AC 2009-411: LAB IN A BOX: THE DEVELOPMENT OF MATERIALS TO SUPPORT INDEPENDENT EXPERIMENTATION ON CONCEPTS FROM CIRCUITS

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Lab-in-a-Box: Development of Materials to Support Independent Experimentation on Concepts from Circuits

Abstract

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 at home various d.c. and a.c. circuits using an inexpensive electronics kit, digital multimeter, and a software oscilloscope and, thus, has not require significant resources to implement. The inclusion of LiaB in our ECE curriculum 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 that have been traditionally lecture-based with no lab component and has been adopted by three community colleges. The aim of the first set of experiments that are under development, funded by a grant from the National Science Foundation, is to reinforce abstract concepts on first-order and second-order RLC circuits introduced in the companion circuits lecture course. The students construct circuits with physical components rather than symbolic parts in PSpice and determine the time-varying voltage drops and currents in the circuit by direct measurement rather than by plugging values into their calculators. Experiments enable students to explore how the component tolerances, the initial state of the capacitor and/or inductor, and the frequency response of the circuit affects the output signal. An approach to integrate evaluation and assessment is being undertaken, where methods to measure the educational outcomes are considered concurrently with the development of the learning materials. A description of our pedagogical approach to the development of these learning materials and the integration of evaluation and assessment metrics will be described.

Introduction

During the past several years, members of the Electrical and Computer Engineering (ECE) faculty at Virginia Tech at have been concerned about declining enrollments in both the Electrical and the Computer Engineering programs. Of particular concern was the declining enrollment of women in our programs. Analysis of our enrollment data showed that the percentage of women undergraduates in our ECE department was under the national average for the two degree programs – 12% in the electrical engineering (EE) program and 6% in the computer engineering (CpE) program. The ECE averages were also significantly less than the percentage of women that matriculated into the College of Engineering as freshmen engineering majors (20%). Surprisingly, we also found that a significant portion of the women, underrepresented minorities, and nontraditional students in the department arrive as transfer students, usually from one of the community colleges in the Virginia Community College System (VCCS).

From these studies, it became clear that a part of the problem arose because our EE and CpE curricula were very mathematically oriented and thus aligned more to analytical thinking with little experimental coursework, which made learning the material in the two degree programs difficult for those who are visual learners. An additional factor that was handicapping our visual learners was the fact that a number of informal learning opportunities outside of academia had vanished. It was noted that far fewer of our incoming sophomores had direct experience in any aspect of electrical engineering that was common in past decades. While our students made extensive daily use of a number of complex electronic devices, they had no experience in dealing with electronics from an experimental point of view as interest in ham radio has waned, sales of home electronic kits are negligible, and the motivation to disassemble and reassemble computers has been reduced because of the general availability of plug-and-play accessories, the increased use of surface mount technology that made component replacement impossible for the home enthusiast, and the low replacement cost of the entire system. This reduced level of informal learning had the unintended effect of equalizing the level of experience among white males, women, and underrepresented minorities in the degree program.

Unfortunately, the students' lack of prior experience appeared to increase the difficulty that the students have with the abstract concepts presented in the two introductory circuits courses, as evidenced by an increase in the students' frustration level (noted informally through comments to the course instructors during office hours and by a general decrease in several of the metrics measured on the Student Evaluation of Instruction at the end of each semester) and a sense by the instructors that they have had to either reduce the course content to achieve a reasonable depth of learning overall or abandon a large percentage of the students. Thus, we determined that we needed to revise both the EE and the CpE curriculums, especially in the early years, to have a significant active "hands-on" learning component.

One possible way to achieve this goal would be to develop simulation laboratory exercises in which the students do their "experiments" on a computer, using for example, such tools as MatLab or MultiSim. We have found it very challenging to develop computer-based exercises that do not reduce the degrees of freedom provided to the students, and thus provide fewer opportunities for the deeper learning than would be obtained when the students are engaged in building, testing, and debugging the circuits that they have designed. In part, this may be due to the fact that engineering students have a high level of computer literacy and tend to find 'short-cuts' and 'game the system' in the computer-based exercises and thus reduce the opportunities for learning.[1] There are also concerns that the switch to computer-based laboratories might lead to a variant of the digital divide within our student population where affluent male undergraduate students may display greater competence short-term on the computer-based laboratory exercises, yet not gain significant understanding of the course materials from their participation.[2] Thus, after considerable thought, we rejected this course of action.

Instead, we developed an alternative approach—the Lab-in-a-Box concept—to teaching the introductory circuits courses involved hands-on experiments that were developed to reinforce concepts taught during the course lectures and were conducted by students at home using equipment that they owned individually. This pedagogical approach of integrating concrete and abstract learning received overwhelmingly positive feedback from students enrolled in the d.c. circuits course and was included as an instructional component during the development of the a.c. circuits course in the following year. These laboratories have proven to be very successful.

Through these efforts, we now have an integrated approach to providing hands-on experience for students beginning with the spring semester of their freshman year and culminated in the spring semester of their junior year with their second electronics course. Despite these significant advances, there remain problems with our pedagogy. Students are often unsure of their experimental abilities and seek validation of their methodologies. This attitude can slow, and occasionally prevents, some of the students' ability to perform the initial laboratory exercises, resulting in poor grades and the development of a dislike for the subject. Follow we outline methodologies to resolve these issues.

Rationale for LiaB

It is well-documented that students have a wide range of learning styles.[3-5] Engineering students are no different. Felder and Smith have developed a taxonomy of these learning styles[6] 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)[7]. Of particular significance is research on gender and ethnicity differences in learning styles where it has been clearly demonstrated that, at least in the sciences, technology, engineering, and mathematics (STEM), women are generally more visual learners than are men.[8,9] Hands-on experience greatly enhances the learning experience for all students, but is generally more important for women and minorities than for white males. Nonetheless, it is clear that most people learn by doing.[10,11] It is also clear that these observations are in contradiction to the usual methods of teaching undergraduate electrical engineering courses. The problem thus arises as to how one may introduce a hands-on experience in these courses without incurring the very high cost of facilities, equipment, and personnel.

We have addressed this problem in our introductory circuits courses with LiaB[12,13], a series of hands-on exercises that reinforce the abstract concepts that are the foundation of the electrical and computer engineering disciplines. These hands-on experiments were first incorporated as a series of homework assignments in each of the two circuits courses. To perform these hands-on lab exercises, each student purchased a relatively inexpensive electronics kit with breadboard (known as an analog and digital trainer or ANDY board) with on-board power supplies and a simple function generator (Fig. 1), a digital multimeter, a bag of components (resistors, capacitors, op amps, LEDs, etc.), and a sound card for their computer that enabled them to use a freeware software oscilloscope package. The ANDY board was designed by Virginia Tech ECE personnel in collaboration with an industrial firm who now manufactures and distributes the kits to the students, thus removing the Virginia Tech ECE Department from all aspects of the supply and distribution chain, yet provides the students with a simple and efficient single source for all of the components of the system. Some measurements are made with a digital multimeter (DMM), while signal traces for time-varying signals are observed using the software oscilloscope. All work can be performed by the students at home or at a study break table using entirely student-owned equipment; no dedicated laboratory space or university-owned equipment is required.

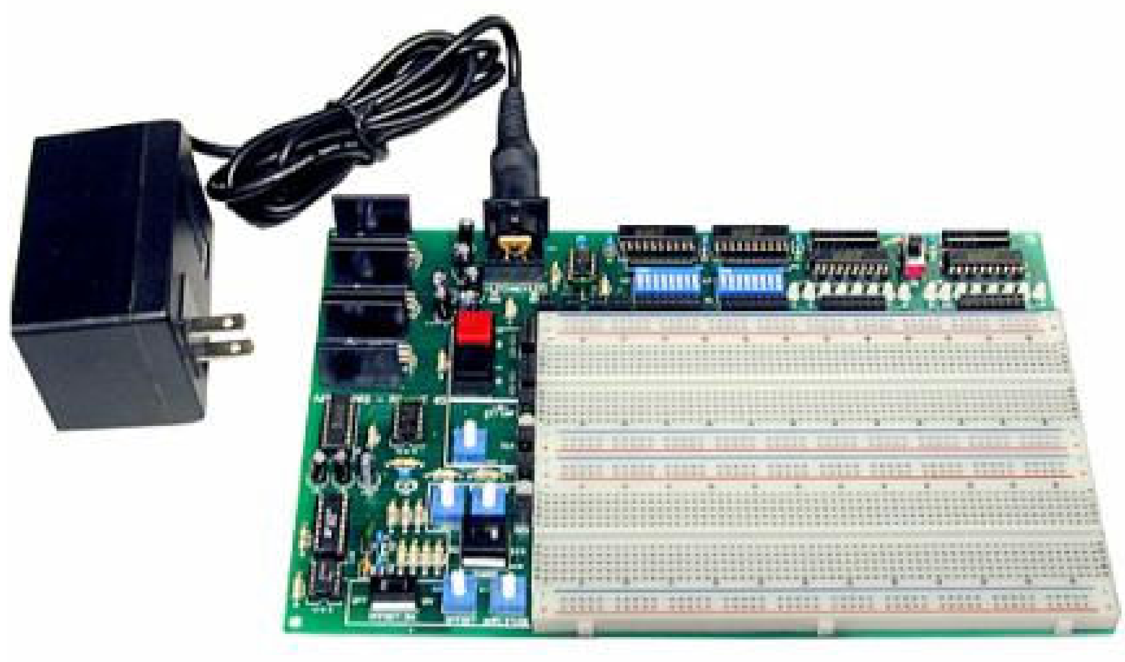

Figure 1: The RSR/VT A and D trainer.

The laboratory exercises are designed to first teach the students simple measurement techniques using a DMM, as well as procedures for wiring circuits. In addition, elementary concepts of propagation of errors and the difference between accuracy and precision are introduced. Creativity and design are minimized as the purpose is to build skills that the students will use repeatability in subsequent exercises and, thus, must be taught to perform the measurements properly. The last exercise is course-ending capstone design experience. The goal is to design, build, and demonstrate the correct operation of a circuit that must meet predefined specifications. Here, students have complete flexibility in their circuit design as long as it meets the design requirements. The exercise incorporates experimental techniques and circuit theory that have been presented to the students in previous lab exercises and in the circuits lecture course. A critical learning outcome from this exercise is that the students learn that there is no single correct answer to the exercise, but there are definitely circuits that do not meet the design requirements. The same philosophy is followed in the a.c. circuits course, only each experiment becomes increasingly more sophisticated. For most of the semester, the students build predefined circuits which are designed to teach various aspects of a.c. circuits. Capstone design experiments such as those developed for the d.c. course are also available for the a.c. course. Again, the emphasis is on developing experimental techniques and skills. At this time, there are some thirty experiments published in the laboratory manual[13] where the first nineteen experiments reinforce concepts covered in the d.c. circuits course and the second set of nineteen experiments bolster the lecture materials from the a.c. circuits course.

We have obtained very positive results during an early assessment for the initial nineteen experiments via a survey instrument[12] in addition to positive feedback from the department faculty members. An additional nineteen experiments have been developed and are about to be incorporated into the two laboratory courses. We have been extremely pleased to learn that many students are now using their LiaB systems to develop projects in some of their upper division ECE courses.

Pedagogical Approach to the Development of Supporting Learning Materials

We have identified broad topic areas where tutorials would be useful to students as they design and simulate their circuits in the pre-labs and later when they construct, test, and debug their circuits. Each learning module, which will include a multimedia module, will be constructed based on Gagne's instructional events:[14] gain attention, state objectives, activate prior knowledge, present material, provide learning guidance, motivate practice, and provide feedback. In addition, each multimedia module will be constructed based on current knowledge of multimedia learning.[15,16] With few exceptions,[17-19] the multimedia learning modules on circuits and electronics that are generally available on the internet consist of Powerpoint slides with occasional audio accompaniment. A concern that we will work to address during the development of the multimedia materials during our project is to insure that we engage the students in active learning; i.e., we will develop supporting interactive materials to complement any Powerpoint slide presentations that we develop. Secondly, the interactive learning materials must stimulate student thinking, rather than gaming. The learning materials may include circuit simulations,[20] tutorials to reinforce the theory upon which the laboratory exercise is based, general reference material on the laboratory equipment, and material related to specific exercises[21] as well contextual information on applications of the materials by engineers in industry.

At the beginning of each effort to develop a specific learning module, we identify the learning objectives to be covered, the instructional method(s) that will be used, and techniques to evaluate the learning module, and to assess whether the learning objectives have been achieved. The construction of each module is a joint effort of both subject matter experts and multimedia learning experts. The construction of each multimedia module will follow the same instructional template:[22]

1. *Introduction:* The introduction section of each module will include a short vignette designed to gain students' attention and activate their relevant prior knowledge. This vignette will be used to connect the new module's focus to students' prior knowledge and will be based on a relevant application of the new module's focus. The introduction will end with a stating of the module's objectives.
2. *Explanation:* The explanation section of each module will include a description of the issue or problem under study; an explicit discussion of the knowledge, skills and/or mathematics necessary to address the issue or problem; and the provision of a solution strategy.

3. *Demonstration:* The demonstration section of each module will include an elaboration of the explanation through the provision of worked examples, simulations and animations designed to scaffold students' understanding of the problem, knowledge and solution strategies under study.
4. *Participation:* The participation section of each module will provide students' with the opportunity to practice and assess their new knowledge and skills. This participation, or practice, may involve the solving of equation-based problems, answering of multiple-choice questions or manipulation of simulations. In each of these cases of participation, the student will be provided with explicit feedback based upon their responses.

Multimedia Learning Tutorial

The initial set of tutorials that have been developed have been concentrated on issues that arise early in the first semester circuits laboratory course - how to launch OrCAD Capture 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. These tutorials are available to students as downloadable files on a departmental website (http://www.ece.__.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. In addition to these tutorials, we have developed several interactive tutorials using ActionScript.

As an example how these tutorials will be integrated into the laboratory exercises, we will describe a Flash tutorial on a simple half-wave rectifying circuit and how it will be incorporated into the lab exercise. The Flash tutorial allows the student user to adjust the turn-on voltage of the diode over a wide voltage range (0-10V). The output voltage is then displayed, where the calculations are based upon a piecewise model for the diode (Fig. 2). The student user can select a button (SWAP), which causes the anode and cathode connections of the diode to be switched. The tutorial will be coupled with the experiment on a half-wave rectifier to assist students as they first analyze the voltages and currents in the circuit and then as they test and debug the circuit that they have constructed on the circuit board. The laboratory write-up will ask the students to take their results from a previous lab exercise in which they measured the I-V characteristics of a p-n junction and developed a piecewise model for the diode and use these results to set the turn-on voltage of the diode in the Flash tutorial. They will also be asked to explain the differences between the results obtained from the Flash tutorial, their own calculations, the PSpice simulation (which is based upon an ideal diode model for the diode), and the measurements that they obtained on the physical circuit that they build. The graduate teaching assistants (GTAs) for the laboratory course will be instructed to suggest to the students who come to office hours for assistance in the half-wave rectifier lab exercise that they first compare their results with the voltages from the Flash tutorial and from their PSpice simulation. Once the students have these results, the GTAs will provide assistance on debugging the circuit.

To develop the learning material - in this case, a Flash tutorial, we first identified the learning objectives that the students should gain from the laboratory exercise and which objectives were weak in the current exercise, which is performed early in the first electronics course. A number of the students did not understand the basis for the differences they observed from the results obtained from their hand calculations using the piecewise model of a diode, from the PSpice simulation, and from their measurements on the physical circuit. Secondly, a considerable portion of the students were unable to debug their circuits to identify problems in construction (e.g., inserting the diode backwards) or measurement techniques. A Flash tutorial was selected because it can provide visual information without significant time delay and multiple screens are not launched as can be the case with a PSpice simulation. To incorporate evaluation of the Flash tutorial and assessment of the achievement of the learning objectives into the course materials, the laboratory exercise will be redesigned to include questions about the differences between the ideal diode and piecewise models, which we will use as an assessment tool to evaluate the students' depth of learning.

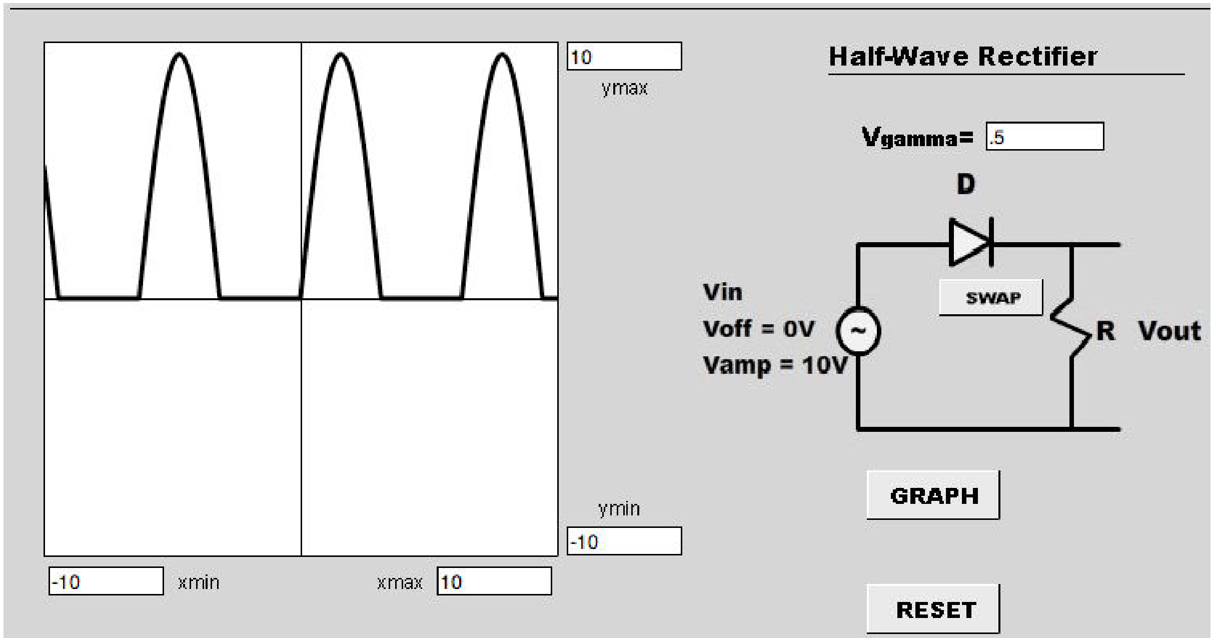

Figure 2. Screen shot of the Flash Tutorial

There are numerous experimental best practices and worked examples that reinforce fundamental circuits and electronics concepts that can be addressed. To determine the tutorials that will be developed in the future, concepts will be ranked in order of priority based on feedback from students and our experience in grading of experiments during the past five years. Additional topics will be added after discussions are held with the faculty members who have taught the courses and after soliciting suggestions from the course GTAs and from the undergraduate students while enrolled in the course. The methodology that will be used to develop these tutorials will be similar to that used in the development of the Flash tutorial and its integration into the lab exercise, as described above.

Conclusions

The multimedia learning materials have been and are under development to support the independent learning of students enrolled in the introductory circuits and electronics laboratories at Virginia Tech. These courses were designed around an innovative teaching tool, the Lab-in-a-Box, in which students design, construct, and test circuits outside of a traditional laboratory classroom. The multimedia learning materials include podcasts, QuickTime, and Flash tutorials that address topics on issues that a significant percentage of the students enrolled in these courses express (during office hours or on course evaluations) or demonstrate (by poor performance on the lab exercise) that they have had difficulties. The pedagogical approach to the development and integration of the tutorials and the evaluation and assessment techniques was described using the example of laboratory exercise on a half-wave rectifier. The assessment of the tutorials developed and integrated into the LiaB laboratory exercises is in the initial stage. Additional tutorials are under development and identification of other tutorial topics has begun.

Acknowledgements

The authors acknowledge the support of the Virginia Tech Bradley Department of Electrical and Computer Engineering 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.

Bibliography

1. Wecker, C., C. Kohnlet, and F. Fischer, (2007). "Computer Literacy and Inquiry Learning: When Geeks Learn Less." Journal of Computer Assisted Learning, **23**, pp. 133-144.
2. Van Joolinger, W.R. T. de Jong, and A. Dimitrakopoulou, (2007). "Issues in Computer Supported Inquiry Learning in Science." Journal of Computer Assisted Learning, **23**, pp. 111-119.
3. McKeachie, W.J., P.R. Pintrich, Y-G Lin, D.A. Smith, and R. Sharma (1990). Teaching and Learning in the College Classroom: A Review of the Research Literature (2E), Ann Arbor: University of Michigan.
4. Bransford, J.D., A.L. Brown, and R.R. Cocking (2000). How People Learn: Brain, Mind, Experience, and School (Expanded Edition), Washington, DC: National Academy Press. (http://www.nap.edu/openbook.php?record_id=6160)
5. Larkin-Hein, T., and D.D. Budny (2001). "Research on Learning Style: Applications in the Physic and Engineering Classrooms." IEEE Tr. Ed. **44**(3), pp 272–281.
6. Felder, R.N., and L.K. Smith (1988). "Learning and Teaching Styles in Engineering." J. Eng. Ed. **78**(7), pp 674–681. (See also a recent update to this paper at http://www.ncsu.edu/felderpublic/Papers/LS-1988.pdf).
7. Felder, R.N. (1996). *Matters of Style*, ASEE Prism **6**(4), pp 16-23. (See also http://www.ncsu.edu/felder-public/Papers/LS-Prism.pdf)
8. Thom, M. (2001). Balancing the Equation: Where are Women and Girls in Science, Engineering and Technology? New York: National Council for Research on Women.
9. Margolis, J., and A. Fisher (2003). Unlocking the Clubhous: Women in Computing, Cambringe: MIT Press.
10. Myers, C., and T.B. Jones (1993). Promoting Active Learning: Strategies for the College Classroom, San Francisco: Jossey-Bass.
11. Felder, R.N., and R. Brent (2003). "Learning by Doing." Chem. Eng. Ed. **37**(4), pp 282–283. (Seealso http://www.ncsu.edu/felder-public/Columns/Active.pdf).
12. 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)
13. Hendricks, R.W. and K. Meehan (2009). Lab-in-a-Box: Introductory Experiments in Electric Circuits (3/E)Hoboken, NJ: John Wiley and Sons.
14. Gagne, R.M., W.W. Wager, K.C. Golas and J.M. Keller. (2005). Principles of Instructional Design. Toronto, Canada: Thomsoon-Wadsworth.
15. Mayer, R.E.. (2005). The Cambridge Handbook of Multimedia Learning. Cambridge, UK: Cambridge University Press.
16. Doolittle, P.E., K.P. Terry, and G.J. Mariano. (2008). The Effects of Working Memory Capacity on Learning and Performance in Multimedia Learning Environments. In R. Zheng (Ed.), Cognitive Effects of Multimedia Learning. Hershey, PA: Idea Group.
17. D. Millard and G. Burnham. (2001). Innovative Interactive Media for Electrical Engineering Education, Proceedings of the 31st ASEE/IEEE Frontiers in Education Conference, 10-13 October 2001, pp. S3C-17-22.
18. Millard, D., W. Jennings, A. Sanderson, A. Wong, A. Patel, W. Brubaker, M. Perala, and D. Slattery. (1997). Interactive Learning Modules for Electrical, Computer and Systems Engineering, Proceedings of the 27th IEEE Frontiers in Education Conference, 5-8 Nov. 1997, Paper S1D, **3**, pp. 1165-1168.
19. Millard, D.L. Interactive Learning Modules for Electrical Engineering Education. (2000). Proceedings of the 50th Electronic Components and Technology Conference, pp. 1042-1047.
20. Castro, M.A., G. Diaz, C.Martinez Mediano, and E.Lopez Aldea. (2004). Work in Process – Integration of New Tools and Technologies in Electronics Teaching, Proceedings of the 34th Annual IEEE Frontiers in Education Conference, October 20 – 23, 2004, Savannah, GA, **1**, pp. T1C-10-11.
21. Giuma, T.A., P. Holt, and D. Williams. (1996). Multimedia Tools in Electrical Engineering Laboratories, Proceedings of the IEEE Southeastercon' 96, 11-14 April 1996, pp. 529 – 532.
22. Hicks, D. and P.E. Doolittle. (in press). Fostering Analysis in Historical Inquiry Through Multimedia Embedded Scaffolding. Theory and Research in Social Education.