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Principal Investigator: Ferri, Bonnie H.
Award ID: 0618645
Organization: Georgia Tech Research Corp
Submitted By:
Ferri, Bonnie - Principal Investigator
Title:
A Cohesive Program Of Experimental Modules Distributed Throughout The ECE Curriculum

Project Participants

Senior Personnel

Name: Ferri, Bonnie
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Williams, Douglas
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Michaels, Jennifer
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Jackson, Joel
Worked for more than 160 Hours: No
Contribution to Project:

Post-doc

Graduate Student

Name: Wagner, Dane
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Sconyers, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Garcia, Jennifer
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Ahmed, Safayet
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Uluagac, Selcuk
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Qu, Hongyi
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed Website and built all website recources

Name: Laskin, Rachel
Worked for more than 160 Hours: No
Contribution to Project:
Modified State Machine project, helped to develop circuit modules

Name: Twu, Philip
Worked for more than 160 Hours: Yes
Contribution to Project:
Developed experiments for embedded programming and for signals and systems.

Undergraduate Student

Name: Curry, Jessica
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Chislett, Allison
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Johnson, Kevin
Worked for more than 160 Hours: No
Contribution to Project:

Name: Tom, Theodore
Worked for more than 160 Hours: No
Contribution to Project:

Name: Hayes, Evan
Worked for more than 160 Hours: No
Contribution to Project:

Name: Sanders, Sean
Worked for more than 160 Hours: No
Contribution to Project:

Name: Freeman, Justin
Worked for more than 160 Hours: No
Contribution to Project:

Name: White, Christopher
Worked for more than 160 Hours: No
Contribution to Project:

Name: Aginskiy, Artem
Worked for more than 160 Hours: No

Contribution to Project:
Developed random process experiment

Name: Tucker, John
Worked for more than 160 Hours: No
Contribution to Project:
Build an electromagnetics experiment under the guidance of Professor John Buck.

Technician, Programmer

Name: Steinberg, James
Worked for more than 160 Hours: No
Contribution to Project:

Name: Jones, Edgar
Worked for more than 160 Hours: No
Contribution to Project:

Other Participant

Research Experience for Undergraduates

Organizational Partners

Georgia Southern University
Many of the existing projects have been and are being ported to Georgia Southern for evaluation and for refinement.

Other Collaborators or Contacts

The faculty participants listed below have participated in one of the following ways: used the experiments in their classes, suggested experiments and provided guidance on their development, been part of an assessmnet study for the project, or have done substantial development work on the experiments.

Miroslav Begovic
Doug Blough
Ahjit Chatterjee
John Dorsey
Greg Durgin
Bonnie Ferri
Al Ferri
Tom Habetler
Ayanna Howard
Joel Jackson
Jennifer Michaels
Justin Romberg
David Taylor
Patricio Vela
Eric Verriest
Yorai Wardi
Doug Williams
Sudha Yallamanchilli
David Schimmel
Allen Robinson

Mary Ann Ingram
John Barry
John Buck
Geoffrey Li
Shanda Bernadin

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)
See attached file

Findings: (See PDF version submitted by PI at the end of the report)
See attached file

Training and Development:
The students working on the projects all viewed the experiments through the eyes of students learning the material for the first time. They all performed their jobs by critically examining what topics are obvious and what topics or concepts are not obvious.

Outreach Activities:
ECE participated in 4 summer middle school and high school camps in 2007 and several outreach activities including a Boy Scout Merit Badge Workshop. Participants in this project who participated in the camps or workshops include Bonnie Ferri, Doug Williams, Ayanna Howard, and Dave Schimmel. All the camps and workshops included equipment or was based on development work that was funded by this grant. One camp, which is run by the Women in Engineering Program in the Dean of Engineering Office, covers various topics on computing, technology and engineering. Bonnie Ferri ran sessions on digital logic for that camp using the boards and basic digital logic experimental equipment for the binary addition experiment. The other middle school camp for girls is a First LEGO League camp that taught basic mechanisms and gears, effective use of sensors, design, and programming. We marketed this camp in a way to encourage the formation of all-girl teams or at least girl-led teams for the First LEGO League annual competition. We used the LEGO kits purchased by the grant for this camp. The camp was initiated and organized by Jeff Davis, Bonnie Ferri, and Doug Williams, with participation by Ayanna Howard. ECE sponsored 2 one-week camps, called HOT (Hands-On Tech) Days, for high school students. These camps featured interactive, hands-on activities organized by 6 to 8 different ECE faculty members. The 2007 camps included materials from this project involving LEGO robotics and the binary addition experiment. The 2008 camps will add new material on electronics. Lastly, we ran a merit badge workshop for Boy Scouts using the philosophy of TESSAL. The merit badges taught were Electronics and Radio. While the Georgia Tech Radio club handled the Radio Merit Badge, the Electronics Merit Badge was closely associated with TESSAL. The IEEE offers supplemental materials for this merit badge, but we found this matierial to be very dry since it was based on lectures and theory. We developed hands-on modules to teach the concepts outlined in the merit badge requirements. We will refine these materials for future offerings of the workshop and then offer them to the IEEE as part of their merit badge support. The number of students who participated in the camps and workshops during May 2007 ? April 2008 is 125.

ECE participated in 4 summer middle school and high school camps in 2008 and several outreach activities. Participants in this project who participated in the camps or workshops include Bonnie Ferri and Doug Williams. All the camps and workshops included equipment or was based on development work that was funded by this grant. Bonnie Ferri ran sessions on digital logic for a middle school camp for girls using the boards and basic digital logic experimental equipment for the binary addition experiment. The other middle school camp is a First LEGO League camp that taught basic mechanisms and gears, effective use of sensors, design, and programming. The camp was initiated and organized by Jeff Davis, Bonnie Ferri, and Doug Williams. ECE sponsored 2 one-week camps, called HOT (Hands-On Tech) Days, for high school students. These camps featured interactive, hands-on activities organized by 6 to 8 different ECE faculty members. The 2008 camps included materials from this project involving the binary addition experiment. The planned 2009 labs will use the two power experiments developed for this project.
Some of these experiments were used in K-12 classrooms, specifically science classes in Sagamore Hills Elementary School and Henderson Middle School. The demographics of these schools are: Sagamore Hills is 45% African American and Hispanic, Henderson Middle is 52% African American and Hispanic. The experiments used in the classes included the power generation experiments plus the electronic labs that were used for the Boy Scout Merit Badge activity developed during the previous year's project activities.
The number of students who participated in the camps and workshops during May 2008 ? April 2009 is 105. The number of students who used this equipment in their elementary school or middle school classrooms is 161, for a total of 266 K-12 students during this time period.

During May 2010 - July 2011, the number of K-12 students who participated in outreach activities using modules developed by the TESSAL Center is 450. A workshop with 350 students (including some teachers) was held in December in association with the IEEE Conference on Decision and Control. Students did hands-on activities using TESSAL modules. In addition, 4 summer camps were held at Georgia Tech including one for middle school girls, and 3 for high school students. These all used TESSAL modules as part of their activities.

Journal Publications

Books or Other One-time Publications

. Ferri, J. Auerbach, J. Jackson, J. Michaels, D. Williams, "A Program For Distributed Laboratories In The ECE Curriculum", (2008). Conference Proceeding, Published
Bibliography: ASEE Annual Conference and Exposition. Pittsburgh, June.

B. Ferri, J. Auerbach, H. Qu, "Distributed Laboratories: A Finite State Machine Module", (2010). Conference Proceeding, Published
Bibliography: World Congress In Computer Science, Computer Engineering and Applied Computing, International Conference: Frontiers in Education Conference on Computer Science and Computer Engine

B. Ferri, J. Auerbach, J. Michaels, and D, Williams, "TESSAL: A Program for Incorporating Experiments into Lecture-Based Courses within the ECE Curriculum", (2011). Conference Proceeding, Published
Bibliography: ASEE Annual Conference and Exposition, Vancouver, Canada, June.

S. Uluagac and D. Williams
, "Building Hardware-Based Low-Cost Experimental DSP Learning Modules", (2008). Conference Proceeding, Published
Bibliography: ASEE Annual Conference and Exposition, Pittsburgh, PA,

G. Droge, B. Ferri, J. Auerbach, "Distributed Laboratories: Control System Experiments with LabVIEW and the LEGO NXT Platform", (2012). Conference, Accepted
Editor(s): ASEE Annual Conference and Exposition
Bibliography: San Antonio, TX

B. Ferri, J. Auerbach, "A Portable Finite State State Machine Module Experiment for In-Class Use in Lecture-Based Course", (2012). Conference, Accepted
Collection: ASEE Annual Conference and Exposition
Bibliography: San Antonio, TX, June

Web/Internet Site

URL(s):
http://www.ece.gatech.edu/research/tessal/index.html
Description:
This site was developed as part of this award and presents the experimental modules developed for this award.

Other Specific Products

Product Type:

Teaching aids

Product Description:
We have developed 16 small-scale experiments that can be used in lecture-based courses to enhance students'learning.
Sharing Information:

We are sharing the experiments with colleagues at Georgia Tech. We will share the experiments with local schools in Atlanta. We are presenting the work at conferences. We will summarize all the results on a website.

Contributions

Contributions within Discipline:

The assessment data is extremely supportive that the hands-on activities inserted into lecture courses supports students' understanding and their confidence in Electrical and Computer Engineering material even one semester after the course has ended.,

Contributions to Other Disciplines:

The project is aimed at Electrical and Conputer Engineering. We have supplied one of the experiments to the School of Mechanical Engineering for use in two of their courses.

Contributions to Human Resource Development:

Numerous students have worked on this project, four of them female. Two of the four female students were from underrepresented groups. All the students gained experience in developing instructional tools.

Contributions to Resources for Research and Education:

We have a 460 square foot lab dedicated to this project. Currently a teaching assistant spends 3 hours a day in the lab so that students who use the lab can have access. The lab has 10 computers, two lab benches, a TA desk, and storage space to store the experiments that are done outside of the lab (either in a classroom or taken home by students).

Contributions Beyond Science and Engineering:

The basic contributions to the public welfare so far have been in the area of outreach to the middle school and high school students. We expect to achieve a major contribution by developing a model for the use of small scale experiments in lecture-based courses. We also have been working closely with National Instruments as they develop their myDAQ boards give them feedback on what pedagogical features they should include.

Conference Proceedings

Ferri, BH;Ahmed, S;Michaels, JE;Dean, E;Garyet, C;Shearman, S, Signal Processing Experiments with the LEGO MINDSTORMS NXT Kit for Use in Signals and Systems Courses, "JUN 10-12, 2009", 2009 AMERICAN CONTROL CONFERENCE, VOLS 1-9, : 3787-3792 2009

Ferri, B;Auerbach, J, Work in Progress - A Program to Incorporate Portable Labs Into Lecture-Based Electrical and Computer Engineering Courses, "OCT 27-30, 2010", 2010 IEEE FRONTIERS IN EDUCATION CONFERENCE (FIE), : - 2010

Auerbach, J;Ferri, B, Work in Progress - The Costs and Benefits of Using Alternative Approaches in Lecture-Based Courses: Experience in Electrical Engineering, "OCT 27-30, 2010", 2010 IEEE FRONTIERS IN EDUCATION CONFERENCE (FIE), : - 2010

Categories for which nothing is reported:

Any Journal

A Cohesive Program of Experimental Modules Distributed Throughout the ECE Program

Final Report, March 2012

Project Start Date: August 2006

Findings

A primary purpose of the project evaluation is to figure out if students benefit from adopting hands-on experiments in lecture-based courses to teach complex engineering concepts. The three expected student outcomes that were identified are specified below:

1. Student achievement on tests/homework/assignments will benefit from the hands-on instructional approach.
2. Students will be more positive about the course and/or course material as active learners using the modules as well as show more interest in the topic area.
3. Students will benefit from the hands-on approach in subsequent courses in terms of performance and interests.

Results and Assessment:

The process of incorporating active learning opportunities in lecture-based courses presents challenges for instructors who must make the modifications to the course to accommodate these enhancements. Since a primary goal of TESSAL is to realize the widespread use of portable laboratories throughout the curriculum, the assessment model must also focus how to best support this goal. Using both quantitative and qualitative data to understand and evaluate the utility of the broad-based inclusion of portable laboratories, three research questions were identified that will contribute to our understanding:

1. Will student interest and response to course topics be more favorable in lecture classes that integrate hands-on learning opportunities?
2. Will student achievement on course-related assignments improve in lecture classes that integrate hands-on learning opportunities?
3. What strategies can be used to provide a low cost, portable means of introducing experiments in lecture courses?

Since the implementation of TESSAL is an incremental process, answers to these research questions comes incrementally. Throughout the project, several assessment tools have been used and include pre- and end-of-course surveys, a quasi-experimental design concept inventory testing, post-course surveys (taken a semester later), monitoring student performance on related assignments/tests, and observation. The next section provides examples of findings thus far, primarily addressing the first research question and implications for developing efficient strategies for implementation.

The findings from both Introduction to Computer Engineering and Systems and Controls courses demonstrate that student interest increases in the classes that utilize the portable labs. Survey data shows that students respond more favorably to the course material and are more likely to report better understanding of material covered by the experiments as compared with the traditional lecture. Further analysis of the implementation of the experiments reveals that supplemental materials and efficiency have an impact on student response to the experiments, which confirms the need to develop a set of "best practices" to achieve widespread integration of portable labs in lecture-based courses.

Signals and Systems Experiments[1]: The objective of the experiments is to enhance student learning of theoretical material through experimentation. In a junior level Systems and Controls course, data has been collected from six classes. Among the six is one pair of a control and an experimental class, both taught by the same instructor. The portable lab experiments that were used were the light sensor project and the motor velocity position and control project. Several observations can be made. Anecdotally, it was found that requiring students to use Bode plots and root locus in the experiment forced them to understand the concepts on a much deeper level. Without the experiments, mediocre or poorer students tend to make a weak attempt at homework problems that use these concepts. With the experiment, especially the demonstration aspect, students have to make the motor work properly in closed-loop response. It forces them to learn the concepts.

To assess the learning objective on a more rigorous level, two assessment tools were used. First, a Concepts Inventory style of test was used, which provides an objective testing method for quantifying students' knowledge of specific topics. The Systems and Control Concepts Inventory Test used here to measure the impact of the experiments includes twenty-five multiple choice questions that address fundamental concepts covered in the course and includes several questions from the Signals and Systems Concepts inventory[2], both continuous-time and discrete-time. A portion of the questions were based on Kent Lundberg's work on a controls concept inventory. Additional questions to test basic control design concepts were drafted and reviewed by faculty teaching in that field. These questions were written in the style of the Signals and Systems Concepts inventories to be conceptual not computational in nature and were on the topics of root locus, Bode plot design, implicit digital control design, Nyquist plots, and PID control.

The Systems and Controls Concepts Inventory was administered in the two classes taught by the same instructor during two consecutive semesters taught by the same instructor. In each class, the test was given at the beginning of the course and again at the end of the course. The Control System Module was used in only one course (the experimental group) and the other course served as the control group. Some of the questions are on material related to the concepts supported by the experiment and some questions are on theoretical topics not related to the experiment. One measure of success is if higher percentages of students perform correctly on the questions related to the experiment as compared to the performance of students in the control class. The preliminary findings from this analysis are presented in Table 1 below.

Table 1 Systems and Controls Concepts Inventory Test % correct comparison / experimental & control classes **Concept Inventory Questions Directly Related to Lab**			
Brief Description of Question	% correct experimental N=30	% correct control N=28	difference
Q A: identify a difference equation corresponding to a transfer function	63.0%	57.1%	+5.9
Q B: select the z-domain pole-zero plots corresponding to a discretized system	11.1%	10.7%	+.4
Q C: determine the transfer function of a digital filter corresponding to a discrete time system	63.0%	46.4%	+16.6
Q D: identify the purpose of a PD controller	74.1%	57.1%	+17.0
Q E: identify the purpose of a PI controller	81.5%	53.6%	+27.9

Another way to look at this data is to consider performance on both the pre-test and post-test and the percent gains for each student cohort. This data is depicted in Table 2, which reveals that on every question related to the Systems and Control module, a higher percentage of students in the experimental class performed better on the post test as compared to the control class.

Table 2 Systems and Controls Concepts Inventory Test % change pre- post- tests / experimental & control classes **Concept Inventory Questions Directly Related to Lab**		
Questions	% change experimental	% change control
QA: identify a difference equation corresponding to a transfer function	+28.6%	+17.1%
Q B: select the z-domain pole-zero plots corresponding to a discretized system	+11.1%	-2.6%
Q C: determine the transfer function of a digital filter corresponding to a discrete time system	+41.1%	+16.4%
Q D: identify the purpose of a PD controller	+58.5%	+43.8%
Q E: identify the purpose of a PI controller	+69.0%	+36.9%

The other assessment tool is a pre-experiment survey and a post-experiment survey.

While the students in the experimental section reported higher levels of understanding the material covered by the experiments compared to the control class, follow-up surveys administered one semester later support the lasting impact of using the experiments. From the control class, 21% of students took other Systems and Controls class and 33% did so from the experimental class. More compelling however is that only 29% of students from the control class said that their interest in applications of control engineering had increased since taking the course, yet 62% from the experimental class reported this gain.

On this same survey administered one semester after the Systems and Controls class was completed, students were given a list of nine topics. In the experimental class, portable labs were integrated into the course that covered 9 of the topics listed in Table 3. For several of the topics, the percentages of "solid understanding" students are relatively close for each of the two classes. On other topics, such as root locus methods, discretization of continuous-time systems, discrete time control systems and to a lesser extent implementation of digital filters, the percentage of students reporting "solid understanding" is considerably higher. This pattern is reversed for one of the two topics, Nyquist stability criterion, that was not addressed by the portable labs used in the experimental class. This is noteworthy for two reasons. First, one argument against the integration of experiments in lecture classes is that it can be too time-consuming and can dilute coverage of other topics. Second, since the differences for several of the topics are so large in terms of the percentage of students indicating "solid understanding" from the experimental class, this data may suggest that active learning may increase the likelihood that students will retain the information.

Table 3
Follow-Up Survey for System and Controls Students from Previous Semester
Percentage of Students That Rated "Solid Understanding" for 11 Topics Covered in the Course

	Control	Experimental
Implementation of digital filters	29%	48%
Transient response of 1st and 2nd order systems	71	67
Steady state response of systems	71	71
Root locus methods	36	52
Frequency response methods	43	48
Routh-Hurwitz stability criterion*	36	38
Nyquist stability criterion*	36	10
PID controllers	29	43
Lead and lag controllers	36	38
Discretization of continuous-time systems	14	62
Discrete time control systems	14	43

*Topics not covered by portable lab experiments

State Machine Assessment[3]: The State Machine Module was developed for courses that cover digital logic, which is taught by several different instructors. Early in the implementation phase, an assessment plan was developed that specified on-going evaluation in ECE 2030 Introduction to Computer Engineering courses during the first three years of implementation. Data has been collected from 11 classes over five semesters during that period. Six of those classes include three control and three experimental sections where each pair is taught by the same instructor. This is a required course for both Computer Engineering and Electrical Engineering majors. The course is also a technical elective for Industrial and Systems Engineering majors, so the makeup of any particular class tends to be a mix of these majors. Within the context of curriculum-wide reform by using portable laboratories throughout the curriculum, the value of the state machine module to increase students' understanding of state machine concepts and design, and enhance their interest and enthusiasm in learning the course material is assessed. The assessment of using the module consists of two primary strategies: reviewing test performance on those questions that correspond to the material covered by the experiment and conducting student surveys about their interest and understanding of the material as well as feedback about the experiment itself.

Since finite state machines can be difficult to understand, a survey conducted at the end of each semester asked students to compare their understanding of those concepts to that of other topics in the course. The survey data presented in Table 4 shows that for six classes (three pairs of experimental and control classes and each pair taught by the same instructor), higher percentages of students in each of the control classes report that they did not understand the state machine material as well as other material in the class. While all three pairs demonstrate differences, for the spring 2008 pair, 82.8% of the students in the control group reported that their understanding of protoboards/breadboard was not as good as other topics in the course compared to 5.7% in the experimental group.

Table 4
Percentage of student reporting that their understanding of protoboards/breadboard was not as good as other topics in the course

	Control	Experimental
Pair #1 Spring semester 2008	82.8%	5.7%
Pair #2 Fall semester 2008	74.3%	47.6%
Pair #3 Fall semester 2009	66.7%	31.9%

Another interesting point regarding the data in Table 4 is that the same instructor taught the spring and fall 2008 sections, and it was the first semester using the portable laboratory experiment that the highest percentage of students reported the better understanding of the material covered by the lab. One difference among the experimental sections is completion of the pre-lab state machine homework assignments. For the spring 2008 students, only one student did not complete the homework and only one student of 39 reported that there was inadequate in-class preparation for the lab. In fall 2008, 9 students out of 24 did not complete the pre-lab assignment. Not only were students not as conscientious about the pre-lab assignment, but close to half reported that they needed more preparation. Of all 6 sections, this one had the most comments that pertained to the need for more time, better preparation and more instructions.

Surveys were also conducted at the beginning of each semester when students were asked a series of questions about their knowledge and experience in specific topic areas. This was one way to ascertain if the control and experimental student cohorts were similar in their self-perceptions before taking the course. One of the questions asked if students had experience working with protoboards before taking the class. There were only a handful of students who reported any experience, and there is no evidence that the experimental classes had more students with that experience.

Survey data from the other sections of Introduction to Computer Engineering support the need to complete the pre-lab assignments and to manage efficiently the execution of the experiment. In another section with a different instructor who did only the experimental class, 7 of 28 students did not do the pre-lab assignment and 40% of the students reported they did not understand protoboards as well as the other material. In a different section taught by another instructor who reported that the pre-lab video did not work and the instructor did not attend class, 42% of students did not understand protoboards as well as other material. However, several of the comments stated that students wanted to see more in-class experiments. In analyzing survey data for the 8 sections that had the portable lab component, the data suggest that the classes where the experiment was managed efficiently and students completed the pre-lab homework were more successful in terms of understanding the complex topic and concepts covered by the lab.

One additional noteworthy finding from the survey data is the enthusiasm expressed by students in a section of the course where several supplements to the experiment were available. In this section of Introduction to Computer Engineering, the instructor had not only a pre-lab homework assignment and on-line video-tutorial, but additional on-line supplements. While 30% of the students reported less understanding of protoboards than other topics, all of the students reported adequate preparation for the laboratory and 8 of 13 comments suggested having more experiments like that one. Since this class had 6 associated supplements, additional analysis will be needed to determine if any supplements are more effective than others in helping students understand protoboards.

Analysis of test performance provides additional insight about the impact of using the experimental platform in class. For one of the control and experimental pairs, students in each class were given state machine quizzes as well as a question on the final exams covering the same concepts. On the state machine quiz, there were basically no differences between the two classes, with mean scores of 30.7 in the experimental class and 29.7 in the control class (out of 40 points.) Performance in each class on the final exam question about state machines yielded similar findings. Looking more closely at test performance addresses a potential complication often cited when using an entire lecture slot for a hands-on experiment that pertains to the material that is not covered in class due to the time used for the experiment. A negative impact on final exam scores in the experimental class is not found. The table below shows performance on the final exam in each course section both with and without the state machine question included in the totals. Scores used to calculate the mean excluding the state machine questions were normalized for ease of comparison.

Table 5 Comparison of Mean Scores on Final Exam in Control and Experimental Class Sections		
	Mean Including State Machine Q.	Mean Excluding State Machine Q.
Hands-on Experiment Class Section	71.6%	70.1%
Lecture-only Class Section	69.8%	68.1%

What these findings indicate is that students performed similarly in both class sections and there were no apparent negative consequences to replacing an entire lecture period with a hands-on experiment that provide an active learning experience. Additionally, when the test score data is considered along with the survey data from both sections, students from the experimental class report more confidence, enthusiasm and mastery over the state machine material.

Analysis of test performance in another section of the same class (although not part of the quasi-experimental design described above) reveals a somewhat different pattern and may reveal the impact of other factors, or interventions, on test performance. In this section of the course, all supplemental components were fully implemented and students were given adequate notice when all assignments were to be completed. The scatter plot in Figure 1 depicts student performance on the state machine question on the final exam and performance on the remainder test questions. All test questions were designed to be of equal level of difficulty. Based on the distribution, students tended to perform better on the state machine problem compared to the other questions on the test.

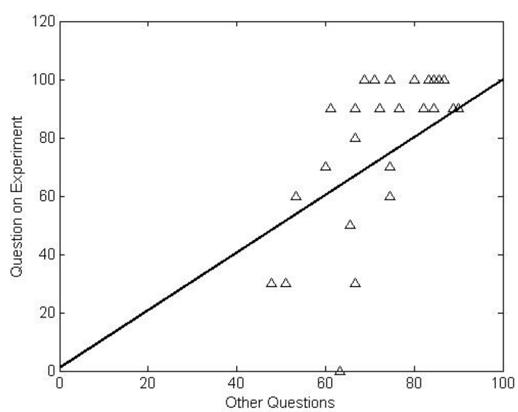


Figure 1: Student Grades on Final Exam and State Machine Question[3]

The survey data from this same class may in part explain the high performance on the state machine question. On the end-of-course survey, students were asked a series of questions about the use of the supplemental materials. For example, 87% of students reported that they did the pre-lab state machine assignment before the in-class experiment, all but one student viewed the video tutorial before class and 82% said they read the on-line fundamental concepts tutorial. Moreover, all students responded that there was adequate preparation for the in-class experiment. The comments from this student group were all positive with the only complaints that students need more hands-on assignments.

Dissemination

Several of the lab modules were given to a partner school Georgia Southern for use in their courses. They used the State Machine module, the controls modules, and the power generation modules during the Fall 2011.

The PI, Bonnie Ferri, submitted a Phase III grant proposal with Ken Connor from RPI and Kathleen Meehan from Virginia Tech. The proposed work combined the current NSF programs that focus on different platforms in order to develop a center for Hands-On Learning in ECE using portable platforms. In addition, Connor, Meehan, and Ferri organized a workshop at the 2012 ASEE Conference in San Antonio on Hands-On Learning. Two of the modules developed as part of this project will be taught during that workshop.

The following papers have been published as part of this CCLI grant:

B. Ferri, J. Auerbach, J. Jackson, J. Michaels, D. Williams, "A Program For Distributed Laboratories In The ECE Curriculum," the 2008 *ASEE Annual Conference and Exposition.* Pittsburgh, June 2008.

Ferri, B.H, Ahmed, S. Michaels, J., Dean, E., Garvet, C., Shearman, S., "Signal Processing Experiments With LEGO MINSTORMS NXT Kit for Use in Signals and Systems Courses," *Proceedings of the American Control Conference*, St. Louis, pp. 3787-3792., June 2009.

B. Ferri, "Portable, Low-Cost Experiments for Lecture-Based Courses", NI Week, Austin, August 2009,

B. Ferri, "In-Class Experiments Using myDAQ and LEGO NXT for Lecture-Based Courses", NI Week, Austin, August 2011.

B. Ferri, J. Auerbach, H. Qu, "Distributed Laboratories: A Finite State Machine Module," *Proceedings of the World Congress In Computer Science, Computer Engineering and Applied Computing, International Conference: Frontiers in Education Conference on Computer Science and Computer Engineering*, Las Vegas, NV, July 2010.

B. Ferri and J. Auerbach, "Work in Progress - A Program to Incorporate Portable Labs Into Lecture-Based Electrical and Computer Engineering Courses," 2010 IEEE Frontiers in Education Conference (FIE 2010), Washington, DC, October 2010, p 2 pp.,2010..

J. Auerbach and B. Ferri, "Work in Progress - The Costs and Benefits of Using Alternative Approaches in Lecture-Based Courses: Experience in Electrical Engineering," 2010 IEEE Frontiers in Education Conference (FIE 2010), Washington,, DC, October 2010, p.2 pp. 2010.

B. Ferri, J. Auerbach, J. Michaels, and D, Williams, "TESSAL: A Program for Incorporating Experiments into Lecture-Based Courses within the ECE Curriculum," ASEE Annual Conference and Exposition, Vancouver, Canada, June 2011.

G. Droge, B. Ferri, and O. Chiu, "Distributed Laboratories: Control System Experiments with LabVIEW and the LEGO NXT Platform," submitted to the ASEE Annual Conference and Exposition, San Antonio, June 2012.

B. Ferri, J. Auerbach, "A Portable Finite State Machine Module Experiment for In-Class Use in Lecture-Based Course**,** submitted to the ASEE Annual Conference and Exposition, San Antonio, June 2012.

References:

1. G. Droge, B. Ferri, and O. Chiu, "Distributed Laboratories: Control System Experiments with LabVIEW and the LEGO NXT Platform," submitted to the ASEE Annual Conference and Exposition, San Antonio, June 2012.
2. K. Wage, J. Buck, T. Welch, C. Wright, "The Signals and Systems Concept Inventory", *2002 Proceedings of the ASEE Conference*.
3. B. Ferri, J. Auerbach, "A Portable Finite State Machine Module Experiment for In-Class Use in Lecture-Based Course**,** submitted to the ASEE Annual Conference and Exposition, San Antonio, June 2012.

A Cohesive Program of Experimental Modules Distributed Throughout the ECE Program

Final Report, March 2012

Project Start Date: August 2006

Summary of Project:

This project seeks to improve undergraduate learning by developing a cohesive program where experiments are introduced into a wide selection of ECE courses that currently do not have labs. Most of the experiments we developed are low cost and portable, which facilitates a decentralized laboratory environment where students perform the experiments at their homes or in the classroom rather than in dedicated laboratories. We involved numerous faculty members and numerous courses. This project is associated with a center that we have initiated under this grant: The Center for Teaching Enhancement using Small-Scale Affordable Labs (TESSAL).

This report summarizes the experiments, the list of courses that have used the experiments, a list of faculty who have participated in this project, the assessment procedures, outreach activities, and publications.

Description of the TESSAL Laboratory Modules

The TESSAL Center has 13 modules in the areas of digital logic, circuits, electromagnetics, signals and systems, control systems, power generation, and random processes. Most of the experiments are low cost and portable, which facilitates a decentralized laboratory environment where students perform the experiments at their homes or in the classroom while at their desks, rather than in dedicated laboratories. These labs were designed with the following objectives and features.

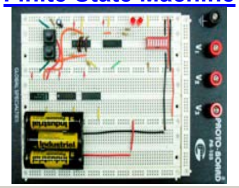
To maximize the benefits of incorporating experiments into a lecture course, the laboratory module should not only excite students about the material, it should fully support or demonstrate a fundamental principle that is hard to understand from theory alone. The concepts demonstrated in the lab should appear in standard course evaluation methods such as in-class exams. One way to satisfy these needs is for the laboratory modules to contain supplemental material including a tutorial for students on the fundamental concepts being taught and an online quiz for them that gives representative questions on the material that might be found on a standard exam.

To maximize the wide-spread usage of distributed laboratory modules, certain logistical considerations must be met. Essentially, each experimental module should be made as accessible as possible to as wide a range of instructors as possible. These experimental modules should be designed primarily for faculty who neither have resources for high-end experiments nor want to spend a lot of time developing, building or maintaining experiments. They should not be fragile, and they should be portable. Furthermore, the hands-on demos and experiments must be easy for students to use without the need for a lengthy learning period.

Table 1, taken from the supporting website, shows the available labs and the concepts that they address.

TABLE 1: TESSAL Laboratory Modules

Digital Logic

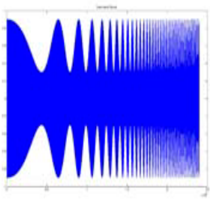
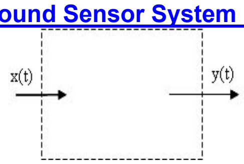
Labs	Concepts	Goals &Description
Finite State Machine 	Design of combinational circuits using a decoder, State transition table and diagram, Pin diagrams	The goal of this experiment is to reinforce state machine concepts by having students design and implement a state machine using simple chips and a protoboard. This experiment also introduces students to basic physical components

RC Circuits

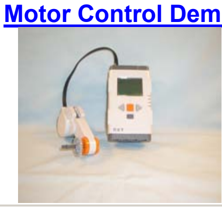
Labs	Concepts	Goals &Description
Resistive and RC Circuits 	Resistive networks, first and second-order circuits, step response, time constant	The goal is to introduce physical RC components and explore how they behave in circuits. Students use myDAQ boards connected to their laptops.
Frequency Response 	Frequency response, resonance, filtering	Students explore steady-state sinusoidal responses of first and second-order circuits at difference frequencies. They take measurements to plot the Bode Plot using myDAQ boards.

Signals and Systems

Labs	Concepts	Goals &Description
Light Sensor 	Aliasing, Frequency Analysis, Digital Filtering	Data is recorded by one or two light sensors while the light in the room is turned on and off. The students are asked to design and implement a lowpass filter to remove noise. The source of the noise is investigated
Shaded Disk 	Periodic Signals, Chirp Signals, Aliasing, Highpass and Lowpass Filters	A motor turns the disk resulting in a sinusoidal signal measured from the light sensor. Students are asked to design and implement various types of filters.

Sound Sensor Modulation 	Amplitude Modulation and Demodulation, and Pulse Code Modulation	A signal is generated on a computer, modulated, and transmitted via the computer's speakers. The sound sensor measures sound intensity, and acts as an envelope detector to recover the original signal.
Sound Sensor System ID 	Frequency Analysis, System Identification	A system is created consisting of a sequence of components: modulator, speakers, air channel, and sound sensor. Though some of the components are nonlinear, the overall system has a linear range. The system is found from input/output data records.
Quadrature 	Aliasing, sensor processing	Two light sensors are mounted in quadrature with respect to the disk. This experiment is used to show students how to process and merge data. In this case, they would use the light sensor data to implement an encoder.

Control Systems

Labs	Concepts	Goals &Description
Motor Control Demo 	Effect of Feedback Control, Root Locus	The experiment is meant to be passed around in class. Students can enter different gains into the processor and run a position control program.
Motor Velocity Control 	P, PI, and PID Control, Ziegler-Nichols Tuning Rules, Frequency Response	Students are introduced to PID control by using simple design methods for speed control of a motor. They are asked to find the frequency response of the open and closed loop systems experimentally.
Position Control 	System Identification, Root Locus, Control Design and Implementation	Students are asked to identify a system, design a dynamic controller to achieve time domain specifications, discretize and implement the control, and show the tracking response to sine waves of different

Electric Energy

Labs	Concepts	Goals &Description
Solar Energy 	Current-voltage curves, Maximum power point, Dependence on angle if incidence and distance	Performed in class, this experiment demonstrates the current-voltage-power relationships in solar generation. .Students use a solar panel and equipment to record voltage and current. The experiment can be performed using a portable DVM or using a signal measurement device and the student's laptop.
Generator 	Power generation, efficiency, effect of load (LED and incandescent bulbs)	A generator, a small DC motor, is hooked up to two possible loads: an LED bulb and an incandescent bulb. Students learn about efficiency as they turn the generator shaft and feel the large difference in effort between powering an incandescent and an LED bulb. With the myDAQ, the current and voltage waveforms for each load can be viewed and analyzed.

Electromagnetics

Labs	Concepts	Goals &Description
Radio Frequency Identification 	Basic electromagnetic principles, RF principles, Induction and magnetism	This lab shows students the effects of electromagnetic principles on RFID equipment. Students use an antenna, RF tag, RFID reader, their own laptop, and a ruler. Students examine the sensitivity of the range and orientation of the RF tag to the antenna. They also examine the effects of measurements through a dielectric field (obtained by reading the tag through the desk).

Each of the modules in Table 1 links to supporting material on the TESSAL website. The supporting web resources include:

- Tutorial on fundamental, theoretical concepts demonstrated in the lab
- Instructional videos for how to run the labs
- Laboratory procedures for students to follow to do the lab
- Online problems representative of those found in lecture-based course exams
- Instructor resources for building the platform and for implementing it

These resources satisfy two goals for the center: 1) to maximize the benefits of incorporating the experiments into the course and 2) to maximize wide-spread usage of the experiments. The website material ties the experiments to lecture material as well as provides support for students and instructors. Student support is aimed at tying the experimental material closely to the fundamental concepts taught in lectures and at streamlining the experimental procedures so that there is not a large learning curve. The instructor support materials are built to encourage a target group, those faculty who normally teach lecture courses rather than labs, to adopt the experiments by making it simple to use and easy to incorporate into classes.

These modules have been used in 10 different courses. Over 1600 students have participated in the TESSAL Center laboratory activities, and 21 different instructors have been involved. Through this experience, a list of best practices has emerged for the logistics of implementing the experiments.

A working list of best practices for out-of-class experiments includes:

- Assignment must be mandatory and thus on the course syllabus to ensure compliance.
- Use a reservation system for students to reserve modules ahead of time.
- Penalize groups 5% for each instance of tardiness (more than ½ hour late).
- Put the modules in small, sturdy boxes; tackle boxes or tool boxes work well to protect modules that might otherwise get damaged if put into a book bag.
- Have a place where students can come to work on the lab during TA office hours so that they can ask questions.

A working list of best practices for in-class experiments includes:

- Test all experimental modules before class.
- Ensure adequate time in class for both instruction and implementation phases. The experiment should not be seen as an add-on.
- Strongly encourage all students to come prepared for the lab (or risk not completing it). Preparation includes completing prelab assignments, reading the fundamental concepts tutorial, printing the lab instructions for class, and viewing the instructional video.
- Have the instructional video available on the instructor's laptop for students who need to review it during the lecture.
- Limit the number of TA check points in the labs to a level that can be completed by the available number of TAs during the allotted class period.

Summary of Courses

The table below lists the courses that are currently targeted to use the TESSAL experiments. Most of these courses have already been using the experiments and two courses are participating in an assessment this semester.

Course	Status
ECE 2030 Introduction to Computer Engineering	Two experiments have been developed. One has been used extensively in camps and the other has been used in class, has been assesses extensively, and has been put into the new syllabus for the revised course.
ECE 2040 Circuits	Two experiments developed and implemented in numerous sections of this course, and these experiments have been put into the syllabus for the revised course
ECE 3025 Electromagnetics	Two experiments and one project have been developed and used in the course.
ECE 3065 Electromagnetic Applications	Two experiments have been developed and used in class.
ECE 3070 - Electromechanical and Electromagnetic	Two experiments have been developed. One

Energy Conversion	has been used in class.
ECE 3075 - Random Signals	Two experiments have been developed and used in class.
ECE 3085 - Introduction to Systems and Controls	Several experiments have been developed and used in classes: a demo to be passed around in class, take home projects, and in-class projects
ECE 3090 - Software Fundamentals for Engineering Systems	Projects have been developed.
Autonomous Control of Robotics (new course with no permanent number yet)	Experiments developed and used in course
ECE 6561 Computing for Control Systems	Experiments have been used in course
ME 2016 Computing Techniques	Experiments have been used in course
ME 4053 ME Systems Lab	Experiments have been used in lecture part of course.

The following new courses are being developed to be taught in Fall 2012 as part of a curriculum revision: ECE 2035 Programming for Hardware/Software Systems, ECE 2036 Engineering Software Design, ECE 3084 Signals and Systems. These courses are currently being planned to have projects with student-owned physical components that can be used in multiple courses. The best practices learned from this project will be utilized in developing those labs.

Total Number Participants in the TESSAL Program (excluding K-12 Activities)

25 faculty members participated in this project in one of the following ways: used the experiments in their classes, suggested experiments and provided guidance on their development, been part of an assessmnet study for the project, or have done substantial development work on the experiments.

20 Student developers participated in one of the following ways: built experiments, wrote lab instructions, or used the experiments in courses for which they were the instructors of record.

Number of Different Courses: 12
Number of Students (excluding student developers): 2249

K-12 Outreach

Elementary school, middle school, and high school summer camps, workshops, and in-school activities were held using these portable hands-on activities labs with very ethnically diverse groups of student. A total of 831 K-12 students were served through these activities.