AC 2011-1104: USE OF ELECTRONICS EXPLORER BOARD

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Use of Electronics Explorer Board
in Electrical Engineering Education

Abstract
According to a report published for The Royal Academy of Engineering, UK (2006), the pace of change in industry is expected to intensify in both the technological and non-technological domains. Certain disciplines, including *electrical/electronic and system engineering* are seen as particular likely to be of increasing importance over the next ten years. The same report claims that certain topics are seen by students to be more difficult than others which can lead to skills' shortage in some particular areas. Noting for example that analog electronics is often perceived as a harder subject than digital electronics, students are inclined to decide on the latter, leading to a shortage of skilled engineers in analog electronic design.

At the level of digital circuits, the "more you push the technology, the more analog it becomes", therefore more integrated circuit designers, both analog and digital, need to have a familiarity and comfort level with analog circuits.

Additionally, in today's world, the tools, technologies, and methods used by engineers in electrical engineering design evolve quickly and continuously. Educational programs must keep pace with these changing tools, technologies, and methods in order to produce graduates who meet the needs of employers and are competitive in the marketplace. To meet this need, engineering education programs must target their laboratory experiences to take advantage of the newest technologies and expose students to the tools and methods employed by practicing engineers, while emphasizing fundamental concepts and principles.

A new approach, in which every student has their own integrated analog circuit design station, holds the promise to significantly improve educational outcomes in this area. A new product called the "Electronic Explorer Board" has recently come to market that provides everything students need to design, build, and test analog circuits in a single, low-cost, and portable station.
This paper presents a study of the effectiveness of providing students with unlimited access to Electronic Explorer Boards, beyond the traditional laboratory settings. The study conducted at Rose Hulman Institute of Technology tries to determine if the use of Electronic Explorer boards helps to improve the learning process, development of problem solving skills, the attainment of specific knowledge and skills, and the proper use of instrumentation tools.

Introduction
According to a report published for The Royal Academy of Engineering, UK (2006) [1], the pace of change in industry is expected to intensify in both the technological and non-technological domains. Certain disciplines, including *electrical/electronic and system engineering* are seen as particular likely to be of increasing importance over the next ten years. Looking at particular skills and attributes needed for engineers, there is strong evidence that the top priorities in terms of future skills will be: *(a) practical applications, (b) theoretical understanding and (c) creativity and innovation.*

The same report claims that certain topics are seen by students to be more difficult than others which can lead to skills' shortage in some particular areas. Noting for example that analog electronics is often perceived as a harder subject than digital electronics, students are inclined to decide on the latter, leading to a shortage of skilled engineers in analog electronic design[1].

At the level of digital circuits, the "*more you push the technology, the more analog it becomes*". Therefore the well rounded integrated circuit designer, in both analog and digital circuits, needs to have a familiarity and comfort level with analog circuits. However, the lack of conceptual framework for the understanding of analog circuit behavior has left many electrical and computer engineering students believing that analog circuit design is an impossible topic to master. The current method of teaching analog circuits focuses on procedural, quantitative and analytical methods to describe individual circuits [2].

According to[3], there are four types of learners: *Type 1(concrete, reflective)-the diverger; Type 2(abstract, reflective)-the assimilator; Type 3(abstract, active)-the converger; Type 4 (concrete,* active*)-the accommodator.* Traditional science and engineering instruction focuses almost exclusively on lecturing, a style comfortable for only *Type 2 learners*. Effective instruction involves teaching all learning styles–motivating each new topic (Type 1), presenting the basic information and methods associated with the topic (Type 2), providing opportunities for practicing the methods (Type 3), and encouraging exploration of applications (Type 4). *By* providing students with more opportunities for hands-on experience, encouraging exploration of applications and providing more time for practicing the techniques and concepts taught in theoretical lectures, a more effective instruction can be provided, addressing all four types of learners.

Additionally, in today's world, the tools, technologies, and methods used by engineers in electrical engineering design evolve quickly and continuously. Educational programs must keep pace with these changing tools, technologies, and methods in order to produce graduates who meet the needs of employers and are competitive in the marketplace. To meet this need, engineering education programs must target their laboratory experiences to take advantage of the newest technologies and expose students to the tools and methods employed by practicing engineers, while emphasizing fundamental concepts and principles.

Today, university-based educational programs invest heavily in many new tools and technologies, often only using them in more advanced or project-based courses. Faculty and staff contribute large amounts of time preparing new course materials that students need to learn these new tools. Because new tools are often far too expensive and complex for use outside of the laboratory, the vast majority of programs provide only limited access to these technologies in the form of two or three hour weekly lab sessions, constraining the amount of time students can use the tools. During these sessions, students must apply concepts learned in lectures, use complex laboratory equipment to build experiments, develop hardware debugging skills.

According to[4], there are 13 fundamental objectives of Engineering Instructional Laboratories, that students should understand or acquire skills in: *(1) Instrumentation; (2) Models; (3) Experiment; (4) Data Analysis; (5) Design; (6) Learning from Failure; (7) Creativity; (8) Psychomotor; (9) Safety; (10) Communication; (11) Team work; (12) Ethics in the Laboratory;*

(13) Sensory Awareness. In the current laboratory setting and approach there are significant time and resource constraints, and students have to master complex tools and technologies. As a result, students tend not to achieve all their lab objectives, and consequently do not develop the skills required by the engineering industry.

A new approach, in which every student has their own integrated analog circuit design station, holds the promise to significantly improve educational outcomes in this area. A new product called the “Electronic Explorer Board”[5] has recently come to market that provides everything students need to design, build, and test analog circuits in a single, low-cost, and portable station.

This paper presents a study of the effectiveness of providing students with unlimited access to an integrated analog circuit design station (Electronic Explorer Board), beyond the traditional laboratory settings. By allowing the students to have their own Electronic Explorer Boards with which they can work anytime and anywhere, students have more time to achieve the instructional lab objectives. In addition, by providing students with more opportunities for hands-on experience, encouraging exploration of applications and providing more time for practicing the techniques and concepts taught in theoretical lectures, a more effective instruction is provided, addressing all four types of learners, as described earlier. The study conducted at Rose Hulman Institute of Technology (RHIT) tries to determine if the use of Electronic Explorer boards helps to improve the learning process, development of problem solving skills, the attainment of electronics’ specific knowledge and skills, and the proper use of instrumentation tools. Quantitative data are analyzed by comparison to historical data gathered from student groups that did not have unlimited access to the Electronic Explorer board.

Presentation of Electronic Explorer Boards

The EE board is a complete, integrated analog circuit design workstation that students can use to design, implement and test all types of analog circuits. It combines a solder less breadboard, programmable power supplies, and multiple test and measurement devices into a single device that is both low cost and highly portable. It uses a USB2 port and a PC running the free Waveforms™ software for control and display to create a powerful design station. See figure 1.

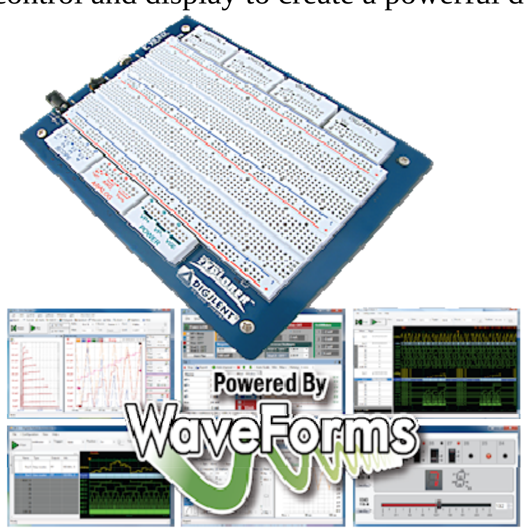

Fig. 1 Electronic Explorer Board

The EE board contains the following instruments built directly onto the underside of the circuit board:

- 4-channel, 40MSa oscilloscope with AC/DC coupling, 40V input range, 16Kbyte buffers, and full-time FFT, XY and math functions;
- 2-channel, 40MSps arbitrary waveform generator with 14-bit converters, up to 32Kbyte buffer depth, 4MHz bandwidth, 10V p-p outputs at up to 100mA, and standard, complex (damped and swept, AM/FM modulated) & user-defined waveforms;
- Two programmable power supplies (+/- 10V at up to 2A) with precise voltage and current limit settings, plus a 3.3V/5V fixed supply, four voltmeters, and two reference voltages;
- 32-channel logic analyzer that captures up to 100MSa per second with 16KSa/pin
- 32-channel digital pattern generator with 2KSa/pin buffers at up to 40MSa per second (pins are shared with logic analyzer);
- 32-channel static I/O function generator that allows DC signal values to be driven into the EE board or read from the EE board (pins are shared with logic analyzer);
- All instruments share a common trigger control allowing for full cross-triggering;

Several additional features are also available:

- a real-time Bode plot feature uses one waveform generator channel and an oscilloscope input to plot magnitude against frequency
- waveform generator outputs can be driven from the PC's sound card, allowing audio files to be used as signal sources;
- Captured oscilloscope waves can be routed back to a PC's sound card so that filtering or other effects can be heard as well as seen;
- All files use the "comma separated value" type (or .csv), allowing captured waveforms to be used to drive the waveform generator, and allowing other tools (like MS Excel) to create files to drive the arbitrary waveform generator, or display waveforms captured on the oscilloscopes.

Input signals to all of the instruments are available on smaller, dedicated and clearly labeled breadboards. The use of breadboards allows instruments to be quickly and easily connected to circuit nodes using only simple jumper wires. In use, students construct circuits in the central breadboard area, and use jumper wires to connect the power supplies and precision voltage references as needed to their circuits. Then other jumper wires can be used to connect circuit inputs to waveform generators or digital signal drivers, as well as circuit output nodes to the oscilloscopes or voltmeters.

The EE board ships with a parts kit that contains 140 pre-trimmed jumper wires and several components, so building and measuring basic circuits is very easy. All inputs to the EE board instruments and power supplies are short-circuit and ESD protected, so no damage can occur from incorrect jumper wire placement, regardless of what input or output is connected to what.

There are several other systems that address the same application area, including Mobile Studio developed at Rensselaer Polytechnic Institute, National Instrument's MyDAQ and Elvis products, a variety of digital and analog trainers available from several companies, and individual PC-based oscilloscopes and logic analyzers. The "trainers" typically contain breadboards, power supplies, and low frequency (100KHz max) function generators, but they do not contain oscilloscope channels, advanced waveform generation features, or other instruments, and so they do not compare well to the EE board (see for example the *Global Specialties PB-500* or *Circuit Specialists XK-550*). A collection of stand-alone PC-based instruments could be combined with power supplies and a breadboard to offer equivalent functionality, but without interoperability (like cross-triggering and waveform sharing), and at a very much higher cost. The Elvis product from National Instruments addresses the same general application area, but its focus is the LabView software environment and the ability to create custom virtual instruments, in contrast to the EE board's focus on basic circuit experiments (it is also designed as a non-portable lab instrument, at roughly ten times the cost of the EE board). RPI's Mobile Studio and National Instruments MyDAQ are the most equivalent existing products, and are compared in the table below.

TABLE 1.

Feature	**EE Board**	**MyDAQ**	**Mobile Studio**
Analog Inputs	Four Channel, 40MSa +/- 20V 70MHz Analog bandwidth 16Kbyte buffer	Two Channel, 200KSa +/- 10V 400KHz Analog bandwidth 4Kbyte buffer	Two Channel, 1MSa +/- 10V Bandwidth not specified Buffer size not specified 10 more channels 0-2.5V
Analog Outputs	Two Channel, 40MSa +/- 10V, 100mA 16Kbyte buffer	Two channel, 200KSa +/- 10V, 2mA 8Kbyte buffer	Two channel, 500KSa Voltage not specified Buffer size not specified
Digital I/O	32 signals, 100MSa Up to 5V input	8 signals Frequency not specified Up to 5V	16 signals Frequency not specified Voltage not specified
Digital Multimeter	Four channel voltmeter	Single channel Voltage, Current, or Resistance	-
Power Supplies	+10 to 0V (prog), 2A max -10 to 0V (prog), 2A max 5V, 1.5A max 3.3V, 1.5A max	+15V, 32mA max -15V, 32mA max +5V, 100mA max	-
Reference voltage	Two channel, +/- 10V	-	-
Breadboard	2x830 tie point	-	-
Parts Kit	60+ components 140 jumper wires	-	-
Software	Waveforms™ Free	LabView™ Student version included	Unknown
Cost	$299 Student	$199 Student	*$130 (estimated)*

The EE board has more analog inputs with higher bandwidths, wider input ranges, and deeper buffers, all of which allow for a larger useful range of measurements. The EE board’s analog outputs are also much higher bandwidth, with deeper buffers and higher power, allowing for a greater range of stimulus inputs. An external power supply and breadboard are required with Mobile Studio and MyDAQ (some smaller circuits could use the limited supplies from MyDAQ), adding an estimated $200 to the cost of these products. Based on feature and price comparison, the EE board offers a clear advantage to engineering students building and studying a wide range of circuits.

Short Description of the Courses Using the EE boards

At Rose Hulman Institute of Technology, in the academic year 2010-2011 fall quarter, in the course ECE 250- Electronic Device Modeling, students were given Electronic Explorer boards at the beginning of the quarter, and they were allowed to keep them for the entire quarter. The use of the EE boards was optional this academic year.

The course ECE 250-Electronic Device Modeling is a sophomore level course, intended to provide students with the basic understanding of the nonlinear devices used in electronic circuits, such as diodes and transistors. Topics are covered in the following order: theoretical analysis, simulation and laboratory verification. Theoretical analysis of the circuit is covered to understand the operation of the circuit or to design a circuit. Circuit simulation using industry standard analysis tools (OrCAD PSpice) is used to verify the theoretical analysis or circuit design. The circuits are constructed in the labs if the simulation agrees with the theoretical analysis. Measurements of the circuit performance are made and compared to the theoretical calculations and simulation results.

Important course objectives are: Characterize two and three terminal devices by means of I-V plots; Derive a linearized small-signal model given the large signal characteristics; Describe a circuit and analyze its operation in terms of the bias and small signal-model, or its large-signal switching model; Use OrCAD PSpice or other computer simulation tool to model circuit behavior and discuss the difference between the DC, time-domain and frequency domain analysis; Measure the DC characteristics of a 2 or 3 terminal device in the laboratory; Construct and test small rectifier and transistor circuits in the laboratory; Use elementary troubleshooting techniques and critical error analysis in the laboratory; Use standard written and oral formats to report laboratory/computation results; Demonstrate the similarity of operation between all 3 terminals devices that can be used as amplifiers or switches*;* Show how these three terminals devices can be used as switches or amplifiers*;* Understand the properties of semiconductor materials such as doping, carrier concentration, conductivity, drift and diffusion current.

Laboratory experiments cover circuits with rectifying and Zener diodes, circuits with bipolar junction transistors (BJTs) and field effect transistors (FETs) as amplifiers and switches.

Students enrolled in the ECE 250 class were allowed to use the EE boards to build and test their circuits at home, before coming to the lab sessions. Measurements using the instruments of the EE boards were compared with the measurements using traditional laboratory instruments (Agilent technology), especially for the most difficult portions of the laboratory experiments. Students' presence in the lab was requested in order to answer instructor's questions, to check if their laboratory experiments and the interpretation of their results were correct and to prepare professional laboratory reports. Instructor had more time to spend with students with weak backgrounds, helping them with the debugging skills and the interpretation of their measurements, especially for more advanced laboratory experiments such as: switching time of diodes, one stage amplifiers with BJT and FET transistors. Examples of student's lab work using the EE board and Agilent Oscilloscope are presented in the next figure.

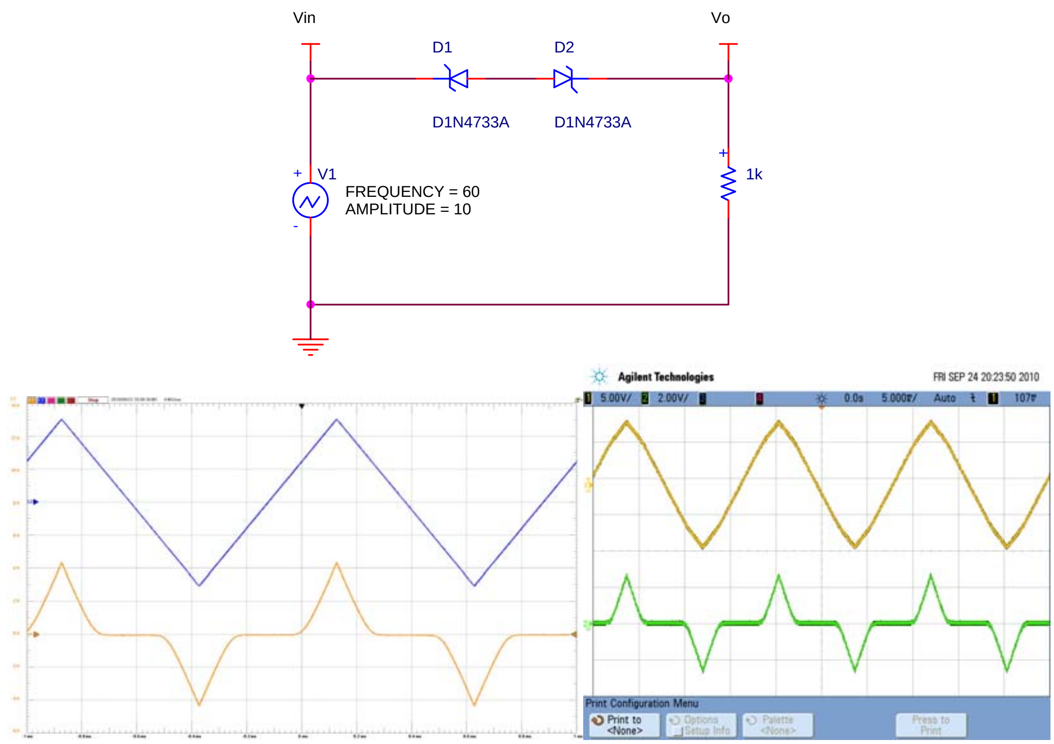

Fig.2 Zener Diodes Clipping Circuit using the EE Board and the Agilent Oscilloscope

Additionally, students enrolled in ECE 333 Digital Systems were offered EE boards in the academic year 2010-2011, fall and winter quarters. Due to the limited number of EE boards, only a small group of students were able to use them in the fall quarter and the winter quarter of the academic year 2010-2011 and assessment data related to this course will be provided at the time of the conference.

ECE 333 Digital Systems course covers important concepts related to the analog behavior of digital circuits. Important course objectives related to the analog behavior of digital circuits are: Interpret a manufacturer's data sheet to determine parameters including DC noise margin, rise/fall time, propagation delay, and the drive current capability; Determine output values from input specifications and transfer characteristic curves for conventional CMOS and TTL output and Schmitt-trigger devices; Discuss transmission line effects (distributed system effects) that influence signal integrity.

The static and dynamic analog behavior of digital circuits is covered in two laboratory sessions. Students are using the EE boards for these two labs and also for other "purely" digital labs. Examples of student's lab work are presented in the next figure.

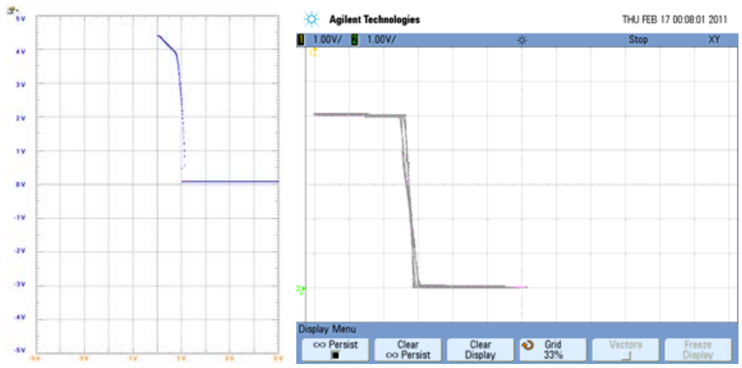

Fig.3 The Transfer Characteristics of TTL (a) and CMOS (b) Inverter using the EE Board (a) and the Agilent Oscilloscope (b)

Both courses are taught in a 10 week quarter with 3 lectures per week and a single 3 hour lab per week. More details about the courses can be found at [6].

ASSESSMENT DATA

At Rose Hulman Institute of Technology the study is conducted by the course instructor. The course ECE 250-Electronic Device Modeling was taught by the same instructor, using the same syllabus and textbook[7] in the last two academic years, fall quarter. At RHIT, due to the small student population and the small class size, a blind study was not possible. Various assessment techniques are used trying to gain support for the study. The study will continue in the next two academic years.

The impact of unlimited access to EE boards on the students' educational experience is investigated by looking at how students' learning was improved. Evaluation of students' learning was gained through course exam grades, practical labs grades and concept inventory results. Additionally, end of quarter course's evaluations were investigated to evaluate students' perception about their learning.

In the academic year 2009-2010, 25 students were enrolled in the Electronic Device Modeling course. Traditional laboratory equipment (Agilent technology) was used for the laboratory experiments during the 3 hours of lab sessions. In the next academic year, 10 students were enrolled in the Electronic Device Modeling course and they were given EE boards. Five students decided to use the EE boards on regular basis for the laboratory experiments and to explore other circuits on their own, at home.

-The exam grades and the final grades show an increase from the academic year 2009- 2010 to the next academic year. The first exam covers circuits with diodes, the second exam covers bipolar junction transistors and the third one covers circuits with field effect transistors and calculations of input/output impedance of single stage amplifiers. All exams include conceptual (theoretical) questions and three problems, some of them similar to laboratory experiments. The exams had the same degree of difficulty in both academic years.

The final grade for this class includes exam grades, hws, prelab and lab assignments and the laboratory practical exam. See table 2.

TABLE 2.

	Exam 1 (DIODES)	Exam 2 (BJTs)	Exam 3 (mainly FETs)	Final grade
Academic year 2009-2010	73.66	66.76	85.5	78.9
Academic year 2010-2011	77	82.2	87.5	85.09

A possible interpretation of the positive trend is the fact that in the second year, a great emphasis was placed in the proper interpretation and understanding of the lab results (comments and explanations of the waveforms, comparison with simulation results and prelab calculations, etc.). This was possible, due to the fact that students were capable to build and test their circuit at home and had more time for a proper analysis and interpretation of the lab results. Also, some students tried some simple experiments at home and some of the homework problems using the EE boards.

-An interesting component of the course is the laboratory practical exam. Students are given the schematics of a circuit, similar with one of the lab 's circuits, and they need to (re)build the circuit and measure various currents and voltages, showing if they have the right debugging skills and if they are comfortable working with the instruments in a limited time frame. The lab practical is individual. For regular labs, students work in teams of two.

TABLE 3.

	Laboratory Practical Exam
Academic year 2009-2010	79.04
Academic year 2010-2011	79.5

In the second academic year, students scored only slightly better, but students were given 15 minutes less than in the previous academic year. It is interesting to note that 4 out of the 5 students who used the EE boards scored extremely high in the laboratory practical exam, while 3 out the 5 of the students who did not use the EE boards scored extremely low. For the laboratory practical exam, students were given the option to use the traditional lab instruments (Agilent technology) or the EE boards. Some students opted to use both instruments, accomplishing more than the rest of the group in a very limited time frame.

-A standardized concept inventory was administered at the beginning and the end of the quarter. Taking this concept inventory was optional. The second year shows a slight increase.

TABLE 4.

	Pre-course survey	Post –course survey	Gain
Academic year 2009-2010	12.33	15.125	3.75
Academic year 2010-2011	12.5	17.5	5

Possible interpretations of the results are:

-The use of the EE boards did not affect all the concepts covered in this course, such as the physics of the semiconductors.
- The concept inventory was optional, and as a consequence, some students did not put that much effort and work in it.

-End of quarter course evaluations showed some interesting results. Students evaluated, among other things, the course and their learning experience. The scores are on a scale from 0 to 5, 5 being the maximum.

TABLE 5

	Course evaluation	Quality of learning in this course
Academic year 2009-2010	3.0	3.5
Academic year 2010-2011	3.0	3.3

The rating of course stays the same. This course is perceived as a difficult course in the ECE sophomore curricula and the scores are not extremely high. Students' perception of their learning quality in this course decreased from 2009-2010 to the 2010-2011 academic year. Possible explanations for the trend are:

- In the second academic year, 3 or 4 students out of 10, had weak backgrounds in term of electrical circuit's skills (using KCL and KVL theorems to solve circuit with independent and dependent sources). Consequently, they had a difficult time dealing with several models of non-linear elements (transistors, diodes) for a.c. and d.c. circuits, especially when they had to calculate the input and output impedances of single stage amplifiers with BJTs and FETs transistors. One student in particular had extremely negative comments about the course, especially the inclusion of the physics of semiconductor. Being such a small group, his evaluations and scores affected the overall score.
- The academic year 20010-2011, there was a migration to Windows7, and several students had problems installing the OrCAD PSpice software required for this course on their laptops. This was perceived as a difficult task, requiring more work for this course.
- Students did not perceive the use of the EE boards as beneficial, due to the fact that the use of the boards at home and in the labs was optional.

It is interesting to note that instructor's evaluations increased.

It is important to note that four of the students enrolled in the Electronic Device Modeling course, decided to keep the EE boards and they are currently using them in the Digital Systems course or other courses.

Suggestive students' comments show appreciation regarding the use of the EE boards and the impact of the EE boards on their learning process.
"I used the board as a quick prototyping space for analog circuits. It helped me to actually witness some of the concepts of amplifier design which helped me understand in a way that no lecture could. The Digilent Electronics Explorer board opens up the field of electronics to a whole, new, wide audience of individuals who could not have afforded it before."
"The Explorer Board allowed me to work on labs on my own time. This worked to decrease the urgency in completing the lab in the lab period. As a result, I believe I had more time to comprehend what was happening."

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Conclusions
This paper presents the benefits of providing students with unlimited access to EE boards in electrical engineering design education, allowing hands-on experiences outside the traditional laboratory settings. The preliminary study tries to measure the effect on student's learning and student's performance when students own their EE boards. The authors of the paper have reasons to believe, supported by the results of the study, that the student ownership model has the potential to help students achieve a higher level of learning in the field of electrical engineering. Students gain an in-depth knowledge of engineering principals as well as their practical applications. Designed and priced for student ownership, time and exposure barriers that limit natural curiosity, creativity, and innovation are overcome. The needs of potential employers will be met as students are already familiar with the sophisticated hardware, powerful software tools, and practices employed by practicing engineers.

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