
<td>0</td>
<td>0</td>
<td>18 (36%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>design a circuit by choosing a set of resistors, capacitors, and/or inductors based upon the results of your calculations?</td>
<td>0</td>
<td>0</td>
<td>18 (36%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Pedagogical contribution of LiaB.** Students view the LiaB courses as a significant contributor to their personal understanding of circuit design. Of the ECE 2074 students, 73% (pre-course survey) and 81% (post-course survey) indicated that the hands-on portion of the class including the ANDY board, multimeter, and oscilloscope, contributed more than average or a major portion of their knowledge. Among the ECE 3074 students, we see a shift where pre-course only 51% thought LiaB experiments would be an above-average or major contributor, and post-course, 84% responded in that manner. Through their use of the LiaB kit, more students found value in the hands-on experience.

**Impact on career preparation.** The majority of students in both classes indicated that LiaB was useful to demonstrate AC and DC circuits in practical applications and for their development and confidence as a future electrical or computer engineer. Table 3 shows agreement with related statements by course (post-course survey). A total of 86% of ECE 2074 students and 74% of the ECE 3074 students agreed or strongly agreed that LiaB projects were very important to their professional preparation. Results show strong support for inclusion of this hands-on approach.

**Time on task.** On average, students in ECE 2074 reported spending 5.7 hours \((n=80, sd=2.8)\) on the LiaB projects, including validation time. The numbers were similar in ECE 3074, with a mean of 5.3 hours \((n=38, sd=2.2)\)

**Discussion**

The assessment was designed to determine if LiaB contributed to an increase in student motivation in the field, supported their understanding of the concepts presented in the companion lecture courses; and increased their self-confidence to design, simulate, construct, and characterize circuits. The results of the pre-course and post-course surveys provide strong support for each of these three outcomes.
Table 3. Reported Agreement on Contribution of LiaB to Career Development Among Students in ECE 2074 and ECE 3074

<table>
<thead>
<tr>
<th>ECE 2074 – n=80</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>To what extent do you agree with the following:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Lab-in-a-Box experiments have demonstrated to me how the AC and DC circuits are used in practical applications.</td>
<td>21 (26%)</td>
<td>40 (50%)</td>
<td>15 (19%)</td>
<td>2 (3%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>The hands-on Lab-in-a-Box projects are very important in my preparation as an electrical or computer engineer.</td>
<td>6 (16%)</td>
<td>23 (61%)</td>
<td>6 (16%)</td>
<td>3 (8%)</td>
<td>0</td>
</tr>
<tr>
<td>The hands-on Lab-in-a-Box will give me confidence in my abilities as a future electrical or computer engineer.</td>
<td>35 (44%)</td>
<td>33 (42%)</td>
<td>10 (13%)</td>
<td>0</td>
<td>1 (1%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ECE 3074 – n=38</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>To what extent do you agree with the following:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Lab-in-a-Box experiments have demonstrated to me how the AC and DC circuits are used in practical applications.</td>
<td>11 (29%)</td>
<td>17 (45%)</td>
<td>9 (24%)</td>
<td>1 (3%)</td>
<td>0</td>
</tr>
<tr>
<td>The hands-on Lab-in-a-Box projects are very important in my preparation as an electrical or computer engineer.</td>
<td>22 (28%)</td>
<td>41 (52%)</td>
<td>14 (18%)</td>
<td>1 (1%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>The hands-on Lab-in-a-Box will give me confidence in my abilities as a future electrical or computer engineer.</td>
<td>5 (13%)</td>
<td>22 (58%)</td>
<td>9 (24%)</td>
<td>2 (5%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Students gain experience, confidence, and motivation from LiaB. The pre-course survey confirms the startling lack of hands-on experience working with circuits and provides an opportunity for students to gain those skills. Reported levels of confidence rose significantly, even after just 10 weeks working with LiaB among students in both courses. Students are motivated by the problem-solving aspects and appreciative of the flexibility to work at a time and in a location of their choosing.

I like being able to work on the projects at home and I can see myself using the ANDY board for personal projects after I'm finished using it for class. (ECE 2074)

I became an engineer to build things and apply what I learn to real word activities, and the Lab-in-a-Box allows me to start applying what I learned in class. I thoroughly enjoy the labs to the point where they make all of my other classes more interesting since I'm applying what I learned. (ECE 3074)

I am very motivated to learn and Lab in a Box actually interests me so I can work on it for a while without getting bored. (ECE 2074)

Students acknowledge the contribution of LiaB to their learning. One of the stronger pieces of evidence for the student-perceived value of LiaB comes from students in the ECE 3074 course. While only half felt LiaB would be a significant contributor pre-course, by the post-course
survey that number had risen to 86%. The ability to put theory into practice in a hands-on way 
cannot be understated.

I feel like I understood how circuits worked immediately after assembling a lab in this 
lab-in-a-box. During my other lecture class it took me a few days to grasp the idea of 
parallels and series working together, along with resistors. Once I did these labs, it just 
made sense as I assembled and observed it. (ECE 2074)

Doing the Lab-in-a-Box projects is the best way to put what we have learned to the test. I 
believe that it puts us far ahead of students who haven't completed hands on projects like 
these from other schools. We have already designed, simulated, built, tested and 
debugged, and analyzed circuits, which is the way it is done at the professional level. I 
feel confident in my abilities to complete almost any project that could be given to me at 
this point, after having a few circuit lab classes under my belt. I am a hands-on learner, 
and I feel that many engineers are also this way. The lecture definitely helps me to learn, 
but completing the Lab in a box projects really makes the information sink in. (ECE 
3074)

Students recognize how hands-on LiaB projects contribute to their professional preparation. 
Students inherently seem to understand the importance of being able to work with physical 
circuitry rather than just simulations. Fewer than 5% of the students disagreed that LiaB was 
important to their preparation and/or confidence as a future electrical or computer engineer.

The Lab-in-a-Box experiments helped contribute to my training as a future engineer as it 
taught me troubleshooting skills in figuring out why implemented circuits were not 
working as designed. It helped me see how much deviation there can be from our 
analysis. (ECE 3074)

Honestly, before this semester I was scared that I wouldn't like or be any good with the 
hardware portion of my CPE curriculum. After taking this class, and building other 
circuits in ECE2504 this semester. With the help of both ECE2074 and ECE2504, I am 
more confident in my hardware abilities, and I do hope to have more hardware projects 
in the future. (ECE 2074)

Challenges. The LiaB approach is not without its challenges. The two main weaknesses 
suggested by students involved deviations from the printed lab manual and issues related to the 
validation process supervised by graduate teaching assistants.

Addendums to the printed lab manual text are at times unavoidable. It is suggested that this be 
addressed up-front with students as changes, when properly documented and communicated, are 
an expected occurrence for engineers. This is a real-world scenario and part of the skill set that 
must be developed.

The in-lab project validations present a challenge due to the fact that students do not arrive in an 
orderly staggered fashion but with a peak just prior to the due date and time.
Conclusions

Despite the challenges, LiaB has been shown to be a successful approach to increase student motivation, learning, and hands-on experience among engineering students. Students appreciate the flexibility it offers and gain confidence working with the circuit components and measurement tools.

As this curricular approach is developed further, additional questions of its impact on student learning, preparation for later courses, retention in the major, and preparation for careers are raised. Future assessment efforts will be broadened to include some of these research questions.

Acknowledgements

The authors acknowledge the support of the Bradley Department of Electrical and Computer Engineering, Virginia Tech, and the National Science Foundation Department-Level Reform of Undergraduate Education (DLR) Award #0343160 and Course, Curriculum, and Laboratory Improvement (CCLI) Phase II Award # 0817102.

Bibliographic Information
