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Innovations in Remote Laboratories & Simulation Software for Online and On-Site Engineering Students

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Abstract

Laboratories are an essential component in engineering classes to bring together theory and hands-on experimentation to help students learn complex concepts. This is very challenging to do, especially with on-line engineering classes. This paper describes how state-of-the art technology was used to create and improve laboratories for on-line and on-site students in the Applied Engineering and Computer Science Departments at National University. Starting in the fall of 2012, new remote laboratories for on-line electric circuits classes were designed and implemented using equipment from National Instruments: ELVIS (Educational Laboratory Virtual Instrumentation Suite). New laboratories for circuit design classes were also created using Multisim simulation software from National Instruments. Qualitative and quantitative assessment data were collected at the end of each month-long course at National University. Data from multiple electric circuits classes of on-line students show a 13-28% increase in students' satisfaction with their learning, the teacher, course content, and technology. Data from multiple digital circuit design courses show a 28-48% increase in these same areas of student satisfaction.

Key Words

Virtual laboratory, simulation, circuit design, ELVIS, Multisim, remote laboratories, electric circuits.

Introduction

Engineers learn by doing; hence, laboratories have long been an essential component to engineering classes in almost all disciplines. As the trend in higher education moves to more on-line classes, multiple modes of translating laboratories to on-line classes need to be investigated [1-6]. Simulation software is one way to engage students to learn complex engineering theories by modeling the behavior being studied. Remote laboratories go one step further than simulation software in that they attempt to enable students to do hands-on work outside the traditional classroom.

This paper will describe National University's investigation into creating, implementing, and assessing the use of remote laboratories and simulation software in applied engineering and computer engineering classes respectively. National University is unique in that our classes are offered in a one-month format, where students take one class each month. The majority of our students are working adults who are typically older than undergraduate students at other universities; the average age of students at National University is 30 years old so we are interested in evaluating how these non-traditional students respond to novel methods of on-line laboratories. This paper will describe how each course was designed, how each laboratory activity was implemented, what the student project entailed, and how the students were assessed afterwards. The same course learning objectives, assessments, final exams, and lecture materials were used each month; the only difference in the student assessment results reported later is that some months used the remote lab in applied engineering, or the simulation in computer engineering, and some months did not use the remote lab or simulation. In this way we hoped to determine whether the use of remote laboratories and simulations could improve student satisfaction, as measured from the course evaluation taken by all students at the end of the one-month class.

I. Remote Laboratory Experiments in Applied Engineering

The objectives of the new remote laboratories in applied engineering are to illustrate the basic concepts of electrical circuits, both DC and AC. In-class demonstrations of the equipment were conducted by the instructor, and out-of-class projects were developed for students to use the breadboard and circuits on the ELVIS platform[7].

A. Course Design

EGR 230, Electric Circuits and Systems, is a required course for all undergraduate engineering students at National University and was first taught to online students in 2008 in an asynchronous mode, meaning that students could access the course material at any time and any place. Materials available include PowerPoint slides, reading materials in MS Word and PDF formats, audio/video files, and a “webliography” of links to information available on the internet. Additionally, online students use email, weekly synchronized chats, asynchronous threaded discussions, group meetings, and phone calls for interaction and engagement with the professor and other students in the class. All these activities are recorded and stored in the eCollege system for repeated student use. In 2011-2012, we first attempted to incorporate the “hands-on” component into online engineering classes by conducting remote lab experiments that the instructor set up on a breadboard in the classroom. This section will describe how we used laboratory equipment first for on-line lab demonstrations and then for remote laboratory experiments where the students could run the equipment and collect real physical measurements of voltage across different circuit components such as resistors and capacitors from their own computer or mobile device.

B. Laboratory Design

ELVIS stands for Educational Laboratory Virtual Instrumentation Suite and the equipment is shown in Figure 1. According to the National Instruments website[7] “ELVIS has 12 of the most commonly used laboratory instruments including an oscilloscope (scope), digital multimeter (DMM), function generator, variable power supply, dynamic signal analyzer (DSA), bode analyzer, 2- and 3-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyzer in a single platform.” The virtual instrumentation panel is shown in Figure 2; instruments used in EGR 230 laboratory demonstrations to on-line students include the DMM, function generator, and oscilloscope. While the instrumentation panel is virtual in the sense that students change settings on the computer rather than on physical knobs on an oscilloscope or function generator, the data collected is real: measurements of voltage across resistors were made in various configurations in DC and AC circuits.

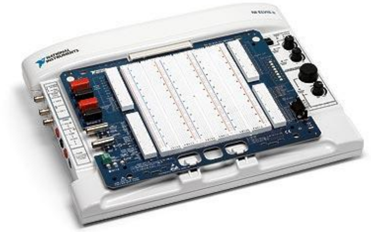


Figure 1: ELVIS equipment from National Instruments

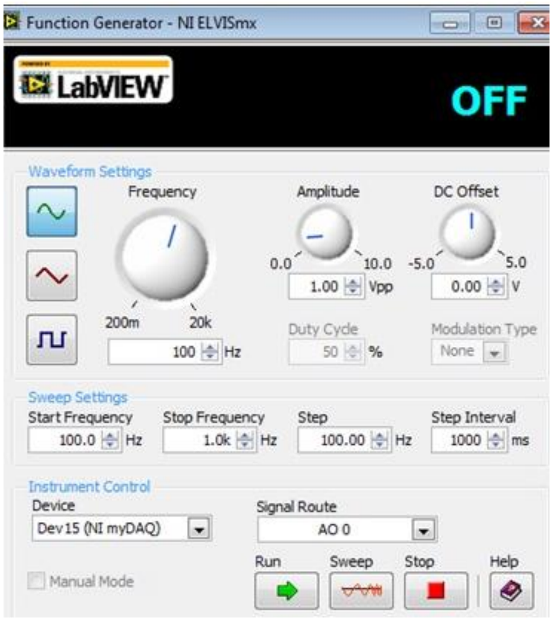
Figure 2: ELVIS virtual instrumentation panel

C. Student Lab & Project

First, the instructor conducted demonstration experiments with resistors that introduced concepts in DC circuits in order to show students how the ELVIS lab equipment worked. The demonstration was done within our eCollege on-line course platform using ELVIS and a webcam. A second on-line laboratory demonstration was led by the instructor to introduce AC circuits and how the function generator and oscilloscope worked. These two laboratory demonstrations are described in detail in another publication[8] but the highlights are summarized here.

During the scheduled synchronous session with the online students, the instructor used a webcam mounted over the ELVIS board so that the students could watch the instructor conduct the laboratory demonstrations where we compared voltage drops across resistors in different configurations: series, parallel, and combination. The lab equipment demonstrations were coupled with the theory presented in the PowerPoint lectures and the homework calculations done on similar resistor configurations. During the synchronous chat session, the instructor questioned the students to get them involved in the laboratory experiments – for example, to get them to predict the DMM voltage measurement before it was actually made.

In the second laboratory demonstration, we began by exploring how a resistor works in an AC circuit compared to the behavior of a resistor in the previous DC circuit labs. The instructor explained how the AC source (the function generator shown in Figure 3) and the AC measurement tool (the oscilloscope shown in Figure 4) worked.



Waveform Settings

Frequency: 100 Hz (200m – 20k)

Amplitude: 1.00 Vpp (0.0 – 10.0)

DC Offset: 0.00 V (-5.0 – 5.0)

Duty Cycle: 50 %

Modulation Type: None

Sweep Settings

Start Frequency: 100.0 Hz

Stop Frequency: 1.0k Hz

Step: 100.00 Hz

Step Interval: 1000 ms

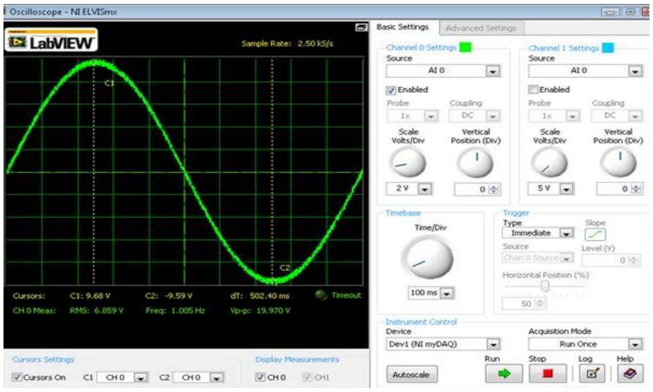
Instrument Control

Device: Dev15 (NI myDAQ)

Signal Route: AO 0

☐ Manual Mode

Figure 3: Function Generator Virtual Instrumentation



Sample Rate: 2.50 kS/s

Cursors: C1: 9.68 V C2: -9.59 V dT: 502.40 ms

CH 0 Meas: RMS: 6.859 V Freq: 1.005 Hz Vp-p: 19.970 V

Channel 0 Settings: Source AI 0; ☑ Enabled; Probe 1x; Coupling DC; Scale Volts/Div 2 V; Vertical Position (Div) 0

Channel 1 Settings: Source AI 0; ☐ Enabled; Probe 1x; Coupling DC; Scale Volts/Div 5 V; Vertical Position (Div) 0

Timebase: Time/Div 100 ms

Trigger: Type Immediate; Source Chan 0 Source; Level (V) 0; Horizontal Position (%) 50

Instrument Control: Device Dev1 (NI myDAQ); Acquisition Mode Run Once

Cursors Settings: ☑ Cursors On; C1 CH 0; C2 CH 0

Display Measurements: ☑ CH 0 ☑ CH1

Figure 4: Oscilloscope Virtual Instrumentation

Data were collected by the students during the online laboratory demonstration to explore the effect of resistors and capacitors in an AC circuit. A 5-volt peak-to-peak sine wave was used as the AC source. The DMM was used to measure the voltage across the component (resistor alone, capacitor alone, or resistor and capacitor in series) as the frequency was increased to 100, 200, 500, and 1000 Hz. The voltage change, dV, was calculated as a fraction of the original 5 volts and is shown as a percentage in Table 1. The students learned that increasing the frequency of the AC source has no effect on the voltage drop across the resistor when it is alone in an AC circuit. A capacitor in an AC circuit has very different behavior, as shown by the rapid decrease of voltage as the frequency increases. And when the resistor and capacitor (R+C) are in series in an AC circuit, the voltage decreases but levels out since the resistor will affect the maximum voltage drop in the circuit. These concepts were covered in theory by the textbook and the instructor lectures, but the on-line lab demonstration and data collection enabled students to better apply what they learned from the textbook. This experiment was done during class time when the instructor and all students were logged into the eCollege website.

Table 1: Voltage data and calculations from on-line AC circuit experiment.

	100 Hz	**200 Hz**	**500 Hz**	**1000 Hz**
Resistor	1.29 V	1.29 V	1.29 V	1.29 V
dV (%)	74.2	74.2	74.2	74.2
Capacitor	1.61 V	0.871 V	0.367 V	0.192 V
dV (%)	67.8	82.58	92.66	96.16
R + C	1.81 V	1.48 V	1.35 V	1.33 V
dV (%)	63.8	70.4	73	73.4

After these two laboratory demonstrations where the instructor was the “hands” for the student to make measurements, the students were given instructions on how to connect to the ELVIS lab equipment themselves, using a remote desktop session to access the server that the ELVIS equipment was connected to. A USB hub was connected to the server so that up to 7 ELVIS boards could be accessed by the students. The remote access was tested using a Windows XP desktop, Windows 7 desktop, Apple Mac laptop, and an iPad so that the students had a variety of options to connect directly to the lab equipment and operate it from home.

The general steps for doing remote laboratory experiments with the ELVIS equipment are listed here:

1. Login to the server via Remote Desktop connection
2. Launch NI virtual instrumentation for ELVIS boards
3. Test function generator and oscilloscope to confirm connectivity
4. Proceed with laboratory experiments

Specifically, the instructions to complete step 1 are as follows:

1. Start – Accessories – Remote Desktop Connection

2. Computer: 50.58.155.50
Username: ELVIS-HOST1\elvisrdp
You will be asked for credentials when you log in
Select: Connect

3. Select “ELVIS remote desktop user” icon
Password: CMPypob98@

These instructions work for Windows computers. Apple computers have a slightly different set of commands for starting a remote desktop connection. From an iPad, first the Remote Cloud app had to be installed in order to facilitate a remote desktop connection.

D. Student Assessment

At the end of each month-long class at National University, quantitative student assessment data are collected: 7 questions for student self-assessment of learning; 16 questions for assessment of teaching; 3 questions for assessment of course content; and 3 questions for assessment of web-based technology. Each question asks for a student response on a scale of 1-5, with 1 being lowest and 5 being highest.

Table 2 shows the quantitative survey data from the EGR 230 class taught by the same instructor online, with and without the ELVIS laboratory demonstrations. The class size was 15 students, and prior to ELVIS being used, there were no on-line laboratory experiments used in EGR 230. The ELVIS lab activities were not graded when they were used in the course. The GPA reported in the table below is the average EGR 230 grade point average of all the students in the class, and thus is a measure of student performance in the class.

Table 2: Course Assessments of EGR 230

	Class without ELVIS lab	**Class with ELVIS lab**	**% Change**
Student Learning (5.0 scale)	3.69	4.30	+17%
Teaching (5.0 scale)	3.84	4.35	+13%
Course Content (5.0 scale)	3.37	4.32	+28%
Technology (5.0 scale)	3.53	4.16	+18%
GPA (4.0 scale)	2.67	2.88	+8%

Students' satisfaction with their learning, the teaching, the course content, and course technology is 13-28% higher, and the average GPA of the class is 8% higher, when the ELVIS laboratory demonstrations were used. As stated earlier, the same course learning objectives, assessments, final exams, and lecture materials were used each month with the same instructor; the only difference in the student assessment results reported is that some months used the remote lab with ELVIS and some classes did not use the lab.

Some qualitative assessment data in the student and instructor comments are included below. The comments show that overall they saw benefit from using the online experiments, but there were drawbacks too. The biggest hurdle in implementing the remote lab was firewall and security settings on student home computers that sometimes made a remote desktop connection difficult.

One instructor commented, "I taught this class with and without support tools such as LabView and ELVIS. I noticed that students got much more engaged during classes when I used these tools. Although the use of LabView and ELVIS take away some class time to explain to students its operation, it is my belief that the benefits introduced by those tools greatly enhance the learning experience. The introduction of these tools allows students to explore the subject in a much deeper and personal way. I notice students making inquires that they would not do otherwise.”

Another instructor remarked, “"I have taught the Electrical Circuit Systems, an introductory circuit course for non-electrical engineering majors, several times both online and onsite with and without using ELVIS. I found using ELVIS was very helpful for my teaching both online and onsite classes. My students also appreciated this tool, acknowledged higher self-learning and rated my teaching very high.”

II. Simulation Software in Computer Engineering

The objectives of the new laboratories in computer engineering are to illustrate the basic concepts of digital circuit design. In-class exercises and out-of-class projects were developed and deployed using Multisim simulation software from National Instruments[9].

A. Course Design

The course covered the foundation in design and analysis of the operation of digital gates and the design and implementation of combinational and sequential logic circuits. Concepts of Boolean algebra, Karnaugh maps, flip-flops, registers, and counters along with various logic families and comparison of their behavior and characteristics were covered[10]. Also included are the circuit schematic development and computer modeling and simulation of digital systems. Experiments explore designs with combinational and sequential logic. Students work through design activities that include testing, troubleshooting and documentation. Upon successful completion of this course students are trained for and are able to:

1. Design and implement digital/computer circuits with modern design tools.
2. Determine the behavior of a digital logic circuit (analysis).
3. Translate descriptions of logical problems to efficient digital logic circuits (synthesis).
4. Integrate previously designed components into a large-scale system to meet specified requirements.
5. Manipulate and design basic combinational operators (and, or, not, etc.) and sequential circuits.
6. Manipulate and design combination of operators to form higher level functions (multiplexer, counter) and memory element (flip-flop).

B. Laboratory Design

The laboratory portion of this course covered the design, build and test of the following circuits:

1. 4-bit Binary to BCD Converter
2. 4-bit Signed Number Adder with Overflow
3. 2-bit Comparator
4. Synchronous Counters
5. Shift Registers
6. Final Project

For this research, the following final project was assigned to the students, covering design, build and test of combinational and sequential circuits using Multisim:

> *Design and build the logic for the strikes-and-balls display of a baseball scoreboard. The scoreboard will have two lights (LEDs) for strikes and three lights for balls. The scoreboard operator will have two pushbuttons: one for strikes and the other for balls. Each press of the strike pushbutton turns on one more of the strike lights unless two are already on. If two are on, all lights, including strikes and balls, are cleared [Note that the count sequence for the strike lights is a binary 00-01-11-00]. The balls pushbutton works in a similar manner. Each press causes one more light to come on unless three are already on. If three lights are already on, then all lights, including strikes, are cleared.*

C. Student Lab & Project

Students analyzed and presented their project scope showing a baseball scoring scheme including the strikes and balls. Some implemented the *out* and the *inning* counts too, although those were not required. Once the requirements were complete and approved, this was designed as shown in Figure 5.

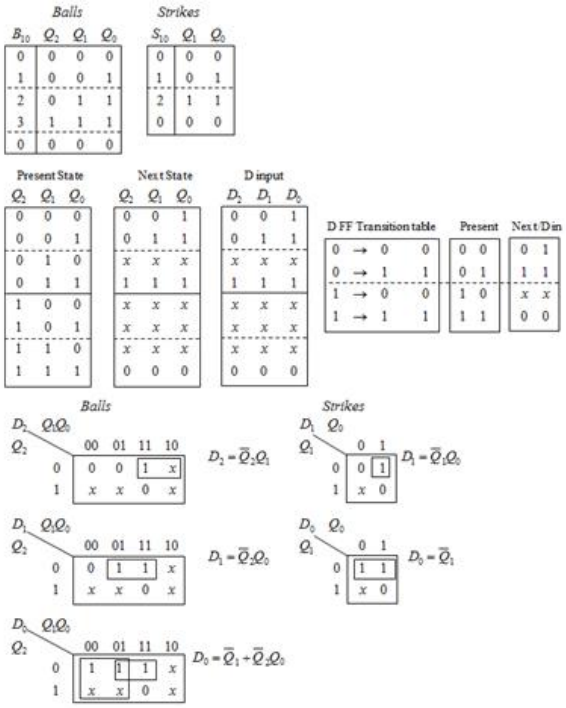
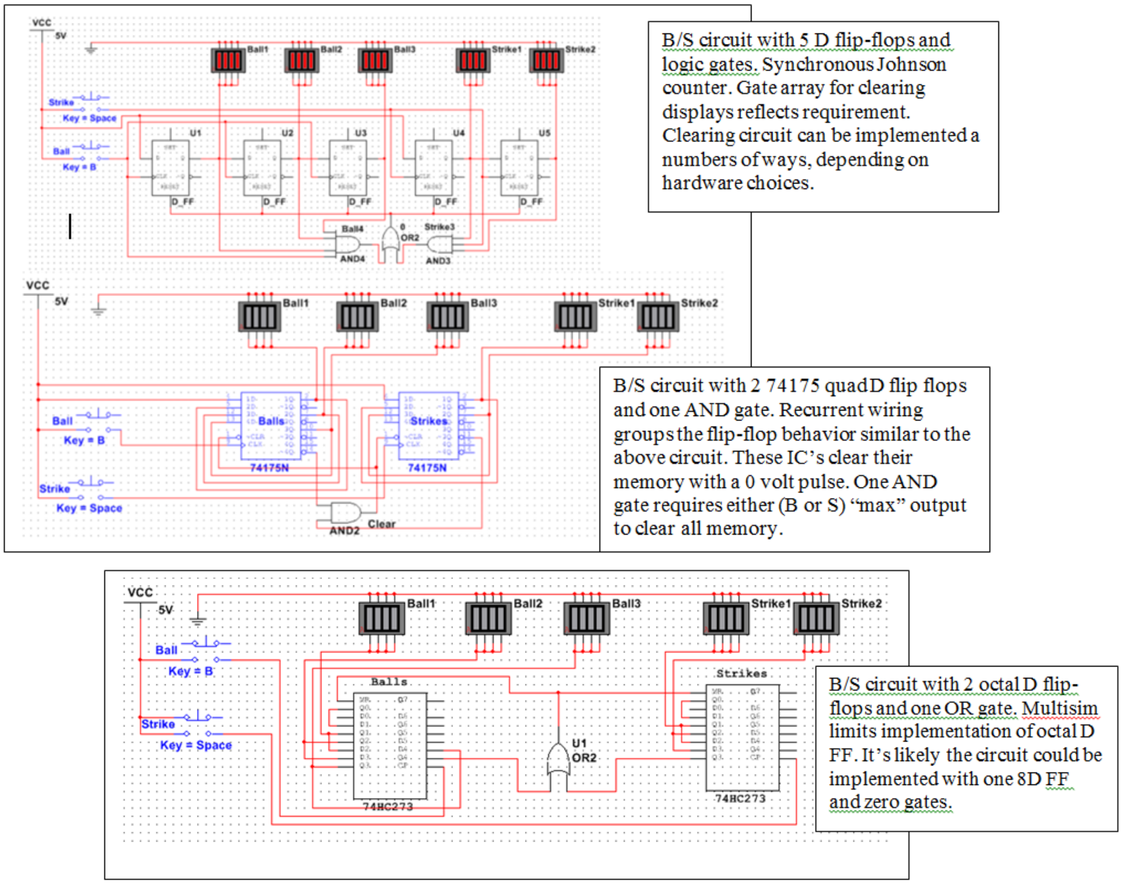


Figure 5: Project Design

In order to determine the specific design requirements, a number of tables were prepared to describe the logic. This illustrates the binary output or LED light display for balls and strikes. The decimal counts are in the left columns. Note that the count will only reach full and then it cycle to zero. In baseball, the *count* is ternary for strikes and quaternary for balls with the most significant digit becoming *out* or *walk*, respectively. The state tables and a transition table for D flip-flops are shown in Figure 5. The 74175IC, used in this design, is a quad D flip-flop.

Once the design was complete and approved, this was implemented with Multisim. Figure 6 shows the schematics of three different circuits that were designed to solve the balls and strikes display project. A number of solutions created more hardware options to guarantee a positive outcome. Balls and Strikes were displayed at the top with LEDs.



B/S circuit with 5 D flip-flops and logic gates. Synchronous Johnson counter. Gate array for clearing displays reflects requirement. Clearing circuit can be implemented a numbers of ways, depending on hardware choices.

B/S circuit with 2 74175 quadD flip flops and one AND gate. Recurrent wiring groups the flip-flop behavior similar to the above circuit. These IC's clear their memory with a 0 volt pulse. One AND gate requires either (B or S) "max" output to clear all memory.

B/S circuit with 2 octal D flip-flops and one OR gate. Multisim limits implementation of octal D FF. It's likely the circuit could be implemented with one 8D FF and zero gates.

Figure 6: Project Implementations

Figure 7 shows an alternate design implemented by some groups where the balls and strikes were kept track of by a circuit called AD313 (Alternate Design 313) and this was used by the top circuit to display the number of balls and strikes.

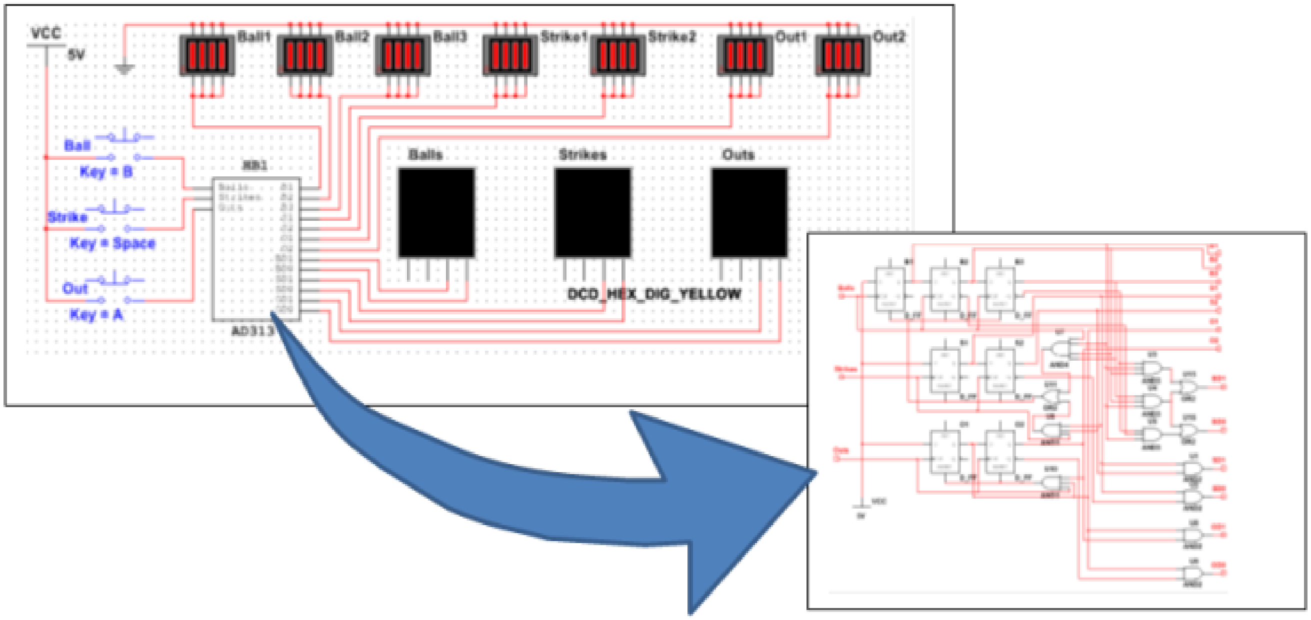


Figure 7: Alternate Implementation

With more hardware and logic, a digital ball and strike counter may be designed and implemented for use in all levels of the game. One possible circuit is shown below. It incorporates numerical LED readouts or indicator lights and a new IC chip. This circuit could also be used for the scoreboard.

D. Student Assessment

Three classes without Multisim labs (Class1, Class2, Class3) and four classes that used the Multisim hands-on projects (Class4, Class5, Class6, Class7) were analyzed. Assessment results are summarized in Table 3. The class sizes ranged from 10-20 students, and prior to Multisim being used, there were no laboratory experiments used in CSC 340L. The GPA reported in the table below is the average grade point average of all the students in the class, and thus is a measure of student performance in the class.

Table 3: Assessment of Classes Using Multisim Projects

	Class without Multisim lab				Class with Multisim lab				
	Class1	Class2	Class3	**Avg**	Class4	Class5	Class6	Class7	**Avg**
Student Learning (5.0 scale)	2.60	3.45	4.07	3.37	4.49	4.02	4.49	4.44	4.36
Teaching (5.0 scale)	2.37	4.45	4.05	3.62	4.65	4.50	4.72	4.73	4.65
Course Content (5.0 scale)	2.14	3.00	2.89	2.68	4.20	3.99	3.82	3.85	3.97
GPA (4.0 scale)	2.71	2.00	3.00	2.57	2.80	3.74	2.63	2.93	3.03

Student self-assessment of learning improved from an average of 3.37 to 4.36, a 29% increase; assessment of teaching improved by 28%, from 3.62 to 4.65; and assessment of course content improved by 48%, from 2.68 to 3.97. The final parameter analyzed was the mean GPA; this increased from 2.57 to 3.03, an 18% improvement. Overall, these were significant improvements over the classes that did not use these hands-on Multisim projects.

Instructors also reflected on their use of Multisim in these classes, "I have taught Digital Logic Design courses without labs, with labs using hardware (breadboard, ICs, resistors, etc.), and with labs using Multisim simulator. I find Multisim to be extremely useful and it has helped me in teaching complex topics with quick hands-on examples. This has enabled me to cover conceptual topics in more depth and, usually, more topics quickly. Student response has been very positive and their assessment of learning has improved significantly. Labs using hardware are equally good, maybe even better, but that takes more time for the students to implement and debug. I think Multisim is the best choice."

Conclusions and Future Work

Assessment data from electric circuits classes of on-line, non-traditional, applied engineering students show a 10-30% increase in students' satisfaction with their learning, the teacher, course content, and technology when remote laboratory experiments using ELVIS equipment was used. Assessment data from digital circuit design classes in computer engineering using Multisim show a 28-48% increase in these areas. Further horizontal integration of these remote laboratories in other Applied Engineering classes is planned, with additional vertical integration within the engineering program to electronics classes and embedded systems classes. Further work is also planned in Computer Science to expand and extend these laboratories to on-line classes.

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