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The 'Invisible Handshake' Project as a Practical, Hands-on Experience in a Biomedical Electronics Class

Dr. Richard Goldberg, University of North Carolina, Chapel Hill

Richard Goldberg is a research associate professor and Director of Undergraduate Studies in the Joint Department of Biomedical Engineering at University of North Carolina at Chapel Hill and North Carolina State University. He teaches several instrumentation courses and a senior design class. His primary interest is in rehabilitation engineering and assistive technology for people with disabilities.

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Abstract

Most Biomedical Engineering (BME) programs include a class in introductory electronics. This can be an intimidating class for someone whose skills and interests shy away from the electrical engineering side of BME. To address this concern, our biomedical electronics class culminates in a practical, hands-on experience, called the Invisible Handshake project. While the use of Project Based Learning (PBL) is well established, there are unique challenges to incorporating a comprehensive PBL experience that encompasses many different topics in electrical engineering, such as analog and digital electronics and data acquisition. This project incorporates all of the course material into a single design experience and helps students gain confidence in their design and troubleshooting skills. In this project, the students design and build a system that has applications in biomechanics or other BME areas. The objectives of this project are to help students achieve the goals of the class by incorporating all of the course material into a single design experience; to be relevant and fun for the students; and to be personalized for each student so that their work reflects their own skills. For this project, students must design and develop analog and digital circuitry; implement data acquisition to a LabView program; and solder, test and troubleshoot the final circuit. The project culminates in a poster and demonstration session. Assessment indicates that the project was successful in helping students achieve the goals of the class. Students completed a Likert scale survey before and after the project. These results were evaluated using an unpaired t-test and a p-value less than 0.05 was considered statistically significant. Results show that the project made a significant difference in students' confidence in designing and troubleshooting analog and digital circuitry. The quality of the projects was impressive and the students clearly had a lot of fun, in spite of the many hours of hard work.

Introduction

Biomedical Engineering (BME) is a broad field and the curriculum must include exposure to a variety of areas ranging from electrical and mechanical engineering to tissue and genetic engineering. Electronics, in particular, can be an intimidating area for someone whose skills and interests shy away from the electrical engineering side of BME [1]. Most programs have an introductory electronics class taught in the sophomore or junior year, and this course can be discouraging for some students if they are not able to grasp the material in class or succeed in building electrical circuits in the lab. However, it is important that all students, no matter what their primary area of interest, have an understanding of electronics because this material can be an important part of their work in their future careers.

In the Joint Department of Biomedical Engineering at UNC-Chapel Hill and NC State University, we previously had a two semester electronics sequence at UNC-Chapel Hill that was taught outside of our department. In order to make the class more relevant to our students, we brought it into our department and condensed it to a one semester required class. We used this as an opportunity to incorporate Project Based Learning (PBL) in the class. This was accomplished by incorporating biomedical applications in both the class and lab, and to establish a design project in the latter part of the semester.

It is well established that PBL is an effective method to help students gain a deeper understanding of the material and remain more engaged in the class [2]. It is also well established that PBL can be used effectively as part of a BME curriculum [3-5]. However, there are unique challenges to incorporating PBL as part of an electronics class that encompasses a number of different topics in electrical engineering. The goal was to enable all BME students, regardless of their interest or comfort in electronics, to better grasp the material and have a positive experience in the class.

This paper focuses on the Invisible Handshake project, a 6 week design project that incorporates PBL in this introductory electronics class. In order for this project to be successful, it was determined that the project must meet the following objectives:

- help students achieve the goals of the class by incorporating all aspects of the class, including analog electronics, digital electronics, data acquisition to a computer, and circuit prototyping
- be relevant to BME students by incorporating BME applications
- be personalized for each student to insure that the result reflects their own skills and understanding of the material from the class
- be fun and creative for the students

This class has been taught for two years, starting in fall 2014, and the project has been highly successful in both years. Before and after the students worked on the project, they completed a survey to assess the impact of the project. These assessments demonstrated that the project had a significant impact in helping the students achieve the goals of the class, and in helping the them gain confidence in their electronics skills. The remainder of this paper provides further details on the project and the results of the assessment.

Methods

The Biomedical Electronics class is 15 weeks long and incorporates topics that are typical of an electronics class. The general timeline and topics are shown in Table 1.

There are 7 formal labs during the semester, and each lab involves the development of one or more circuits. Typically, the lab involves a BME application, such a measuring human movement using a sensor, such as a force sensitive resistor or infrared photodiode. In each lab, students also collect data from their circuit using myDAQ data acquisition module (National Instruments, Austin TX), and these data are then displayed on a computer using LabView software (National Instruments, Austin TX).

While most of the project work takes place during the digital electronics portion of the course, the Invisible Handshake project is introduced early in the semester. This is done with a guest lecture by a faculty member, who discusses the applications of electronic circuits in their research. The purpose of this is to provide a context for the project. The students should understand that while their project is being developed just for this class, this type of circuit development has real world applications. Because most of the students will be tracking human motion as part of their project, the guest speaker in past years was a faculty member whose research involves tracking human motion.

Table 1: Timeline of class showing the relationship between topics, labs, and project work

Weeks	Topics	Labs	Project work
1-10	**Analog Electronics** • Analysis of DC circuits with resistors, diodes, and op-amps • Analysis of circuits with capacitors • Analysis of AC circuits, including filters	6 formal labs and 1 informal lab exercise	Project is introduced early in the semester, and project proposal is due in week 9
11-15	**Digital Electronics** • A/D and D/A conversion • Analysis of digital circuits with logic gates • Development of circuits using digital ICs, such as timers, flip-flops, etc.	1 formal lab and 1 informal lab exercise	Most of the project work takes place during this time period

About 7 weeks into the semester, the project is described in more detail. The purpose of the project is to develop an electronic circuit that detects a particular sequence of measurements from the body. These could be human motion or other measurements such as heart rate or blood pressure. Once that sequence is detected, it should trigger some kind of action to take place, both in circuitry and on their computer using LabView. This action could be as simple as illuminating an LED (both a real LED in the circuit, and a virtual LED in LabView), or something more complex, such as triggering motors to spin and movies to play.

The specific criteria of the project are:

Detection of movements and timing

- The circuit must detect at least 2 different events (i.e. movements or other measurements), i.e. events A and B.
- Those events must be separated by a time delay T.
- The circuit must only trigger if it detects the proper sequence of event A, followed by a time delay T, followed by event B.

Reset button

- The circuit must have a button to reset the circuitry so that it starts off again waiting to detect event A.

Sensors

- The circuit must incorporate at least one analog sensor worn on the body. Students can use the same sensor to detect both events, or they can use multiple sensors.

Analog circuitry

- The circuit must have at least one analog circuit component. For example, this could be a filter and/or an amplifier.

LEDs

- Students must incorporate LEDs in key points throughout the circuit. This will help with troubleshooting and will also help the user to understand the operation of the project. An LED should be illuminated:
    - when each event is detected
    - during any major timing constraints (i.e. if an event must occur within a 1 second period, turn on the LED during that time)
    - when the complete sequence of events is detected

myDAQ and LabView

- When the complete sequence of events is detected, the circuit must send a trigger signal to the myDAQ data acquisition module.
- A LabView program should detect this to trigger an action, which could be playing a song or video or other response.
- Students can use the myDAQ and LabView to provide additional functionality, such as a graphical user interface for the project. Students should not use LabView to replace something that they could easily build in circuitry instead.

After students were presented with these criteria, several deadlines were established to help the students make steady progression during the last 6 weeks of the semester (Table 2).

Table 2: Project deadlines in latter half of semester

Date	Deadline	Description
Week 7		Project criteria described.
Week 9	Project proposal due	This was not graded, but it was discussed with each student during the lab period to insure the goals were reasonable and would meet the project criteria.
Week 13	Breadboarded circuit due	The circuit was graded during the lab period, according to the rubric below.
Week 15 (last week of semester)	Final project poster session	This final project was graded by faculty and teaching assistants, according to the rubric below. This was part of a poster session and all students and faculty in BME were invited to attend.

Tables 3 and 4 show the rubrics that were used in grading the breadboard circuit and the final project.

Table 3: Grading rubric for breadboard circuit (total possible 20 pts)

Criteria	Points
Does your circuit reliably detect two different movements without false positives or false negatives?	5
Does your circuit implement a timing component that works properly?	5
Does your circuit have at least one analog component that works properly (filter, amplifier, etc)?	3
Does your circuit have a reset button that works properly?	2
Is your circuit neatly done on the breadboard or is it a rat's nest? Neatly done means: use color coded wiring, avoid use of extra long arching wires, avoid crisscrossing wires	3
Do you have a neatly done, current circuit diagram (hand-drawn or Multisim)? Neatly done means: wires should be straight lines, avoid use of crisscrossing wires, components should be labelled	2

Table 4: Final project grading rubric

Criteria	Points
Circuit functionality: Soldered circuit meets all of the same criteria as the breadboarded circuit (two motions detected, timing component, analog component, reset button)	10
Best practices: Soldered circuit follows "best practices", such as: • all components properly powered from regulators or directly from battery; • use of multi strand wires to connect your board to anything (i.e. sensor) that is not mounted directly on the board; • LEDs are in series with a resistor and not connected directly between a digital output and ground; • use of decoupling capacitors between power and ground adjacent to at least half of your digital ICs	5
Neatness: Circuit layout is neat (see breadboard grading rubric for details)	5
Effort: Project shows a serious effort	5
Final report: This is complete, well organized, presented neatly, and with clear and concise writing.	5
Poster: This is complete, well organized, presented neatly, and with clear and concise writing.	5

A survey was administered to students in week 11, shortly after the start of the more intensive phase of the project, and again on the last day of class, after completion of the project. During this period, there were no additional formal labs, and in-class activities and homework focused on digital electronics, which supported the background that students needed to complete the project.

Figure 1 shows the questions asked in each survey. From the Likert scale results, the mean and standard deviation were computed, and an unpaired t-test analysis was performed to compare the difference between the pre- and post-project results. A p-value of 0.05 or less was considered statistically significant.

Figure 1: Pre-project survey administered to students. The post-project survey asked the same questions, as well as a few additional questions about which skills were most impacted by their work on the project.

As you prepare to start this project, please rate your confidence level for the following:

	high confidence	somewhat confident	neutral	low confidence	zero confidence
Designing analog circuits	○	○	○	○	○
Troubleshooting analog circuits	○	○	○	○	○
Designing digital circuits	○	○	○	○	○
Troubleshooting digital circuits	○	○	○	○	○

The ABET objectives for this class are below. Up to this point in the semester, please rate to what extent this class achieved these ABET objectives.

	highly achieved	somewhat achieved	neutral	did not achieve
Circuit analysis and troubleshooting skills	○	○	○	○
Prototyping skills (in the case of electronics, this would be soldering a circuit on a protoboard)	○	○	○	○
Scientific writing skills	○	○	○	○
Ability to find appropriate sources for technical information (in the case of this class, this would be understanding how to use datasheets)	○	○	○	○

Results

This project has been implemented in fall 2014 and fall 2015, which are the first two years that this class was taught in its current form. In the first year, there were 38 students, and in the second year, there were 52 students. The enrollment is expected to gradually increase to 80 in the next few years. The project is currently supported by the faculty member, 3 undergraduate lab TAs, and one graduate student TA. The total cost of the project supplies was about $50 per student, paid from the class budget. This includes the cost of components that were damaged and needed to be replaced. Each student purchases their own NI myDAQ Circuits Textbook

Bundle that they use all semester, at a cost of $225 each. The bundle includes the myDAQ data acquisition hardware, and LabView and MultiSim software.

Project themes varied widely according to the students' interests. The most common themes were sports, movies, and music. Some examples of themes are:

- Detect when Harry Potter moves his wand in a specific motion to cast a spell. When this motion is detected, play a segment on the computer from a Harry Potter movie.
- Detect when the user casts a fishing line. After a random amount of time, give a signal that the fish has been caught, and then detect when the user reels in the line. Once successful, reward the user with a video of someone catching a fish.
- Deal a hand of cards (shown on the computer screen via LabView) for a game of Blackjack. Detect whether the user gives a "hit" or a "stay" motion with their hands. Respond accordingly and continue the game.
- Detect whether the user has dozed off in their chair by monitoring heart rate and head position. Wake them up with an alarm.

The success of the project was assessed in a variety of ways. Student performance on the project was evaluated using the final scores on the project grading rubric. For each criterion in the rubric, it was determined that an 80% score or greater (8 out of 10 points, or 4 out of 5 points) would indicate overall student success in that criterion. The percentage of students who scored above that minimum was computed, as well as the overall average score of the class. Student learning was also evaluated using the results of a survey that was administered before and after the project period. These results from fall 2015 are shown in figures and tables below. The results from 2014 were similar.

Table 5: Summary of student project grades

Rubric criterion	Minimum score to indicate success	% of students above minimum score	Average score
Circuit functionality	8 out of 10	83%	8.62
Best practices	4 out of 5	98%	4.72
Neatness	4 out of 5	96%	4.63
Effort	4 out of 5	94%	4.85
Final report	4 out of 5	88%	4.49
Poster	4 out of 5	94%	4.62

Figure 2: Results of Likert Scale survey on student confidence, pre and post project.

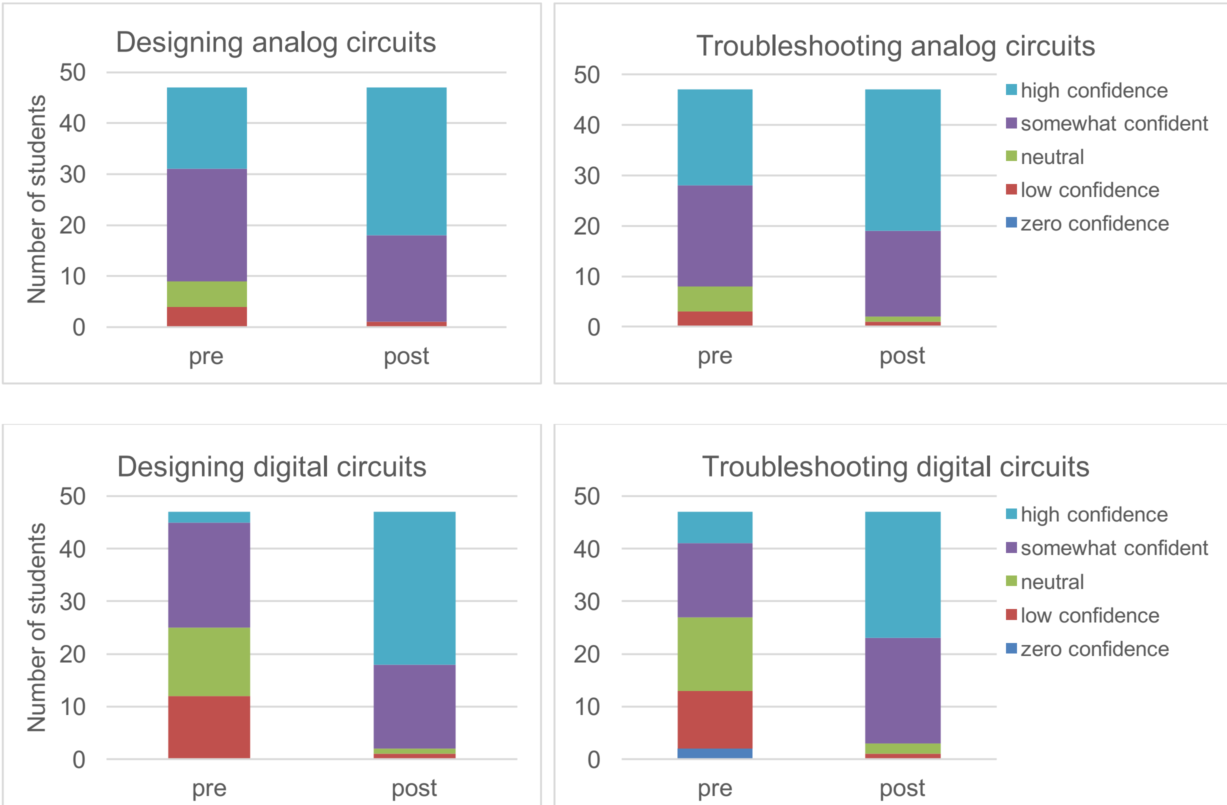

Table 6: Summary of survey results on student confidence level before and after their work on the project. These are mean scores from 47 out of 52 students in fall 2015, measured on a Likert scale in which 1=zero confidence and 5=high confidence. (*) denotes that an unpaired t-test showed statistical significance ($p<0.05$) in the post project vs. pre-project survey results

Rate your confidence level for the following	Pre project	Post project
Designing analog circuits*	4.06 ± 0.89	4.57 ± 0.62
Troubleshooting analog circuits*	4.17 ± 0.87	4.53 ± 0.65
Designing digital circuits*	3.26 ± 0.90	4.55 ± 0.65
Troubleshooting digital circuits*	3.23 ± 1.09	4.43 ± 0.68

Table 7: Survey results on whether class achieves several objectives, before and after their work on the project. These are mean scores from 47 out of 52 students in fall 2015, measured on a Likert scale in which 1=did not achieve and 4=highly achieved. (*) denotes that an unpaired t-test showed statistical significance ($p<0.05$) in the post project vs. pre-project survey results

Rate to what extent the class achieve these objectives	Pre project	Post project
Circuit analysis and troubleshooting skills	3.55 ± 0.54	3.74 ± 0.44
Prototyping skills (in the case of electronics, this would be soldering a circuit on a protoboard)*	3.02 ± 0.97	3.85 ± 0.36
Scientific writing skills	3.23 ± 0.84	3.23 ± 0.67
Ability to find appropriate sources for technical information (in the case of this class, this would be understanding how to use datasheets)*	3.32 ± 0.66	3.77 ± 0.43

In the survey, students also reported that the project had an impact on the following areas, in order of importance:

- Designing digital circuits
- Troubleshooting circuits
- Interpreting data sheets
- Designing analog circuits
- Project planning
- Understanding of how real circuits work vs. how they ideally should work on paper
- Use of best practices in circuit building (wiring, decoupling caps, etc.)
- How to wire a circuit neatly
- How to solder

Discussion

Survey results show an increase in student confidence before and after their work on the project. This increase is more significant for digital electronics, which is expected because when the pre-survey is administered, students have previously completed 6 formal labs and 1 informal lab in analog electronics, but only 1 formal lab and 1 informal lab in digital electronics. Therefore, most of the students' hands-on experience with digital electronics is obtained through their project work.

The survey results also show that students gave a higher rating for achievement of class objectives after the project completion. For two of the objectives, this increase was statistically significant. However, for "circuit analysis and troubleshooting skills", there was an increase but it was not statistically significant. This is likely due to the fact that at the start of the project, students already had exposure to these skills and gave a high rating (average 3.55 on a 4.0 scale) for this objective in the initial survey. There was not much room for further increases in the final survey. For the "scientific writing skills" objective, the students' rating did not change as a result of the project, which is not surprising because this was not a focus of the project.

The results indicate that a high percentage of students received successful scores in each criterion of the project grading rubric. These results, combined with the student survey results, indicate that students effectively achieved the learning objectives of the project. These learning objectives are listed in Table 8, which also describes how the Invisible Handshake project implements these objectives.

Table 8: Project objectives

Project objectives	Implementation
Incorporate analog circuit design	The circuit must measure an analog signal from a sensor and must include an analog component such as a filter and op-amp.
Incorporate digital circuit design	The circuit must include a digital timing component. This is typically accomplished with 555 timer ICs, counters, multivibrators, and logic gates.
Incorporate data acquisition and LabView programming	When the complete sequence of events is detected, the circuit must send a trigger signal to the myDAQ, which is then detected by a LabView program.
Incorporate prototyping and soldering skills	The students must first develop the circuit on a solderless breadboard; subsequently, they solder the circuit on a protoboard.
BME applications	The project incorporates BME applications because the students are measuring signals from the body, either physical movements or physiological signals.
Personalized	The general criteria are broad enough so that each student's project will be unique. While the students may help each other, each student is ultimately responsible to complete their own project.
Creative and fun	Within the project criteria, students can be creative and choose a theme that interests them. This helps motivate the students to be successful in this project.

Of particular note were the last two objectives in table 8. Throughout the semester, students worked in pairs in the lab and it was sometimes difficult to assess whether every student had full confidence in completing the lab exercises. Because the Invisible Handshake Project was personalized, each student had to be more independent. In addition, since each student chose a project theme that was important to them, they had a lot of fun with the project. An unexpected consequence was that it gave the faculty and TAs an opportunity to get to know them personally, as their project themes reflected their interests and hobbies.

Based on the first time implementing this project in fall 2014, several changes were made for fall 2015. The project was introduced earlier in the semester to allow students more time to plan and think about their project ideas. In addition, an extra deadline was added in fall 2015 to grade the breadboard prototypes. This requires students to complete all of their circuit design a full week before the start of Thanksgiving break. With the design work complete, the remaining work is to transfer that circuit to a soldered protoboard. While students underestimated the amount of work involved in soldering and troubleshooting their final circuits, most students did succeed in getting the bulk of their project complete before Thanksgiving.

For fall 2016, several additional changes are planned. Students will start work on the analog portion of the circuit earlier in the semester, getting experience in the lab portion of the course using accelerometers and gyroscopes. In addition, students will be required to implement Multisim simulations of their analog circuitry.

Summary

The Invisible Handshake project incorporates Project Based Learning in an introductory electronics class. In this project, students design a circuit that detects a sequence of events, which could be body movement or a physiological signal that is measured from the body. The general criteria leave room for creativity. The project enables students to tie together all aspects of the class, including analog and digital circuit design, and data acquisition to a computer, while also incorporating BME applications of electronic circuits. Because the project is personalized, students must work independently and they can be creative and choose a theme that interests them.

Assessment results show that this project has been successful in helping students gain confidence in their electronics design and development skills, and in achieving the goals of this class.

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