

A Digital Logic Design Laboratory for Electrical Engineering and Computer Science Undergraduates

Theodore W. Manikas, Gerald R. Kane, Jeff G. Kohlbeck
Department of Electrical Engineering
University of Tulsa
Tulsa, OK 74104

Abstract

An important part of the undergraduate curriculum for both electrical engineering and computer science students is coverage of digital logic design. Typically, this is accomplished by both a lecture and lab course. The purpose of the lab course is to have the students develop practical design skills. Traditional digital logic design courses focus on logic gates. However, most contemporary practical industry designs use programmable logic devices. At the University of Tulsa, our digital design laboratory course starts with traditional logic gate design, then gradually incorporates programmable logic devices, up to the point where students are building practical logic circuits.

The laboratory course is scheduled for a three-hour time slot. However, since the projects typically take more than three hours to complete, students are expected to perform the majority of their work outside of class. The course web site contains the project schedule and links to information for each lab. At the start of each class, the instructor discusses the current project assignment, and then the instructors and teaching assistants are available for the rest of the class period to provide assistance. The instructor and teaching assistants also have scheduled office hours during the week for further assistance on the lab projects.

There are ten lab experiments. During the first set of projects, students become familiar with basic digital hardware by constructing simple combinational circuits, and learning troubleshooting skills. Next, students construct a tester board to be used for all subsequent projects. During the second set of projects, students become familiar with hardware description languages and programmable logic devices. Finally, students apply their knowledge to the design of practical circuits such as a scrolling bank sign, digital-to-analog converter, and analog-to-digital converter.

Because students are constructing complete digital design projects, the digital design lab typically requires more effort than traditional laboratory courses. However, many students comment that they find the lab more useful and enjoyable than other lab courses because they get to construct complete working designs.

I. Introduction

The study of digital logic design is an essential part of most electrical engineering and computer science undergraduate programs. This includes both the theoretical and practical aspects of digital logic. Thus, the lecture course must be supplemented by a lab course in order to have the students develop practical design skills¹. At the University of Tulsa, we have developed an undergraduate digital design lab that enables electrical engineering and computer science students to learn design skills that will serve them in their future work.

Traditionally, digital logic courses have focused on small discrete components, such as logic gates. However, most practical industry designs use programmable logic devices^{2,3}. Thus, our lab starts with logic gates, and then moves on to programmable logic devices, up to the point where students are building complete designs. Originally, our course was designed to fit the traditional three-hour lab format. However, students complained that there was insufficient time to complete the projects. Thus, we revised our lab schedule so that students can finish their projects outside of the normal lab time. This new format allows us to assign more detailed (and more realistic) projects. The combination of time management, design, and troubleshooting skills are required in real engineering projects, so it is imperative that students develop these skills during their undergraduate career in order to succeed in their engineering endeavors. Our lab course helps students achieve these goals.

II. Course Structure and Implementation

The course is scheduled for a three-hour time slot each week during a fifteen-week semester. At the start of each lab session, the instructor discusses the next lab experiment for approximately thirty minutes, and then the students start work on the lab. Since the lab experiments require more than three hours to complete, students are typically given one week to complete an experiment. The lab is open all week, and the instructor and teaching assistants are available during scheduled office hours throughout the week for consultation and grading.

All course information is posted on the course web site, including lab experiment instructions. Students must purchase a kit of parts that are stocked and sold by the local student IEEE chapter, and a set of basic tools. All other equipment is available in the lab.

Students must also purchase a composition book (10-1/4" × 7-7/8", 80 sheets, 5 × 5 quad ruled) to be used as their lab journal. All lab work must be recorded in this journal and checked by an authorized grader. Journals must be submitted to the instructor by the end of the last scheduled lab of the semester.

There are ten lab experiments. Each lab is worth ten points, for a total possible lab course score of 100 points. All grades are recorded in each student's lab journal - the final course grade is based on the sum of all lab grades as shown in Table 1. Labs that are completed one week late are worth eight points, while labs that are completed two weeks late are worth five points. The exception to the policy is for the last three project labs: due to their difficulty, these labs are not due until the end of the semester. Thus, students must learn to manage their time so that the work is completed on schedule.

Total points	Final grade
81 - 100	A
71 - 80	B
61 - 70	C
51 - 60	D
0 - 50	F

Table 1 - Course grading scale

Since the lab course is coordinated with the co-requisite lecture course, the first lab experiment is not assigned until sufficient background material has been covered in the lecture course. The *first* experiment introduces the students to practical applications of combinational logic circuits, such as gates and multiplexers. Students start by constructing basic input and output circuits, and then proceed with constructing logic circuits to implement specific functions. All circuits are constructed on a breadboard, which allows for rapid construction and modifications. The purpose of this first project is to get the students, especially computer science students with no prior hardware background, comfortable with constructing digital hardware.

In the *second* lab experiment, the students learn how to identify and repair problems in logic circuit designs. Using the same parts from the previous lab experiment, students are given a known faulty circuit to construct, along with the desired truth table. Each student must identify and correct the problems so that the circuit functions as specified.

The *third* lab experiment uses the knowledge of combinational logic gained in the previous experiments to design and construct a circuit that will generate characters to be displayed on a seven-segment display. For the *fourth* lab experiment, students construct a tester board to be used for all subsequent experiments. Students learn how to assemble a printed circuit board, including how to solder components. This reflects the actual design process in industry, where designs are first developed on a breadboard, then refined and implemented on a printed circuit board. The tester board contains a logic probe, input switches and output LED's, a 5-V power supply, and variable-speed clock. This board is used along with the breadboard for all subsequent lab experiments. The printed circuit board is a multipurpose board that contains a microcontroller and is also used for other courses.

As mentioned in the introduction, many contemporary industrial designs use programmable logic devices. Thus, in the *fifth* lab experiment, students learn how to develop ABEL programs^{4,5} for PEEL devices⁶ to generate characters on a seven-segment display. The ABEL hardware description language is used since it is easy to learn, and the development software and PEEL devices are relatively inexpensive. This trend continues into the *sixth* lab experiment, where students implement a simple arithmetic-logic unit (ALU).

The *seventh* lab experiment covers a variety of useful counters. The knowledge gained from completing this experiment, combined with the experience of the previous lab experiments, is applied to the *eighth* lab experiment to develop a "practical" circuit - a bank sign that displays a scrolling message. In the *ninth* lab experiment, students develop a digital-to-analog converter. An analog-to-digital converter is developed in the *tenth* lab experiment.

III. Observations and Outcomes

This course typically requires more work than traditional lab courses, since the students are constructing actual working digital designs. However, many students comment that they enjoy this course more than other lab courses *because* they get to construct real designs. For many computer science students, this course is often the only opportunity to work with hardware. Some of these students discover that they enjoy hardware design as much as software design, and decide to take more electrical engineering courses.

Many students do additional designs using their lab parts after the course has been completed. An example is modifying the scrolling bank sign to display alternate messages. Students also use the tester board for other courses. The skills developed in the digital design lab, such as time management, troubleshooting, and project planning, are applied to upper level laboratory courses and to senior projects.

Bibliography

- [1] N. L. V. Calazans and F. G. Moraes, "Integrating the Teaching of Computer Organization and Architecture with Digital Hardware Design Early in Undergraduate Courses," *IEEE Trans. Education*, vol. 44, pp. 109-119, 2001.
- [2] M. S. Nixon, "On a Programmable Approach to Introducing Digital Design," *IEEE Trans. Education*, vol. 40, pp. 195-206, 1997.
- [3] S. Sehati, "Re-Engineering the Practical Laboratory Session," *Int. Journal of Electrical Engineering Education*, vol. 37, pp. 86-94, 2000.
- [4] Xilinx, ABEL Hardware Description Language, Xilinx Corp., www.xilinx.com.
- [5] N. Balabanian and B. Carlson, *Digital Logic Design Principles*: John Wiley & Sons, 2001.
- [6] ICT, PEEL Programmable Logic Devices, Integrated Circuit Technology Corp., www.ictpld.com.

THEODORE W. MANIKAS

Theodore W. Manikas is an Assistant Professor of Electrical Engineering at the University of Tulsa. Previously, he was a Systems Analyst for the NSABP Biostatistical Center at the University of Pittsburgh, and was also an Electronic Design Engineer for Troxler Electronic Laboratories in North Carolina. He is a member of the ASEE, ACM, and IEEE. He received the B.S. in electrical engineering from Michigan State University, M.S. in electrical engineering from Washington University (St. Louis), and the Ph.D. in electrical engineering from the University of Pittsburgh.

GERALD R. KANE

Gerald R. Kane is a Professor and the Chair of Electrical Engineering at the University of Tulsa. He is a member of the ASEE, ACM, and IEEE. He received the B.S.E.E. from Washington University (St. Louis) and the M.S. and Ph.D. from Rice University.

JEFF G. KOHLBECK

Jeff Kohlbeck is a Senior Instructor of Electrical Engineering at the University of Tulsa. He received a B.S. in electrical engineering and a M.S. in electrical engineering from the University of Tulsa