ADVANCES IN CLABS METHODOLOGY FOR ENGINEERING TECHNOLOGY LABORATORIES

Farrokh Attarzadeh, Deniz Gurkan, Mequanint Moges, Miguel Ramos, Victor Gallardo, Shruti Karulkar
Department of Engineering Technology
University of Houston
mmoges@uh.edu, fattarzadeh@uh.edu, dgurkan@uh.edu, maramos3@central.uh.edu, jgallardo@uh.edu, snkarulk@uh.edu

Abstract

One of the most desired educational outcomes of an engineering technology department is the creation of *skillful technologists who are able to approach the design and application of both hardware and software with the aptitude and creativity to solve problems*. Technical solutions in today's job market require special skills and training that promote cognitive flexibility, creativity, knowledge transfer and adaptability. The evaluation of previous experiences in teaching laboratories shows the necessity to create a new teaching method that engages the students in the active learning process with a hands-on approach. The CLABS (read as C-LABS for Computer Laboratories) project, an initiative of the University of Houston's College of Technology, is an outgrowth of student and faculty opinions to design learning-centered instructional tools which would increase student engagement and address the unique requirements of stand-alone laboratory instruction. This paper will present advances in the CLABS environment over the past four years – which include the addition of components such as peer mentoring and concept mapping to our project-based approach to laboratory practices – and resulting performance improvements in the Computer Engineering Technology students' skills and learning experiences.

1. Introduction

In a dynamic and competitive global market, graduating students need the ability to be creative in their approach to software and hardware problems and adapt to market needs. Therefore, a desired outcome of higher-education institutions is to provide students with the knowledge base to meet these challenges. However, science, technology, engineering, and mathematics (STEM) education will reach this goal only when the education is engaging, interactive and delivers a set of leadership, teamwork, problem solving, analytical thinking, and communication skills.

Since laboratory teaching plays an important role in engineering technology education, it should receive special attention and contribute to the development of the stated skills in student professional development. There is a consensus that traditional "cook book" style laboratory manuals do not contribute effectively to the development of the skills needed for student to be creative problem solvers. Therefore, programs and departments need to develop engaging laboratory experiences with problem solving emphasis combined with various skill and knowledge acquisition.

The authors at the Computer Engineering Technology (CET) Program at the University of Houston have developed a set of laboratory experiments for the freshman and sophomore level courses with the following objectives: **(i)** create active and hands-on student engagement to develop excellent problem solving and troubleshooting skills; **(ii)** provide opportunities for the students to develop teamwork skills; and **(iii)** encourage lifelong curiosity towards science and technology by establishing a just-in-time learning environment with project-based materials, instruction, and research emphasis.

The objectives of this project are listed:

1. Laboratories should culminate towards a project, namely, an end product.
2. Experimental, computational, simulation, testing, teamwork, and communication skills should be gained through varying educational practices in laboratory instruction.
3. Active student engagement should be enhanced to increase curiosity and research aptitude.
4. Design and troubleshooting practices should be integrated to nurture creativity and innovation.
5. The instructional methods should span learning styles of diverse body of students to raise strengths of each individual learner.

Effective Spring 2008, through funding from NSF and in partnership with Texas A&M-Corpus Christi and Houston Community College, the authors initiated the peer mentoring and concept mapping component in the labs.

This paper presents the laboratory teaching model developed within the CLABS project to revamp undergraduate laboratory education in the computer engineering technology program. It presents the model and gives an example of the digital laboratory developed at the sophomore level. The paper also highlights students' feedback and assessment used for continuous improvement. The last section summarizes conclusions and lessons learned throughout the teaching of the laboratory with the new model.

2. Overview of the Digital Circuits and Systems Course

Digital Circuits and Systems (ELET 2303) and its laboratory (ELET 2103) is required for all CET students in the Engineering Technology (ET**)** department. The main objective of this course is to teach students the principles of basic gates, combinational logic circuits, Boolean algebra, simplification methods using Karnaugh maps, counters, sequential circuits, IC loading effects, and memory devices. This is normally accomplished through lectures, several homework assignments, and examinations. The course is offered two times a year with an average enrollment of 98 students per year. This course is a prerequisite for the *Microprocessor Architecture* course (ELET 3405) taught in the CET program.

How the Course was Taught The course was previously taught with not much attention given to its laboratory components. Often, for a three hours block lecture, an absent of the instructor, a holiday, or a disaster such as hurricane, forced the laboratory to be cancelled or the laboratory instructor was confronted with lecturing on the subject and hence not being able to complete the laboratory.

The following weaknesses were observed in the past delivery methods:

- Lecture and laboratory were not in sync
- No simulation was used in the lecture and laboratory
- Attrition rate in the course was a concern
- No time to discuss a more realistic, application-based examples
- Laboratory used a cookbook manual void of practical examples and riddled with repetitive procedures
- Most students quickly lost interest because it was very monotonous

The program decided to develop experiments in-house and include application-oriented experiments with intensive use of simulation packages. It is very crucial for freshman and sophomore students to stay engaged as they are not yet fully mature, and have not developed good study habits. They may drop out quickly once they encounter difficulty understanding the basic concepts or find the subject boring. Other decisions included instilling self-discipline in students and making the experiments interesting. In the next section, the laboratory experiment model developed as a foundation for all the labs is explained.

3. Laboratory Experiment Model

The main motivation in the CLABS Project [1-7] laboratory experiment model, as shown in Figure 1, is to create a lab experience that engages the student in the active learning process through creative lab activities with special attention to cognitive processes. The educational activities listed below are derived from the cognitive process of Bloom's Taxonomy [8]: knowledge, comprehension, application, analysis, synthesis, and evaluation. Each lab experiment has the following components:

1. *Objectives*: Specific expected outcomes.
2. *Introduction*: Brief introduction.
3. *Pre-lab*: Before the lab session, where applicable, simulation and creation of electrical circuit diagrams, calculation and verification of parameter values.
4. *Parts list and equipment*.
5. *Experiment Body*: Implementation and procedures.
6. *Application*: Real-life example related to the main concept of that experiment.
7. *Conclusion*: Analysis.
8. *Report*: Experimental data and simulations, results and knowledge evaluation.

The laboratory experiment model is linked to the educational objectives of the ABET TC2K (Technology Criteria 2000) [9] as outlined in Fig. 1. The Objectives, Introduction, Pre-Lab and

Parts List and Equipment conform to the Knowledge and Comprehension section of the laboratory experiment model. In this section, the student teams are introduced to the laboratory. The teams consist of two students where students choose their own partners. This part of the experiment is simulation and calculation intensive in which tools such as PSpice, LabView, MultiSim or Electronics WorkBench are used by the students to discover and verify expected results. Once the simulations and calculations have been completed, each team implements a sequence of hands-on procedures that go from basic to complex and lead to a final application. During the procedure section, each team constructs digital circuits simulated in the previous Pre-Lab section. The students then compare the obtained results from the procedures with the results obtained in the simulations and draw conclusions. These conclusions are recorded in pre-designed worksheets that are to be turned-in and graded according to knowledge comprehension, quality and validity of the results. Finally, students are presented with a small application-based project that uses the knowledge gained and reinforces the lessons learned in earlier procedures.

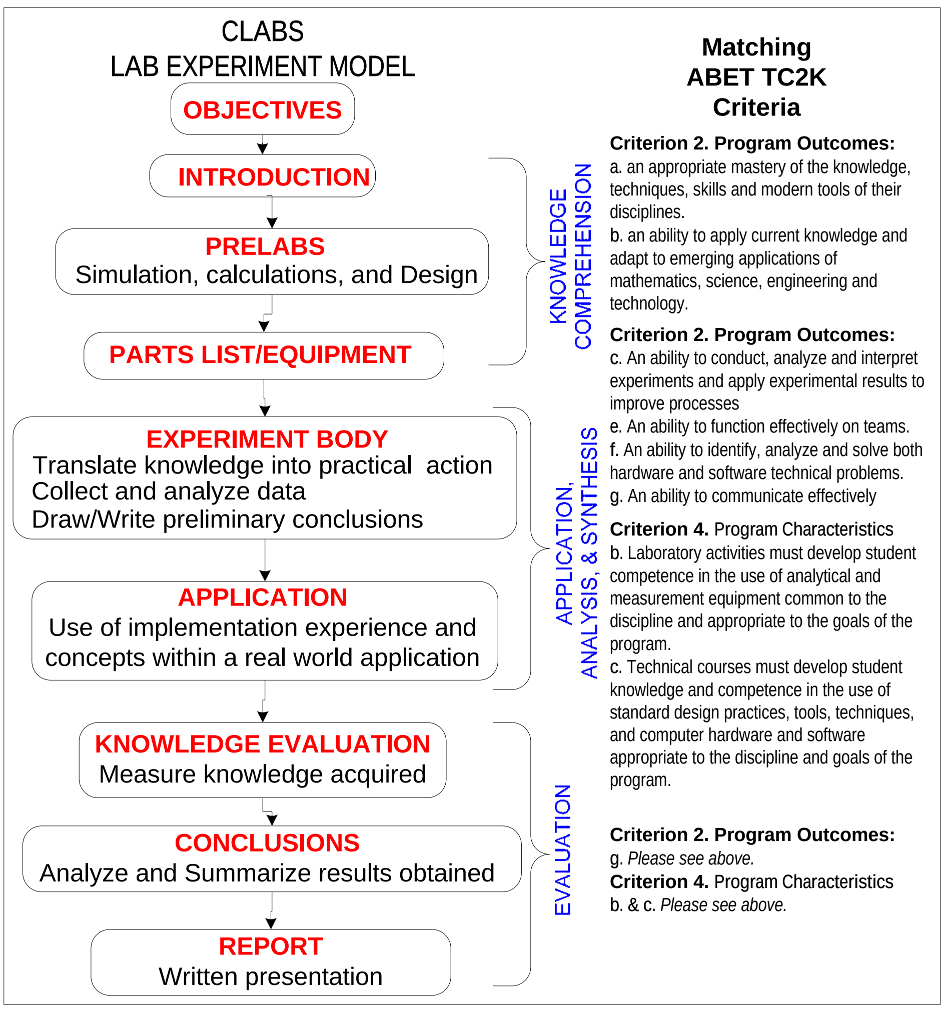

Figure 1. LABORATORY EXPERIMENT MODEL, MATCHING EDUCATIONAL COMPONENTS, AND ABET TC2K LEARNING OUTCOMES

Upon completion of the project, the team's work is ready to be evaluated. A series of knowledge-based questions are asked to test the team's comprehension of the laboratory activity. In addition, teams are required to provide a formal report that includes their findings in addition to the result of the simulations, calculations, data verification and comparisons through concrete evidence (such as simulation diagrams, graphs and mathematical analysis), logical diagrams, and conclusions.

At the end of the semester, a complex project is introduced where teams apply everything they have learned during the semester. The results of this project are then presented in a formal report, a prototype and a presentation given in front of their peers, lab assistants, lab managers, faculty in charge, invited faculty and other guests. All teams' projects are evaluated by everyone present in the presentations. Effective in Spring 2008, capstone students are required to visit and evaluate student's final projects in any of the labs and submit a two-page report regarding their observations.

This approach is a departure from the traditional laboratory model in that concepts are introduced early and mastered through mutiple applications. For example in experiment 1, students are introduced to IC handling, LEDs (LEDs are covered in the subsequent course), IC inverters, truth tables, simple Boolean expressions, logic probes, and simulation. Students simulate and build a logic probe. In experiment 2, OR and AND gates, Boolean expressions, theorems and simplification methods are introduced and several application-based examples such as Calculator Low Power Indicator System, Car Start Control Circuit, and Tank Alarm System are discussed. Students then design, simulate and build other logic circuit applications such as Elevator Control System, Rocket Launcher Countdown System, and Processing Plant Alarm Circuit. Another departure from traditional method is that the lecture is delivered in sync with lab. In the next section, the experiments developed are outlined.

4. **Concept Mapping** [10]

Tools used to engage learners in meaningful processing of input into cognitive information are called cognitive tools [11]. The computer as cognitive tool is called a *mindtool* because, when used in this way, it becomes an extension of the mind. Mindtools are knowledge representation formalisms for analyzing the world, accessing information, interpreting and organizing personal knowledge, and representing personal knowledge to others [12]. Mindtools have the following attributes: (1) can be applied across subject matter domains, (2) represent knowledge; (3) engage learners in critical thinking about the subject; (4) assist learners to acquire skills that are generalized and transferable to other contexts; (5) are simple but powerful in encouraging deeper thinking and processing of information; (6) facilitate active learning and (7) are relatively simple to learn and to use. Mindtools have been shown to be effective in engaging students in critical thinking and inference-making.

Some mindtools are semantic organization tools. Semantic organization tools enable learners to analyze and organize what they know or what they are learning. As a student integrates new concepts into his/her personal mental schema or knowledge structure, a semantic organization tool facilitates this process by engaging the student in a process of documenting and formalizing his/her schema. Once documented, his/her schema can be shared. Learning depends on the creation of a new schema or knowledge structure, or on existing structures being revised, extended, or reconstructed altogether.

A widely used semantic organization tool is a concept map (CMAP), also known as semantic network or mind map. A concept map is a spatial representation of the concepts and their interrelationships that are intended to represent externally the structural knowledge (mental schema) that a learner has stored in long-term memory [13, 14]. Concept maps are graphical visualizations with nodes that represent concepts and labeled lines that represent the links or relationships between concepts [15]. They formalize ideas like "quadratic – is type of – polynomial", "stored procedure – implements – business logic", or "optical network – is a medium for – transport of data."

Concept mapping is the process of constructing a concept map for a knowledge domain. The process of concept mapping requires a learner to identify the important concepts of a domain, arrange those concepts spatially, identify the links or relationships between those concepts, and label the nature of the links between concepts to represent what he/she knows or is learning. Because the process of building a concept map engages the learner with the content, it is an active learning strategy that can be used during class or for homework instead of traditional lectures or assignments. And while the only tools needed to construct a concept map are pencils (preferably colored) and paper, today's digitally native students may prefer developing interactive maps with computer-based concept mapping tools. Fortunately, a number of concept mapping software applications are readily available, but most people start constructing CMAPS using pencil and paper.

Students are introduced to the concept maps during their first semester in the DC lab. Peer mentoring is provided outside of the lab time to help students better grasp the concepts. They continue to use the CMAP as a component of their AC lab to conceptualize their understanding of the AC circuits. By the time they reach the digital circuits and systems laboratory, they are normally fluent in the use of the CMAP. An example of the CMAP developed for the final project, explained later, in the lab is shown in appendix A.

5. Experiments Developed

The following experiments were developed in-house in Summer 2005, pilot-tested in Fall 2005 and fully deployed in Spring 2006. A major update to these experiments is scheduled to take place in Spring 2010. Each experiment has many components and last between one to two weeks. Experiment 9 is considered the term project.

Experiment 1: Design of a Simple Logic Probe

Concepts: Breadboarding Sockets, Handling of IC's while Breadboarding, Analog/Digital Trainer Board and Logic Probe.

Simulations and Procedures: Simple Logic Probe
Experiment 2: Basic Gates, Truth Tables and Simple Boolean Expressions

Concepts: Logic Gates (OR & AND), Boolean Algebra, Truth Table, Sum-of-Products Expressions

and Product-of-Sums expressions.
Examples: Calculator Low Power Indicator System, Car Start Control Circuit, and Tank Alarm System.
Simulations and Procedures: Elevator Control System, Rocket Launcher Countdown System, and Processing Plant Alarm Circuit.

Experiment 3: Combinational Circuit Design

Concepts: Combinational Circuit Design, Number System Conversion, NOR, NAND,

Exclusive-OR (XOR), Exclusive-NOR (XNOR) Gates. Simplifying Boolean expressions using Karnaugh Mapping.
Examples:

Simulations and Procedures: 2-Bit Cubing System, 3-Bit Squaring System, Logic Gate Controller, and Burglar Alarm System.

Experiment 4: Flip-Flops and Related Devices

Concepts: Flip Flops and Related Devices, Primitive Flip-Flop using NAND Gate Latch, Clock Signals and Clocked Flip-Flops, Schmitt Trigger, and Sequential Circuits.

Examples:

Simulations and Procedures: Generating Non-Overlapping Clock Pulses, Astable Multivibrator using 555 Timer IC, Triggering One-Shot using 555 Timer IC and Logic Sequencer.

Experiment 5: Digital Arithmetic Circuits

Concepts:

Examples: Addition of Two 2-Bit Numbers.

Simulations and Procedures: One's Complement machine, Two's Complement Machine, and 4-Bit Adder/Subtractor Circuit, Complementing System.

Experiment 6: Counters, IC Counters and Their Applications

Concepts: Counters and IC Counters, Mod Number, Asynchronous and Synchronous Counters, Synchronous Counter Design, Shift Register Counters, and BCD Counter.

Examples:

Simulations and Procedures: MOD-8 Ripple Up-Counter, Mod-3 Parallel Up-Counter with an Active Low Decoding Gate, Triggering One Shot using Decoding Gate Output, Mod-32 Up-Counter, and 2-Bit Shift Register.

Experiment 7: MSI Logic Devices and Their Applications

Concepts: MSI Logic Circuits, Decoder, Decoder/Drivers and Seven Segment Displays, Encoder

Multiplexers, Demultiplexers, and Magnitude Comparators.

Examples:

Simulations & Procedures: Security Monitoring System, and Three-Step Control Sequencer.

Experiment 8: Device Characteristics

Concepts: Device Characteristics, Current and Voltage Parameters, Chip Power Supply Current Requirements, Fan-In and Fan-Out, Propagation Delays, Output Current Sinking and Sourcing, and Input Voltage Levels.

Examples:

Simulations & Procedures: Input Characteristics of the TTL Logic Gate, Output Characteristics of the TTL Logic Gate, and Average Propagation Delay Time of a TTL NAND Gate.

Experiment 9: Term PROJECT

The term project for the digital circuit and systems laboratory consists of the design, simulation,

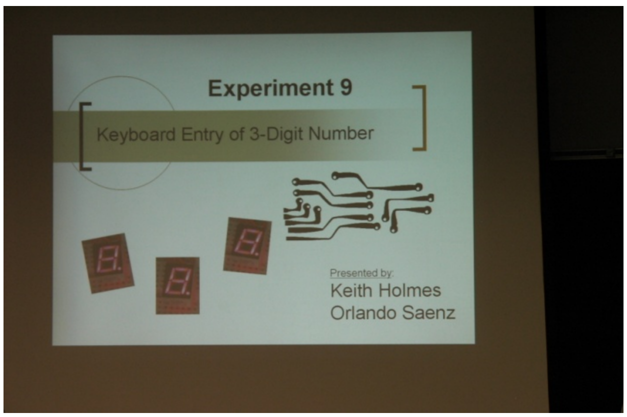

FIGURE 2. PROJECT PRESENTATION

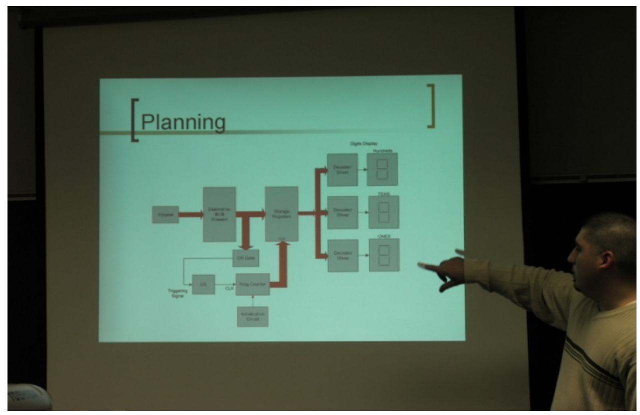

FIGURE 3. PROJECT BLOCK DIAGRAM

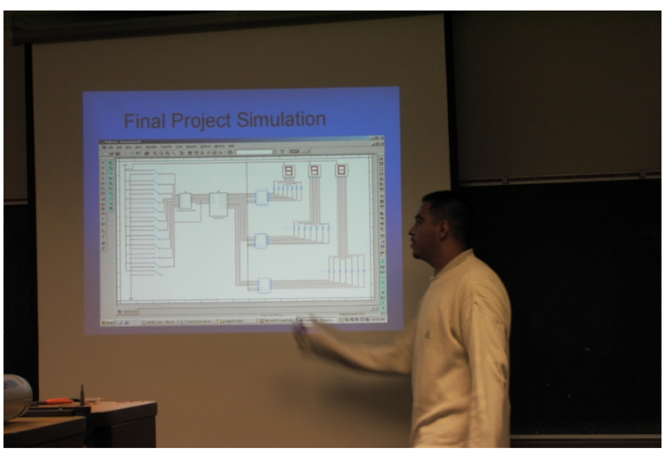

FIGURE 4. PROJECT SIMULATION

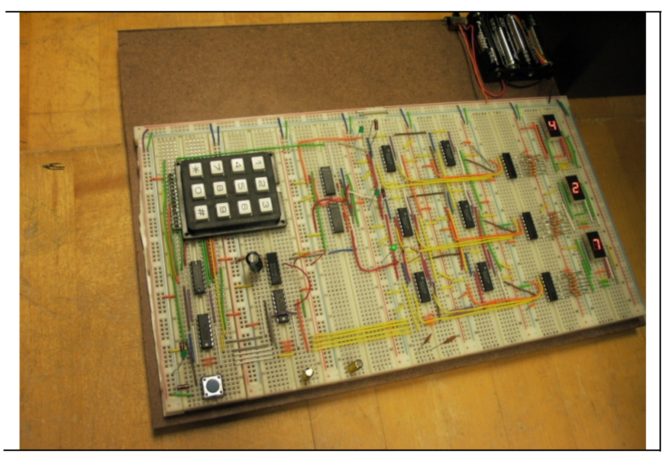
FIGURE 5. PROJECT PROTOTYPE

construction, troubleshooting, prototype, presentation and final report for a Keyboard Data Entry and Storage System. Figures 2-4 show the presentation, block diagram and simulation of the system. Figure 5 shows the actual prototype. The corresponding hand-sketched CMAP for the final project is given in Appendix A.

6. Student Surveys

Each semester, a midterm survey and final survey is conducted in all freshman and sophomore laboratories in the CET program. Student responses to the surveys in the digital circuits and systems lab validate the approach developed for the laboratory instructions by the CLABS team. Sampling of the student responses at the end of the recent semester is shown in Figures 6-9.

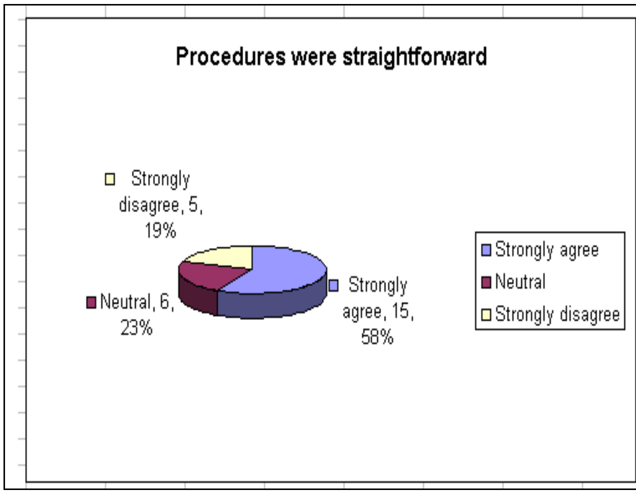

FIGURE 6. EXPERIMENTAL PROCEDURES

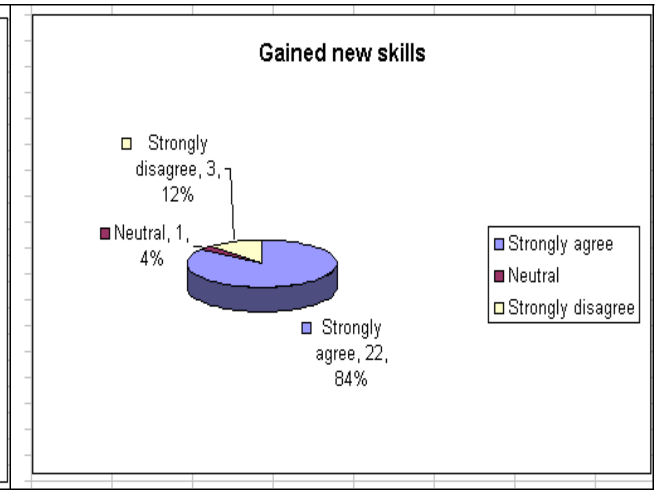

FIGURE 7. SKILLS ACQUIRED

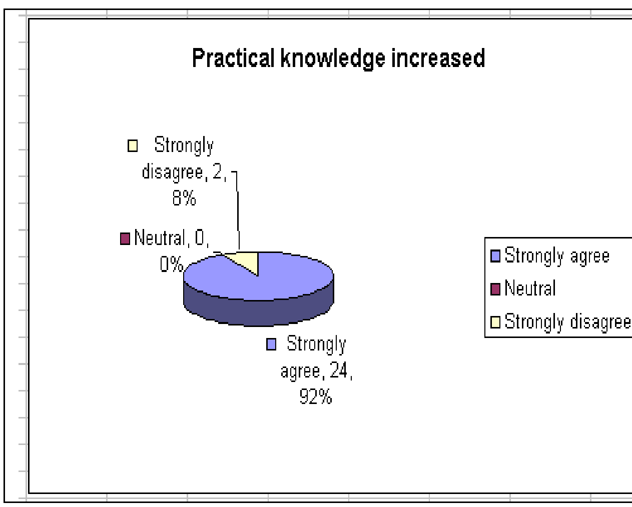

FIGURE 8. APPLIED KNOWLEDGE ACQUIRED

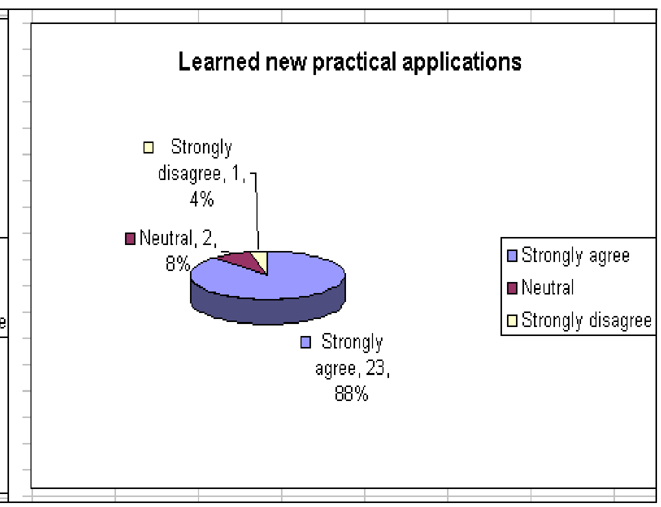

FIGURE 9. PRACTICAL APPLICATIONS

Most junior and senior courses complete similar surveys and the authors are working on a method to better track the students as they progress through the curriculum. Of particular importance is the comparison between students who start as a freshman in the CET and those who transfer as a junior. In the senior project class, where many assessments are performed, the outcome of the CLABS initiative will come to bear. In the Spring 2008 semester, about 65% of the students in the senior project class have started as freshman in the CET program. Majority of them happen to have their partners (typically four in each team) from the same group as when they were freshman and sophomores. Early indications are that they take their study very seriously, have produced better weekly progress reports and had quicker jump start for their projects, with some contemplating to file for a patent.

7. Short and Long Term Goals

The CLABS team has the following short term goals:

- Develop more application-based experiment
- Automate the manual tasks such as making the lab-related documents totally web-based
- Develop tracking system for the students until they reach the capstone course
- Introduce wire wrapping
- Persist on continuous assessment

The long term goals are:

- Scientific analysis of the assessments and link to factors such as transfers students vs. non-transfers
- Sharing the progress of the CLABS and disseminate useful information
- Automate assessment process

8. Conclusion

At the beginning and during the pilot testing, where different sections were not required to adhere to the new CLABS Project labs model, there were some conflicts between the students and the CLABS Project team as the amount of work required of them was quite different and more engaging compared to other sections. Working together and making some mid-course adjustments throughout the pilot testing, all freshman and sophomore labs are now into full-deployment and problems arising in various sections has subsided. Continuous and consistent assessment in all laboratory sections is essential to monitor the progress of the students. Tracking students until they reach the senior project course is very critical because it is in this stage where the results of the CLABS Project can be identified and indeed it is paying off. This semester, some students who were enrolled in the CLABS laboratory are now in the senior project class under the supervision of the author. Initial observation indicates that their performance, dedication, hard work and sense of responsibility is quite evident compared to other students in their team and other teams.

Projects of this magnitude require strong support from the faculty, administration, and funding to make it a reality. Because of the CLABS Project, new laboratory materials have been developed in-house and students have begun to realize the benefits of their hard work. The faculty and technical staff continue to monitor the program very closely and make adjustments as necessary to ensure continuous improvement.

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Biographies

FARROKH ATTARZADEH earned his PhD in Electrical Engineering from the University of Houston in 1983. He is an associate professor in the Engineering Technology Department, College of Technology at the University of Houston. He teaches software programming, operating systems, digital logic, and is in charge of the senior project course in the Computer Engineering Technology Program. He has developed a concept referred to as EMFA (Electromechanical Folk Art) as a vehicle to attract young students to the STEM fields. He is the Associated Editor for student papers at *the Technology Interface Journal* (http://engr.nmsu.edu/~etti/), and Chair, Conference/Organization Member Affairs for IAJC (http://www.iajc.org/). He is a member of ASEE and has been with the University of Houston since 1983. Dr. Attarzadeh may be reached at FAttarzadeh@central.uh.edu

DENIZ GURKAN earned her PhD in Electrical Engineering from the University of Southern California in 2003. She is an assistant professor in the Engineering Technology Department, College of Technology at the University of Houston. She teaches computer networking, wireless communications, optical networking, and sensor networking in the Computer Engineering Technology Program. She is an active researcher in sensor networks with over 50 peer-reviewed articles. Her research lab, Interoperable Smart Sensors and Networking (ISSNet) has been funded by NSF, NASA, and small businesses with research focus.

MEQUANINT A. MOGES earned his Ph.D. in Electrical and Computer Engineering from State University of New York at Stony Brook in 2005. He is an instructional assistant professor in the Department of Engineering Technology, College of Technology at the University of Houston. Dr. Moges teaches various courses including DC/AC Circuits, Data Communications, Computer Networks, Telecommunications and Advanced Wireless Networks. His research interests are in the areas of wireless sensor networks, load scheduling in parallel and distributed systems and grid computing. Prior to his current he was involved in the design of electrical systems of different nature viz. industrial, public as well as low voltage communication systems. In 2008 he received the College of Technology's Fluor Daniel Award for teaching excellence. He is also a recipient of Stony Brook Presidential Fellowship for the academic year 2001-02 and an AUSAID scholarship from the University of New South Wales, Sydney, Australia for the academic year 1996-1997. Dr. Moges may be reached at mmoges@central.uh.edu

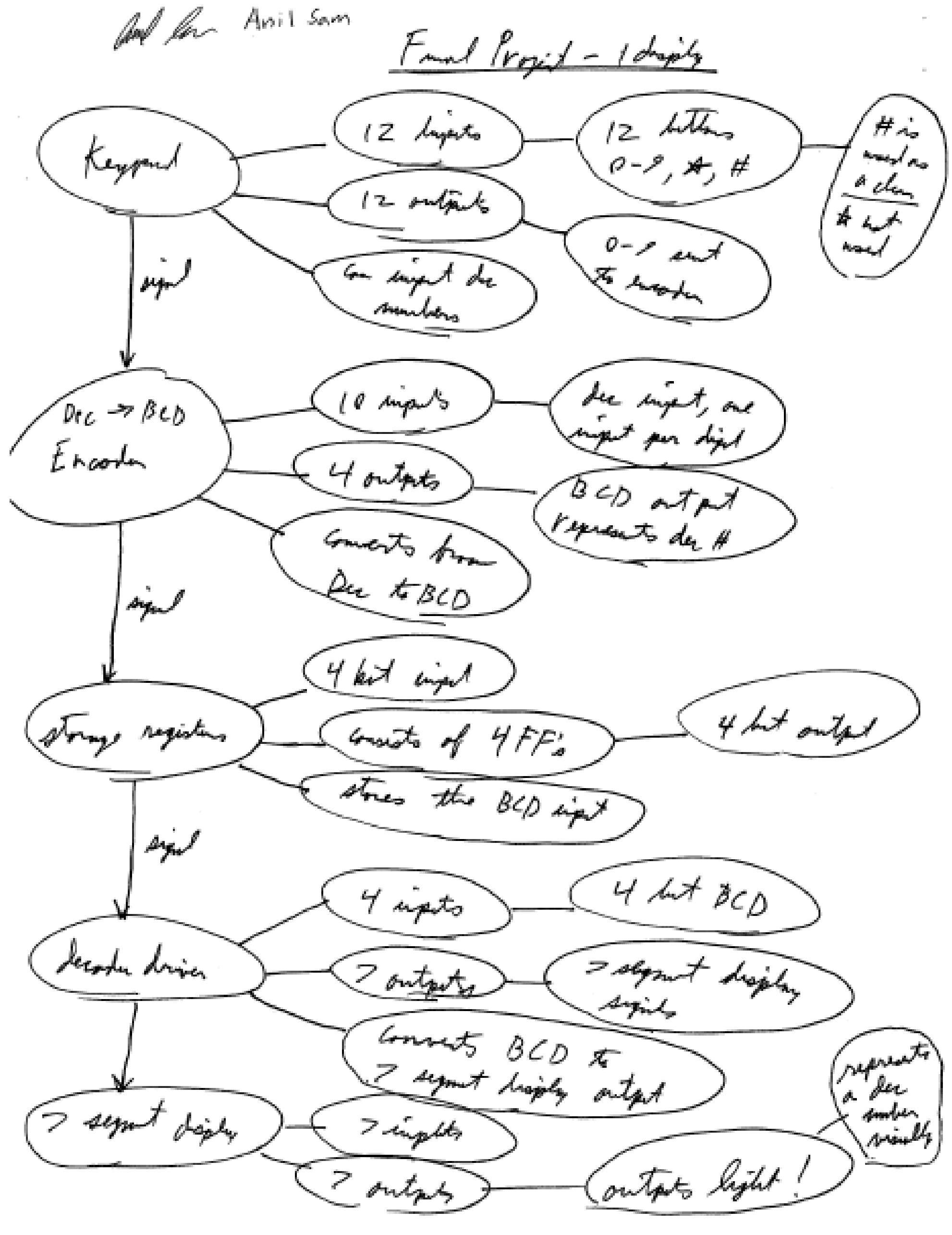
MIGUEL A. RAMOS earned his Ph.D. in Educational Research, Measurement and Evaluation from Boston College in 2004. He is the Assistant Dean for Assessment and Accreditation Services in the College of Technology at the University of Houston. Dr. Ramos has worked as Program Evaluator for Boston Connects, a school-community-university partnership designed to address non-academic barriers to school success via a web of coordinated health and social service resources in ten public elementary schools. He has also worked as a federal education researcher for the Southwest Educational Development Laboratory evaluating the effectiveness of reform models developed to improve student academic performance by enhancing systemic coordination of academic resources. In addition, Dr. Ramos has served as a consultant in a variety of contexts investigating a range of issues including program effectiveness, organizational communication, assessment and public policy, and research methodology. Dr. Ramos may be reached at MaRamos3@central.uh.edu

VICTOR J. GALLARDO is the Instructional Lab Manager for the Computer Engineering and Electrical Power programs (also he is a Ph.D. candidate in Electrical Engineering). He has had experience at the industry, education and research institutions. He worked at Texas Instrument as hardware applications engineer in TMS6000 DSP group. He has been a consultant for Houston Independent School district where he developed Computer-Based Lab Experiments for Science and Mathematics. Mr. Gallardo current research interest includes Adaptive Optics, Real Time Image Processing with applications in Human and Computer Vision, as well as Intelligent Reconfigurable Instrumentation. His has several years of experience in hardware design for high speed digital systems, robotics, control, sensors and multiple interfaces to microprocessor, DSP, and microcontroller-based systems. He is cofounder

of CORE (Coordination Of Robot Education) and has authored and coauthored more than 30 technical papers, technical reports, and applications reports. He is a member of IEEE. Mr. Gallardo may be reached at vjgallardo@uh.edu

SHRUTI KARULKAR is pursuing her Masters in Electrical Engineering from the University of Houston. She is graduate research assistant for the NSF funded C Maps project in College of Technology. Previously she has worked with Wipro Technologies as a program engineer in embedded systems division. Shruti can be reached at snkarulk@mail.uh.edu.

Appendix A


Anil Sam
Final Project - 1 display
Keypad
12 inputs
12 buttons 0-9, *, #
is used as a clear
12 outputs
0-9 sent to encoder
Can input dec numbers
signal
Dec → BCD Encoder
10 inputs
dec input, one input per digit
4 outputs
BCD output represents dec #
Converts from Dec to BCD
signal
storage registers
4 bit input
consists of 4 FF's
4 bit output
stores the BCD input
signal
Decoder driver
4 inputs
4 bit BCD
7 outputs
7 segment display signals
Converts BCD to 7 segment display output
7 segment display
7 inputs
7 outputs
outputs light!
represents a dec number visually