Innovative Engineering Outreach: Capacitive Touch Sensor Workshop

Mr. Bradley Lance Pirtle, University of Oklahoma

Bradley Pirtle is a student at the University of Oklahoma where he is pursuing a Bachelor's degree in Computer Engineering and a Master's degree in Computer Science. Bradley's research focuses on using machine learning to generate more effective control systems for multi-agent robotic systems. While not conducting research, Bradley spends his time promoting interest in science and engineering amongst prospective middle school and high school students.

Dr. Chad Eric Davis, University of Oklahoma

Chad E. Davis received the B.S. degree in mechanical engineering, M.S. degree in electrical engineering, and Ph.D. degree in engineering from the University of Oklahoma (OU), Norman, in 1994, 2000, and 2007, respectively. Since 2008, he has been a member of the Electrical and Computer Engineering (ECE) faculty, University of Oklahoma. Prior to joining the OU-ECE faculty, he worked in industry at Uponor (Tulsa, OK), McElroy Manufacturing (Tulsa, OK), Lucent (Oklahoma City, OK), Celestica (Oklahoma City, OK), and Boeing (Midwest City, OK). His work experience ranges from electromechanical system design to automation of manufacturing and test processes. His research at OU involves GPS ground-based augmentation systems utilizing feedback control. Dr. Davis holds a dual discipline (electrical and mechanical) professional engineering license in the state of Oklahoma. He currently serves as the faculty advisor for Robotics Club, the Loyal Knights of Old Trusty, and Sooner Competitive Robotics at OU and he serves as the recruitment and outreach coordinator for OU-ECE. He received the Provost's Outstanding Academic Advising Award in 2010 and the Brandon H. Griffin Teaching Award in 2012.

Prof. Jessica E Ruyle, University of Oklahoma

An Oklahoma native, Dr. Jessica Ruyle graduated Magna Cum Laude with a B.S. in Electrical Engineering from Texas A&M University in 2006. While at Texas A&M University she completed three internships with Sandia National Laboratories and was President of HKN. She moved to the University of Illinois at Urbana-Champaign for graduate school. She completed an M.S. degree in Electrical Engineering in 2008 and a Ph.D in 2011. Her graduate research has resulted in two patent filings. The first patent, the culmination of her masters research, was for a pattern reconfigurable microstrip antenna. The second patent resulted from her doctoral research and was for a placement insensitive RFID antenna. Her technical research interests lie in the development and characterization of new electromagnetic devices and platforms such as antennas and packaging to improve the performance of wireless systems in challenging environments. She is also interested in broadening participation in electrical and computer engineering (ECE) by determining better ways to recruit young women to the profession and retaining women in ECE programs.

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Abstract:

The United States is rapidly falling behind internationally in Science, Technology, Engineering, and Mathematics (STEM) recruiting with currently, only 16 percent of American high school seniors interested in a career in STEM. A summer camp for high school students, designed to increase interest in STEM, was hosted at the University Oklahoma during the summer of 2013. Amongst the many engineering-focused projects available for the students to complete was the Capacitive Touch Sensor Workshop, which was created by the ECE department. During this project, students constructed a functional touch keypad using only an Arduino and household supplies, such as cardboard, aluminum foil, and tape. At the conclusion of the project, students were able to take their completed keypads home along with a flash drive that included all of the software and information they would need to improve or modify their device. This workshop not only allowed students to create an exciting, useful, and functional tool from scratch, but also provided a mechanism for exploring new ways to program the device and learn more about important ECE topics such as capacitance and electricity. This paper will provide the necessary details for this hands-on activity to be replicated so that others can use it to motivate students to choose ECE as their field of study.

I. Background:

The labor of scientists and engineers has benefited the world immeasurably, with a recent study by the United States Department of Labor estimating STEM-related fields contribute more than 50% of the United States' sustained economic expansion. Despite this, the lack of American scientists and engineers is a growing concern in the United States. In 2012 the Department of Labor showed STEM fields account for only 5% of the U.S. workforce.[1]

As of 2012, more than 13 million Americans remained unemployed. However, a study by the Manufacturing Institute showed the manufacturing sector had nearly 600,000 unfilled jobs, largely due to a lack of skilled labor. William Swanson, the chairman and CEO of Raytheon, explained this quandary concisely at the Massachusetts' STEM Summit, saying, "Too many students and adults are training for jobs in which labor surpluses exist and demand is low, while high-demand jobs, particularly those in STEM fields, go unfilled."[2]

Clearly, bolstering the number of students enrolling in STEM fields is a national imperative. Unfortunately, the numbers seem to be trending in the opposite direction. The number of engineering related bachelor's degrees awarded in India, Japan, China, and South Korea has quadrupled since 1975. Conversely, in the United States between 1994 and 2001, the number of bachelor's degrees awarded in STEM has increased by a meager 25 percent, while the number of degrees awarded to U.S. citizens in U.S. universities has decreased by 10 percent.[3] These trends seem to indicate an increase in the number of scientists and engineers worldwide, while the number of scientists and engineers in the United States is languishing.

One important vector for improvement is to include more women and underrepresented minorities in the STEM education pipeline. Women constitute 46% of the American labor force, yet only 9% of today's practicing engineers are women. Similarly, 43% of the students in the United States are of African American, Latino, or Native American descent. Yet of the engineering-related bachelor's degrees awarded in the United States, less than 15% are awarded to underrepresented minorities.[1] By creating an engineering program that more closely resembles America's demographics, the alarming gap between genders and ethnicities will begin to close - which will simultaneously increase the number of STEM laborers.

II. ECE Outreach:

Increasing the overall number of STEM graduates is not only a national concern, but on a smaller scale it is of vital importance for individual college departments who need to maintain a sufficient level of students. Between the years of 2004 and 2008, the number of undergraduate students enrolled in the University of Oklahoma's School of Electrical and Computer Engineering (OU-ECE) dropped from 387 to 246. This alarming trend led to the creation of a corrective action plan to increase OU-ECE undergraduate enrollment numbers. In 2013, OU-ECE undergraduate enrollment numbers rose to 428, as shown in Figure 1. This 74% increase in a five year period was achieved due to several factors that were planned, which are described in previous work.[4, 5, 6] Outreach to students in grades 6 to 11 was an emphasized effort. Even though enrollment increases would not be seen quickly with this long-term focused outreach effort, research suggested that this was the optimal time to influence students to select a major.[7] Since OU-ECE numbers were at such a low level in 2008 and they needed to be increased immediately, considerable effort was also spent in recruiting events aimed at seniors in high school and college freshman. Figure 1 shows that during the first two years OU-ECE had modest enrollment increases likely due to the effectiveness of the short-term recruiting practices aimed at seniors in high school and college freshman, but as the students OU-ECE reached with the long-term outreach activities enrolled in college, the numbers began to increase more rapidly.

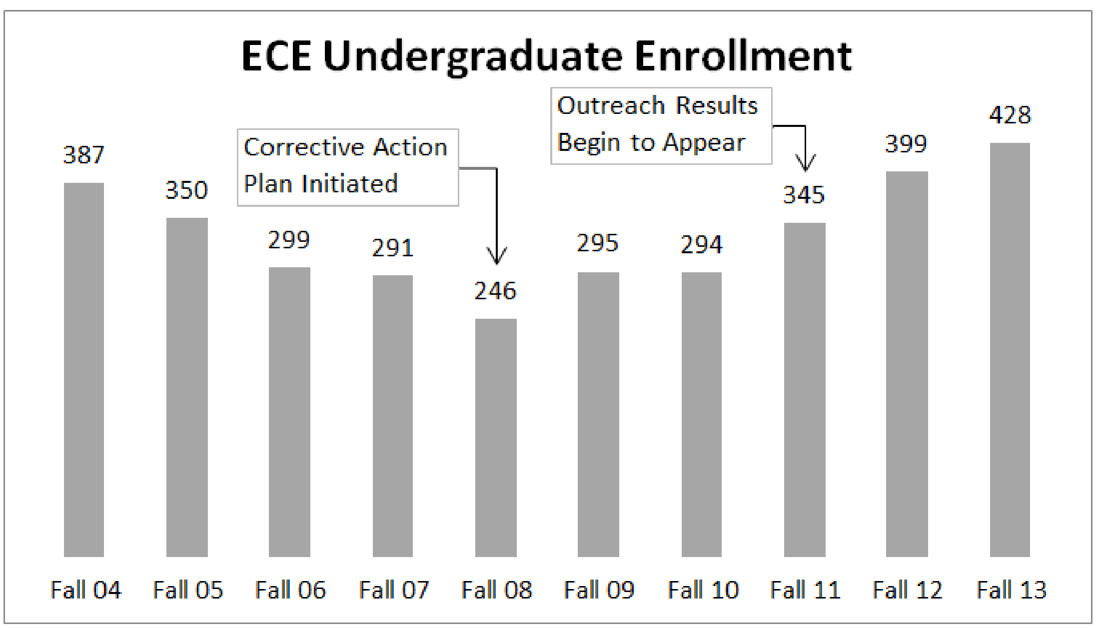

Figure 1. ECE Undergraduate Enrollment Data at OU-ECE

The goal of the correction action plan activities is to present advanced engineering technologies, innovative demonstrations, and hands-on activities at a level that the individual student can understand and appreciate. The long-term outreach portion of the program was put in action primarily through summer science and engineering camps. Many of these camps placed a large emphasis on recruiting students from traditionally underrepresented backgrounds into STEM. These camps give OU-ECE a chance to show youth who are not aware of what electrical and computer engineers do how exciting the field of ECE is and steer them toward considering it as a major. The difficulty in this form of outreach is that creating ECE-focused hands-on activities that students can understand and appreciate takes a lot of time and creativity. One OU-ECE activity that received overwhelmingly positive feedback was the Capacitive Touch Sensor workshop. Since this workshop applies directly to the smartphone, which is one of the most easily relatable engineering achievements, students are highly motivated and attentive. This workshop is described in detail in this paper so that others can implement it and together many more students can be reached with this creative and innovative activity.

III. Project Details:

The Capacitive Touch Sensor workshop was offered during the 2013 summer science camps hosted by the University of Oklahoma. The objective of the workshop was to create a fully functional touch keypad using only an Arduino and household supplies, such as cardboard, aluminum foil, and tape. By limiting the project to basic electronics, the students were gently introduced to difficult engineering concepts without being overwhelmed. Additionally, by using household supplies, the incredible versatility of engineering was demonstrated, exciting the students' imaginations. To facilitate the recreation of this workshop at other universities, all code is provided as an Appendix to this paper.

The complex functionality of the keypad can be accomplished with surprisingly simple circuitry. A small piece of aluminum foil is attached to a 1 MΩ resistor, which is in turn attached to the output pin of an Arduino (IO pin 2 in this example). The 1 MΩ resistor and the sheet of aluminum foil act as a simple RC-circuit, which is repeatedly charged at a constant frequency by the output pin of the Arduino. The voltage level of the capacitor (sheet of aluminum foil) can then be continuously measured on the analog input pins (pins 4, 6, and 8 in this example).

When the user touches the sheet of aluminum, the capacitor rapidly discharges. By testing for this rapid discharge, as opposed to the relatively slow discharge of the untouched RC-circuit, one can programmatically detect the user's touch. This technique can be scaled to support any number of "buttons," being limited only by the number of analog-inputs present on the microcontroller.

Because of the students' unfamiliarity with traditional schematics, a Fritz schematic was used to illustrate to the students which components to use and the connections to make between them (Fig 2). Critically, this circuit is simple enough to be constructed by students with little or no prior electronics experience during the camp.

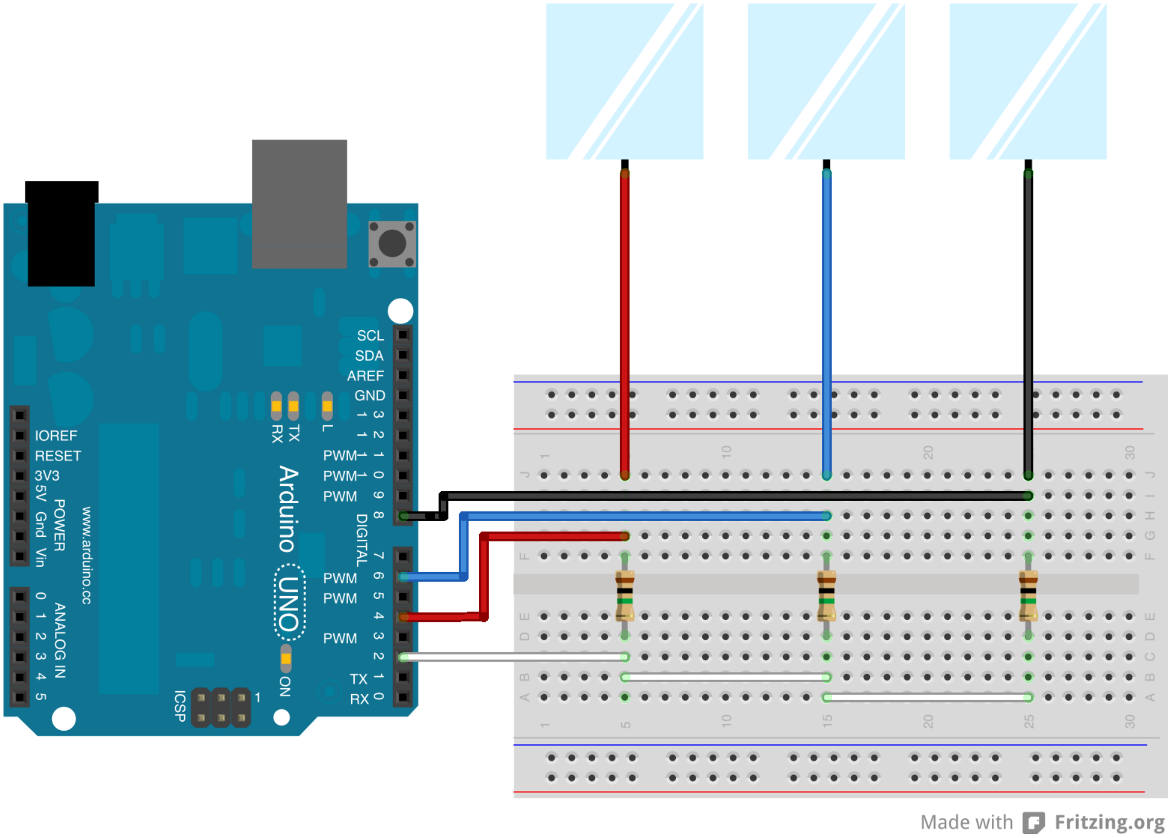

Figure 2. Arduino Schematic

After populating their breadboards, the students uploaded the provided code to their Arduinos. The students then placed the Arduino and breadboard inside of a cardboard box enclosure, securing the sheets of aluminum foil to the top of the cardboard enclosure with tape. Figure 3 shows the original prototype with the breadboard and Arduino outside of the cardboard box enclosure. The students were also given the opportunity to personalize their enclosure by using colored electrical tape and colored markers.

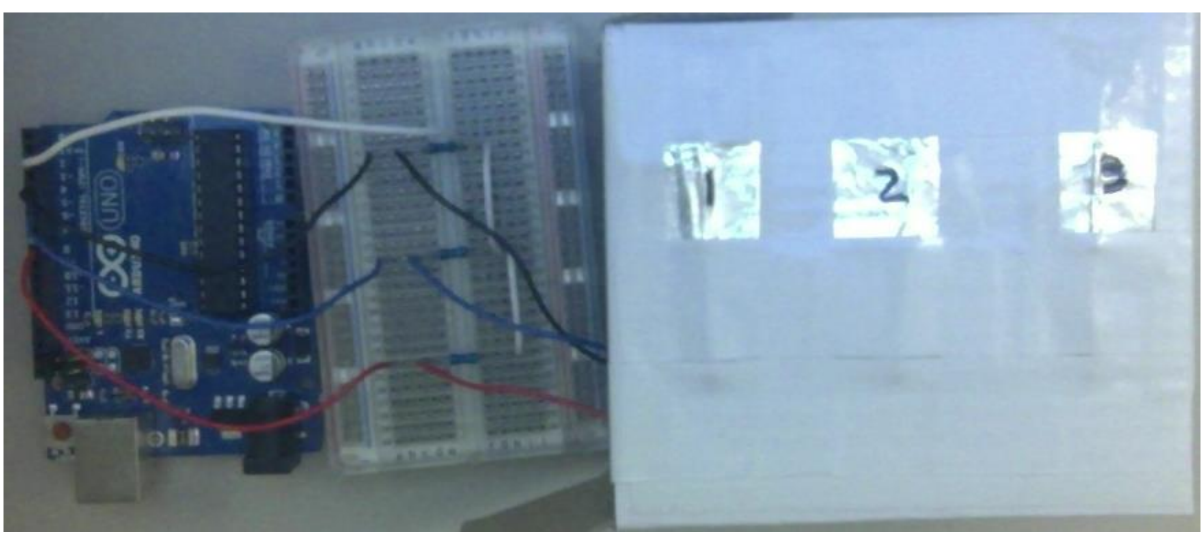

Figure 3. Cardboard Enclosure for Keyboard

IV. Processing:

"Processing" is an open-source programming language, which originated from the MIT Media Lab. Much like the Arduino, Processing was created with the intent of introducing programming to a much broader, less technical audience. Because of Processing's easy-to-use tools for programmatically creating GUIs, it was used to create several interactive demos for the students. Processing is frequently used in other OU-ECE outreach activities because it is "natively capable of generating robust, visually appealing displays using intuitive commands, and has a clean, simple user interface that lends itself to being incorporated in to the demonstrations."[8] For the capacitive touch project these demos allowed the students to visualize their interactions with their keypads on a computer screen, which added a sense of legitimacy to the project. Rather than creating a simple keypad only capable of lighting up a few LEDs, the students instead created a keypad capable of interfacing with a powerful, internet-connected computer. This addition greatly excited the imaginations of the students.

The first Processing demo created for the students displayed three colorful squares, which corresponded to the three aluminum foil buttons the students had just created. When the students touched one of the buttons on their keypads, the Arduino detected the press and transmitted this information via a serial connection to the Processing script, which illuminated the appropriate button onscreen (Fig 4).

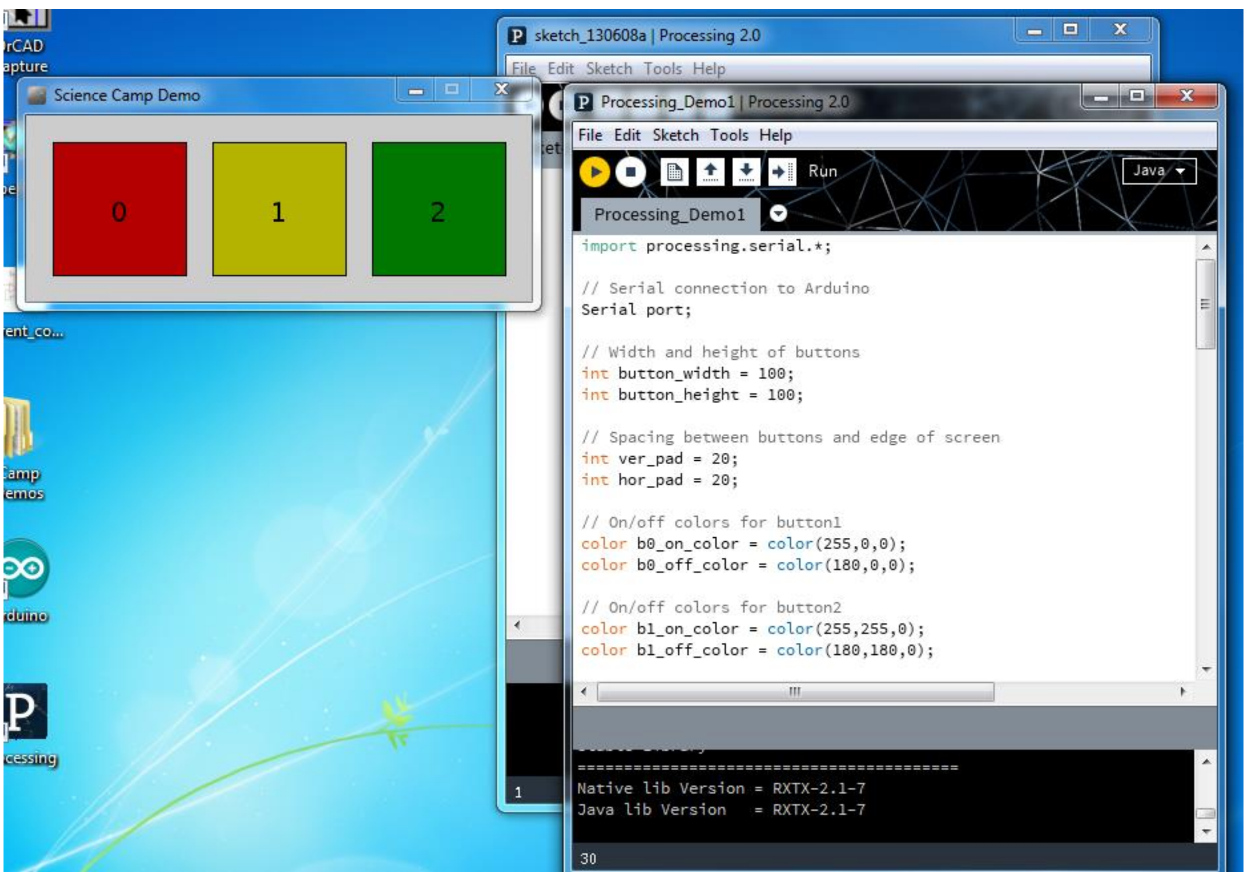

Figure 4. Processing Demo #1

After the students were satisfied their keypads were working properly, a second Processing demo was executed. This demo utilized the student's keypads as a security pad. The students were challenged to guess a secret password. When the password was entered incorrectly, a large red button was illuminated on the computer screen. When the students entered the password correctly, however, a green button was illuminated and the students were congratulated (Fig 5)

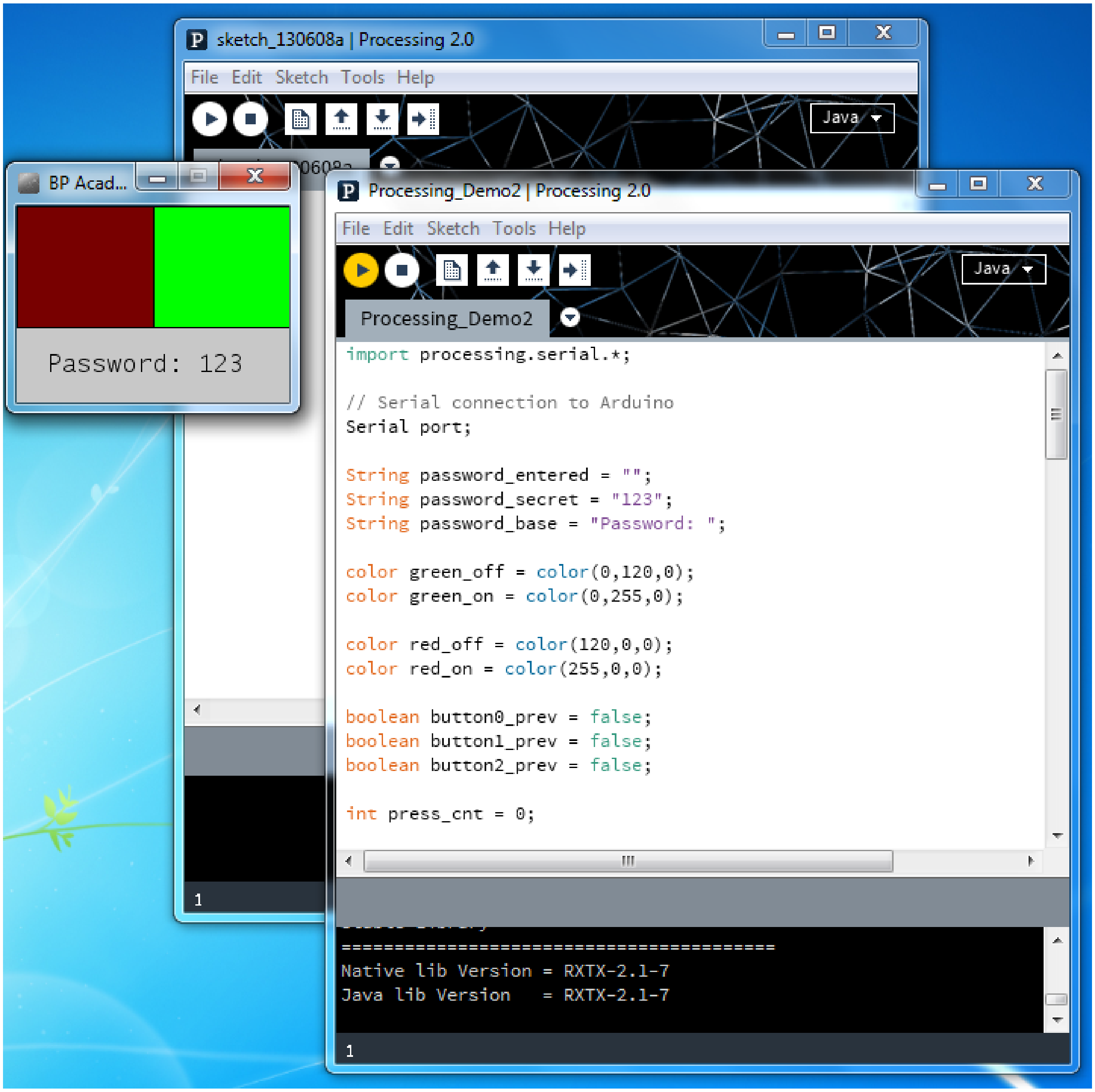

Figure 5. Processing Demo #2

At the conclusion of the project, each student had built a fully-functional keypad capable of interfacing with a computer. The students were encouraged to continue experimenting and learning by allowing them to take their keypads home (except for the Arduino). The students were also given an ECE branded thumb-drive, which contained a copy of the instructions for building their keypads, OU-ECE contact information, a link for purchasing their own Arduinos, and a list of electronics books and references.

V. Conclusion:

More than ever before, the United States needs engineers. However, the short-term strategy of recruiting high school seniors and freshman is not sufficient. A much longer-term plan needs to be implemented that reaches students at younger ages through innovative hands-on activities, such as the one described in this paper. If more educators spent the time and effort to create activities in their engineering area and share their work with others it will assist in motivating more students to select engineering as a major. OU-ECE has seen incredible results by focusing on these activities. Every summer many kids come to camps at OU-ECE and have no idea what ECE is all about and leave the outreach activities saying “that is what I am going to do when I get to college”. OU-ECE plans to use the Capacitive Touch Workshop again in future outreach events in order to better assess its effectiveness.

VI. References:

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[2] Engler, John. "STEM Education Is the Key to the U.S.'s Economic Future." *US News*. U.S.News & World Report, 15 June 2012. Web. 03 Jan. 2014.

[3] Zimmer, Marc. "Are American Scientists an Endangered Species? | Inside Higher Ed."*Are American Scientists an Endangered Species? | Inside Higher Ed*. Inside Higher Ed, 2 July 2007. Web. 03 Jan. 2014.

[4] C. Davis, M. Yeary, and J. Sluss, “*Results and best practices of a two year study on recruiting programs to boost ECE undergraduate enrollment*”, ASEE Annual Conference and Exposition, paper AC 2011-1539, pp. 1-17. June 2011.

[5] C. Davis, D. Vreeland, C. Griffin, and M. Yeary, "Creating a Culture of Student-Driven ECE Recruiting and Retention." ASEE Annual Conference and Exposition, paper AC 2013-7885, paper AC 2012-5156, June 2012.

[6] C. Davis and J. Sluss, “Lessons Learned from an ECE Recruiting and Retention Program that Increased Undergraduate Enrollment Over 60% in Four Years”, ASEE Annual Conference and Exposition, paper AC 2013-7881, June 2013.

[7] S. Berryman, “Who will do science? Minority and female attainment of science and mathematics degrees: Trends and causes”. The Rockefeller Foundation. pp. 65-76, November, 1983.

[8] Blair, T.B.; Davis, C.E., "Innovate engineering outreach: A special application of the Xbox 360 Kinect sensor," *Frontiers in Education Conference, 2013 IEEE* , vol., no., pp.1279,1283, 23-26 Oct. 2013 doi: 10.1109/FIE.2013.6685036

VII. Appendix:

Arduino Code – Main Program

```
#include <CapacitiveSensor.h>

// Create CapacitiveSensor objects for collecting discharge time of buttons
CapacitiveSensor cs_2_4 = CapacitiveSensor(2,4);
CapacitiveSensor cs_2_6 = CapacitiveSensor(2,6);
CapacitiveSensor cs_2_8 = CapacitiveSensor(2,8);

// If the button discharges more rapidly than the threshold time, then it is considered "pressed"
long discharge_time_threshold = 10000;

void setup()
{
  // Setup serial connection for transmitting button data
   Serial.begin(9600);
}

void loop()
{
    // Determine the amount of time taken by each button to discharge
    long discharge_time_B1 =  cs_2_4.capacitiveSensor(30);
    long discharge_time_B2 =  cs_2_6.capacitiveSensor(30);
    long discharge_time_B3 =  cs_2_8.capacitiveSensor(30);

    // If the discharge time is less than the threshold, then the button has been pressed
    int button1 = discharge_time_B1 > discharge_time_threshold ? 1 : 0;
    int button2 = discharge_time_B2 >  discharge_time_threshold ? 1 : 0;
    int button3 = discharge_time_B3 > discharge_time_threshold ? 1 : 0;

    // Concatenate the state of all three buttons into a single value for serial transfer
    unsigned int state = (button3 << 2) | (button2 << 1) | button1;

    // Transmit state of buttons over serial port
    Serial.write(state);

    // Small delay to allow for data to be transferred completely over serial port
    delay(100);
}
```

Arduino Code – Processing Demo #1

```
import processing.serial.*;

// Serial connection to Arduino
Serial port;

// Width and height of buttons
int button_width = 100;
int button_height = 100;

// Horizontal and vertical spacing between each button and the edge of window
int ver_pad = 20;
int hor_pad = 20;

// On/off colors for button1
color b0_on_color = color(255,0,0);
color b0_off_color = color(180,0,0);

// On/off colors for button2
color b1_on_color = color(255,255,0);
color b1_off_color = color(180,180,0);

// On/off colors for button3
color b2_on_color = color(0,255,0);
color b2_off_color = color(0,120,0);

void setup() {
   // Setup serial connection to Arduino to obtain button status
   String arduinoPort = "/dev/tty.usbmodem1411";
   port = new Serial(this, arduinoPort, 9600); // connect to Arduino

   // Setup window on screen
   size(380, 140);
   frame.setTitle("BP Academy Demo");

   // Set properties for drawing text
   textAlign(CENTER, CENTER);
   textSize(20);

   // Set properties for drawing rects
   rectMode(CENTER);
}

void draw() {
   // check if there is data waiting
```

```
    if (port.available() > 0) {
        // Read button's state from Arduino
        int state = port.read();

        // Extract button-values for each button
        boolean button0_on = ((state & 1) >> 0) == 1;
        boolean button1_on = ((state & 2) >> 1) == 1;
        boolean button2_on = ((state & 4) >> 2) == 1;

        // Draw button 0 to screen
        color button0_color = button0_on ? b0_on_color : b0_off_color;
        drawButton(0, button0_color);

        // Draw button 1 to screen
        color button1_color = button1_on ? b1_on_color : b1_off_color;
        drawButton(1, button1_color);

        // Draw button 2 to screen
        color button2_color = button2_on ? b2_on_color : b2_off_color;
        drawButton(2, button2_color);
    }
}

/** Draw this button to the screen **/
void drawButton(int button_num, color button_color) {
    // Calculate the center-point of this button
    int hor_pos = hor_pad + (hor_pad + button_width) * button_num + button_width/2;
    int ver_pos = ver_pad + button_height/2;

    // Draw rect for button
    fill(button_color);
    rect(hor_pos, ver_pos, button_width, button_height);

    // Convert button's number to string
    String button_str = String.valueOf(button_num);

    // Draw string label for button
    fill(0);
    text(button_str, hor_pos, ver_pos);
}
```