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Restructuring Digital Design Courses in Electrical and Computer Engineering Technology Programs, Preparing the Engineer of 2020

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Abstract

As the complexity of microelectronic systems is steadily increasing, universities must update their curriculum to cope with the increased demands of the industry. New technologies and tools are frequently introduced into the engineering workplace, and educational programs must find a way to integrate many of these into their offerings. In the areas of digital system design, the industrial use of programmable logic devices (FPGA, CPLD), associated EDA tools and HDL languages is increasing rapidly and consequently the demand for highly qualified engineers with this type of expertise is increasing at a fast rate.

Trying to address the current and future needs of the industry in the areas of digital system design, instructors and members of the Industry Advisory Board of the Electrical and Computer Engineering Technology Department at Farmingdale State College-SUNY, are in the process of restructuring the digital design sequence of courses, placing a strong emphasis in the study of modern tools, technologies and current industrial practices while considering the characteristics of the student population at this school and their educational needs. The results of the current restructuring process, challenges presented by the process, "lessons learned" are presented. Plans for the future include more access to "hands-on experiences" for students using hardware platforms secured by grants and industry donations.

I. Introduction

The publication *"The Engineer of 2020: Visions of Engineering in the New Century"*, by The National Academy of Engineering (NAE) Committee on Engineering Education (CEE) aims to identify the opportunities and challenges for the 21st century, anticipating and shaping the future practice of engineering, the characteristics of the engineering workforce and their education. Engineering schools should attract the best and brightest students and be open to new teaching and training approaches[1].

According to published reports, there is strong evidence that the top priorities in terms of future skills will be: (i) practical applications, (ii) theoretical understanding and (ii) creativity and innovation [1, 2, 3]. Industry evolution has proved that the need for well-prepared engineers with good practical skills is constantly increasing. A study of the Royal Academy of Engineering, "Educating Engineers for the 21th Century", reported that industry seeks for engineering graduates who have practical experience of real industrial environments[3].

As the complexity of microelectronic systems is steadily increasing, universities must update their curriculum to cope with the increased demands of the industry. Further, the technical curriculum is in a constant state of flux due to the rapid and continual increases in the complexity and amount of knowledge students must assimilate. New technologies and tools are frequently introduced into the engineering workplace, and educational programs must find a way to integrate many of these into their offerings. In the areas of digital system design, the industrial use of programmable logic devices (CPLD, FPGA), associated CAD tools and software languages is increasing rapidly and consequently the demand for highly qualified engineers with this type of expertise is increasing at a fast rate.

According to the United States Department of Labor, the job outlook is on the rise and it will continue to expand for at least the short- to medium-term future[4,5]. While the majority of electrical and computer engineering programs have updated their curricula, devoting a large portion of the digital design courses to the study of the programmable logic devices, and Hardware Description Languages (HDL) and associated computer tools, only a small percent (less than 20 %) of the 4-year technology programs at US academic institutions currently have a curriculum component in HDL and programmable logic devices, as stated in [5, 6].

Trying to address the current and future needs of the industry in the areas of digital system design , instructors and members of the Industry Advisory Board of the Electrical and Computer Engineering Technology Department at Farmingdale State College (FSC), are in the process of restructuring the digital design sequence of courses, placing a strong emphasis in the study of modern tools, technologies and current industrial practices while considering the characteristics of the student population at this school and their educational needs.

The rest of the paper is organized as follows: Section II introduces the digital design education at Farmingdale State College and other engineering technology programs. Section III presents the digital design sequence of course at FSC. Section IV presents the changes made in the digital design sequence of courses at FSC. Section V presents the challenges presented by the process, “lessons learned”, etc. Section VI concludes the paper.

II. Digital Design Education

Digital design represents an integral part of any electrical, electronic and computer engineering technology education program. In digital design, the design tools, and technologies used in industry to design digital hardware evolve quickly and continuously, with revolutionary tool changes occurring every 5 to 10 years [7]. Novel and more “hands-on” educational approaches are possible due to the continued revolution in electronic miniaturization which makes possible portable, low-cost, robust digital platforms (based on FPGA and CPLD) that allows for valuable hands-on experiences for students anywhere and anytime [7]. The programmable platforms can be integrated with lectures in the classroom or online, whenever students want to try out their own ideas, explore creative projects and ideas, using their own computers and associated free computer-based-tools. Enriching students educational experiences, by providing more opportunities inside and outside the traditional classroom and laboratory setting, enhance the learning process[7,8].

In the Department of Electrical and Computer Engineering Technology Department at FSC the digital design education is accomplished by a sequence of three courses: EET 105-Introduction to Digital Electronics, EET 223-Digital Electronics and EET 316-Digital Design. Each course is taught by various instructors, both from academia and industry. Annual meetings with the Industrial Advisory Board provide continuous feedback regarding the curriculum and the content of the EET and CET courses, including the digital design sequence of three courses.

The first digital course in the sequence, *Introduction to Digital Electronics,* presents fundamental concepts of digital electronics, specifically combinational logic circuits. The second one, *Digital Electronics* reinforces the analysis and design of combinational and introduces sequential logic circuits. The third course, *Digital Design*, introduces the student to more advanced concepts in digital design, such as description of digital circuits using Hardware Description Languages (VHDL) and FPGA (Field Programmable Gate Arrays). More details about the courses are provided in section III and IV of this paper.

The EET and CET courses at FSC are designed considering also the student population. Over 90 % of the students are commuters and they hold full time jobs. The Department of Electrical and Computer Engineering Technology, part of the School of Engineering Technology, plays an important educational role in the region, attracting a large number of transfer students from the community colleges located in the greater New York metropolitan area and Long Island region. Approximately 50 % of the junior classes in both EET and CET programs are transfer students from community colleges. The sophomore level classes also have a large number of transfer students. The students enrolled in the EET and CET programs have a large range of skills and aptitudes, in terms of math, sciences, experience with laboratory test equipment and computer-based-tools, programming, etc. In a survey of May 2013 graduates, 92 % of respondents reported being employed, with 63% employed in their degree or similar field[10].

By comparison, based on information collected from: (i) various schools' web pages, (ii) journal and conference papers, (iii) and/or discussions with instructors teaching digital design courses in different engineering technology departments, it is reasonable to conclude that the majority of Electrical, Computer and Electronics Engineering Programs cover digital design education in two courses. Usually the first course cover number systems, Boolean algebra, logic gates, description of combinational and sequential circuits, while the second course is dedicated to more advanced topics in digital design, Finite State Machine and some type of programmable logic devices (PROM, CPLDs FPGA) and a hardware description language, usually VHDL language. Such examples are the engineering technology programs at Wayne State University[11], University of Toledo[12,] Michigan Tech University [5,6,7], Texas A&M University[13], etc. In some cases, microprocessors related concepts are incorporated in the digital design sequence of courses, such as the engineering technology program at Cleveland State University[14], New York College of Technology[15], University of Arkansas[16], etc. Functional verification of digital systems and project based learning do not seem popular topics, except[5,6,7]. Some universities supplement the digital sequence of courses with an advanced one, focusing on testing of digital systems[13] or PLDs[5]. The EET and CET programs incorporating HDL and FPGA in their curricula seem to be split between Xilinx (associated with Digilent) and Altera university programs, using educational platforms and associated CAD tools from these two companies.

III. Digital Design Sequence of Courses at Farmingdale State College

EET 105-Introduction to Digital Electronics is a two credit course, offering freshman students plenty of "hands-on experience" through one hour of theory/week and three hours of lab/week during a fourteen weeks semester. The theory and labs are merged; in the same session, the lab activities follow the lecture. The educational objectives of this course is to introduce the students to the fundamental concepts of digital electronics, such as: number systems, basic logic gates and circuits, Boolean algebra, K-Map techniques, arithmetic circuits, code converters, decoders, encoders, multiplexers.

During the lab sessions, using the PB-501 Circuit Trainer equipment, students successfully implement and test basic combinational logic circuits, based on discrete components from the 74HCxx series. Based on the course objectives, after taking this course, the students should be able to: (i) represent numbers in various number systems; (ii) apply minimization techniques and implement logic circuits; (iii) implement adders, decoders, multiplexers, comparators using logic gates. Student knowledge is assessed from answers to selected questions of final exam that relate to course objectives and student outcome. The goal for the course is that 70% of the students to meet the course assessment standard, which states that an overall score over 84 % exceeds the standard, an overall score between 70 % and 84 % meets the standard, an overall score between 60% and 69% approaches the standard, while an overall score below 60 % does not meet the standard.

EET 223-Digital Electronics is a four credit course (theory-3 credits, lab-1 credit), offering sophomore students three hours of theory/week and three hours of lab/week. The educational objectives of this course are design and analysis of combinational and sequential logic circuits, with an emphasis on sequential circuits such as latches, flip-flops, registers, counters. Students are also introduced to Integrated Circuits (ICs) family's electrical characteristics, the internal structure of CMOS and TTL logic gates and the major characteristics and differences between various ICs technologies (CMOS, TTL, ECL). During the lab sessions, using the PB-501 Circuit Trainer, students successfully implement and test advanced combinational and sequential logic circuits, based on discrete components from the 74HCxx series. After taking this course, the students should be able to: (i) analyze and design combinational circuits using MSI circuits, such as adders, decoders, multiplexers, comparators (ii) analyze and design sequential circuits using latches, FFs, registers, counters; (iii) understand the characteristics and differences between ICs technologies. Student's knowledge assessment is similar with EET 105 course.

EET 316-Digital Design is a four credit course (theory-3 credits, lab-1 credit), offering junior students three hours of theory/week and three hours of lab/week. The course introduces students to digital design, using VHDL to describe digital circuits (combinational, sequential, FSM) and to perform functional verification and FPGA platforms to implement the digital circuits. Computers are used extensively throughout the course, this being a design oriented course using mainly Xilinx design tools and hardware. After taking this course, students should be able to: (i) design and analyze combinational and sequential logic circuits; (iii) trace the behavior of digital circuits by completing and analyzing timing diagrams.(iv) Use VHDL and Schematic Capture to design, simulate, and implement digital circuits; (v) Draw a state diagram and implement solution to a digital design problem using a Finite State Machine based controller. Student's knowledge assessment is similar with the previous two courses.

The last ABET evaluations for the EET and CET programs at FSC was in 2013.

IV. Changes in the Digital Design Sequence of Courses

In the last three academic years, the junior level course **EET 316-Digital Design** was updated continuously (syllabus and laboratory experiments). The modifications were made by the first author of this paper, who was appointed course coordinator for this course in the fall of 2014, in collaboration with adjunct faculty, members of the Industry Advisory Board and industry representatives. Students' feedback was also considered.

In the academic year 2012-2013, new FPGA platforms were acquired for the labs and students were introduced to them at the end of the semester. The platforms used for the lab experiments are Nexys™3, based on XILINX Spartan-6 FPGA chip and manufactured by DigilentInc[17]. The Nexys™3 board is presented in figure 1.

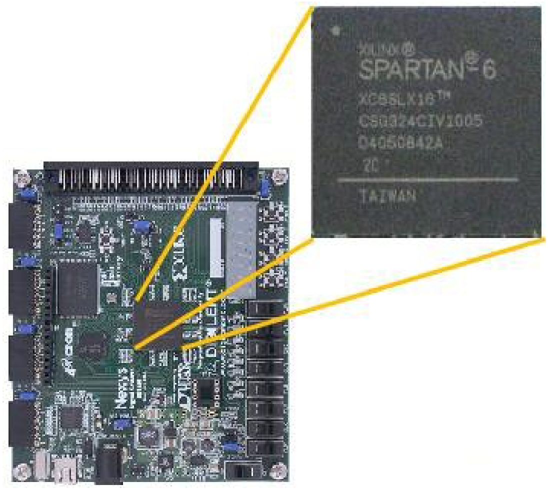
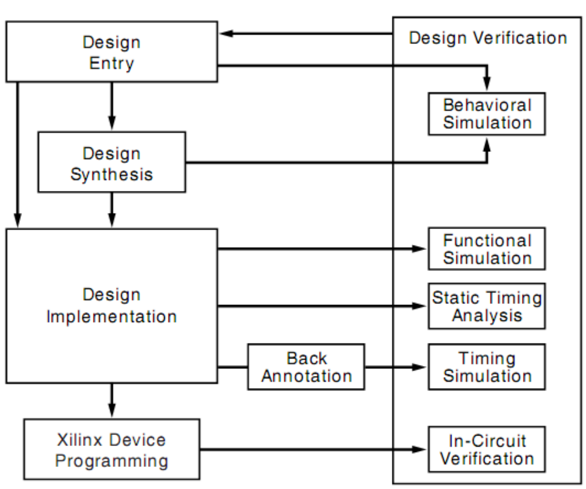


Figure 1 Nexys™3 Spartan-6 FPGA boards

In the academic year 2013-2014, a new lab manual was created, teaching students design entry, and prototyping using Xilinx ISE® tools and Digilent ADEPT software. The laboratory tutorials were based on materials provided at workshops sponsored by the NSF ATE grant *"DUE-1003736 – Developing the Digital Technologist for the New Millennium"* and posted on-line at[18]. The first author of this paper attended the NSF workshops, finding them extremely informative.

The first draft of the lab manual covered both Schematics and VHDL description of the circuits, about 60 % of the laboratory experiments using Xilinx Schematic Editor, while the rest were covering VHDL description of the circuits. Figure 2 presents the design process. The labs were reflecting the topics covered in the theory section of the course.



Design Entry:
- HDL (**VHDL** or Verilog) or
- Schematic Drawings

Design Synthesis:
- Translate VHDL and schematic files into industry standard format, EDIF file.

Design Implementation:
- Translate Map, Place and Route.

Device Programming:
- Generate a configuration file (.bit file) for FPGA programming
- Download the bit file (.bit) into the FPGA platform

Figure 2. Design Process Overview

In the academic year 2014-2015, the lab manual was updated, adding more experiments, but no changes were made to the theory class, compared with the previous academic year. In the first part of the theory class, combinational and sequential circuits were reviewed, with an emphasis on design examples. The second part of the course was dedicated to new concepts such as Finite State Machine and then description of digital circuits using VHDL, from basic logic gates to controllers. Because too much time was spent on reviewing concepts in order to accommodate transfer students from different community colleges, it was not enough time to cover advanced concepts, including functional verification (test benches) of digital circuits. Students seem also to forget by the end of the semester digital circuits (covered at the beginning of the semester) when the description of these circuits in VHDL was introduced. Due to this issue, the theory courses dedicated to VHDL language did not advance at the desired pace.

In the academic year 2015-2016, changes were made in the order of course's topics, based on instructor's observations and students' strong feedback. Students were hold responsible for reviewing concepts from previous digital and logic design courses and more time was spent covering new and advanced concepts. The VHDL language was introduced much earlier in the semester. After covering *Combinational Logic Design,* the next topic was *Description of Combinational Logic Circuits using VHDL* followed by *Functional Verification (test benches) for combinational circuits*. In the same manner, sequential circuits and Finite state Machine were covered. The new approach allows instructors to introduce new concepts such as clock skew and meta-stability of digital circuits and to discuss why asynchronous inputs to a Finite State Machine (FSM) are problematic and how to design circuits to mitigate the problem. More time was spent on FSM and controllers, including Data Path and Control Unit and Hierarchical Design, paving the path to introduce projects in the next academic years. A complete set of Power Points presentations covering VHDL concepts were created and were posted on Black Board Learn Management System.

The lab manual was again updated to follow topics covered in the theory class. The labs are: Lab_0_Introduction to XILINX tools; Lab 1_Basic logic Gates; (Schematics); Lab 2_Full Adder (Schematics); Lab 2A_Multiplexer (Schematics);Lab 3_BCD to SSD (Schematics); Lab 4_ Basic logic Gates(VHDL); Lab 5_Functional Verification of Comb_ Circuits (VHDL); Lab 6_BCD to SSD (VHDL); Lab 7_Sequence Generator (Schematics);Lab 8_Clock Divider (Schematics);Lab 9_Fibonacci Series (Schematics) Lab 9.A_Digital Average (Schematics-optional);Lab 10_Sequence Generator (VHDL); Lab 11_Clock-Divider-1Hz Clock (VHDL); Lab 12_Fibonacci (VHDL) Lab 13_OneShot_FSM (VHDL).

For the **academic year 2016-2017**, new changes are considered and are in work. The lab manual will be updated again, incorporating more complex labs covering VHDL and Functional Verification (Test Benches). The number of Labs covering Schematics will be reduced significantly. An educational Title III grant was awarded, allowing instructors to develop design projects for this class, emphasizing Project-Based-Learning. More time will be dedicated in the concept of functional verification (writing test benches). According to the findings of the educational research study presented in[19], extensive coverage of functional verification improves the learning process and the achievement of concepts and skills in digital design and encourages a deeper approach to learning, producing highly qualified graduates for today industry's needs.

Additionally, students enrolled in this class are strongly encouraged to participate with original projects in regional and national Design Contests. In the spring of 2014, a team of two students from participated in the Diligent Design Contest at City University of New York[17]. Figure 3 presents students and their instructors attending the Award Ceremony at CUNY, May 2014.

Figure 3. Digilent Design Contest, NY, 2015

Another course that went through reviews and updates over the last year was the freshman level course **EET 105-Introduction to Digital Electronics**. This course is taught in the fall and spring semesters, and is populated by a large number of students; about 20 % of them are undecided about their future major. This course helps students to understand and appreciate the Electrical and Computer Engineering Technology programs as valuable paths for their future careers.

The changes were made by the first author of this paper, who was appointed course coordinator for this course in the fall of 2013, with advice and support from industry representatives. In the theory course, less time was spent covering Boolean algebra theorems and minimization techniques including K-Maps, and more time on Arithmetic circuits (Adders, Subtractors, Multipliers), MSI circuits (Mux, Decoders, Encoders, etc.), timing diagrams, preparing students for the Digital Design and Microcontrollers courses. Results of employers' survey, conducted by Furtner and Wider[5], show that employers give low priority to topics such as Boolean Algebra and K-Maps, while HDL (Verilog, VHDL) are heavily ranked.

For this course, as a result of an educational Title III grant *"Developing Hands-On Experiments to Improve Students Learning via Activities outside the Classroom"* a set of experiments were created, allowing students to work at home, at their own pace. The experiments were created to help students improve their debugging skills and to become proficient using sophisticated test equipment outside the traditional laboratory settings. They also allow students to develop essential employability skills and meet certain general education learning outcomes, such as: (i) design and conduct experiments, as well as analyze and interpret data; (ii) ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. The experiments were developed around the Analog Discovery Platform, a modern PC-based test equipment manufactured by Digilent Inc. The experiments and associated tutorials were made available to students through Black Board Learn Course Management Systems. The Analog Discovery™ platform, presented in figure 4 enables students to quickly and easily experiment with advanced technologies and build and test real-world, functional circuits anytime, anywhere - right on their PCs[17].

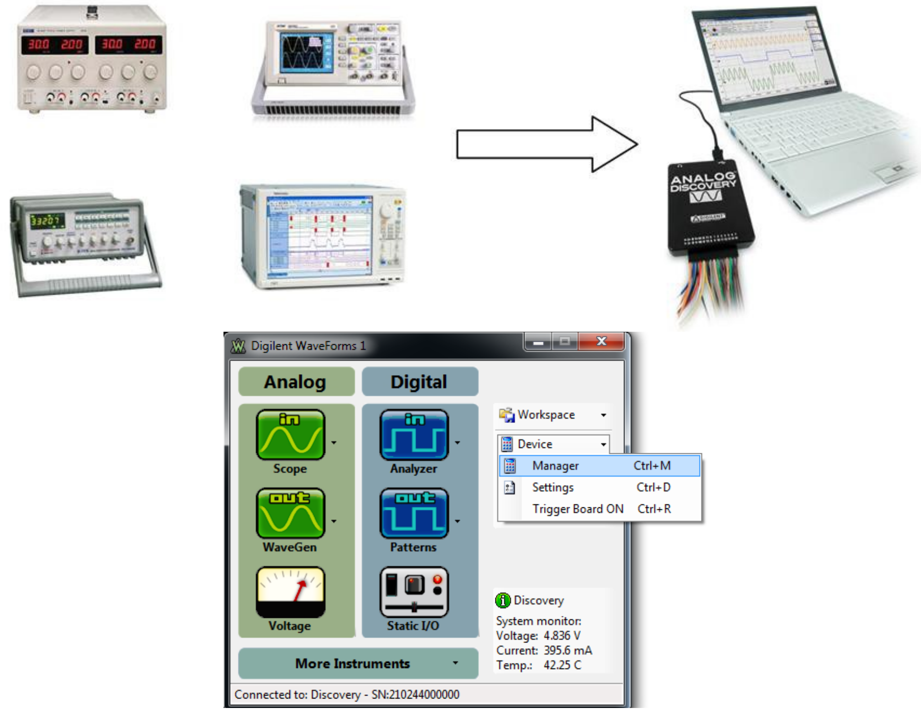


Figure 4. Analog Discovery Board

In the fall semester 2015, students enrolled in the EET 105-Introduction to Digital Electronics course were introduced to the Analog Discovery platforms and the set of experiments created for this platform. The experiments are similar with the experiments presented in EET 105 Lab manual that is required for this class using the PB-501 Circuit Trainer. This activity was optional for the students, but they were strongly encouraged to use the Analog Discovery platform at home, performing experiments at their own pace. Students interested to explore more digital circuits received the boards from the instructor and they were allowed to keep them for the entire semester. Students were also provided with a minimum of hardware required to perform the experiments. Logistic issues involved retrieving these platforms from the students and making sure that enough platforms are available during one semester.

In figure 5 is presented an introductory experiment using the Analog Discovery platform. In this experiment the truth table for various logic gates, such as Inverter, NAND, NOR, Exclusive-OR gates is verified. The tutorial explains in detail how to connect the ICs to the Analog Discovery board and how to use the existing resources.

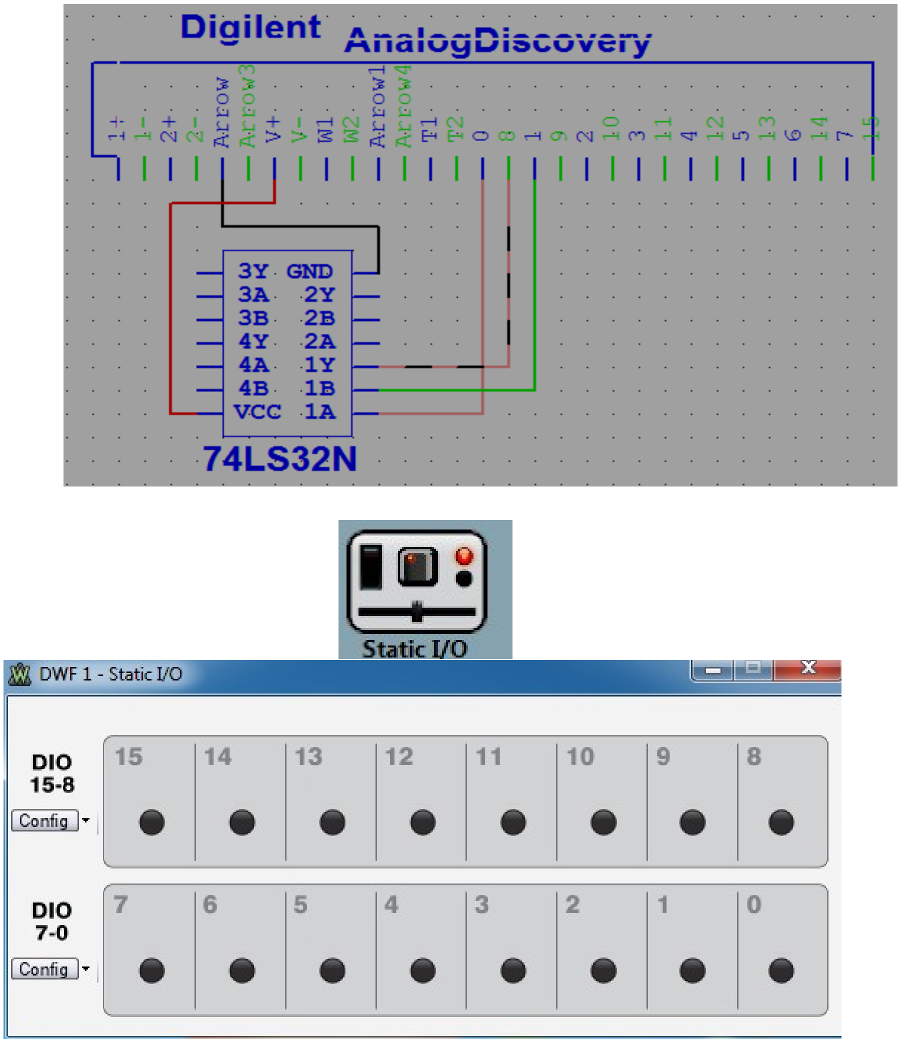


Figure 5. EET 105 Lab using the Analog Discovery Board

For the next academic year a new lab manual for this class is in work and the possibility of using the Analog Discovery boards during the regular lab hours is investigated. There are logistics issues related to the scheduling of the course, the number of sections of instructors teaching this course every semester, etc.

For the **EET 223-Digital Electronics**, the author of this paper made changes only in the theory class, being assigned to teach this class only two times in the last three years. Changes in this course are in work and they are coordinated by another instructor in the EET department. In the theory course, more time was spent on sequential circuits and timing diagrams and less time on reviewing combinational circuits and the specific characteristics of combinational and sequential circuits from the 74HC xx and 74SNxx series.

In the second part of the course, the electrical DC and AC characteristics of CMOS family were covered, emphasizing concepts such as low power dissipation, noise margin, rise time, fall time, ground bounce, reading and understanding the electrical characteristics from a data sheet, etc. Using the Analog Discovery Boards, several experiments and tutorials were created, for in-class demonstration and/or lab experiments. Such an example is presented in figure 6. In this experiment the transfer characteristics of a CMOS logic gate used as an inverter is investigated.

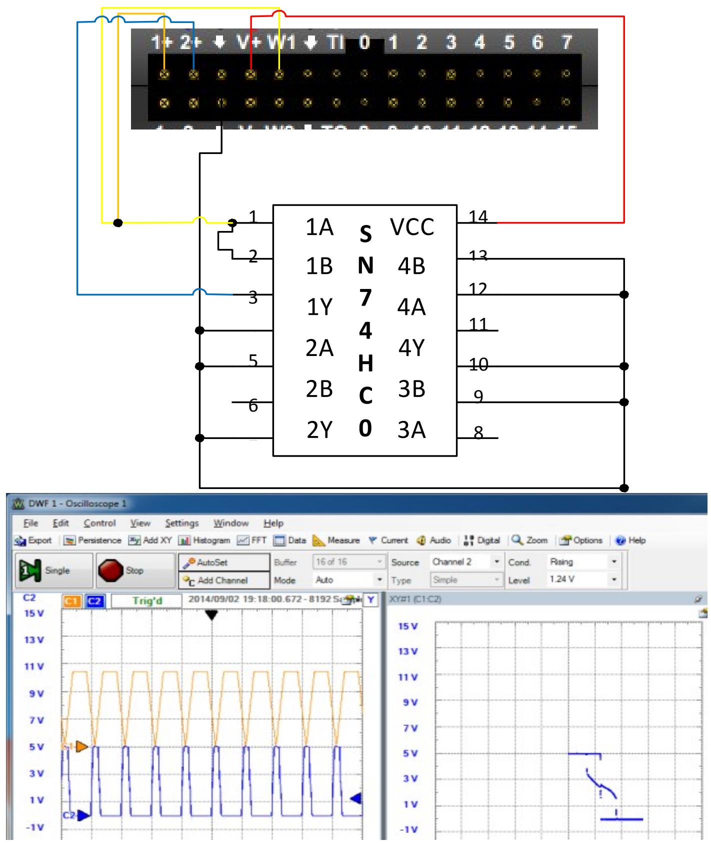


Figure 6. Transfer Characteristics for a CMOS Logic Inverter

V. Evaluation the process

Evaluating the process of changing the digital design sequence of courses at Farmingdale State College-SUNY, the main challenge was teaching a diverse students population, with different needs and different expectations from the courses, while having a large range of skills and experience with laboratory test equipment, computer-based-tools, programing skills, math, etc.

Recent discussions with transfer students from community colleges and personal observations during recent lab sessions pointed to the fact that a large number of these students are familiar with FPGA, Hardware Description Languages and associated computer tools. One possible explanation is the impact of ATE NSF grants sponsoring the advance of digital design education in community colleges in recent years. This finding allows the instructors to accelerate the pace of changing/updating the EET 316-Digital Design course and the prerequisite courses, introducing more advanced concepts, and using state-of-the art technology.

One of the “lessons learned” over the last three years was to be extremely firm holding students responsible for the prerequisite courses, allowing to teach more advanced topics, instead of spending too much time reviewing concepts. Another “lesson learned” is the fact that it is important to start earlier in the semester to encourage students to try “hands-on” experiments outside the traditional laboratory settings, and to spend more time doing in-class demonstration.

The results of the grant *"Developing Hands-On Experiments to Improve Students Learning via Activities outside the Classroom"* will be used in the EET 105 and EET 223 courses on a long term. The Analog Discovery Boards, and associated experiments will be made available to the students, every semester in the next 5-6 years and/or as long this technology is modern and efficient. The assessment process for this "hands-on" pedagogy is a work in progress.

VI. Conclusions

Trying to address the current and future needs of the industry in the areas of digital system design, the digital design sequence of courses is evaluated and reorganized, placing a strong emphasis in the study of modern tools, technologies and current industrial practices while considering the characteristics of the student population at this school and their educational needs. Plans for the future, include more access to "hands-on experiences" for students using hardware platforms secured by grants and industry donations.

Acknowledgements

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References

1. National Academy of Engineering, Committee on Engineering Education, "The Engineer of 2020", [Online], Available: www.nae.edu
2. N. Spinks, N. Silburn, D. Birchall " Educating Engineers for the 21th Century" a study carried by Henley Management College, Royal Academy of Engineering, UK, 2006.
3. "Engineering Graduates for Industry", The Royal Academy of Engineering, February 2010, London, UK,
4. Bureau of Labor Statistics, Available: [Online], http://www.bls.gov
5. N. Alaraje, A. V Sergeyev, "Faculty Professional Development for the Next-Generation Reconfigurable Electronics Workforce", The Journal of Technology, Management and Applied Engineering, 2015
6. N. Alaraje, A. V Sergeyev, J. Reuter, C. Kief, " Professional Development Opportunity for Electrical Engineering Technology Educators in VHDL and FPGA design "2012 ASEE Annual Conference & Exposition Proceedings", San Antonio, Texas
7. N. Alaraje, A. V Sergeyev, F. Scheu, "Digital Logic Design: Meeting Industry Needs through University and Community College Collaborations" 2011 ASEE Annual Conference & Exposition Proceedings", Vancouver, Ca
8. M. Radu, C. Cole, M. Dabacan, J. Harris, "The Impact of Providing Unlimited Access to Programmable Boards in Digital Design Education" IEEE Transactions on Education, May 2011, vol.54, no.2
9. K. Smith, S. Shepard, D. Johnson, R. Johnson, "Pedagogies of Engagement: Classroom-Based Practices", Journal of Engineering Education, vol. 1, January 2005
10. www.farmingdale.edu
11. www.engineering.wayne.edu/et/courses/eet_3100.pdf
12. cset.sp.utoledo.edu/eet3350Bb/eet3350_startHere.html
13. esetweb.tamu.edu/electronics/courses.php
14. www.csuohio.edu/engineering/et/electronics-engineering-technology-program
15. www.citytech.cuny.edu/academics/deptsites/eetech/courses.aspx
16. ualr.edu/engineeringtechnology/programs/degrees/electronics-and-computer-engineering-technology-ecet/
17. www.digilentinc.cm
18. cosmiac.org/thrust-areas/education-and-workforce-development/fpga/ate-developed-material/
19. M. Radu, S. Sexton "Integrating Extensive Functional Verification into Digital Design Education", IEEE Transactions on Education, august 2008, vol. 51, no.3