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Experience of Teaching Introduction to Electrical Engineering with an Online Platform

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1. Introduction

Introduction to Electrical Engineering is a required course for the Bachelor of Science degree in Electrical Engineering (BSEE) at our university. Offered to Electrical and Computer Engineering (ECE) students during their freshman year, it provides them with their first exposure to a hands-on learning environment, where they take on engineering design challenges through the implementation of electric circuits, digital logic, and robotics labs. It has been well documented in the literature [1-4] that exposing students to significant and well-rounded academic experiences in a first-year engineering course improves retention and motivation of the students. This paper describes our experience of teaching the digital logic sections of Intro to EE online during COVID-19 shutdown using an online Field Programmable Gate Arrays (FPGA) platform.

2. Background

Recently the undergraduate Computer Engineering Program – previously a joint program between the Computer Science Department and the Electrical Engineering Department, was transferred to the renamed Department of Electrical and Computer Engineering. Henceforth the syllabus of the Introduction to Electrical Engineering course will be extended for both ELEE and CMPE majors by including digital circuits and systems, using both hardware and software tools [5]. Digital design tools [6] are available to students to work online and complete homework in the form of formative assessment questions. In particular, FPGAs [7] are easy to configure to provide a wide variety of digital designs.

The COVID-19 provoked unexpected shutdown of the university after spring break in March 2020, requiring the application of online teaching tools for the reminder of the 2020 spring semester, posing immediate challenges for the authors and the course instructor [8]. Fortunately, one of the authors had already applied an online FPGA platform to other courses [9]. It enables students with real-time hardware lab experience from anywhere 24/7 without any software installation or hardware setup on the student client's side. This is different from online teaching of a Digital Design course using a combination of online lectures and a home lab kit as studied in [10].

Before the shutdown the class of 37 students had met for 8 sessions, achieving coherence and a sense of purpose. The attending rate of 92% was very good. After the shutdown, instructors had one week to design and implement online courses, and students had to overcome the challenges of style and technology, to adapt to online courses. The attending rate dropped to 63%, meaning about one of three students could not cope with the new challenges imposed by the quarantine. With recorded Zoom meetings available on Blackboard, students did have the flexibility to review the course activities online at their own schedule.

3. Implementation

Course Intro to EE met once a week on Zoom for 2:40 hours. Three sessions were designed for the study of digital logic. In the first session, an introduction to Boolean algebra, digital gates, and the online FPGA platform was covered; the second and third sessions were dedicated to implementing two cases of combinatorial logic: the half adder and the majority voting machines. Typically, the objectives of each session were a) to define the problem and construct the truth table and formulate Boolean expressions; b) to design a diagram of logic gates as in Figure 1; c) to simulate the operation of the circuit with waveforms as shown in Figure 2; d) to compile the design into the FPGA program file and fix the errors if any, d) to test the design using the hardware board online, as shown in Figure 3; and e) to construct the breadboard layout using hardware icons as seen in Figure 4 and test out the design using the FPGA hardware board as in Figure 3.

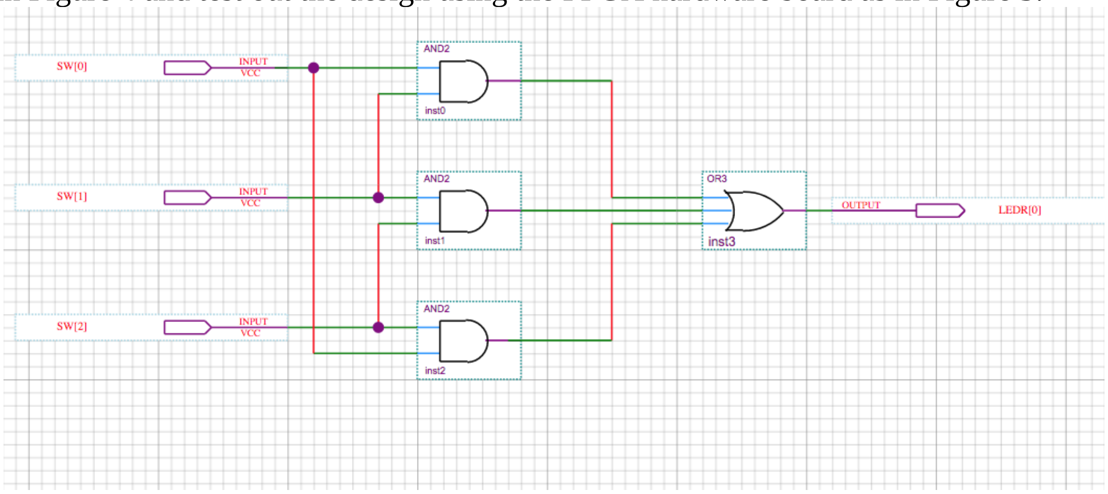


Figure 1. SoP diagram of logic gates for the 3 parties voting machine

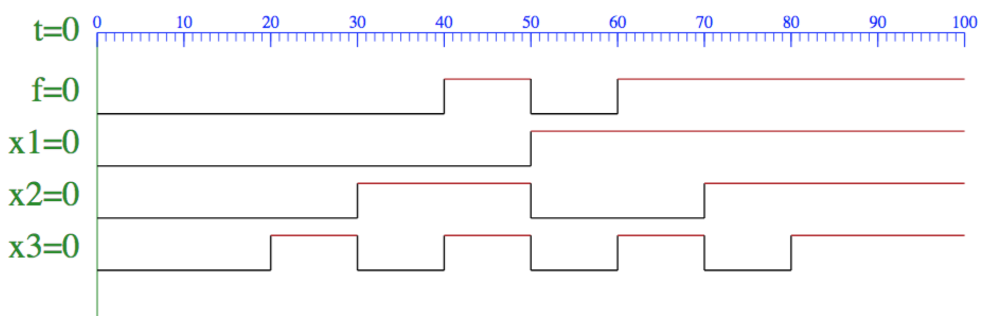
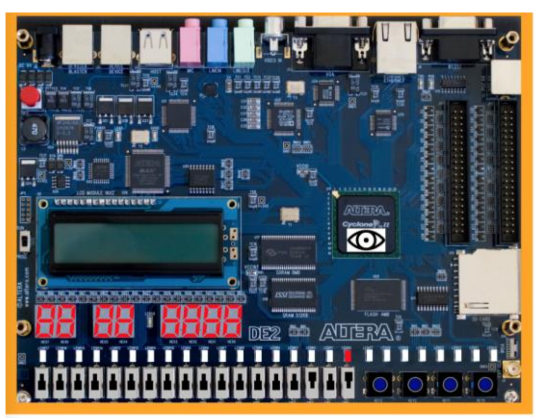


Figure 2. Simulation of the circuit with time signals



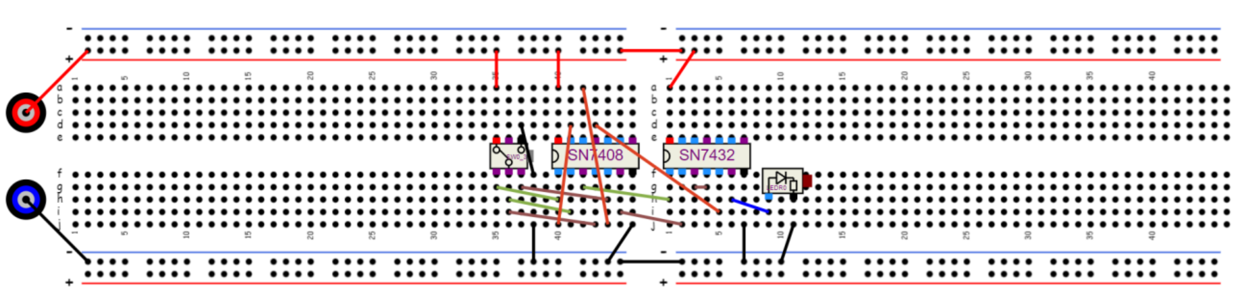


Figure 4. The breadboard layout

It is noted that only fundamental concepts and combinational design are introduced in this course. More advanced topic like Finite State Machine (FSM) and Hardware Description Language (HDL) are reserved for more advanced courses in later years.

4. Results

It is the instructor and coauthor’s opinion, formed after using the online tool with the students, that the platform provided a lot of flexibility to the course. A large collection of resources is offered by the online FPGA platform, such as the list of gates and 74xx symbols for block diagram design, and the readily available parts on the virtual breadboard. Troubleshooting is also easier on FPGA than in a physical lab.

Two student surveys were applied, at end of session 1 and session 3. The first survey was designed to assess the students’ initial experience of the course activities including instructor’s class demo and students in-class practice of logic gates on FPGA, and the homework assignment on FPGA. The second survey was designed to collect feedback regarding the students’ overall learning experience with the online FPGA platform itself.

<u>Survey 1- Student experience with their online learning activities</u>

In this survey a total of 8 statements as in Table 1 were designed to gather students’ feedback on their experience of the class activities on logic gates. Students were asked to rate each statement with strongly disagree, disagree, neutral, agree, or strongly agree.

Table 1. Survey 1 statements regarding class activities

#	Statement
Q1	The purpose of the activity was clear.
Q2	The objectives were met.
Q3	The activity will benefit me.
Q4	The contents included in the activity were related to the objectives.
Q5	The activity increased my interest in Logic Gates.
Q6	The activity increased my enthusiasm for the study of Engineering.
Q7	I can now write a truth table, after examining the status of SWITCHES and LEDs.
Q8	The activity increased my interest in setting up Logic Gates on a breadboard.

A total of 19 anonymous responses were collected. The data were plotted on a stacked bar chart in Figure 5. It is observed that there are more greenish sections than the reddish sections, meaning the students tend to agree with the statements. This confirmed that the students had overall positive view of the associated the online class activities using Zoom and the FPGA platform. It is also observed that there are rooms for improvement in areas associated with Q2, Q5, and Q7 due to the significant sections of neutral ratings. Specifically, Q7 statement on truth table received ratings of 58% agree / strongly agree, 31% neutral, 11% disagree/strongly disagree. This suggested that students may need additional practice to feel competent on the topic.

Additionally, students were asked about what they liked / disliked most about the activity as two open questions. Sample written responses are listed as follows,

- “What I liked most about this activity was the fact that you can build your own Breadboard virtually and test it out.”
- “What I enjoyed the most was that the activity was interactive and allows students to get some hands-on experience.”
- “It was interactive and not overly complicated, which makes it more understandable and interesting as I could follow along well.”
- “The website is not fully accessible but I’m sure with a little more programming it’ll be in its prime.”
- “What I did not like about this activity is the fact that it takes some time for the program to load and have your results. Sometimes the results do not show up.”
- “the program was a little slow and was a little hard to complete the assignment.”

Students found the experience was interactive and engaging and they also reported the issues of the platform not being accessible all the time and the web service being slow.

<u>Survey 2 – Student experience with FPGA platform</u>

In a second survey, students were asked to evaluate the 16 statements specifically on their experience with FPGA as in Table 2 using ratings R from 1 to 5. The ideally expected rating R and score S values are also included for each statement in the table. A simple normalization equation as follows brings the score S into the interval of [-1,1].

$$S(n) = \frac{[R(n) - 3]}{2}, \qquad n = 1,2,\cdots,16$$

Table 2. Survey 2 statements regarding FPGA platform

Q#	Statement with 5 ratings 1=strongly disagree 2=disagree 3=neutral 4=agree 5=strongly agree	Expected Rating R_e	Expected Score S_e
Q1	FPGA class demos by the instructor have been helpful for my learning.	5	1
Q2	FPGA online lab exercises have been useful.	5	1
Q3	My FPGA interface is intuitive.	5	1
Q4	I cannot relate FPGA to real life.	1	-1
Q5	FPGA interface is confusing	1	-1
Q6	FPGA provides me with the real-time hardware lab experience without going to a physical lab.	5	1
Q7	FPGA is recommended for future students of this class.	5	1
Q8	I want to use FPGA in the other related courses in the Digital areas such as Microprocessors and DSP.	5	1
Q9	I enjoy the quick results from the designed circuits using FPGA.	5	1
Q10	FPGA has no relevance to the coursework.	1	-1
Q11	Using FPGA has made me understand things better. I would not have been able to achieve that from just lectures or the textbook.	5	1
Q12	FPGA was not intellectually stimulating.	1	-1
Q13	I would recommend other professors adopt FPGA in their classes.	5	1
Q14	FPGA is slow.	1	-1
Q15	FPGA is readily available from home or any computer with internet access.	5	1
Q16	I understand that FPGA Test represents hardware behavior as I expect from an actual FPGA board and it is not based on simulation.	5	1

The anonymous survey was conducted online on the FPGA website. A total of 47 responses were received from 3 different courses, including 11 responses from Introduction to Electrical Engineering, 14 from Digital Systems Engineering I, and 22 from Digital Systems Engineering II with Verilog. We included data from all the three courses for us to not only understand the Introduction to EE students' evaluation of the FPGA platform usage but also to know how students from the different classes will evaluate the same platform differently.

Figure 6 shows the normalized mean scores by the 16 questions and 3 courses. A few interesting observations can be made. First, all except one response were on the expected sides. It means students consistently rated the platform positively. The only exception is the Q14 response from Intro to EE, meaning that a slight majority of class thought the platform was slow. Second, there were obvious differences in how closely the resulting average scores match those expected scores, i.e. the degree of the platform effectiveness. Moreover, except for one data point of Introduction to EE, Q4, Intro to EE always scores lowest and Digital II always scores best for all 16 questions. Indeed, using an overall score from -1 to 1 representative of all questions as in the equation

$$\bar{S} = \sum_{n=1}^{16} S(n) S_e(n) / 16$$

the surveys from Intro to EE, Digital I, and Digital II gave scores of 0.24, 0.50, and 0.69 respectively. One explanation is that the results reflect the growth pattern of the learning curve of FPGA platform. As students become more knowledgeable about digital logic design, they tend to rate the platform more favorably. Tutorials and more examples on the platform usage will help the first-year students' learning experience. Third, across three courses, Q4, Q5, Q14 receives scores of less than 0.50, suggesting the sense of reality, interface, and server speed are the areas of the platform needing most improvement. In particular, slow web service was also a concern identified by the survey 1 as in the previous section.

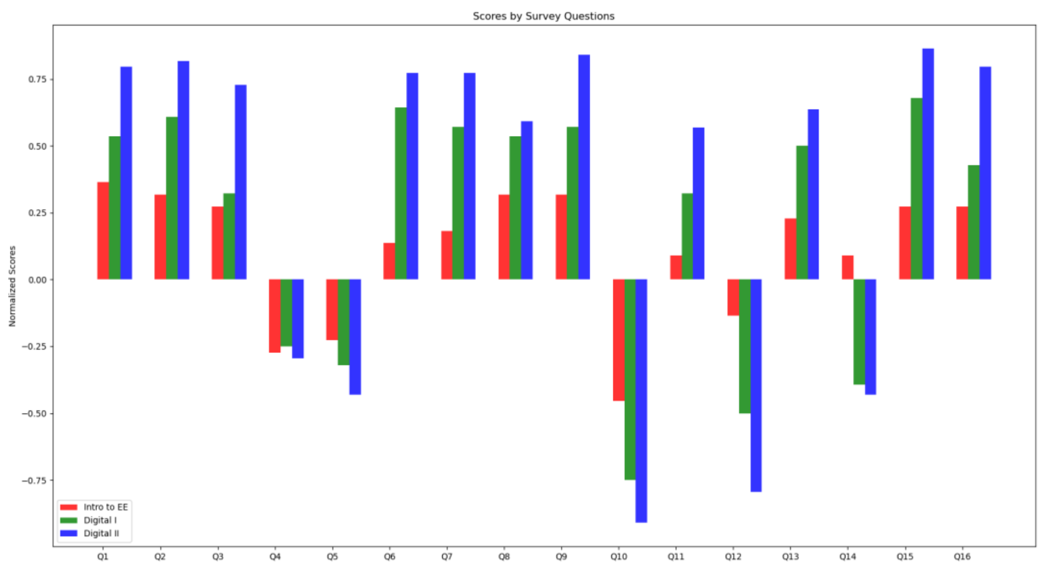


Figure 6. Scores by questions and courses.

5. Conclusions

An online FPGA platform was adopted for teaching Digital Logic for three weeks of the first year Introduction to Electrical Engineering course after all engineering courses had to move online due to COVID-19 in the 2nd half of Spring 2020. Based both the instructor's own experience and two student surveys, the platform had the advantages of providing a lot flexibility in terms of lab access and parts and materials check-out than a physical lab and maintain real-time hardware hands-on lab experience not available on a pure simulation software. We have also identified a few areas such as improvement on the user interface and web server computational speed for better student learning experience in the future.

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