AC 2011-1446: A PROJECT BASED HANDS-ON DIGITAL LOGIC COURSE

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Introduction: A number of teaching paradigms have been utilized to increase the student learning effectiveness for advanced and complex engineering problems. The studies have indicated that student learning experience can be improved when it is supported with hands-on laboratory components, practical applications and theoretical concepts covered in classrooms[1, 2]. A study in a digital logic design (DLD) course concluded that using Programmable Logic Devices (PLD) as a means of practical approach has improved the effectiveness of education quality in the course[3]. Nowadays, the engineering problems have become more complicated and complex, requiring creative thinking and skilled engineers to solve these problems. The student educational experience can be fully supported by offering hands-on laboratory projects as an interactive and visual computerized teaching tool and these projects are shown to improve student understanding of the digital logic circuit concepts[4]. Also, a hybrid software-hardware approach was proven effective to promote the understanding of the theoretical concepts by integrating the theory with hands-on computer simulations[5]. Furthermore, a Karnaugh Mapplet has been both utilized to improve student learning and digital logic skills and proven to be very effective for subject comprehension[6]. The use of Karnaugh-Mapplet has resulted in significant improvement in students' understanding of Karnaugh-map problems as well as better performances in the exams. In addition to these studies, we present an integrative project-based design approach in a DLD course, a sophomore-level core course offered at the Electrical Engineering Department of Texas A&M University-Kingsville (TAMUK) and evaluate the project effectiveness. The goal was to integrate hands-on laboratory learning opportunities in the course currently taught in traditional lecture style and to implement an integrative problem-driven system synthesis approach to enhance student educational experiences such as critical and creative thinking as well as system design skills.

The Course: The DLD course is offered in fall and spring semesters at the Electrical Engineering program at TAMUK and is very fundamental as well as pre-requisite for several advanced level courses in Electrical and Computer Engineering disciplines. The previous course educational format did not include any laboratory component to complement the classroom contents and did not allocate any grade weight for possible practical projects. The new project-based DLD course is still taught in a traditional lecture style, but a number of laboratory experiments and in-depth challenging projects have been included to the course with a thirty percent weight in the student final grades for the hands-on activities. The new course was designed to integrate fundamental knowledge of hardware implementation of logic and arithmetic functions as well as knowledge of relevant subjects and design organization during digital system synthesis.

Traditional DLD courses cover the basic building blocks of digital systems, including optimal implementation of logic functions, different logical number systems, arithmetic operations and circuits, combinational circuits, flip-flops, registers, counters, and synchronous sequential circuits. The course content coverage is usually enhanced by including variables, functions and truth tables as well as the types and operation principles of the digital logic gates such as AND, OR, COMPLEMENT, and 7400 series logic chip circuits. The Boolean algebra is a fundamental topic that is used to simplify the logic expressions and to analyze the combinational logic circuits. Additionally, the design and analysis of combinational networks are introduced. The coverage also includes Read Only Memory (ROM), Programmable Logic Arrays (PLA), some practical components such as encoders, decoders, multiplexers and the operation of latches, e.g., flip-flops, shift registers, counters and the general sequential circuit timing diagrams and synthesis. Computers and digital systems use different number systems such as binary, octal, and hexadecimals systems and these number systems and their conversion principles are introduced in the course.

The project-based DLD course was implemented during the Fall-2009 semester and included twenty students, fourteen of whom were Hispanics.

The Hands-on Activity and Projects: There were two laboratory assignments, two short projects, and one final semester project. Each laboratory assignment focused on laboratory basics and took one lab session (a 3-hour period) to complete. Each short project involved initial design research components and took one week to complete. The comprehensive final semester project focused on advanced topics and allowed two weeks to complete, including the final project report submission. The details of these projects are included in the short projects section.

The laboratory activities took place on Friday afternoons, based on the students' , the teaching assistant and the faculty availability. Majority of the class students were available during the sessions and another alternative time slot was offered for a few students with schedule conflicts. There is no laboratory sessions offered for the DLD course as opposed to some programs in the country have a lecture/lab combination for the course. The uniqueness of the activities in this project is in the coherent lab assignments in which an integrative design approach was implemented, i.e., the basics of the laboratory components and digital systems were covered first and the short projects built on the basic systems. Then, an advanced digital system synthesis problem both combined the acquired skills during the previous laboratory sessions and student design skills delivered during the lectures.

The laboratory assignments were developed to introduce practical concepts for the course subjects and to prepare students for the advanced projects. The two-student teams ensuring diversity were formed and were assigned three projects involving the analysis, design, and practical applications of digital logic design concepts. The team final scores were based on their design performances and report preparations. The students were evaluated on their weekly progress and the final report by the instructor and graduate assistant.

In the first laboratory session, the students familiarized themselves with the basic laboratory equipments and components such as breadboards, function generators, 7400 series chips, logic gates and standard digital integrated circuits with the close supervision of the laboratory graduate assistant. Power supplies and breadboard configurations as well as connections were covered in the first laboratory meeting. The 7400-series standard chips and their biasing and connections of different types of gates such as AND, OR, XOR were practiced in the short assignments. Also, in the first lab meeting, the course instructor and the teaching assistant (TA) led a brief tour in the laboratory to introduce the relevant equipments and components to the students. The TA explained every equipment and part in detail to the whole class and gave short demonstrations by implementing simple digital logic circuits. The second and third laboratory sessions were organized to implement the basic activities. First one of the short assignments was to test the truth table of different logic gates in the laboratory setting. Function generators were explained to the students to emphasize timing, frequency, and different signal functions especially rectangular pulse shape and their usage in DLD courses.

The samples of the representative assignments given in basic activities are described below. They are given to improve the students' understanding of the synthesis of logic functions by using Product-of-Sums (POS) and Sum-of-Products (SOP) simplification as well as their simplified implementation by utilizing Karnaugh-map or Boolean algebra.

- Design the simplest circuit that has five inputs; a, b, c, d and e which produces an output value of 1 whenever exactly three or four of the input variables have the value 1; otherwise output will be 0.
- Design a logic circuit that will implements the function $f(a,b,c) = \sum m(1,2,4,5,6)$

After completing the first assignment, the students gained sufficient experience to implement more complex circuits. In the following weeks, the class students met to implement the remaining two short and final projects under the supervision of TA.

The course instructor developed and assigned a common comprehensive semester project to all teams in the second half of the semester during which the students were to use their knowledge on both combinational and sequential circuit concepts and to integrate their laboratory skills and hands on experience. The semester project required extensive research on theory and practical applications, time and project management, good communication and teamwork skills, critical thinking, and a complete system design and technical documentation. The teams conducted research, elaborated on various design alternatives and designed their own logic circuits. One week after the project was assigned; the teams were required to submit a progress report with their initial design. The reports were evaluated by the instructor and TA and the necessary feedback was conveyed back to the teams. The design implementation specification required minimal cost and predefined project duration. Each team also prepared a workload distribution plan so that the project work would be shared equally and be finished in a timely manner. Weekly faculty-team meetings ensured satisfactory and timely project progress and allowed a steady feedback on design alternatives.

The teaching assistant was responsible to maintain the laboratory equipments and to teach and guide the students about the operation principles of these equipments during the experiments. The TA was available during the laboratory sessions and all the equipments and parts were grouped. The students needed to do short research to determine the proper chip numbers and choose the required parts in the activities themselves. Once the students completed the assignments, they were required to present and test the circuit under the supervision of the TA. The students were also allowed to take the equipments, and breadboard to the outside of the laboratory so that they could continue working on the projects other than laboratory hours. At the end of each project, the teams also documented their scientific findings of the design and project development steps in a technical report format. The mandatory format of the final project report was developed by the instructor. The reports were evaluated based on the format compliance, knowledge content as well as presentation. The report required the following sections: the digital logic circuit implemented (in detail), an abstract, the list of the devices and gates used, a technical discussion section which explained the implementation procedure details, the budget of the circuit, and a conclusion section.

The Short Projects: The laboratory component included two short projects as described below:

- **Project-1:** the students were given digital logic functions such as $f = x_1x_2 + \overline{x}_2x_3$, and were asked to implement them by using the standard 7400 series chips. Figure 1 depicts a typical practical implementation of the logic function f. The students were asked to prepare the truth table of the circuits, and to implement them on breadboards and verify the expected functional operations. An Light Emitting Diode (LED)s were connected to the output of the logic circuits so that Logic 0 and Logic 1 output could be identified easily, i.e., when the light was on, Logic 1 is understood while logic 0 is interpreted when the light was off.

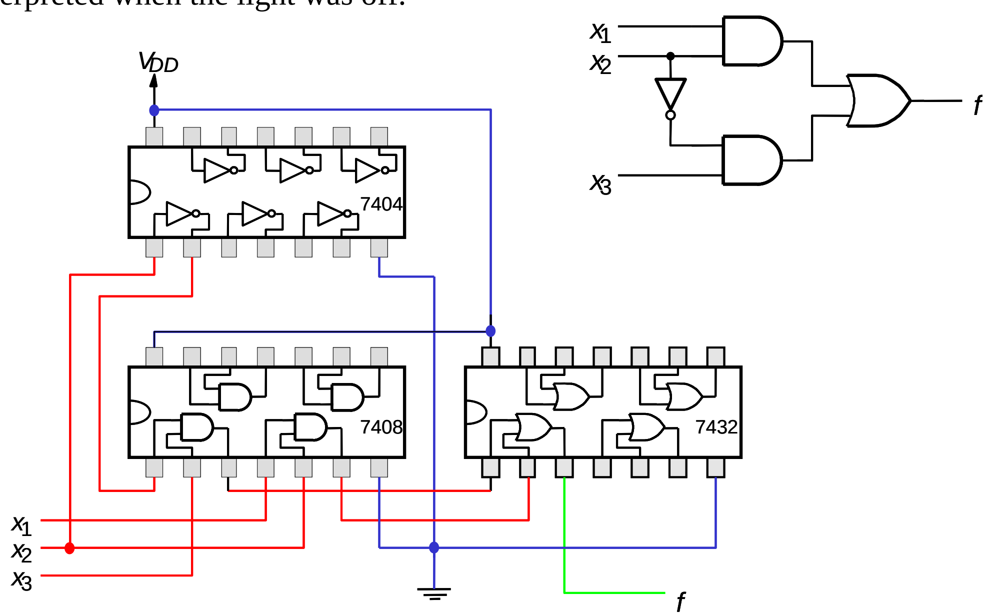

Figure 1. A Digital Logic Network implementation of function $f = x_1x_2 + \overline{x}_2x_3$[7].

- **Project-2:** the students were asked to design a circuit that could multiply a 3-bit unsigned number by a constant of three. They were specifically instructed to use Ripple-Carry Adders in the project design as well as Half-Adders to construct a Full-Adder. To show the results, it was required to connect LEDs to the output of the circuit. Additionally, an extra credit was given if a team was able to show the result of the circuit on a 7-segment display. To do that, they were instructed to design a BCD-to-7-segment display code converter as well.

The Final Semester Project: the students were asked to design a 3-bit and 4-bit up and down counter using T or D flip-flops. Several design approaches included modulo-x counters with synchronous reset. The circuit required a control input, called the Up/Down input, to arrange an up-counter by letting Up/Down=0 and a down-counter by letting Up/Down=1. To show the visible results, LEDs were connected to the output of the circuit as well as a 7-segment display with a BCD-to-7-segment display code converter.

Evaluation
The project effectiveness was measured via two project surveys; a formal course survey and a supplementary survey prepared by the instructor. The course survey was conducted at the end of the semester and included 26 questions to evaluate the student learning experience, as stated in Table I and II. The supplementary survey aimed to receive timely feedback about the laboratory execution and is given in Table III.
The laboratory activities were supported by the Quality Enhancement Plan (QEP) grant, provided by TAMUK, to improve student success and learning through civic, professional, or research engagement at the course level. The questions for the course survey in Table I were prepared by the QEP planning committee and the office of institutional planning and assessment at TAMUK.

Table I. The Final Course Survey Part I
Compared to other courses you have taken or are currently taking, indicate how this course has affected you with regard to the following attributes

Question No.	**Questions**	**Level**				
Q1	Mastery of the general education curriculum	1	2	3	4	5
Q2	Mastery of major field curriculum	1	2	3	4	5
Q3	Mastery of content of this course	1	2	3	4	5
Q4	Mastery of critical-thinking skills	1	2	3	4	5
Q5	Mastery of problem-solving skills	1	2	3	4	5
Q6	Mastery of civic awareness and ethical responsibility	1	2	3	4	5
Q7	Preparedness for continued learning after graduation	1	2	3	4	5
Q8	Preparation for employment as an engineer	1	2	3	4	5
Q9	Ability to apply knowledge in math, science, and engineering	1	2	3	4	5
Q10	Ability to analyze and design analog and digital systems	1	2	3	4	5
Q11	Ability to design a system ,component, or process	1	2	3	4	5
Q12	Ability to function in a multi-disciplinary team	1	2	3	4	5
Q13	Ability to identify, formulate, and solve engineering problems	1	2	3	4	5
Q14	Ability to communicate effectively	1	2	3	4	5
Q15	Ability to use techniques, skills, and modern engineering tools	1	2	3	4	5
Q16	Knowledge of contemporary issues	1	2	3	4	5
Q17	Understanding of professional and ethical responsibility	1	2	3	4	5
Q18	Understanding of engineering in a global and social context	1	2	3	4	5

(Based on the scale: 1: much smaller effect and 5: much greater effect).

Based on the final survey results, more than 85% of the course students agreed that taking this newly designed course had a much greater affect on the mastery of the general education curriculum (Q1 from Table I). Mastery of the major field curriculum and content of the course has been achieved as indicated by the 85% of the students (Q2 and Q3) in the survey as well. The students' average rating was 4.53 for the improvements on both critical thinking skills (Q4) and ability to apply scientific knowledge (Q9). Also, the improvement of a student system, component, or process design ability (Q11) was verified via the rating of 4.47. Furthermore, 84% of the students indicated that their ability to function in a multi-disciplinary team has improved greatly (Q12). Additionally, almost 75% of the students believe that their understanding of professional and ethical responsibility (Q17) and engineering in a global and social context (Q18) has improved after attending this class. The survey results also indicated that the students' average rating was 4.29 who believed that the course prepared them for the employment as an engineer (Q8).

Table II. The Final Course Survey Part II

No.	**Questions**	**Level**			
Q19	During this course about how often have you worked harder than you thought you could to meet the instructor's expectations?	Never	Sometimes	Often	Very Often
Q20	During this course how much has your coursework emphasized: Analyzing the basic elements of an idea, experience, or theory, such as examining the particular case or situation in depth and considering its components	Very little	Some	Quite a bit	Very much
Q21	Synthesizing and organizing ideas, information, or experiences into new, more complex interpretations and relationships	Very little	Some	Quite a bit	Very much
Q22	Making judgments about the value of Information, arguments, or methods, such as examining how others gathered and interpreted data and assessing the soundness of their conclusions	Very little	Some	Quite a bit	Very much
Q23	Applying theories or concepts to practical problems or in new situations	Very little	Some	Quite a bit	Very much
Q24	About how many hours do you spend in a typical work 7-day week preparing for all classes (studying, reading, writing, doing homework or lab work, analyzing	0 16-20	1-5 21-25	6-10 26-30	11-15 >30

	data, rehearsing, and other academic activities)? (8 choices)				
Q25	To what extent has your experience in this course contributed to your knowledge, skills, and personal development in the following areas?				
	acquiring a broad general education	Very little	Some	Quite a bit	Very much
	acquiring job or work-related knowledge and skills	Very little	Some	Quite a bit	Very much
	solving complex real-world problems	Very little	Some	Quite a bit	Very much
Q26	How would you evaluate your entire educational experience at this institution?	Poor	Fair	Good	Excellent

(Based on the scale: very little: 1 and very much: 4).

The second part of the final survey included questions about student engagement, as stated in Table II. Based on the survey results, 80% of the students have agreed that the coursework has emphasized analyzing the basic elements of an idea, experience, or theory, such as examining the particular case or situation in depth and considering its components (Q20). The students' average rating was 3.00 on the observation that the coursework emphasized synthesizing and organizing ideas, information, or experiences into new, more complex interpretations and relationships (Q21). The students also stated that they tend to apply theories or concepts to practical problems or in new situations in about 85% of the times (Q23). In addition, the students commented that their experience in this course contributed to their knowledge, skills, and personal development for acquiring a broad general education, the average was 3.27 on a scale of [0-4]. Furthermore, the students also indicated that acquiring job or work-related knowledge, and skills and solving complex real-world problems ratings as 3.14 and 3.40 on the same scale, respectively. In addition to the student survey results, the faculty member also collected additional information via feedback from the TA, the responses of the students to the questions given in exams, homework sets, and quizzes as well as personal observations to evaluate the success of the laboratory activities to improve the student learning and real-world problem solving skills.

Table III. The Supplementary Survey Questions

Q1	Were the laboratory sessions helpful in developing better understanding of the subjects and concepts introduced in the course? How?
Q2	Would you recommend continuing laboratory sessions for the class? Why?
Q3	In your opinion, how can the laboratory sessions be improved for future students?
Q4	Any other comments?

A second supplementary survey was administered by the course instructor. Based on the anonymous survey results, the students rated the projects very favorably, confirmed their educational achievements and the long-lasting benefits of the hands-on project activities. According to the responses given to the Q1 in Table III, more than 90% of the students have commented that the activities help them to better understand the concepts covered in the lectures. Based on the answers given to Q2, all students strongly agree that laboratory sessions and practical applications were very useful and that they recommend the continuation of the activities in the future semesters. Additionally, based on the feedback for Q3, 10% of the students wanted to see more projects assigned during the semester. The students also expressed their educational achievements and long-lasting effects of the modified course by stating

- "absolutely finally being able to use the knowledge being taught out of a book is very gratifying and useful in helping to teach this complicated subject".
- "Including the project was a good idea. It was very much useful and helpful to me in understanding what exactly was happening in logic design. It also helps the understanding the theory".

Additionally, the two projects given (short and final projects) deal with the concepts of combinational and sequential circuits and the average of the students' grades for the projects are 95.7 and 93.6, respectively**.** Based on the average scores of the laboratory assignments, the student learning and understanding of the concepts in the combinational and sequential circuits are high. Since this course has been taught by different faculty members in previous semesters, the exam grades and questions are not readily available to make a reliable comparison about the relative improvements achieved through the hands-on practical laboratory activities so as a future work, the faculty member plans to ensure comparative data availability.

Conclusion

The project surveys and associated project activity evaluations have demonstrated the effectiveness of the problem-driven design projects in the hands-on laboratory environment to improve the student learning experience. It has been observed that practical applications assist the student population to better understand the theoretical concepts and equip them with critical thinking and problem solving skills. As part of the future plans, a hardware description language (VHDL), and Programmable Logic Devices as means of practical point of view will be utilized and incorporated in more advanced and comprehensive design problems.

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