
AC 2011-2329: LAB-IN-A-BOX: ONLINE INSTRUCTION AND MULTI-MEDIA MATERIALS TO SUPPORT INDEPENDENT EXPERIMENTATION ON CONCEPTS FROM CIRCUITS

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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 Electrical and Computer Engineering (ECE) Department, 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 a software 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 publication of the 3rd edition of a laboratory manual in 2009,¹ the development of online multimedia learning materials to support student experimentation outside of the classroom,²⁻⁴ vodcasts on measurement techniques used in individual experiments linked directly to the lab report template, and the development of online classes for two circuits laboratory courses.⁵ 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.

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

Background on the Lab-in-a-Box Laboratory Courses

Since 2004, the Bradley Department of Electrical and Computer Engineering (ECE) at Virginia Tech has offered a circuits laboratory course to accompany the circuits lecture course. The lab has generally been the first opportunity for most of our sophomore undergraduate students to design, construct, and characterize electrical circuits. 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. The LiaB kit contains an analog/digital trainer, 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.

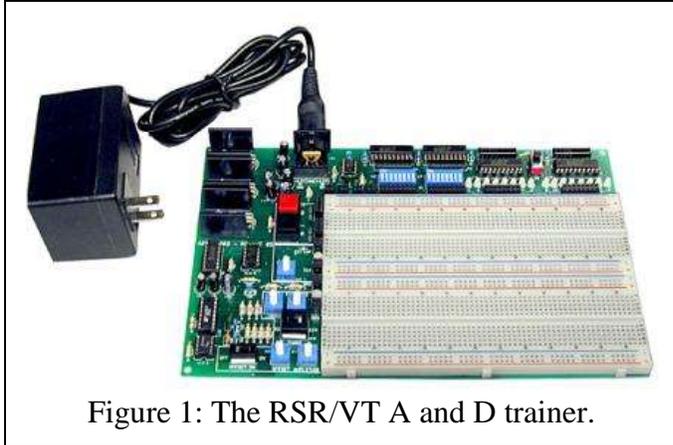


Figure 1: The RSR/VT A and D trainer.

The first four laboratory exercises in the d.c. circuits course are designed to teach the students procedures on circuit construction and how to perform simple measurement techniques, using a DMM initially and, later in the semester, using the USB-powered oscilloscope. Instruction on circuit analysis using hand calculations and MatLAB programs and on circuit simulation using OrCAD PSpice are provided during the weekly lecture that has been integrated into the first circuits laboratory course. Simple

design experiments along with instructions on techniques to debug circuits, assigned during the second half of the course, provide students with the experience needed to conduct a course-ending capstone design experience.

A similar philosophy is followed in the a.c. circuits course. For approximately half of the semester, the students build predefined circuits, which are designed to teach various aspects of a.c. circuits. The measurements performed by the students include amplitude and phase as a function of frequency using the Bode plot and spectrum analyzer tools available in the oscilloscope software package. Data collected using the oscilloscope may be exported directly to MatLAB using a customized interface written by engineers at MathWorks. A similar interface is also available that allows students to describe a mathematical function in MatLAB and then have the function outputted by the arbitrary function generator. Students are expected to perform comparisons between the measurements and the results obtained from circuit analysis and PSpice simulations and identify the source of any discrepancies. Design experiments such as those developed for the d.c. course are also available for the a.c. course. A recent innovation introduced into the a.c. course is the use of online instruction to provide support to students before they begin each of the assigned experiments, replacing the weekly lecture.

There are thirty eight experiments published in the 3rd edition of the laboratory manual¹ where the first twenty one experiments reinforce concepts covered in the d.c. circuits course and the second set of seventeen experiments bolster the lecture materials from the a.c. circuits course. A 4th edition of the laboratory manual will be completed later this year, which will include several additional design experiments for both the d.c. and a.c. circuits laboratory courses, updated instructions that describe the measurement tools available on the USB-powered oscilloscope, and modifications of the a.c. circuits where the design specification has been shifted to a higher frequency. We have obtained very positive results during an early assessment for the initial nineteen experiments via a survey instrument⁶ in addition to positive feedback from the department faculty members. The results from the assessment performed in Fall 2010 for the d.c. and a.c. experiments and associated instructional materials will be described later in the paper.

Online Multimedia Learning Materials

We quickly recognized that a reasonably large fraction, though less than half, of the students enrolled in the course were very uncomfortable performing the experiments at home with limited

interactions with graduate teaching assistants (GTAs) or the course instructor. As one of the goals expressed by the faculty members when initiating the LiaB project was to increase the confidence and independence of the students as they design and construct circuits and experimentally verify their operation, we reviewed our instructional methodology to determine modifications that would address the concerns of the students yet continue to support the goals of the project. To that end, we decided to institute a weekly one-hour in-class lecture that revised the theoretical concepts that are used in the assigned experiment, instructions and live demonstrations on how to perform PSpice simulations and measurements needed to complete the experiment, and a description of the grading process and reporting requirements. Powerpoint slides from the lectures are uploaded to the course Scholar site following the lecture. Instructions on installation of and obtaining licenses for the software used in the courses are provided using the Announcements page on Scholar. In addition to the slides from the lectures and the announcements, students have access to a set of single topic tutorials that cover aspects of PSpice simulations and measurement techniques, and address common issues encountered when using the LiaB hardware and during installation of MatLAB, PSpice, and the oscilloscope software package.

The tutorial topics are concentrated on issues that arise early in the first semester d.c. circuits laboratory course; for example, how to launch OrCAD PSpice and locate the basic components including ground, how to sweep the value of a d.c. voltage source, how to use 'Help' in MatLAB, and how to change the fuse in the digital multimeter. The constructed tutorials are based on Gagne's instructional events⁷, which also formed the pedagogical approach to the development of the vodcasts and the lectures for the online courses. Three formats are used for the tutorials. Some are available to the students as downloadable files from the course Scholar sites and are posted on a departmental website (<http://www.ece.vt.edu/tutorials>) in two formats: .m4v files, which can be played as podcasts, and .mov files, which can be viewed using Apple QuickTime on the students' personal computers.⁸ Others are available as powerpoint slides with audio in Adobe Flash format. In addition to these tutorials, we have developed several interactive tutorials using ActionScript. The tutorials, though mainly directed to students enrolled in the d.c. circuits laboratory, are posted on the a.c. circuits laboratory course, in part, to provide a review to students who have taken the d.c. circuits lab at Virginia Tech and to provide instruction on PSpice and MatLAB to our transfer students who used different tools in the d.c. circuits laboratory courses that they took at other institutions.

Vodcasts Linked to Report Templates

During the development of the LiaB courses, faculty members at Virginia Tech and Virginia Western Community College (VWCC) identified three core learning objectives that the students were expected to achieve upon completing the laboratory classes. The students are expected to know how (1) to build basic circuits to departmental wiring standards, (2) to measure and characterize these circuits, and (3) to analyze and model the performance of these circuits using MatLab and PSpice. While careful documentation of the results from the analyses, simulations, and measurements is desired, the presentation of these results in the format of a formal report is not considered to be a major learning objective of the introductory circuits class and is, instead, one of the learning objectives associated with a power laboratory course taken by our students later in their degree program. The graduate teaching assistants (GTAs) hold office hours to provide guidance to students who have difficulty with some aspect of the circuit design,

construction, and measurement. In addition, the GTAs assess the students' ability to demonstrate how specific measurements were performed and the students' level of understanding about the operation of the circuit. [For further information on the organization and structure of the area where the GTAs hold office hours and validate experiments, known as the Open Electronics Lab, see the schedule and policies posted at www.opel.ece.vt.edu.] The grading of laboratory reports is performed by students paid an hourly rate. To reduce the workload for the undergraduate students and the graders, a standard report template was developed in Microsoft Excel by students at VWCC. Each worksheet in the report template corresponds to a heading in the laboratory procedures - Analysis, Modeling, Measurements, Results, and Conclusion. 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.

Hotlinks to vodcasts are 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. The goal of the vodcasts is to assist students in developing confidence in performing the tasks required for each experiment independently – specifically, the construction of the circuit and the current and voltage measurements. The vodcasts reinforce experimental techniques that are described during the weekly lab lecture. 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. For example, students are asked to determine the magnitude of the current flowing through the capacitor as a function of time by measuring the voltage across a shunt resistor in Experiment 15: A Series RC Circuit. An explanation of this measurement and how to connect the oscilloscope probes is described in the vodcast linked to the measurement worksheet on the report template for Experiment 15 as shown in Figure 2. The vodcasts provide more immediate support to the students as they attempt the experiment on their own than the online tutorials that are posted on the departmental website and on the electronic

construction, and measurement. In addition, the GTAs assess the students' ability to demonstrate how specific measurements were performed and the students' level of understanding about the operation of the circuit. [For further information on the organization and structure of the area where the GTAs hold office hours and validate experiments, known as the Open Electronics Lab, see the schedule and policies posted at www.opel.ece.vt.edu.] The grading of laboratory reports is performed by students paid an hourly rate. To reduce the workload for the undergraduate students and the graders, a standard report template was developed in Microsoft Excel by students at VWCC. Each worksheet in the report template corresponds to a heading in the laboratory procedures - Analysis, Modeling, Measurements, Results, and Conclusion. 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.

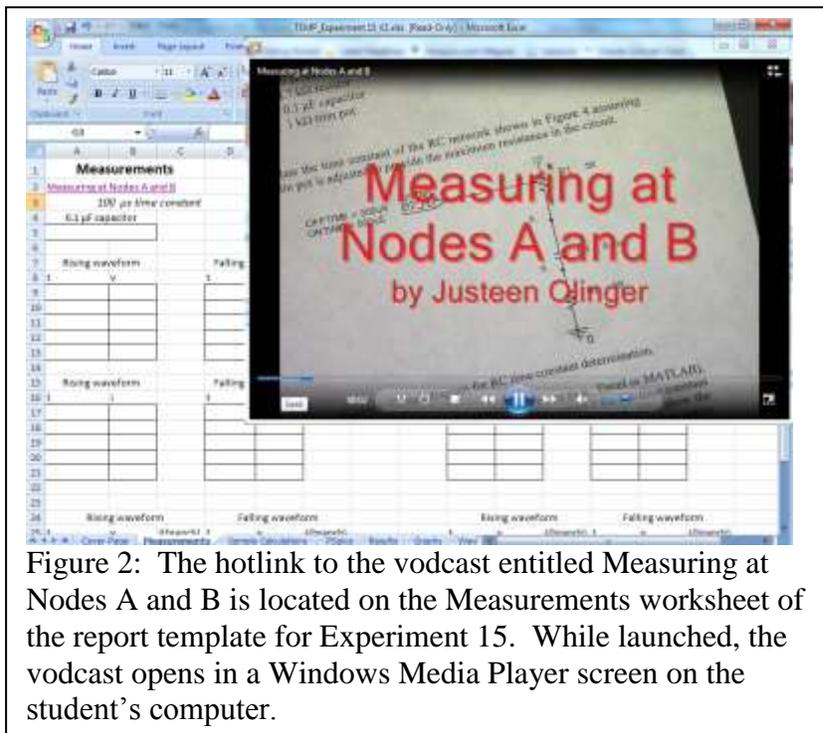


Figure 2: The hotlink to the vodcast entitled Measuring at Nodes A and B is located on the Measurements worksheet of the report template for Experiment 15. While launched, the vodcast opens in a Windows Media Player screen on the student's computer.

Scholar site for the course. Vodcasts to support the d.c. experiments have been recorded and linked with the report templates. Most are under two minutes in length.

Online Laboratory Classes

The creation of online laboratory classes was driven by two different needs. An online version of the d.c. circuits laboratory course addresses a need to offer a distance-learning course during the summer semesters.⁹ Roughly half of our transfer students do not taken a circuits laboratory course prior while enrolled at previous institution, usually because one is not offered. The plans of study for in-coming transfer students from these colleges have to be carefully crafted so that the d.c. circuits laboratory course is taken in their first semester on campus and that the shift in the sequence of the remaining circuits and electronics courses does not negatively impact their graduation date. Approximately half of the transfer students who have not taken a d.c. laboratory course decide, instead, to enroll in the d.c. circuits laboratory course at Virginia Tech during the summer semester to insure that they can take the recommended set of courses identified in the BSEE or BScPE checksheet in their first full semester in the fall. However, almost all have to obtain temporary living arrangements for the summer, which presents a financial burden on the students and their families. A complication to our ability to offer the laboratory course during the summer is the very steep decline in the number of Virginia Tech students who enroll in the summer ECE courses, a likely result of the recent economic downturn and as well as the increased participation by students in internships and in our co-op program. The lower enrollment places in jeopardy our ability to offer the courses during the summer semester, which in turn affects not only those in-coming transfer students who decide to take the laboratory course during the summer but also the Virginia Tech students who participate in the engineering co-op program and take courses offered during the summer so that they can graduate in four years.

A key component to the on-campus d.c. circuits laboratory course is regular one-on-one interactions between each student and the course instructor or graduate teaching assistant (GTA) to verify that the students meet the course's three major learning objectives. 'Face-to-face' communication is, thus, a critical requirement for the success of the on-line laboratory course, where practical instructional support via real-time demonstrations of measurement techniques and methods to debug circuits is provided and each student must demonstrate the circuit's operation to the GTA at the end of each laboratory experiment. We find that Skype is an appropriate platform for this interaction. The web camera that comes standard with the Tablet PC, which students are required to purchase as engineering students at Virginia Tech, has sufficient resolution so allow the GTA or instructor to see the circuit on the student's breadboard, read the display on the DMM, and observe the student and the circuit as he or she connects the oscilloscope probes. The 'Share' option on Skype allows the real-time display of the oscilloscope to be shown on the GTA's or instructor's computer, as shown in Figure 3. The online d.c. circuits course was piloted to a small number of students during Summer 2010. It was clear at the end of the pilot that additional online tutorials and vodcasts are necessary before this instructional format may be used with students who have not had previous experience making electrical measurements. Since then, we have used the online interaction to work with students who were unable to complete the course while on campus during the fall semester, allowing the students to successfully complete the course before the beginning of the spring

semester. The online format for this situation has proven to be highly satisfactory for both the student and the instructor.

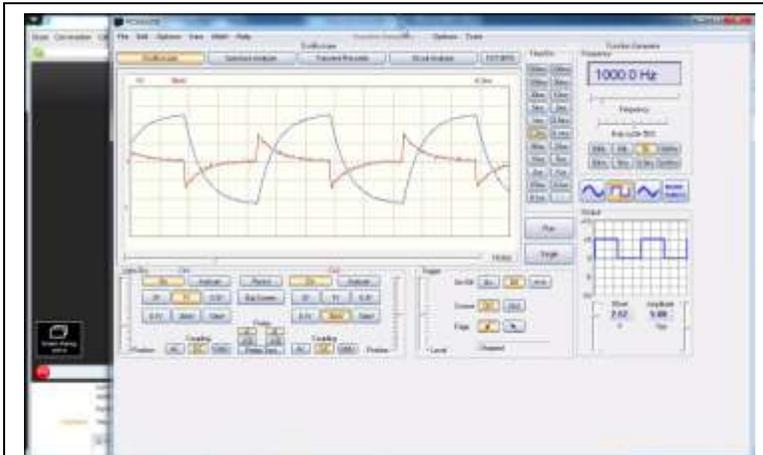


Figure 3: Screen shot from the instructor's computer of the student's oscilloscope measurements in real-time of the measurement of the voltages across the capacitor and shunt resistor in Experiment 15: A Series RC Circuit.

As students progress through the sophomore year, their comfort level in performing the experiments outside of a traditional laboratory classroom grows. This is manifested in comments in the course evaluations by juniors at the end of the a.c. laboratory course where they state that they do not need, and in a number of cases want, the instructional support of a weekly classroom-based laboratory lecture. However, students also write that instructional support is needed to help them perform the more complex analyses and measurements required in the a.c.

circuits experiments. Given this input, we decided to change the delivery method of the weekly lecture to an online, on-demand format in Fall 2010. The lectures are now available on the course Scholar site as powerpoint slides with audio. The format of each lecture, made using an add-on, Abode Presenter, with Microsoft PowerPoint, is as follows. The purpose of the experiment is described in the introductory slides with a brief listing of the learning objectives for that particular lab. Connections to previous experiments, when appropriate, are made to describe the linkages between experiments and to provide limited guidance to students on possible circuits to use in the design experiments. An explanation on the theoretical concept that will be demonstrated experimentally is provided. A brief description of the simulation tools and the experimental methods is then covered. Lastly, the desired outcomes of the experiment is discussed along with a short listing of the tasks that must be performed before the GTAs when demonstrating the operation of the circuit and the information that must be included in the laboratory report. A template for the report is, again, provided. In this course, the template is a Word document with no hotlinks to vodcasts provided. The student assessment of the online format was positive, although there were also several comments suggesting that more detailed information on measurement techniques and the specifications for the design projects should be provided in the online lectures. Less than 5% of the students who provided their input in the assessment survey suggested a return to the weekly in-class lecture format.

Expanded Application of the LiaB Pedagogy

In addition to the activities described in this paper, the authors have also been engaged in an expansion of the pedagogical approach into the circuits and electronics courses taught to mechanical engineering (ME) undergraduate students. ME students not only have to gain an exposure to topics in electrical and computer engineering 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. Faculty from Departments of Mechanical Engineering and Electrical 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 three-hour 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 ME students use the same LiaB kit that is used in the circuits courses taken by the ECE students. The same pedagogical approach has been implemented in the design of the laboratory experiments, where the ME students perform an analysis and simulation of the circuit prior to its construction and then measure the voltages and currents to verify the operation of the circuit. Weekly lectures are given to demonstrate experimental and simulation techniques and to provide instructions on the operation of the DMM and oscilloscope. Online tutorials are also made available to the ME students. The most significant difference between the experiments conducted by the ME students to those performed by the ECE students is that there are no design experiments assigned to the ME students. The first offering of the combined lab and lecture versions of the circuits and electronics courses was in 2010.

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. We have developed a set of hands-on experiments that are designed to promote student comprehension, depth of learning, and application of the fundamental concepts in electromagnetic fields. These experiments utilize eye-safe optoelectronic devices that operate in the visible wavelength region, which enable the students to see the application of the concepts. The electronics breadboard serves as an optical table with plastic optical components mounted and aligned to optoelectronic and electro-optical devices using simple optomechanical fixtures positioned in the 0.1" spaced holes. Instructional materials have been created to provide background on associated technologies, applications, laser safety, and the processes used to fabricate some of the custom optical and optomechanical components used in the experiments.

Dissemination of Project Results

As mentioned previously, the 4th edition of the lab manual for electrical and computer engineering students 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. The laboratory manual, published by Wiley Custom Publishers, is available through Wiley as well as through a number of online vendors including Amazon and Barnes and Noble. A laboratory manual for the circuits and electronics courses taught to the mechanical engineering students is also expected to be published in 2011. A website, www.lab-in-a-box.net, is under construction. Material for students and course instructors will be freely available at this site.

We will 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 April 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. In addition to these two venues, we have approached the national Electrical and Computer Engineering Department Heads Association (ECEDHA) and several of the regional ECEDHA organizations to request an opportunity to describe the pedagogy applied in the development of the on-campus and online LiaB courses and the associated instructional materials. Based upon the responses received thus far, we anticipate that we will present the results of this project at 2-3 regional meetings and at the national meeting later this year.

Conclusions

During the past nine years, a considerable amount of effort has been expended to develop the experiments used the LiaB courses and the supporting instructional materials as well as to test several alternative methods to deliver the course. There now exists several hours of online instructional materials available to the students for each experiment assigned in the LiaB courses. The ECE student evaluations of instruction for the two LiaB circuits has increased significantly as online tutorials and other instructional materials have been made available to them. We regularly receive suggestions for new tutorials as well as offers by students to participate in the development of the instructional materials. Faculty members routinely supervise 2-5 students per semester to create new experiments and tutorials incorporating many of these suggestions. There is an appreciation for the perceived limited support provided in the LiaB courses – specifically, that that a GTA or course instructor is not immediately available to answer questions while students perform the experiment as is true in the classroom-based laboratory course – after students complete the a.c. circuits laboratory course. Overall, students make positive comments about the pedagogical approach of the LiaB courses: the demonstration of theory in practice, the level of experimentation and design content in the exercises, and the development of their self-confidence in completing the experiments on their own. The adoption of the pedagogical approach in the circuits and electronics courses for ME students, the interest expressed by students to assist with the continued development of the experiments and instructional materials, and the desire by other ECE faculty to use the LiaB kit in other educational activities demonstrate that the LiaB pedagogy is highly successful.

Acknowledgements

The authors acknowledge the support of the Bradley Department of Electrical and Computer Engineering at Virginia Tech and the National Science Foundation (Awards 0817102 and 0343160). We also wish to acknowledge the contributions of several individuals who, as students at Virginia Tech and Virginia Western Community College, assisted in the development of the online materials, vodcasts, and report templates. They are C. Shek, J. Quesenberry, J. Olinger, K. Diomedi, and B. Lawall.

Bibliographic Information

1. Hendricks, R.W. and K. Meehan (2009). Lab-in-a-Box: Introductory Experiments in Electric Circuits (3/E), Hoboken, NJ: John Wiley and Sons.

2. C. Shek, K. Meehan, and R.W. Hendricks, "Podcast Tutorials on PSpice and Lab-in-a-Box", Proc. ASEE Annual Meeting, June 14-17, 2009 Austin, TX. (available online at www.asee.org)
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. R.L. Clark, Jr., G.H. Flowers, P. Doolittle, K. Meehan, and R.W. Hendricks, "Transitioning Lab-in-a-Box (LiaB) to the Community College Setting", Proc. FIE 2009 Conf., Oct. 18-21, 2009, San Antonio, TX. (available online at <http://fie-conference.org/fie2009/>)
5. K. Meehan, J. Quesenberry, J. Olinger, K. Diomedi, R.L. Clark, R.W. Hendricks, and P.E. Doolittle, "Hands-on Distance-Learning Laboratory Course Using Internet Video Tools", Proc. ASEE Annual Meeting, June 14-17, 2009 Louisville, KY. (available online at www.asee.org)
6. 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)
7. Gagne, R.M., W.W. Wager, K.C. Golas and J.M. Keller. (2005). Principles of Instructional Design. Toronto, Canada: Thomson-Wadsworth.
8. Shek C., K. Meehan, and R.W. Hendricks, "Podcast Tutorials on PSpice and Lab-in-a-Box", Proc. ASEE Annual Meeting, June 14-17, 2009, Austin, TX. (available online at www.asee.org)
9. Meehan K., J. Quesenberry, J. Olinger, K. Diomedi, R.L. Clark, R.W. Hendricks, and P.E. Doolittle, "Hands-on Distance-Learning Laboratory Course Using Internet Video Tools", Proc. ASEE Annual Meeting, June 14-17, 2010, Louisville, KY. (available online at www.asee.org)