Session 3159

Mini-design projects; a Hands-on Approach to Teaching Instrumentation Courses in ET Programs.

Guido W. Lopez,
Eric W. Hansberry
School of Engineering Technology
Northeastern University
Boston, MA

ABSTRACT

Design is the central activity of engineering and the focus of undergraduate engineering education. Effective teaching and learning of underlying engineering science and the principles of engineering design can be readily accomplished in instrumentation courses, through the completion of mini-design projects relative to the measurement of common variables found in engineering systems, such as temperature, pressure, stress, fluid flow, motion, sound, etc. This paper presents and discusses typical examples of highly affordable mini-design projects that have been implemented and used during the instruction of engineering students in a standard introductory instrumentation course in the School of Engineering Technology at Northeastern University. These mini-design projects can be completed within the time constraints inherent to regular academic schedules, and provide students with an appreciation for the realities of engineering practice, in particular, those associated with time and money constrains. This teaching technique blends the perspectives of theoretical discussions in regular lectures and the subtleties encountered in the practice of engineering design. It seeks to develop proficiency through practice guided by concurrent knowledge and the recognizable dimensions and challenges of the engineering product development process. Using this educational approach, class assessment guided by the Technology Criteria 2000 (TC2K) of the Accreditation Board for Engineering and Technology (ABET), effectively reflects satisfactory mastery of knowledge, and the desirable abilities students are expected to demonstrate, as established by TC2K.

Introduction.

It is known to practicing engineers and engineering educators that fundamental knowledge of science and mathematics, and the creative application of this knowledge in the design of systems, components and/or processes are two essential elements of the engineering profession. Engineers must have the ability to solve technical problems, master scientific knowledge, be creative, and apply the proper judgement to provide real solutions to real needs. The focus of engineering education is on the acquisition of knowledge through class lectures, personal study, engineering design and lab experimentation. Time constraints and costs associated with laboratories and design activity may prove to be challenging and often discouraging. Nonetheless, these factors can help to provide students with a concrete appreciation of the realities of the engineering field.

The development of low-cost mini-design projects that provide opportunity to apply scientific and mathematical knowledge is an ideal approach to convey engineering experience. These mini-projects must suit realistically the academic character and time constraints of basic engineering courses. At the same time, they need to provide the proper theoretical and practical challenge for students to comprehend the perspectives of theory and gain experience about optimization of resources, and other subtleties encountered in the practice of engineering.

This paper presents and discusses the characteristics and benefits of this innovative teaching technique. The approach is illustrated with typical examples of affordable mini-design projects that have been implemented and used during the instruction of engineering students in a standard introductory instrumentation course in the School of Engineering Technology at Northeastern University (NU), Boston. This is a 4-credit quarter-based course designed to impart the theoretical basis of operation of instruments commonly used in engineering for monitoring and testing.

These courses commonly include laboratory activity, where students use instrumentation to perform experiments relative to the discipline of their curricula. In this case, however, no official time or resources for laboratory activity were involved or assigned. Because all programs at NU stress heavily practice-oriented instruction, the experiential aspect of the instrumentation course was oriented toward engineering design activity in order to reinforce a nationally recognized tradition (see "America's Best Colleges 2003," U.S. News & World Report), and facilitate the satisfaction of criteria recommended by ABET regarding the educational expectations from engineering technology graduates.

The objective of this approach blended the perspectives of theoretical discussions in lectures and the art of practical problem solving. This skill is developed with practice, and it goes beyond the repetition of procedures in academic laboratory experimentation. The inclusion of experiential design in a lecture-based course provides multifaceted educational gains for students. The development of creativity, teamwork, effective communication and the use of analysis and synthesis skills to solve practical problems effectively supplement abstract cognition of the subject matter. These abilities are recognized as demonstrable criteria that will be used to assess the educational effectiveness of engineering programs.

Logistics and other characteristics of the Mini-Design Project.

The term mini-design was adopted in this case because of the extent of the project. The mini-design project is considered a substantial part of homework assignments in the context of this course. Students are required to complete traditional assignments of a regular lecture-based course including examinations, homework problems and reading assignments. However, the bulk of the homework assignment lies in the development of the mini-design project where theoretical knowledge gained by personal study or class discussion, is to be applied to solve a practical problem of the students' choice. A standard engineering-design structure is utilized to complete this activity, starting with the presentation of a project-proposal, within the first two weeks of class.

The purpose of the design proposal is to examine the extent of the project, determine its feasibility for successful realization based on the availability of resources and time, and make the necessary modifications. The proposal is developed in the form of a memorandum directed to the instructor. The project is explained by establishing an objective, a background about the idea, methodology to be followed, expected results, and expenditures involved within a required $50 budget.

Students are required to work in small groups. Each group develops a mini-design project that consists of designing, building, and testing a measuring unit relevant to the subject of instrumentation. The groups are required to keep detailed records of their activities and develop a report of the design process following standard recommendations and techniques of engineering product-development. This requirement encourages students to function as a coordinated team where a diversity of talents is put to work for a common goal.

The product is developed step-by-step from basic off-the-shelf functional elements. The goal of this process is to relate standard fundamental theory discussed in class to the functioning of constituent elements, and their integration into an instrumentation system. The system is used to measure a pre-determined physical quantity such as, sound, temperature, time, velocity, or flow rate.

Pertinent aspects of instrumentation including sensing, calibration, signal processing, error propagation and data analysis are covered in the lectures. Students are required to identify, discuss and explain these aspects as part of the design process. The design process follows standard procedures of the engineering method including, problem definition, general and detailed specifications, analysis, concept generation and selection, implementation, and communication.

The mini-design project is completed within a period of 6 weeks. A time of 30 minutes per week is set aside from the class for group discussion and status reporting. This time includes instructor supervision. The design groups may meet outside regular class time to develop their design.

At the end of the term, each group is required to submit a final written report and oral presentation to explain the details and characteristics of their project. The written reports and oral presentations are used as measurement tools to assess knowledge and skills acquired and applied by students, in addition to the traditional exams, tests and homework.

Given the relative simplicity of the projects, the construction of the units does not require expensive or sophisticated tools. "Ready-to-use" project boards and other elements such as wires, digital displays and microchips make the construction of the units a simple task. The assembly of the units can be easily completed using basic and inexpensive tools such as screwdrivers, wire-cutting pliers, and soldering stations. The instructor provided these tools when needed and, in many instances, students were able to carry the units with them and work on their assembly at home, in the classroom, or even at outdoor campus resting areas, without the need of a shop room or a lab.

During the oral presentation to their peers, students are required to explain the standard concepts and principles of instrumentation inherent to their projects, issues faced during the design process, and the initiatives adopted to resolve the issues. This requirement encourages students to pursue in-depth knowledge of the subject matter, exercise their ability to apply it, and develop suitable skills to communicate their experiences effectively.

Illustrative examples of student work are presented in Appendix B.

Discussion.

Hands-on instruction is widely accepted in academe as one of the best approaches for training students, particularly in the engineering field. Learning-by-doing collaboratively is an educational pedagogy of active participation, and the practical implementation of ideas is an effective use of cognition. Unlike science, the central activity of engineering is to provide solutions to human needs by designing and implementing technology. In effect, the method of mini-design fosters an environment that encourages students to provide practical solutions to real problems.

When teaching introductory instrumentation and measurement courses, these practical problems do not need to be cumbersome, complicated or expensive, but they need to be real and related to the subject matter. In this way, standard concepts, definitions and principles discussed in lectures no longer remain abstract and/or purely mathematical. The method of mini-design projects helps students to develop a better sense of the subject matter and triggers their interest to cooperate, provide ideas, discuss problems, formulate questions and provide answers. This method also provides an opportunity for students to experience the effect of two very common and very real factors of engineering design: time and money. Indeed, time and money constraints are additional elements of the pedagogy. Students are encouraged to operate within these constrains by establishing a maximum cost of the project, as well as schedules of assignments, and meetings. Since traditional students are not normally enrolled in one single course per term, these constraints compel them to develop better time-management skills.

Mini-design projects are a simple and affordable method to get students actively involved in the learning process. Using this teaching approach, the results are no longer immaterial but a real and observable educational accomplishment.

Conclusion.

The use of mini-design projects in a quarter-based introductory instrumentation course proved to be an effective teaching method to expose students to the subtleties of practical engineering work while simultaneously imparting the underlying theory of the subject. The idea for the implementation of this teaching method was inspired by the eleven requirements of accreditation, Criterion 1 of the TC2K established by ABET-TAC to assess the educational effectiveness of engineering programs (See Appendix A). In effect, requirements ***a*** through ***g*** of Criterion 1 can be satisfied if this mini-design method is implemented in courses that conform to engineering curricula in disciplines including mechanical technology, electrical technology, and computer technology.

Preliminary evaluation of the mini-design teaching approach was based on examination of student academic performance in reports, oral presentations, exams and homework assignments. In general, this evaluation reflected a clearer understanding of the subject matter (Criterion 1, requirement ***a***) when this was related to their practical work than when the subject matter was only imparted by regular lecture. For example, during oral presentations and group discussions, students could explain each other the technical concepts and principles inherent to their designs and articulate with confidence alternatives to resolve technical issues encountered in the process on the basis of subject cognition. Students also showed a better predisposition to apply knowledge and analysis skills to interpret their practical observations and results (Criterion 1. Requirements ***b*** through ***d***, and ***f***) than to solve purely hypothetical academic problems. Regardless of this predisposition, the mini-design projects were instrumental for the instructor to convey the standard concepts and principles of introductory instrumentation and measurement, and relate more effectively to their application in practical systems. Assessment of student understanding via exams, tests and homework problems showed clarity of thought, critical thinking and correctness. The mini-design projects triggered the interest of students to learn, understand and provide solutions. They provided the opportunity to experience teamwork, (Criterion 1. Requirement ***e***), and continue to develop communication skills through the writing of detailed reports and oral presentations to explain the practical work performed (Criterion 1. Requirement ***g***).

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BIBLIOGRAPHICAL INFORMATION.

Guido W. Lopez.

Guido Lopez is a Faculty member of the School of Engineering Technology at Northeastern University, Boston. He teaches Introductory Physics for Engineers, Thermofluids Science, Instrumentation, Laboratory Experimentation, Technology and Design. Before joining NU's faculty, he served as Department Head of the Engineering Math and Science Division at Daniel Webster College, Nashua, NH. He has taught engineering and science subjects at the National Polytechnic School in Quito, Daniel Webster College in New Hampshire, The Lowell Institute of Technology at Northeastern University, and the Wentworth Institute of Technology in Boston. He has performed applied research at the NASA John Glenn Research Center, Cleveland on advanced solar dynamic systems for power generation for the international space station alpha. Lopez received his M.S. degree and, Ph.D. degree in engineering science and Thermofluids science from Northeastern University.

Eric W. Hansberry.

Eric Hansberry is Professor of Design Graphics in the School of Engineering Technology at Northeastern University. He served as coordinator for the Mechanical Engineering Technology Program at NU and as Acting Department Head at the Franklin Institute of Boston. Professor Hansberry holds a number of professional registrations, including civil engineering (MA, NH), and mechanical engineering (NH). He is founding member of the National Society of Architectural Engineers and an Honorary Member of the Tau Alpha Pi. Professor Hansberry holds a BS and MS degrees in Civil Engineering from Tufts University and Northeastern University, respectively.

APPENDIX A

Accreditation Criterion 1- Students and Graduates of the ABET-TAC

2002-2003 Criteria for Accrediting Engineering Technology Programs – Technology Criteria 2000

TECHNOLOGY CRITERIA 2000

Criteria for Accrediting Engineering Technology Programs

Effective for Evaluations during the 2002-2003 Accreditation Cycle

It is the responsibility of the institution seeking accreditation of an engineering technology program to demonstrate clearly that the program meets the following criteria.

Criterion 1. Students and Graduates

An engineering technology program must demonstrate that graduates have:

a. an appropriate mastery of the knowledge, techniques, skills and modern tools of their disciplines
b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology,
c. an ability to conduct, analyze and interpret experiments and apply experimental results to improve processes,
d. an ability to apply creativity in the design of systems, components or processes appropriate to program objectives,
e. an ability to function effectively on teams,
f. an ability to identify, analyze and solve technical problems,
g. an ability to communicate effectively,
h. a recognition of the need for, and an ability to engage in lifelong learning,
i. an ability to understand professional, ethical and social responsibilities,
j. a respect for diversity and a knowledge of contemporary professional, societal and global issues, and
k. a commitment to quality, timeliness, and continuous improvement.

Extracted from the document "CRITERIA FOR ACCREDITING ENGINEERING TECHNOLOGY PROGRAMS" Effective for Evaluations During the 2002-2003 Accreditation Cycle. Incorporates all changes approved by the ABET Board of Directors as of November 3, 2001. Technology Accreditation Commission Accreditation Board for Engineering and Technology, Inc. 111Market Place, Suite 1050 Baltimore, MD 21202. E-mail: accreditation@abet.org. Website: http://www.abet.org.

APPENDIX B

Illustrative examples of Mini-Design Projects

Example 1

Design construction and testing of an electronic device to measure time with a 7-segment digital display.

The design goal of this mini-design project as identified by students was ...*"to use digital circuitry and circuit analysis to build a timing device that will measure elapsed time more accurately than a person using a stopwatch"* This timer was approved as a practical exercise of engineering design in this course because its cost was $50 or less, and the students could construct it in one term. This project assisted students in understanding the theory of instrumentation discussed in class. The theory of instrumentation included calibration, accuracy, error, frequency, circuit integration, and circuit logic.

Specifications for this unit included, a start/stop electronic trigger, 6-digit display, time accuracy within 0.01 second, and manual reset. The functional-element diagram of the unit as presented by design team is shown in Figure 1. The unit uses BCD Up-counters incremented by a 100Hz clock signal generated by a 555-timer circuit. The output signals from the counters are converted into 7-segment digits by the BCD decoders and are subsequently shown on 7-segment LCDs. Photographs of the actual unit built by the design team are presented in figures 2 and 3.

Besides the complexities associated with the design and construction of this unit, the design team was able to experience practical issues related to the finished product. For example, the calibration chart (See Table 1) indicated discrepancies the team was required to explain with further analysis of the experimental data obtained. After a detailed study of the elements of the circuit, students were able to track the cause of the discrepancy to the variability of the clock's frequency. As it turned out, the frequency of the clock varied with time as observed with the aid of an oscilloscope (see Figure 4) . Over a period of 9000 seconds, the frequency of the clock was observed to change from the specified 100 Hz to a value of 121.5 Hz. This variability induced errors in its readings of time as shown in the calibration table.

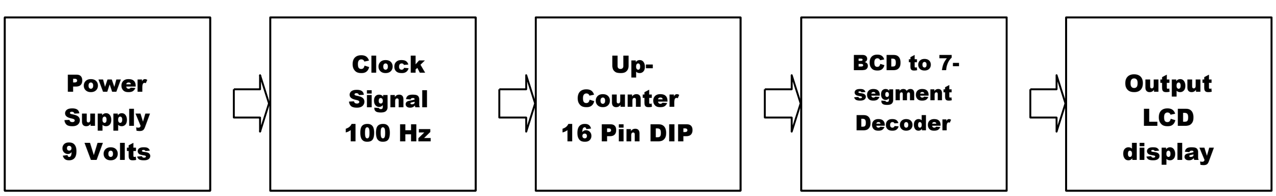

Figure 1.- Diagram of functional elements of timer unit

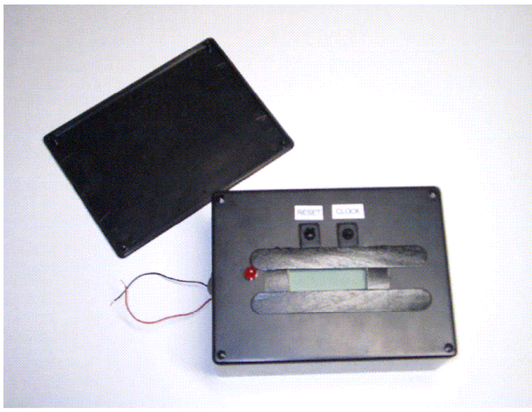

Figure 2.- Front view of the timer unit

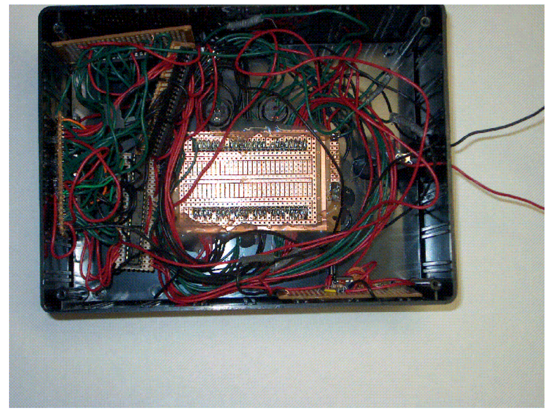

Figure 3.- Internal view of the timer unit

TABLE 1

Calibration table for timer

Test Runs	Our Time	Standard	Difference
1	66.23	60.15	6.08
2	67.16	60.33	6.83
3	66.89	59.92	6.97
4	67.90	59.92	7.98
5	68.29	60.15	8.14
6	136.80	119.96	16.84
7	136.47	120.21	16.26
8	137.25	120.10	17.15
9	137.78	120.00	17.78
10	137.39	120.09	17.30
11	275.89	240.26	35.63
12	278.38	240.23	38.15
13	277.97	240.27	37.70
14	278.82	239.90	38.92
15	280.10	240.08	40.02

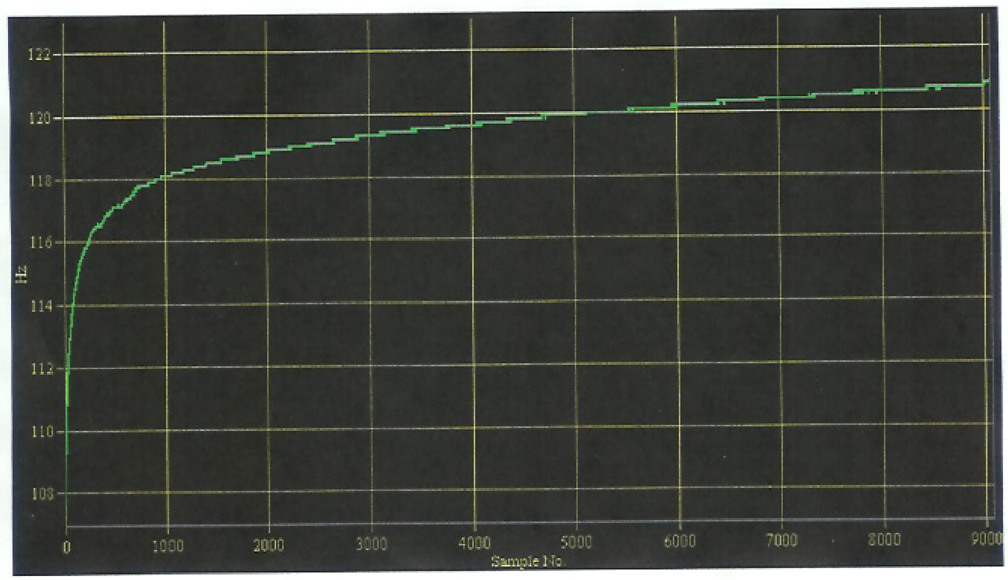

Figure 4.- Variability of the clock's Frequency with respect to time.

Example 2

Design, construction and testing of an electromechanical unit to measure the flow of air.

The objective of this mini-design project as stated by the team's proposal was… *"to construct a device to measure flow rate of gas that can be used by gas companies to measure volumes of output, by pipe manufactures to measure flow rates, and consumers to measure consumption."* This statement offered a unique opportunity to discuss in depth and clarify concepts, definitions and principles related to flow, volume, volume rate, mass, mass flow rate, mass conservation, and the notion of "consumption". This is a project that was approved based on simplicity and feasibility for successful completion.

The measurement of flow of a gaseous substance, in this case, is based on the drag effect of the flow on a flat vane free to swing about a horizontal axis. The vane is connected by mechanical means to a potentiometer. The rotation of the vane resulting from the drag force exerted by the flow produces a change in resistance of the potentiometer. The potentiometer is part of a resistive bridge powered by a battery. The angular displacement of a galvanometer's needle provides an indication of the magnitude of the flow. A schematic diagram of the unit is presented in figure 5, and a photograph of the unit is shown in figure 6.

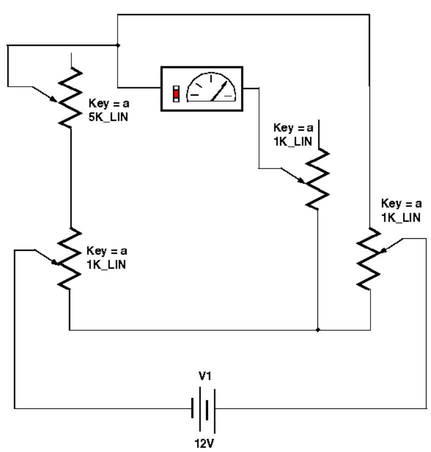

Figure 5. -Schematic diagram of the circuitry of the flow-measuring unit.

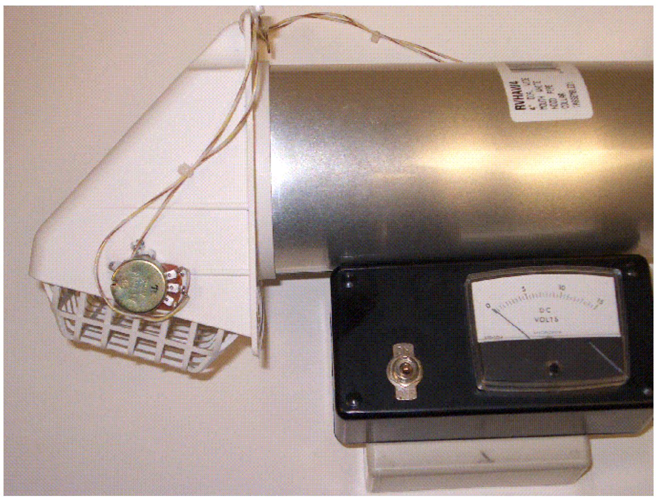

Figure 6.- Photographic views of the flow-measuring unit.

When developing the calibration curve for this device (see Figure 7), the team was directed to study, discuss and explain in detail observable hysteresis effects. The team explained this effect to be the result of friction and poor tolerance at the pivoting point of the vane. These factors did not permit consistency of the vane angular positions for up-loading calibration as compared to down-loading calibration (increasing and decreasing flows, respectively).

	Calibration Table	
	Galvanometer Ouput	
Flow (m^3/s)	Loading (Units)	Unloading (Units
0	0	0.59
0.05	3.4	2.33
0.1	5.12	4.9
0.15	8.53	8.57
0.2	12.09	9.73
0.25	13.12	10.12
0.3	15.17	15.91

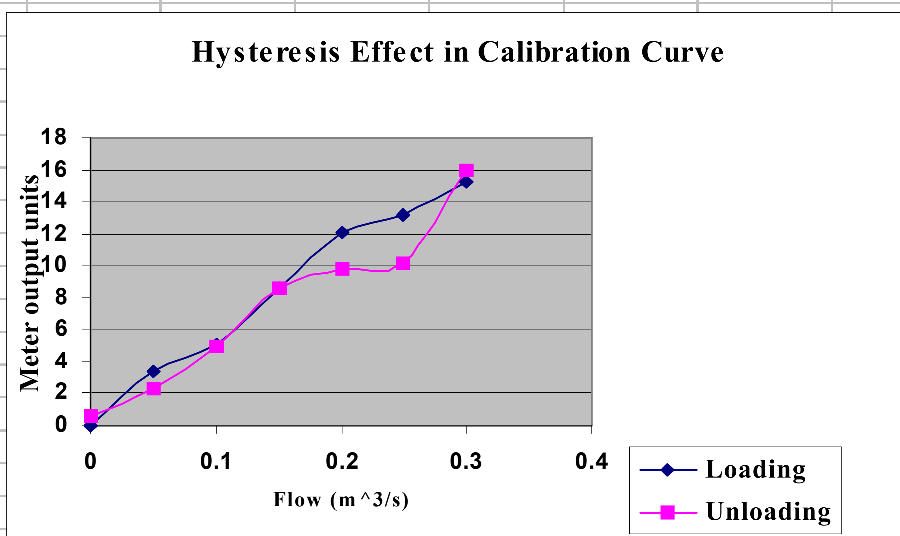

Figure 7.- Calibration of flow-measuring unit and hyteresis effect.

Other examples of mini-design projects include: Design and implementation of a system to measure the temperature of exhaust gases from a gas turbine, and Electronic system to measure temperature, and control the overheating of a computer mother board. All students participating in the activities of this course found the experience extremely valuable. The general consensus was that they had the opportunity to put into practice what they learned in class, and develop further their cognitive and analytical skills to resolve practical problems of engineering.