Digital Design in Community College Courses

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Background

Northern Essex Community College offers three courses in digital circuits: Fundamentals of Digital Logic (a 3-credit course which meets for 3 hours per week for 15 weeks) and its accompanying Digital Logic Lab (a 1-credit lab course which meets once a week for 3 hours for 15 weeks) are taken in the first semester at NECC. The third course, Digital Electronics (a 4-credit course which meets for 3 hours of lecture/recitation per week and one 3-hour lab per week for 15 weeks), is taken in the sophomore year. These courses are required for degrees in Electronic Technology; Fundamentals of Digital Logic is required in several other programs; all three courses are available as electives in Engineering Science and are highly recommended for students in Computer Engineering.

Prior to the fall, 2004 semester, Fundamentals of Digital Logic included an introduction to digital logic design using Karnaugh maps, yet the accompanying Digital Logic Lab did not include logic design. Also prior to fall, 2004 in the laboratory portion of Digital Electronics, there were some labs where Karnaugh maps were used to design simplified circuits (limited to 4 input variables) which were then built with TTL logic chips.

Fundamentals of Digital Logic

Fundamentals of Digital Logic covers Boolean algebra, Karnaugh map simplification, combinational and sequential logic, counters, and shift registers. Digital Logic Lab emphasizes analysis of digital logic circuits built with TTL chips. Experiments are assigned from a laboratory work book and are performed in groups of two. Each of the lab exercises coincides with the specific weekly topic covered in Fundamentals of Digital Logic. The labs begin the course with experiments in basic logic gate functions including AND, OR, NOT, NAND, NOR, XOR and XNOR. Then they progress to Karnaugh map simplification and combinational logic circuits. Multiplexers are then introduced in two lab experiments after which there are experiments with both latches and flip/flops. If time permits, a counter lab is performed. Each student is required to submit individual lab reports. This combination of hands-on lab work with course lectures strengthens the students’ knowledge in basic digital logic circuits.

Changes in Digital Logic Lab

The most significant changes to the Digital Logic Lab were the introduction of both design projects and design assignments. In the fall of 2004, two design projects were given in the semester. The process of deductive learning was implemented by introducing a specific design project. Over the course of the semester, various experiments were studied and then used as
solutions to complete the project. For example, on the first day of class, the students were given
the syllabus and an overview of the course and design project #1.

At first, this seemed overwhelming for the students, but they were assured that both the lab work
and lecture course would help them complete their design project. Students worked in pairs, but
had to produce an individual project report. They had approximately seven weeks to complete
the design. After that time, they were given the second design project. This project was due at
the end of the semester. The design projects were based on material covered in the Fundamentals
of Digital Logic lecture course with emphasis on the application of that material. An example of
a design project is to design a BCD Invalid Code Detector wherein the output for the ten valid
BCD codes is a 0 and the output for the six invalid BCD codes is a 1.

**Summary of Student Survey in Digital Logic Lab**

The following is a summary of student learning for the Digital Logic Lab at Northern Essex
Community College in the Fall, 2004 semester. It is based on both the student survey and
instructor observations. The students were surveyed on how effective different teaching methods
used in the semester were on educating them about specific digital electronic topics. Teaching
methods evaluated were: A) class room examples and handouts, B) textbook examples and
chapter problems, C) lab experiments, and D) design projects. The survey was intended to
include both the Fundamentals of Digital Logic lecture and Digital Lab courses. The degree of
effectiveness was based on a scale from 1 through 4 (4= very effective and 1 = did not help).

The digital electronic topics chosen for the survey were those used in the BCD Invalid Code
Detector design project. This design project required the students to create a truth table for the
BCD Invalid Code Detector, generate a Boolean expression and reduce the expression through
Karnaugh maps and/or Boolean algebra. Students had to implement a digital logic circuit using
AND/OR logic. Once this was completed, the students converted their circuit to NAND gates
only. Finally, the students were required to use an 8-input multiplexer to implement the BCD
invalid code detector.

The survey was given to two different sections of Digital Logic Lab, one taught during the day
and one taught during the evening, both sections taught by Paul Chanley with a total of 18
surveys returned. The surveys indicated that the design project was the most effective teaching
method used to teach the concept of digital circuit design. For “multiplexer application” and
“digital logic gate application” the data is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Class Room</th>
<th>Lab Exercise</th>
<th>Textbook</th>
<th>Design Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplexer Application</td>
<td>3.11</td>
<td>3.00</td>
<td>3.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Digital Logic Gate Application</td>
<td>3.22</td>
<td>3.28</td>
<td>2.68</td>
<td>3.70</td>
</tr>
</tbody>
</table>

Ranking key: 4=very effective, 3=effective, 2=somewhat effective, 1=did not help.

The results regarding the application questions were consistent with the instructor’s class room
observations during lab work. Students were perplexed by circuit applications. A frequently
asked question was “where can I use these circuits?” The design project answered this question
by providing a practical example of digital circuit applications. Also, the survey revealed that the textbook examples and chapter problems were the least effective teaching method for digital circuit applications.

**Summary for Digital Logic Lab**

The modifications and enhancements to the Digital Logic Lab course at Northern Essex Community College that were made in the fall of 2004 focused on design and application. The results were judged effective enough that a new course employing even more emphasis on design and called Digital Design Lab will replace Digital Logic Lab in the fall of 2005. Digital Logic Lab has been a popular course at the college; it is expected that Digital Design Lab will be even more so. Students from several disciplines--Engineering Science, Electronic Technology and Computer Science--will take this course. The collaboration required by students of varying backgrounds to successfully complete the design projects and assignments will continue to add another dimension to the learning experience.

**Digital Electronics**

Traditionally, Digital Electronics reviewed the topics of Fundamentals of Digital Logic before covering programmed logic devices (theory only, no lab work), analog to digital conversion, digital to analog conversion, and memory. In the laboratory portion of the course, there were some labs where Karnaugh maps were used to design and simplify logic circuits (limited to 4 input variables) which were then built with TTL logic chips.

**Changes in Digital Electronics**

In the spring of 2004, Professor Michael Pelletier (Chairperson, Department of Computer Technology and Engineering) attended an advisory committee meeting at Middlesex Community College, a sister institution in Massachusetts, where the Altera CPLD board was being used. Professor Pelletier decided to have Northern Essex Community College join the Altera University Partners Program. Dr. Paul McCormack (now a lecturer at Tufts University) agreed to serve as a technical consultant for the teaching of digital logic design with the Altera UP2 boards.

Successfully working with the Altera CPLD board during the summer of 2004 led first to a decision to buy an additional 20 Altera UP2 development systems at a discount available to university partners and, finally in late August, to a decision to completely revamp Digital Electronics.

A new lab book, Digital Fundamentals: Experiments and Concepts with CPLDs by Leo Chartrand was added to the required lab readings; Experiments in Digital Fundamentals by David Buchla and Digital Fundamentals by Thomas Floyd (the text for Fundamentals of Digital Logic) were made optional to lessen the financial burden on the students.

Digital Electronics was changed to a course emphasizing design of digital circuits. It was mandated in the course syllabus that 10 designs be done using VHDL and the Altera UP2 board.
One design had to be done with TTL logic. Two designs could be done with either TTL or the Altera UP2 boards. (Most students, when given the choice, chose the Altera boards to avoid having to do all the wiring that TTL chips require.) On several designs that were done with both the MAX chip and TTL logic, students were required to cost out each type of design.

Students worked in teams of 2 or 3, but each individual was assigned his or her own Altera board. For each lab that utilized the Altera board, each student had to program the CPLD chip on his or her board and show the instructor that the design worked properly as specified in the problem specifications.

The students were initially organized into four groups, three groups of 3 students each and one group of 2 students. Within the second week of the course, one student from a group of three had to drop the course when his work schedule was changed. Five weeks into the course, one of the students in the original group of 2 left the course when his work schedule was also changed. His lab partner was then integrated into the other group of two, so that over the last 10 weeks of the course there were three groups of 3 students.

- Each group made an oral presentation of their work in the second week of the course and again during the final meeting of the class during final exam week.
- Each group submitted a written report for each design or lab project, with the report writing being rotated among the members of the group. Each member of the group received the same grade for that particular design or lab project.
- Each of the 15 designs or lab projects was worth 5 points; the oral presentation and report of the final project was worth 25 points.
- There were no tests or quizzes.
- Topics were reviewed or new topics introduced when they were needed by the students.
- In the last month of the course it became clear to the instructor that the proposed final project (either Lab 17, 18, 19, or 20 from Chartrand) was too big a leap from the first 15 labs to be a doable project. At this point the course was redesigned to include Lab 16 from Chartrand which introduces VHDL representations of counters and shift registers and the final project/presentation was changed to a digital light meter utilizing a photocell and a tracking analog-to-digital converter.

Amended Assignments

<table>
<thead>
<tr>
<th>Lab</th>
<th>Experiment</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (Handout from Dueck)</td>
<td>Boolean Algebra and Logic Circuits</td>
</tr>
<tr>
<td>2</td>
<td>2 (Chartrand)</td>
<td>Logic Gate Fundamentals</td>
</tr>
<tr>
<td>3 &amp; 4</td>
<td>3 &amp; 5 (Chartrand)</td>
<td>Lab 3: Vending Machine System and Lab 5: VHDL Vending Machine System</td>
</tr>
<tr>
<td>5</td>
<td>7 (Chartrand)</td>
<td>Lab 7: Converting an Older IC Technology Drill Machine System to VHDL</td>
</tr>
<tr>
<td>6</td>
<td>8 (Buchla)</td>
<td>Logic Circuit Simplification</td>
</tr>
<tr>
<td>7</td>
<td>9 (Buchla)</td>
<td>The Perfect Pencil Machine</td>
</tr>
<tr>
<td>8</td>
<td>10 (Buchla)</td>
<td>The Molasses Tank</td>
</tr>
<tr>
<td>9</td>
<td>18 (Buchla)</td>
<td>One-Shots and Astable Multivibrators</td>
</tr>
</tbody>
</table>
Results of Changes in Digital Electronics

From the faculty point of view, the switch to a project-centered course emphasizing collaborative learning and using "just in time" delivery of instruction was a success. During class time (Tuesday and Thursday, 9:15am-11:55am), students appeared more focused and engaged in the work. Some students stayed after the allotted time to continue working; at one time or another all seemed to be taking work home or planning to meet over the weekend. The lab book used for the design problems to be done on the Altera board included a CD-ROM with the MAX+Plus II software. The software was also available as a free download from Altera. Having the software enabled students to develop the solutions at home, save the solutions on a floppy disk and then spend the time in lab programming the chip on the Altera board and debugging the lab.

- Students took responsibility for learning and would ask about topics needed for a particular lab. The instructor would then invite all to listen to a short presentation on the topic. During such presentations, all students seemed engaged, attentive and asked relevant questions.
- Written lab reports were judged to be of higher quality than in previous years.
- Grades in the course were higher than in the two previous years as shown in the following table. (However, the grading system in the course changed radically from fall, 2003 to fall, 2004. In fall, 2002 and fall, 2003 the same final exam, constructed by Professor Michael Pelletier, was administered. In fall, 2004 there was no final exam; instead, there was a final project presentation.)

Grade Distribution in Digital Electronics for courses taught by Professor Michael Pelletier

<table>
<thead>
<tr>
<th></th>
<th>Fall 2004</th>
<th>Fall 2003</th>
<th>Fall 2002*</th>
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<tbody>
<tr>
<td>A</td>
<td>5</td>
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<tr>
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<td>1</td>
<td></td>
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</tbody>
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* Number of students in fall of 2002 was inflated by workers recently laid off by a local electronics company.

**Student Responses in Digital Electronics**

Eight of the nine students completing the course submitted a final questionnaire. The demographics:
- One student was female. 1 student graduated high school in 1963, 1 in 1969, 1 in 1979, 1 in 1981, 1 in 1983, 3 graduated in 2003.
- 6 students reported the course was required in their major; 1 student reported it was an elective; 1 student did not answer the question.
- 1 student reported taking the prerequisite course in Digital Logic during the Spring, 2003 semester, 6 students reported that they completed Digital Logic during the Fall, 2003 semester, 1 during the Spring, 2004 semester.

The responses:
- All 8 answered that they liked the emphasis on digital design in the course;
- 5 reported that they liked working with TTL logic while 2 (from the class of 2003) disliked working with TTL logic;
- All 8 reported that they liked working with the Altera board;
- All 8 liked the lab book by Chartrand that emphasized the Altera UP2 board; whereas
- Only 2 students praised the lab book on traditional TTL logic by Buchla and 4 students (the oldest and the 3 youngest) actually found fault with Buchla's lab book.

When students were asked **how they felt about the course,**
- the oldest student replied, "I enjoyed the course a lot. Class time just flew by."
- Another replied, "It was very good."
- Still another, "This course is very interesting, and I felt more comfortable when I finished this course."
- One of the youngest students responded, "I like this course a lot. I learned a lot of new things and now know how digital systems operate.
- The other two youngest students said, "This course was great; the labs taught me a lot and gave me a feel on what happens in the field" and "It was positive. There were plenty of projects to keep us busy with not too much lecturing."

Reports:
- All the students preferred written lab reports to oral reports, although most reported that they understood the importance of being able to make an oral technical presentation to a group of peers.

When students were asked **how this course compared with other electronics courses they had taken,** they replied,
- "It was much more hands-on."
- "By far this class was more exciting than any of the ones I have taken in the past."
- "A more hands-on approach with less anxiety because of no tests."

**Summary for Digital Electronics**
The shift in emphasis in Digital Electronics to a project-based design course using complex programmable logic devices was well received by the students and the teacher. Students reported that the course was one of the best electronics courses they had taken and that they learned a lot. Students were able to design digital circuits using both TTL logic and CPLDs, to work in teams and to make written and oral reports on their design work.

**Conclusions and Recommendations**

As a result of adding both design projects and design assignments to the lab course during the fall of 2004, the department changed the course name to Digital Design Lab, effective fall, 2005 to more accurately reflect its objective of combining design theory and application. In addition, the format will change from a 1-credit lab meeting for 3 hours per week for 15 weeks to a 2-credit course meeting for 1 hour of lecture and two hours of lab work per week for 15 weeks. The lecture aspect of the lab will introduce digital design topics to the students, including applications, problem solving and trouble-shooting concepts.

The design assignments will be a vital part of teaching these concepts. Typically, a new design assignment will be given each week at the beginning of class. The instructor will discuss the assignment and relevant design topics/applications. Students will be required to complete the design prior to starting any hands-on lab work. The design assignments are based on material covered in the Fundamentals of Digital Logic lecture course. Students will work in groups of two or three and hand in one paper. An example of a design assignment is: Design a digital logic circuit that has four switches (A, B, C and D) as inputs. The output of the circuit should indicate a high (logic “1”) if both A and B are high or if both C and D are high. Use a truth table and basic logic gates (AND, NAND, NOT, OR and NOR).

In addition to the design projects and design assignments, the students will be required to execute lab experiments assigned from a digital electronics experiment workbook. These labs will help students gain knowledge and confidence in digital logic circuits and lab equipment. The experience will also help them to complete their design projects. Experiments will cover topics in basic logic gates: AND, OR, NOT, NAND, NOR, XOR and XNOR. Also, logic circuits will be developed through truth tables and/or Boolean expressions. Another experiment will require students to simplify the circuits with Karnaugh maps or Boolean algebra. After these experiments, the students will be equipped to start design project #1. Lab experiments on multiplexers will then be introduced. When they are completed design project #1 will be due. The course will then move on to latches and J-K flip-flop experiments. These labs will help support the basic concepts required for implementing the second design project. Design project #2 will be either a counter or shift register designed using J-K flip-flops.

The shift in emphasis in Digital Electronics will continue. In the spring, 2005 this approach will be extended to another section of Digital Electronics taught by an instructor other than Professor Pelletier which will be offered to students in the part-time evening program. Most of the digital design will again be done with Complex Programmable Logic Devices (CPLDs) on the Altera UP2 boards. Students will be required to work in teams, to write reports on their logic designs, and to make oral presentations of those designs. During spring, 2005 a departmental committee will investigate choosing a different text book and a different lab book for Digital Electronics.
Bibliography

**Digital Fundamentals**, *8th edition*, Thomas Floyd (Prentice Hall)

**Digital Fundamentals: Experiments and Concepts with CPLDs**, Leo Chartrand, Thomson Delmar Learning


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