A Survey of Digital Systems Curriculum and Pedagogy in Electrical and Computer Engineering Programs

Hector A. Ochoa[1] and Mukul V. Shirvaikar[2]

[1]Stephen F. Austin State University
1936 North St, Nacogdoches, TX 75962 USA

[2]University of Texas at Tyler
3900 University Blvd, Tyler, TX 75025 USA
E-mail: ochoah@sfasu.edu, mshirvaikar@uttyler.edu

Abstract

Digital Systems is one of the basic foundational courses in Electrical and Computer Engineering. One of the challenges in designing and modifying the curriculum for the course is the fast pace of technology change in the area. TTL chips that were in vogue with students building physical circuits, have given way to new paradigms like FPGA based synthesis with hardware description languages such as VHDL. However, updating a course is not as simple as just changing the book, and changing the syllabus. A large amount of work needs to be done in terms of selecting the book that will accommodate the course, the device that should be used, the laboratory content, and even how much time needs to be dedicated for every topic. All these issues, and many more makes it hard to take the decision of updating the course. For that reason, this paper surveys the pedagogy and methodology that is used to teach the digital systems curriculum at different universities. The goal is that it will serve as a resource for faculty looking to update or revamp their digital systems curricula. Within the document they will find a comparative study by electrical and computer engineering program, a list of textbooks, and the devices most commonly used.

Keywords: Digital Systems, FPGA Tools, Laboratory curriculum, Pedagogy, Electrical Engineering, Computer Engineering

1. Introduction

A course on digital systems is one of the foundational courses in most electrical and computer engineering degree plans. It introduces the students to basic logic gates, Boolean algebra, and combinational and sequential logic circuits that are building blocks for most computer hardware.[1] It can be one of the most critical courses for student recruitment and retention, since it is window into the world of electrical and computer engineering.[2] Traditionally this course has been taught using TTL logic chips on breadboards. Such an approach has a number of advantages due to the hands-on element which provide the new student an opportunity to "touch and feel" the design.[3] There has been a trend due to rapid advances in technology to change the approach to one based on programming in hardware description languages.[4,5,6] It can also lead to subsequent courses in microprocessors and embedded systems that are taught using the same approach.[7,8] The advantage of this approach is that the student is in tune with the current practice in industry. However, there is a major disadvantage due to the fact that students lose the haptic feedback from actually building the circuits.[9] This can be a major issue in the choice of major when competing for student attention vis-à-vis other majors like mechanical and civil engineering that are very much hands-on in nature. Another issue may be the requirement that students have to learn VHDL or Verilog programming before taking such a course. Nevertheless, the progress of technology is immutable and educators will have to adapt to these challenges with innovative approaches.[10,11] This paper attempts to measure the current state of digital systems curriculum and pedagogy by surveying several academic institutions. Sample data has been collected from 27 universities that had courses in Digital Systems within the Electrical Engineering program. The data was primarily collected from university websites. The schools were chosen randomly and the breakdown with respect to their classification is as follows: 9 non-Ph.D. granting, 18 Ph.D. granting; 4 private, 23 public; 13 highly selective, 14 not highly selective; Geographical location – 5 West, 6 East, 4 Southeast, 2 Midwest, 1 Northwest, 9 Southwest; Carnegie classification – 18 doctoral, 7 masters, 1 bachelors and 1 community college. The goal is that it will serve as a resource for faculty looking to update or revamp their digital systems curricula.

2. Curriculum and Pedagogy

This section presents an analysis of the curriculum and pedagogy used at different universities where digital systems courses are being required. Furthermore, this section summarizes the various methodologies and materials used to teach this course.

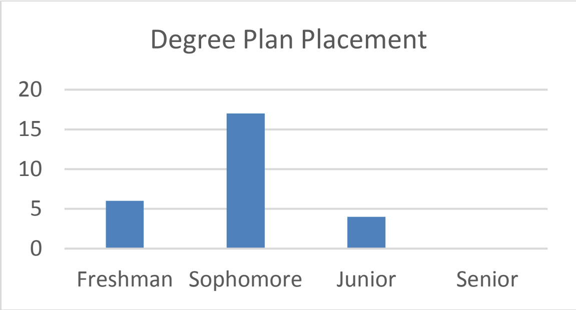

Fig. 1 Frequency distribution of instructional year within the Electrical Engineering degree plan for Digital Systems courses at different universities

Curriculum Analysis

One of the major considerations in teaching digital systems is where it should be placed within the curriculum. Which course or courses need to be pre-requisites? Do students need calculus for this specific course? Do they need to know about C++ programing? If the course uses FPGAs to teach digital systems, the students need to know about computer architecture and FPGAs? All these are typical questions that a faculty member trying to revamp a digital systems course will be facing. The goal in this section is to summarize the placement of digital systems within the curriculum at other universities. Figure 1 shows a frequency distribution of instructional year within the Electrical Engineering degree plan for Digital Systems courses at different universities. As seen in the chart, 6 courses were in the freshman year, 17 in the sophomore year, 4 in the junior year and none in the senior year as per the published degree plan for the program.

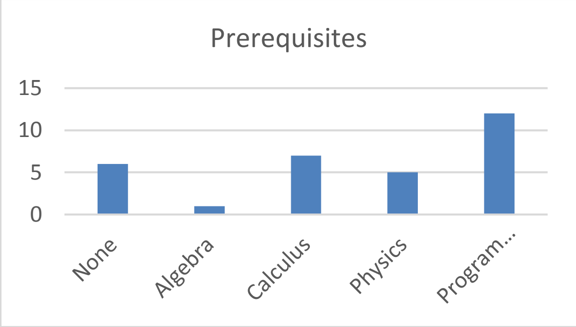

Fig. 2 Frequency distribution of prerequisites for Digital Systems courses at different universities

The prerequisites for the course were also analyzed and Figure 2 shows the frequency distribution. Based on the published syllabi, 6 courses had no prerequisites, 1 had College Algebra and 7 had some form of Calculus as a prerequisite, 5 had Physics as a prerequisite and 12 had some level of Programming as a prerequisite (some had multiple prerequisites hence the larger number).

Finally, every syllabus was analyzed looking for any patterns regarding prerequisites, and curriculum placement. The data was broken down into universities that use a chip-based approach or the HDL approach and then the number of universities that have a programming prerequisite were counted. Furthermore, the number of universities that place the course during the freshman year or the sophomore year were tallied and plotted for each case. The results from this analysis are summarized in Figure 4.

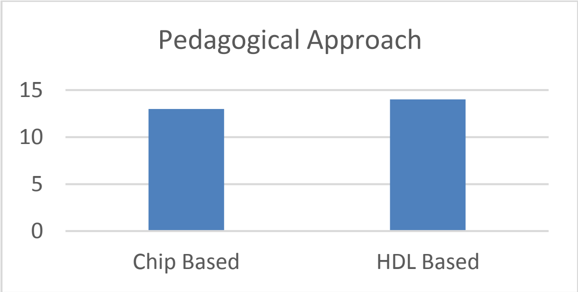

Fig. 3 Frequency distribution of Pedagogy for Digital Systems courses at different universities (HDL – Hardware Description Language)

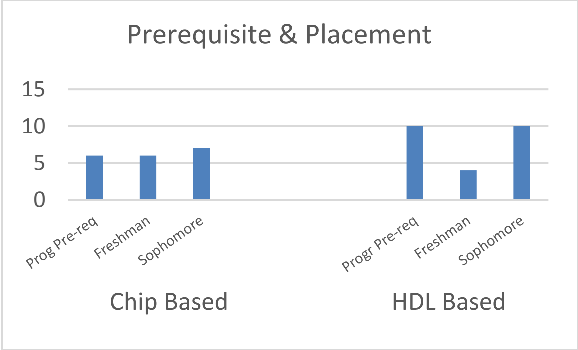

Fig. 4 Programing prerequisites, and program placement based on the course pedagogy.

The data reveals that of the 14 universities using the HDL approach, 10 have a programming prerequisite. Furthermore, 4 of the universities place this course in the freshmen year, while the remaining 10 place it at the sophomore year. On the other hand, of the 13 universities using the traditional approach, 6 of them require programming to take the course. Furthermore, 6 of the universities place the course in the freshman year, while the remaining 7 place it in the sophomore year. It appears that the HDL based courses are more likely to have programming as a prerequisite and be offered in the sophomore year.

3. Curriculum Data Collection

3.1 Pedagogy Classification

The classical method to teach digital systems is to introduce concepts using Boolean algebra principles and fortify them using circuit synthesis on breadboards. This has been fairly effective for several generations for reasons mentioned earlier. Lately, due to the advent of hardware description languages and simulation software, the trend has been to shift to pedagogy based on reconfigurable logic. Figure 3 shows the distribution of traditional chip logic based pedagogy versus a Hardware Description Language (HDL) based instructional basis. Of the surveyed courses 13 were traditional and 14 were HDL based.

Table 1. List of books used to teach Digital System Courses at different universities.

Book Name	Author	Count
Fundamentals of Logic Design	Roth and Kinney	5
Fundamentals of Digital Logic with VHDL Design	Brown and Vranesic	5
Introduction to Logic Design	Marcovitz	4
Logic and Computer Design Fundamentals	Mano and Kime	3
Digital Design	Mano and Ciletti	2
Digital Design and Computer Architecture	Harris	2
Digital Fundamental	Floyd	1
VHDL for Programmable Logic	Skahill	1
Designing Digital Systems	Nelson	1
Digital Design and CPLD Applications and VHDL	Dueck	1
Digital Systems: Principles and Applications	Tocci, Widmer, and Moss	1
Digital Design – Principles and Practices	Wakerly	1
Computer Organization and Design	Patterson, and Hennessy	1

This has resulted in a discussion about prerequisites and stratification based on the qualifications of the student population being served. Furthermore, Figure 5 shows the number of institutions using these two pedagogies broken down by the type of institution.

3.2 Textbooks

Searching for a new textbook can be one of the more overwhelming tasks when trying to update or revamp a course. It is very satisfying opening the envelope that contains an unused and shiny book ready to be adopted. On the other hand, the choice may be difficult due to multiple offerings in the market. It is impractical to order every single book available while trying to find the best suited one for the course. By analyzing a total of 27 course syllabi from different universities, a list of textbooks used to teach digital systems has been created. This list is in Table 1. From the data on the table two books came of top. One of the books is “Fundamentals of Logic Design” by Roth. This book has been the standard for traditional Digital Systems Design. On the other hand, the second book on top is “Fundamentals of Digital Logic with VHDL Design” by Stephen Brown. This book has been adopted by programs that are teaching Digital System Courses using VHDL Synthesis. Furthermore, there is a large assortment of books available to teach digital systems using the traditional pedagogy using TTL devices, and to teach it using Synthesis methods.

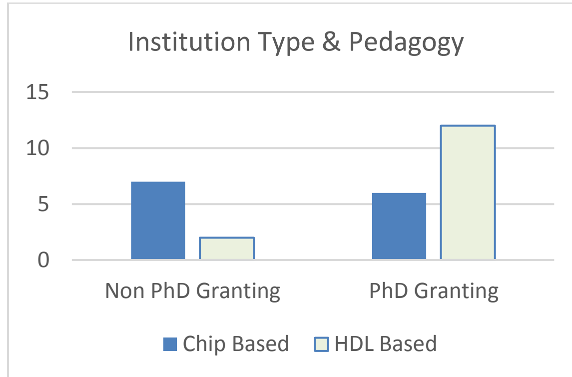

Fig. 5 Number of Non PhD, and PhD granting institutions using the Chip Base approach and the HDL Base Approach.

From the universities teaching digital systems using synthesis techniques. It was observed that some of them are following one of the following ideologies.

1. Full conversion of the digital systems course to include synthesis techniques early on the semester. The textbook is completely aligned with the course.
2. The course includes synthesis techniques, but they are introduced late on the semester, the book is aligned with the course.
3. The course includes synthesis techniques, but at the very end of the semester. The book is a traditional digital systems book, and the course is complemented with online resources, and professor notes. In some cases books related to VHDL are marked as supplemental materials.

Table 2. List of development boards used to teach digital systems using HDL.

Vendor	Development Board
Altera	Altera DE0
	Altera DE1
	Altera DE1
Xilinx	DS001 Spartan II
	Spartan-3E Starter Board
	Virtex II Pro Development System
Diligent	Basys 3 Artix-7 Trainer Board

Table 3. List of simulation software used to teach digital system courses

Vendor	Software	License
DesignWorks Solutions Inc.	LogicWorks	Paid
National Instruments	Multisim	Paid
Logisim	Opensource	Free

3.3 Laboratory Component

A number of different platforms and vendor kits are available for digital systems courses nowadays. The most common ones are based on Xilinx or Altera technology. Several of the vendors and universities provide laboratory curriculum to help course development. Table 2 is a list of the development boards used at the institution to teach digital systems using the HDL approach. While compiling the information it became clear that there is not a standard/preferred used for this methodology. It mainly depends on the faculty and his preference.

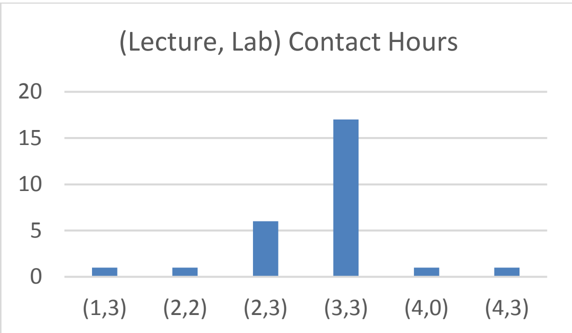

Fig. 6 Frequency distribution of lecture and laboratory contact hours for Digital Systems courses for different universities

Figure 6 shows a distribution of the number of hours devoted to lecture portion of the course and to the laboratory component of the course. The horizontal axis indicates the number of contact hours for lecture and lab for individual courses. As can be seen the format varies widely but the most common ones are (2,3) with 6 and (3,3) with 17. Each of the other formats have only one course in the distribution. It needs to be noted that most of the institutions using HDL on their laboratory procedures, start the first couple of weeks using TTL devices, and once the circuits become very complex they transition into the development boards. Most of them make this transition with the seven segment display controller. In terms of simulation software there are multiple options available depending on the complexity of the designs. Table 3 is a list of the simulation software used by the instructions sampled in this paper. The tables show the vendor, and the type software license. It needs to be clear this is not a comprehensive list of all the simulation software available.

4. Summary

The update of digital systems curriculum is a highly relevant topic of current interest to a number of new and experienced faculty in electrical and computer engineering. This paper provides valuable information for faculty members and committees investigating such a course of action. A survey of commonly used pedagogy, curriculum placement and pre-requisites is presented. The document also analyzes the material covered in the course, and the amount of time dedicated to the laboratory component. A study of the most common books, and devices (FPGAs) is provided. A breakdown of the board specifics and programming language (VHDL or Verilog) used by the surveyed institutions is not currently available but planned for the near future. The overall goal of this paper is not to impose on faculty members the methodology to revamp the course. On the contrary, it is designed to serve as a repository of useful information in a single location, thereby greatly simplifying the above process and saving valuable time and effort. In the end it is up to the faculty member to adopt pedagogies, textbooks, and laboratory components that will address the need of their constituents.

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