Development and Evaluation of an Electrical Engineering and Math Curriculum Module for High School Students

Kylee Burgess
Director: Dr. Shawn Jordan
Second Committee Member: Dr. Sohum Sohoni
Third Committee Member: Dr. Barbara Kinach

Table of Contents

Introduction

Parents in STEM careers are more apt to guide their kids towards STEM careers (Sherburne-Michigan, 2017). There are STEM programs and classes for students who are interested in related fields, but the conundrum is that students need to be interested in order to choose to participate. The goal of this creative project was to introduce engineering concepts in a high school class to reveal and investigate the ways in which engineering concepts can be successfully introduced to a larger student populace to increase interest in engineering programs, courses, and degrees. A lesson plan and corresponding materials - including circuit kits and a simulated ball launching station with graphical display - were made to accomplish this goal.

Throughout the lesson students were asked to (1) use given materials to accomplish a goal, (2) predict outcomes based on conceptual understanding and mathematical calculations, (3) test predictions, (4) record data, and (5) analyze data to generate results. The students first created a simple circuit to understand the circuit components and learn general electrical engineering concepts. A simple light dimmer circuit let students demonstrate understanding of electrical concepts (e.g., voltage, current resistance) before using the circuit to a simulated motor in order to launch a ball. The students were then asked to predict the time and height of a ball launched with various settings of their control circuit. The students were able to test their theories with the simulated launcher test set up shown in Figure 25 and collect data to create a parabolic height versus time graph. Based on the measured graph, the students were able to record their results and compare calculated values to real-world measured values.

The results of the study suggest ways to introduce students to engineering while developing hands-on concept modeling of projectile motion and circuit design in math classrooms. Additionally, this lesson identifies a rich topic for teachers and STEM education researchers to explore lesson plans with interdisciplinary connections to engineering.

This report will include the inspiration for the product, related work, iterative design process, and the final design. This information will be followed by user feedback, a project reflection, and lessons learned. The report will conclude with a summary and a discussion of future work.

Inspiration

Inspiration for this thesis was greatly influenced from my own personal experiences. Growing up, I wanted to be a math teacher. It was not until junior year of high school did I even consider engineering. Since my interest did not arise until later in school, I did not sign up for any engineering courses or programs. I am now graduating from college with a degree focused on electrical engineering systems. However, when I started college, I did not know of even the simplest electrical components. I wish that I had signed up for some of the available engineering programs to better prepare myself for what I will be doing for the rest of my life. With this personal experience and my interest in electrical engineering, software engineering, and teaching, I set out to make a curriculum module that would introduce students to electrical engineering in a math or science class. The module would be designed to increase interest in electrical engineering so students could look into existing programs and courses.

Related Work

To start brainstorming, I researched different programs which create similar products or lessons. The goal of the lesson outlined in this paper is to introduce a larger number of high school students to electrical engineering in a short lesson. The lesson should be presented to students regardless of interest prior to the activity. The lesson should reach sets of students which represent a normal high school math or science classroom. The outreach activities found, which were geared towards high school students, were introduced as electives or optional workshops, so only students who were already interested in STEM would pursue attendance. In what follows, several programs designed to engage middle and high school students in exploring engineering alone or mathematics within engineering contexts are described.

A lesson on integrating power engineering into middle and high school math curricula (Abbott, Warter-Perez, Kang, & Dong, 2012) corresponds most directly to the lesson outlined in this report. The main differences include grade level and topic. The lesson focuses on integrating power management into 7th grade pre-algebra. The author includes five different lessons on various mathematics concepts applicable to power management topics: Positive and Negative Numbers, Computing Percentage Change Using Electric Resistance, Ratios: Power Transformers, Finding the Energy of a Spark, and Building and Powering a DC Power Grid from Renewables. These lessons could be built upon to reach a high school level. The topics would introduce students to electrical engineering but each of these lessons build on one another and would take up significant class time.

In *The Structure of High School Academic and Pre-Engineering Curricula: Mathematics*, Nathan, Tran, Phelps, and Prevost (2008) discuss a rigorous multi-year program to prepare students for the mathematical rigor of an engineering degree in college. The program is designed for students interested in engineering and is focused on deepening and expanding these students' mathematical knowledge specifically in engineering related topics such as the ability to utilize a variety of precision measurement tools to measure appropriate dimensions, mass, and weight. This study would introduce students to engineering but only through mathematical equations. This study would be too long, too rigorous, and too mathematically focused to meet the goals of the lesson in this paper.

In *Inside the Classroom: Challenges to Teaching Engineering Design in High School*[7], Uysal, Yasar, Baker, Kurpius-Robinson, Krause, and Roberts (2007) discuss the experiences of a high school mathematics teacher who designed two semester-long engineering courses with incorporated hands-on design activities. The mathematics teacher had previous industry experience as an engineer. Students were able to sign up for these courses as an elective; of the participants, 86 were male and 4 were female. This study directly connects to the my lesson because of its focus on hands-on design activities to introduce engineering topics. The lesson also was presented by a mathematics teacher with engineering experience which would translate to presenting the lessons in a math class easily. These lessons were too long, however, and were gender unbalanced. Since the course was an elective and participation was optional, only 4 females signed up. The 86 male to 4 female ratio does not match the approximate one male to one female ratio of a normal high school math or science course.

In *Project Pathways*, Krause, Culbertson, and Carlson (2008) describe four semester-long courses for grades 9-12 designed to foster positive attitudes towards science and mathematics in high school students. An interdisciplinary team of mathematics, science, engineering, and education faculty designed interdisciplinary curricula for each course. These courses introduced scientific inquiry, mathematical problem solving, and engineering design through team-based learning on top of promoting conceptual competence in the original core content of each subject class. These lessons greatly aligned with the mission of my lesson because it combined science, mathematics, and engineering principals into a lesson. The interdisciplinary faculty team also aligns with this mission. However, these courses are again semesters long instead of days long and were presented as elective courses.

In *Creative Engineering: Helping Ninth Grade students Discover Engineering*[2], Kotys-Schwartz, Sullivan, Yowell, and Zarske (2005) discuss the development of a 12-week, hands-on, engineering designed-focused ninth-grade elective course. The course was designed to further student interest in careers in engineering and prepare students for college engineering degrees. This study aligned with the goals of my lesson because of its focus on ninth-grade students and increasing their interest in engineering careers through hands-on lessons. However, this lesson was weeks long rather than days long and was an elective course.

Building Math Skills in Context: Integrating Mathematics with Engineering and Technology, A Professional Development Course for Middle and High School Teachers (Pelletier & Chanley, 2007) details a 15 session workshop where graduate students taught middle and high school teachers ways to incorporate math concepts essential to engineering and technology into their technical and mathematics courses. This study focused on making sure the teachers understood the topics and how they are connected to engineering and technology, there was little to no mention of how this information would be presented to the students. This study aligned with the goals of my lesson because it looked to integrate engineering related topics into high school math classes. However, this study does not align with the goal of my lesson because it does not provide details as to how this information is relayed to the students but rather how the teachers are taught to incorporate these topics.

The purpose of the project reported in this paper compared to the programs, lessons, and activities discussed above is to introduce all students to engineering through their normal high school mathematics or science classes. All of the studies surveyed in the related works review were designed as elective courses or workshops which require initial interest in the topics to entice enrollment. The projects found were often weeks, months, semesters, or years long and were too difficult or too easy for the average high school student. This report will discuss an activity designed to take one or two class periods of a general high school mathematics or science course thus creating participation regardless of initial interest in the topics of the lesson. The hypothesis is that the short length of the lesson will create interest in the topics and motivate participants to look into various other engineering programs, courses, and degrees.

Initial Designs

After initial research and discussing designs with my father (a high school math teacher), I chose to focus on a lesson revolved around parabolic motion through projectiles. Parabolas are a focus in many math and science classes so this focus allows the lesson to be used in a wider variety of courses.

The main idea was to create a launching mechanism which the student could control with an electrical control circuit. Students would be able to connect the parabolic motion they learn in class to the electrical engineering knowledge they would gain by creating a motor control circuit on a breadboard.

The first design was going to be a box which would be given to each student or group of students. Students would be able to plug their breadboard into a box to launch a small ball. When the ball was launched, LEDs or a display would show the parabolic motion of the ball. The students would also be able to change the angle of the ball with this design. Ultimately, this design never left the sketching phase because the design would be very costly. The cost ultimately stemmed from the LED display or screen and the extensive number of sensor which would be needed to determine the location of the ball. This design also incorporated the angle of the launch which was dropped in future design iterations because of the already complicated nature of the product and lesson. Simplifying the launch focuses the lesson on the connection between the electrical engineering and the math and physics topics.

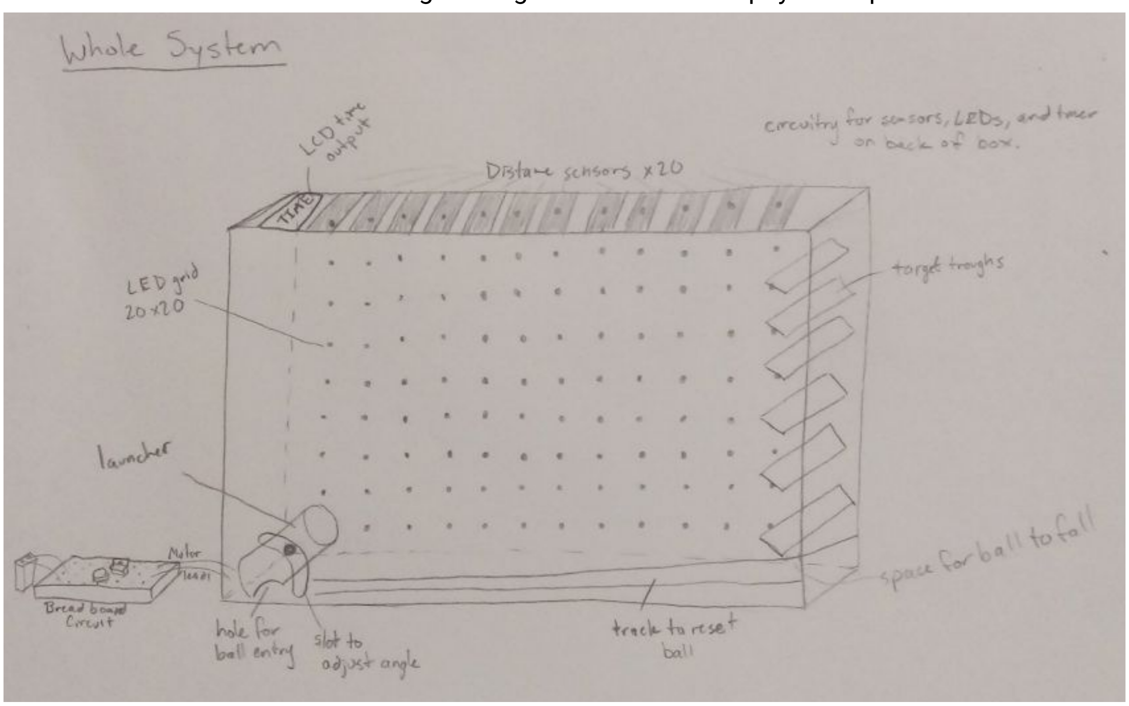


Figure 1: Angle Controlled Projectile Box Design Sketch

The next design resembled the initial design but simplified the launch. The launch angle was no longer adjustable. This new design allowed for the use of one sensor rather than many which would greatly reduce cost and size. However, this design was not chosen because high cost would still arise from having a box and display per student rather than a few stations for the whole class to use.

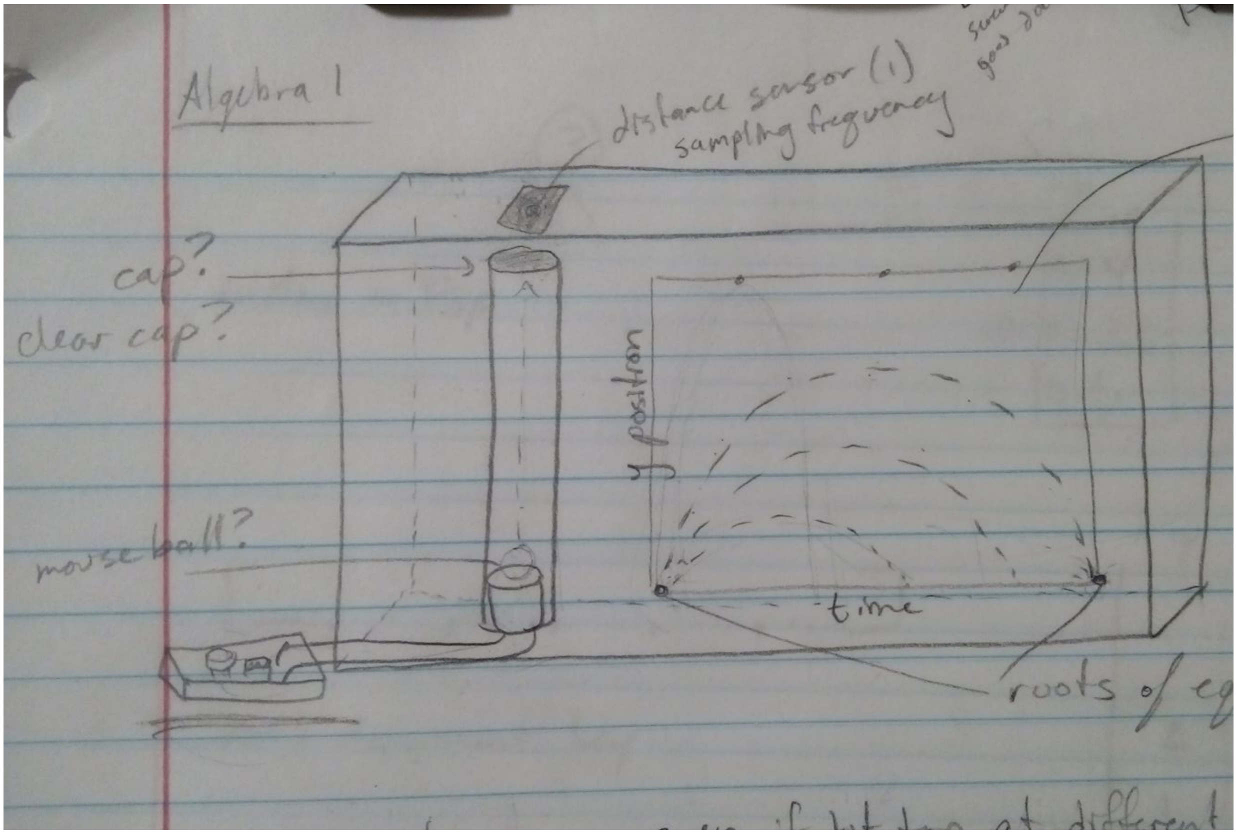


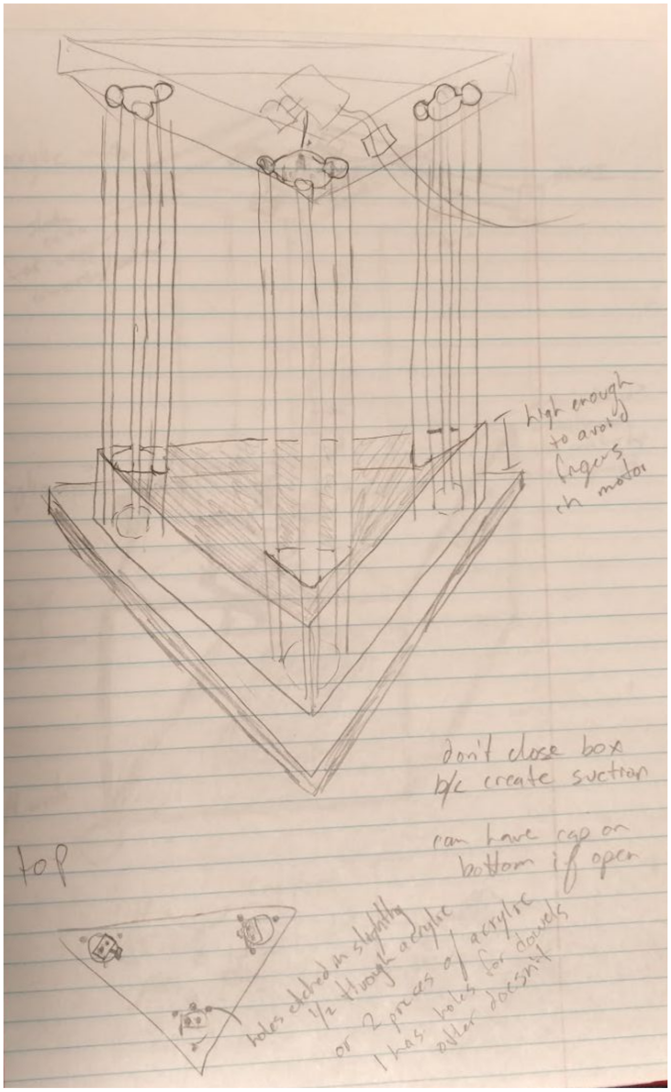
Figure 2: Vertical Projectile Box Design Sketch

The next design was a device with four ball launching stations. The students would bring their breadboard circuits up to a station to test their circuit. Creating one device with a few stations decreased estimated cost and reduced size constraints. This design utilized clear plastic tubing to guide the ball throughout the launch. The problem with this design was that there was not enough air movement when the tubing was lengthened thus causing the ping pong ball to launch inconsistently. The launch inconsistency was discovered after creating a one launch station prototype, so I did not continue with the four station design. While working with the one station prototype, I determined that our initial motor moved too slowly. I was able to test a successful launch by using a wheel attached to an electric drill. I then used video footage of the wheel to determine what speed motor would be needed to launch the ball. The wheel attached to the drill was calculated to be spinning at 267 rpm so motors were ordered which exceeded this constraint.

Figure 3: Needed Motor Speed Testing

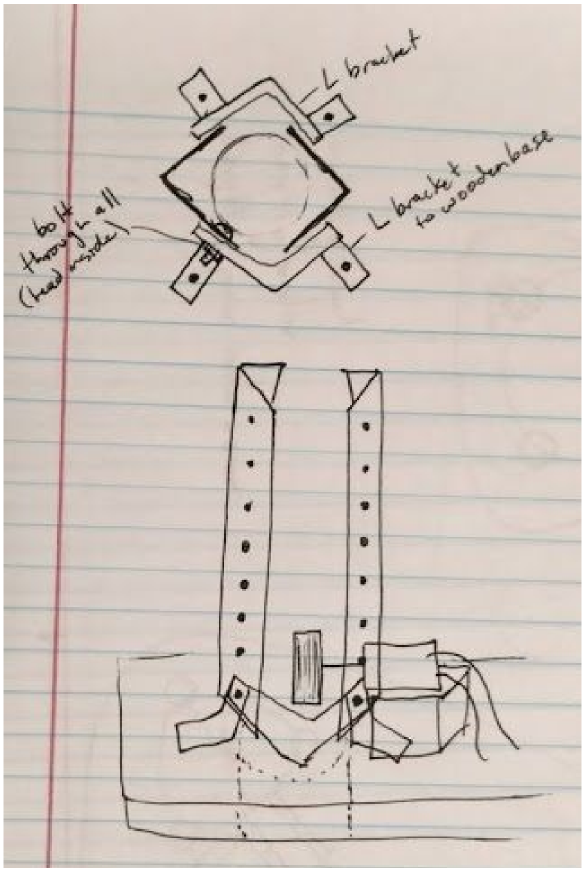
Figure 4: Projectile Launcher Plastic Tubing Prototype

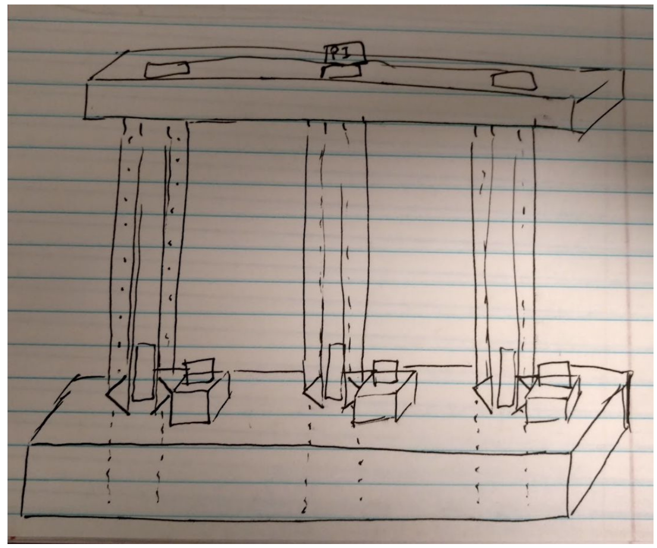
The next iteration involved creating three stations in a triangle shaped design. This design used wooden dowels and laser cut braces to create the ball guides. These open guides removed the previous air pressure problem of the plastic tubing. This design was very light and aesthetically pleasing but was very mechanically challenging. The dimensions were difficult to calculate due to the wood warping. Also, sanding and polishing would take significant time. The idea of creating this design with acrylic and metal dowels rather than wood to reduce warping was discussed but ultimately an entirely new design was pursued due to hypothesised difficulties with adhesives.



Figures 5 & 6: Projectile Launcher Triangle Design Sketch & Prototype

The next design was presented and ultimately chosen because of the ease of assembly. This design included a wooden base and three launch tubes created from angle iron. The angle iron contained holes to allow for reduced air pressure. This design, although bulky and less aesthetically pleasing, created more consistent ball launches than any previous prototype designs. This mechanical design allowed further development of the electrical circuitry.



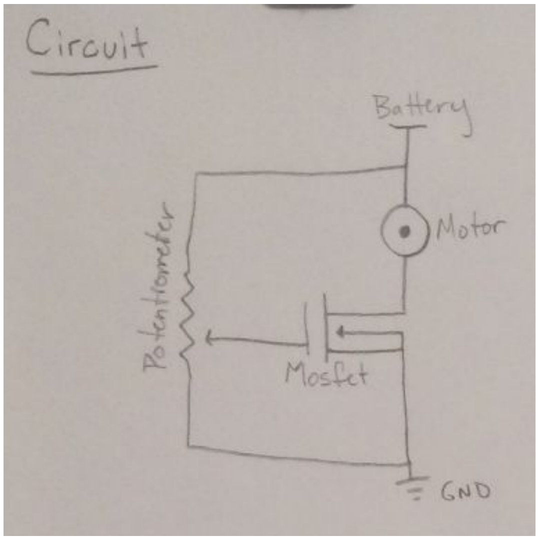


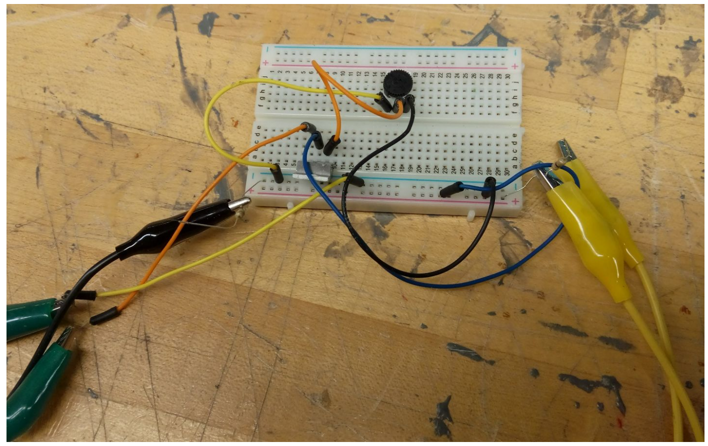
Figures 7 & 8: Projectile Motion Angle Iron Design Sketch

Figures 9 & 10: Projectile Motion Angle Iron Design Full Prototype

Figures 11 & 12: Projectile Motion Angle Iron Design Launch Mechanism Prototype

In parallel to the mechanical designs, I worked on creating a simple motor control circuit. Most motor control circuits involve microcontrollers and PWM signals. However, I did not want to incorporate these components into this project because they would increase complexity for the student. The increased complexity would increase the probability of student confusion during the lesson. Reducing the complexity focuses the student learning which increases the chances of knowledge retention for the reduced set of components and concepts. My main challenge was determining how I could have students supply variable power to a motor with a 9V battery. I wanted to use batteries rather than power supplies because I wanted each individual group to be able to test their designs at their desk. Ultimately, these constraints made creating a control circuit very difficult. The main hurdle was that in order to supply enough power to the motor, a significant amount of power had to go through all the other components as well. This high power caused potentiometers, resistors, and MOSFETs to malfunction due to overheating. Originally, I wanted to use a MOSFET and potentiometer in the circuit; however, after further investigation, I realized that these components would also add unnecessary complexity to the lesson. The final physical motor control circuit ended up using power resistors and a high wattage, low resistance potentiometer to create a voltage divider circuit. This circuit still seemed overly complicated to explain, but was the simplest circuit found which would avoid overheating components.





Figures 13 & 14: Initial Motor Control Circuit Schematic Sketch & Prototype

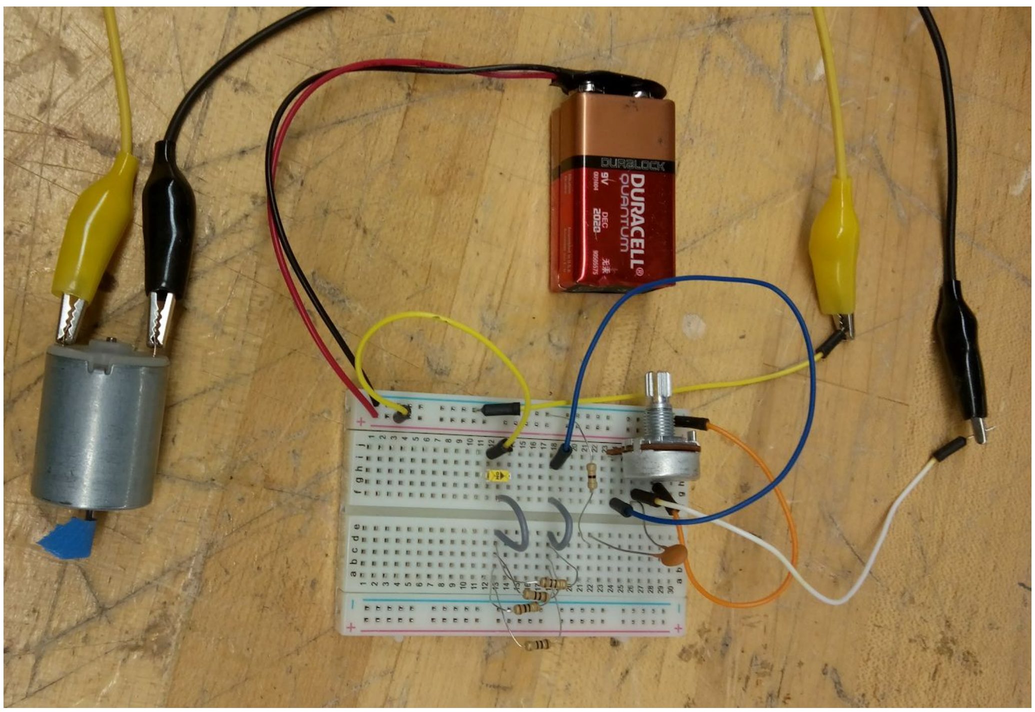


Figure 15: Motor Control Circuit Prototype - No Mosfet

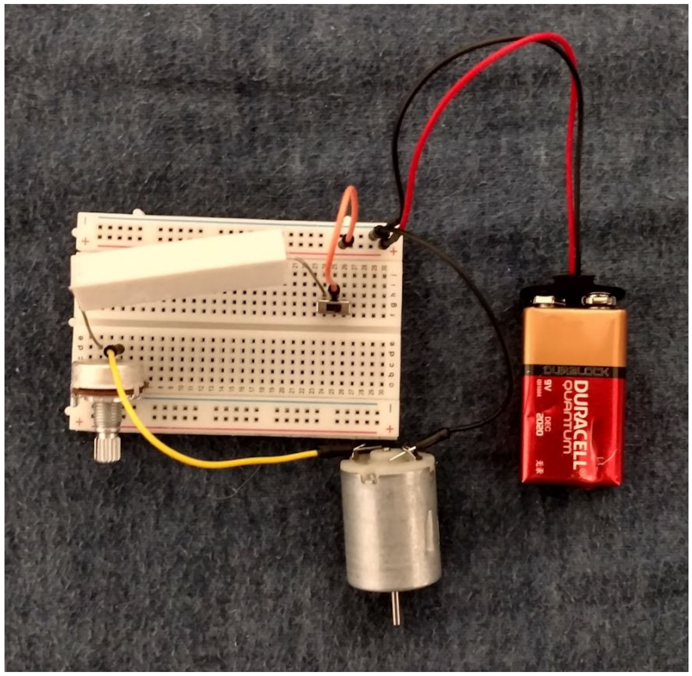


Figure 16: Motor Control Circuit Prototype - Power Resistor

The next focus of the physical launch was to create the circuitry to determine the height of the ball and display a height versus time graph. This circuitry consisted of a Raspberry Pi (See A in Figure 17), an analog to digital converter (ADC) (See B in Figure 17), and a distance sensor (See C in Figure 17). The original idea was to start recording the height of the ball once it moved from its normal resting position. Once this happened, the distance sensor would send a value to the ADC to be converted for the Raspberry Pi to use. This idea worked in theory but worked inconsistently in reality. The first sensors used (Sharp GP2Y0A21YK) did not read a far enough distance to capture the full length of the launch tube. These initial sensors were designed to read from 10cm to 80cm. Further distance sensor were purchased (Sharp GP2Y0A60SZLF), but complications still occurred. The new sensors were designed to read from 10cm to 150cm. Despite the change in sensors, the distance sensors were still inaccurate with the given set up and accurate conversion equations were unable to be created. Another complication was that, after a certain distance, the sensors would detect the sides of the launcher rather than the ball. This was because the sensors use a cone shaped sensing rather than linear, laser-like sensing.

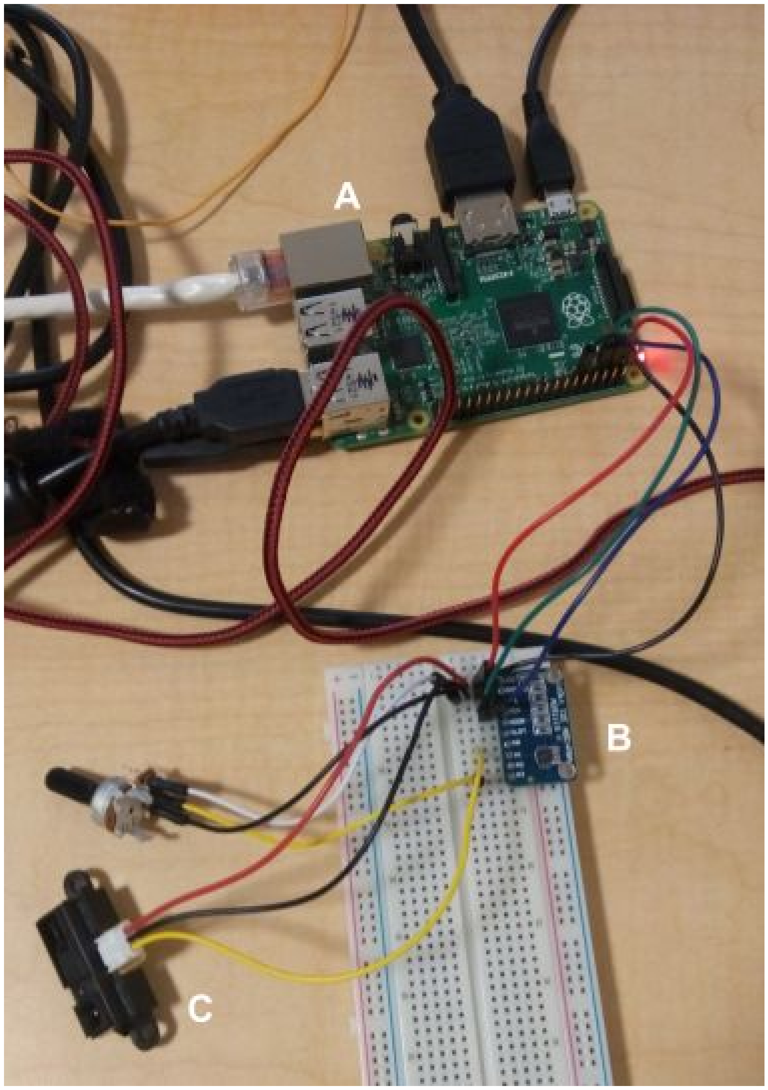


Figure 17: Sensor Circuitry: Sensor, ADC, and Raspberry Pi

The hardware and sensors for this design were revealing further and further complications. Rather than continue finding workarounds and bandaids for each issue, I decided to pivot the project. Rather than focusing on a physical launcher, I decided to make a simulated ball launcher. This significantly reduced hardware and sensor complications. This also greatly reduced costs and manufacturing time. The simulator and circuit kits would be easier to incorporate into future classrooms without bulky, time consuming hardware. This simulator design was ultimately the design presented to the user.

Final Design

Students were asked to devise different methods to launch a ball through a Think, Pair, Share activity. The focus then adjusted specifically to electronic launch systems. First, they were introduced to various electrical engineering concepts and circuit components. Components included breadboards, batteries, switches, resistors, LEDs, motors, wires, battery connectors, and multimeters. Concepts included voltage, current, and resistance. They were then tasked with creating a light dimming circuit (shown in Figures 18 - 20) to calculate and demonstrate how different resistor values will create a different output voltage and thus a different brightness from the LED. The voltage divider equation, $V_{out} = V_{in} (R2/(R1+R2))$, was used by the students to calculate the voltage supplied to the LED. This circuit was then modified to attach to a simulated launch station (shown in Figures 21 - 22). The student groups then tested different resistor values with the launch height. The calculations performed by the students and the simulator to determine launch height from the voltage supplied are provided in the equation sheet in Appendix B. After calculations, the participants were tasked with the goal of determining the resistor value they needed to reach a certain height and what height the ball would reach if they choose a specific resistor value.

The final design consists of a circuit kit and a Raspberry Pi Simulator. The materials used for this activity are shown below:

<u>For Launch Station:</u>

1 - Projector
1- Raspberry Pi
1- Analog to Digital converter
1- HDMI cord
16 - Alligator clips
10 - Jumper wires
*All of the launch station components were provided pre-assembled for this lesson. The Raspberry Pi was just plugged into an outlet and the projector.

<u>For Student Kit (for 3-4 students):</u>

1- Multimeter
1 - Breadboard
1 - 9V battery
1 - Battery connector
1 - LEDs
3 - Jumper wires
1 - Switch
14 - Resistors

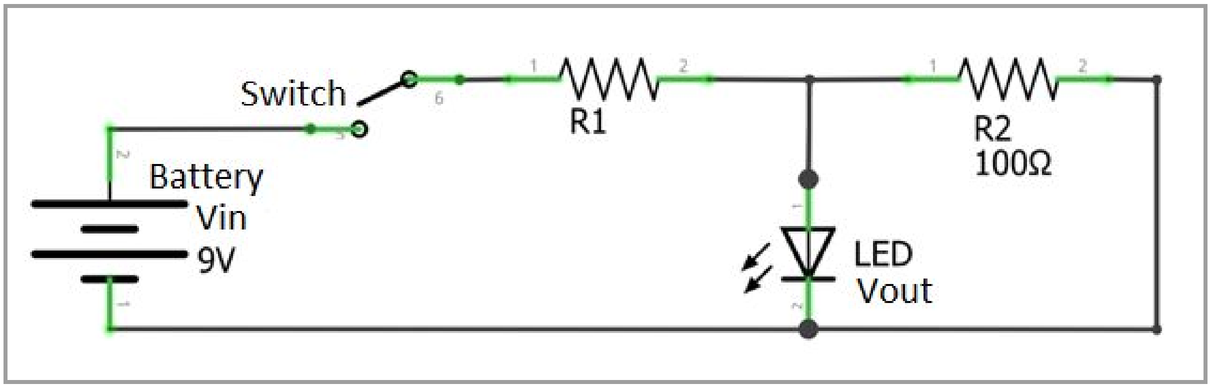


Figure 18: Light dimming circuit schematic

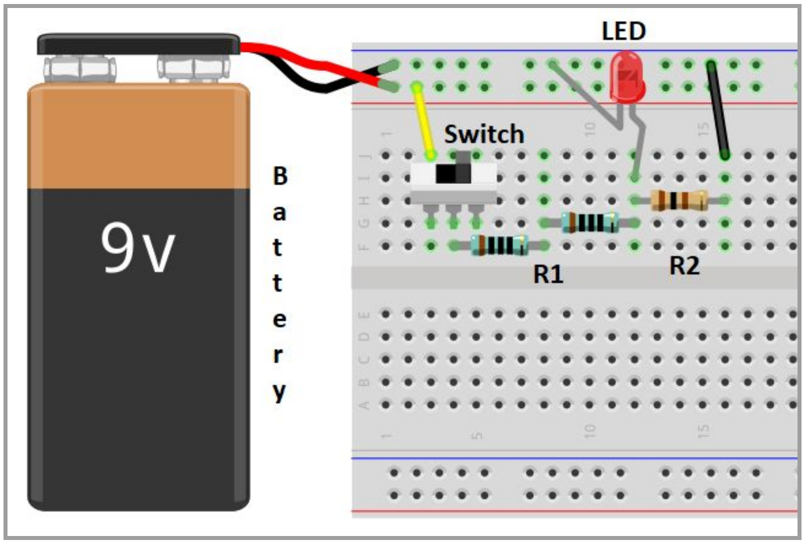


Figure 19: Light dimming breadboard Fritzing diagram

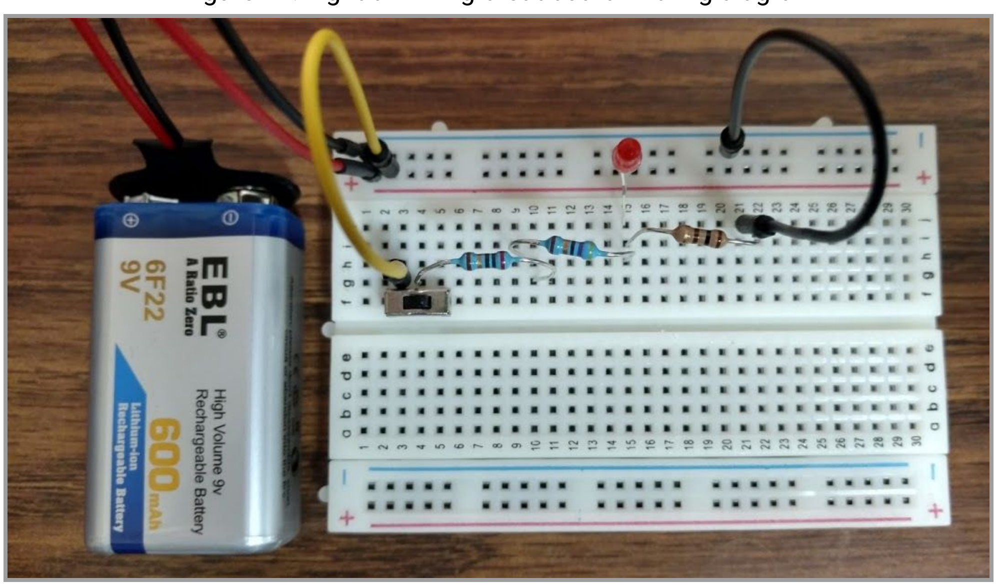


Figure 20: Light dimming breadboard circuit

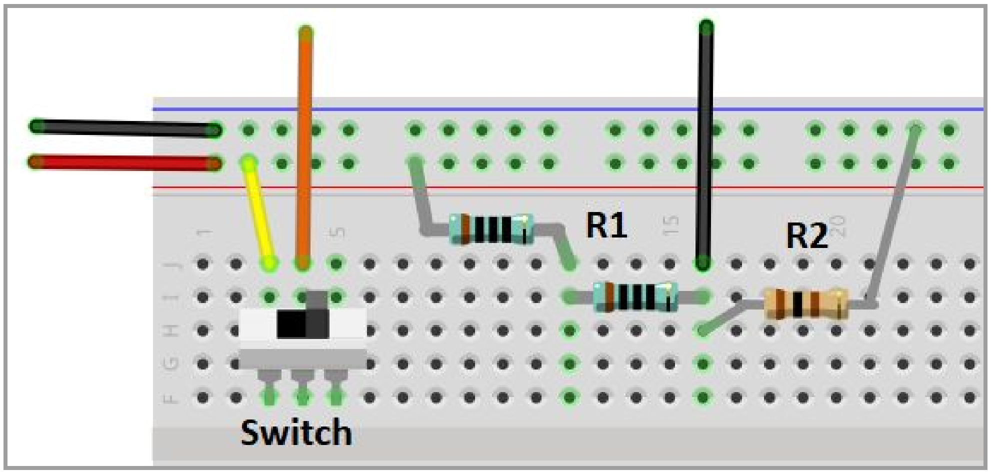


Figure 21: Launch simulation breadboard Fritzing diagram

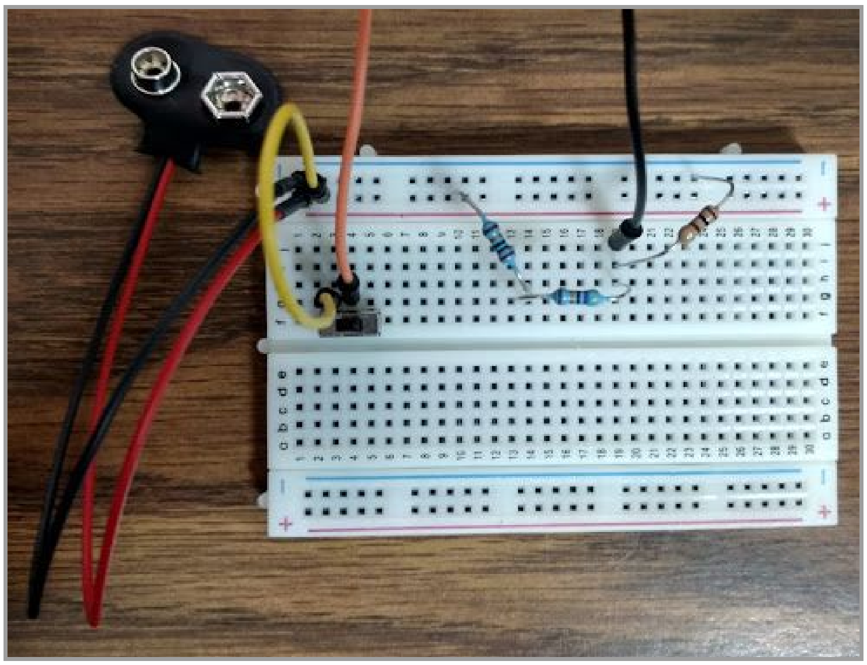


Figure 22: Launch simulation breadboard circuit

The voltage divider circuit is plugged into the simulator circuit in four positions: power, ground, the switch, and the voltage detection. Once the voltage divider circuit is plugged into the simulator, the rest of the calculations and conversions are done by the ADC (See B in Figure 25) and Raspberry Pi (See A in Figure 25). To start, the ADC provides a digital value corresponding to the voltage supplied by the external circuit. The Raspberry Pi then converts this value by using the following equation:

$$Voltage = \frac{3.3V * ADC\ Value}{26551}$$ (Seidle, n.d.)

Once the voltage value is known the motor angular velocity, initial ball velocity, launch time, and maximum launch height can be calculated. See the equation sheet in Appendix B for details on these equations.

Using Python and PyQt5, I created a GUI to display the calculation results, a simulated launch, and a height versus time graphical display. I used four instances of the same window class in order to create four different stations.

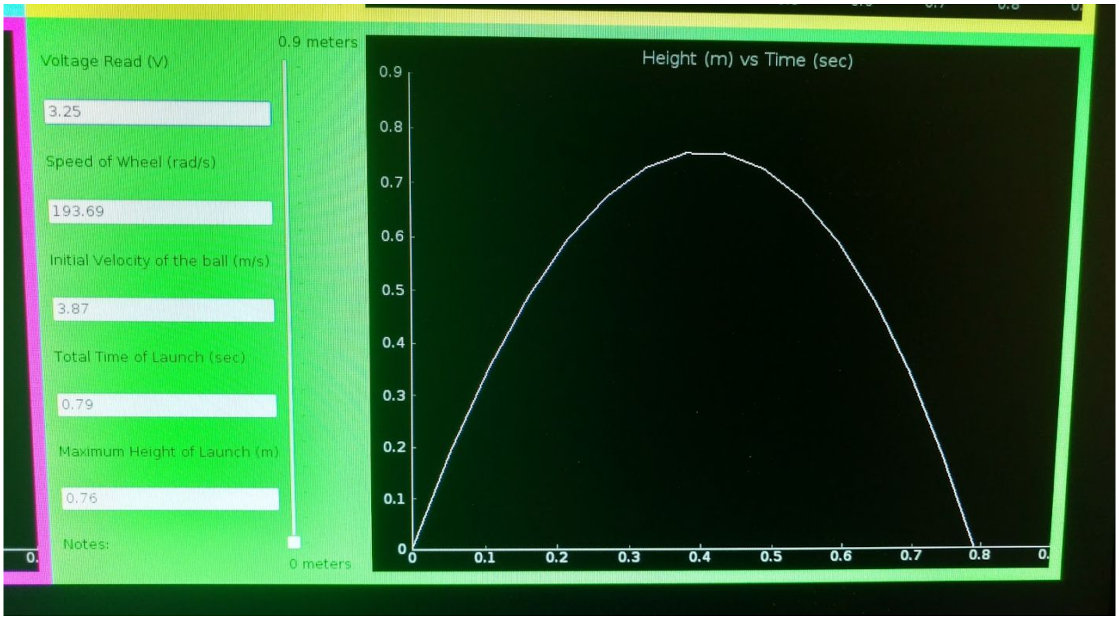


Figure 23: Projectile Motion Simulator GUI - Single Station

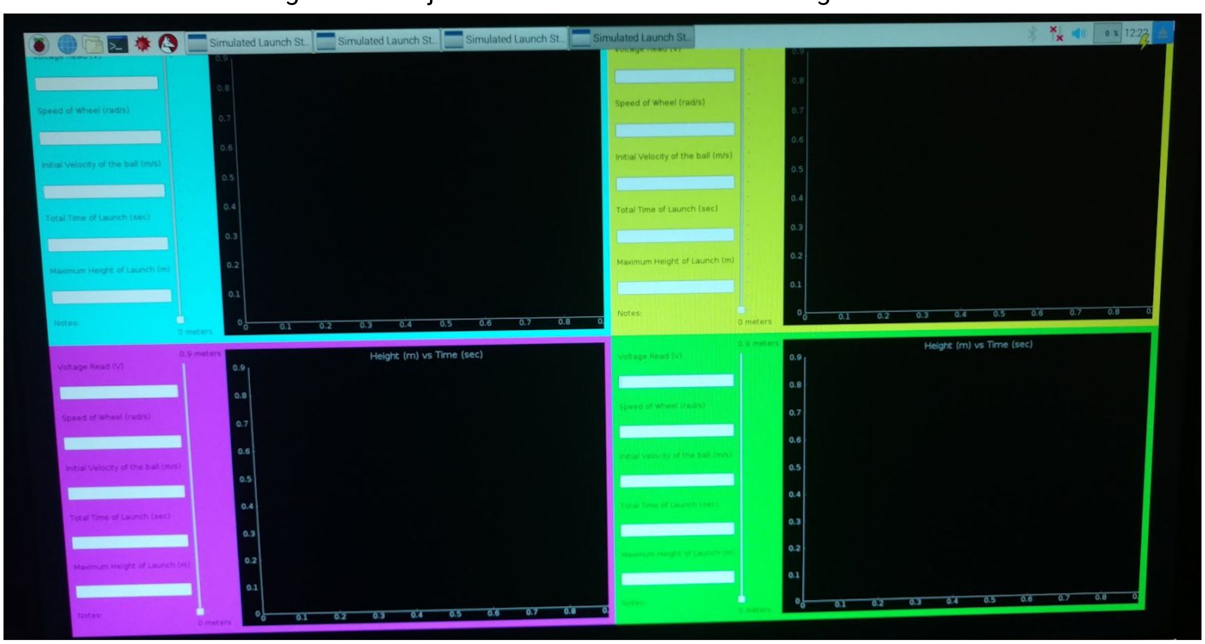


Figure 24: Projectile Motion Simulator GUI - All Four Stations

The four stations were color coded: blue, yellow, pink, and green. The simulation background and wires matched to indicate which wires corresponded to each simulation station. Any of the power and ground (red and black) wires could be used for any of the stations (See E in Figure 25). The wires plugged directly into the Raspberry Pi were connected to the switch (See C in Figure 25) on the student's breadboard to start and stop the simulator. The wires plugged into the ADC (See D in Figure 25) were connected between the student's resistors to sense the voltage.

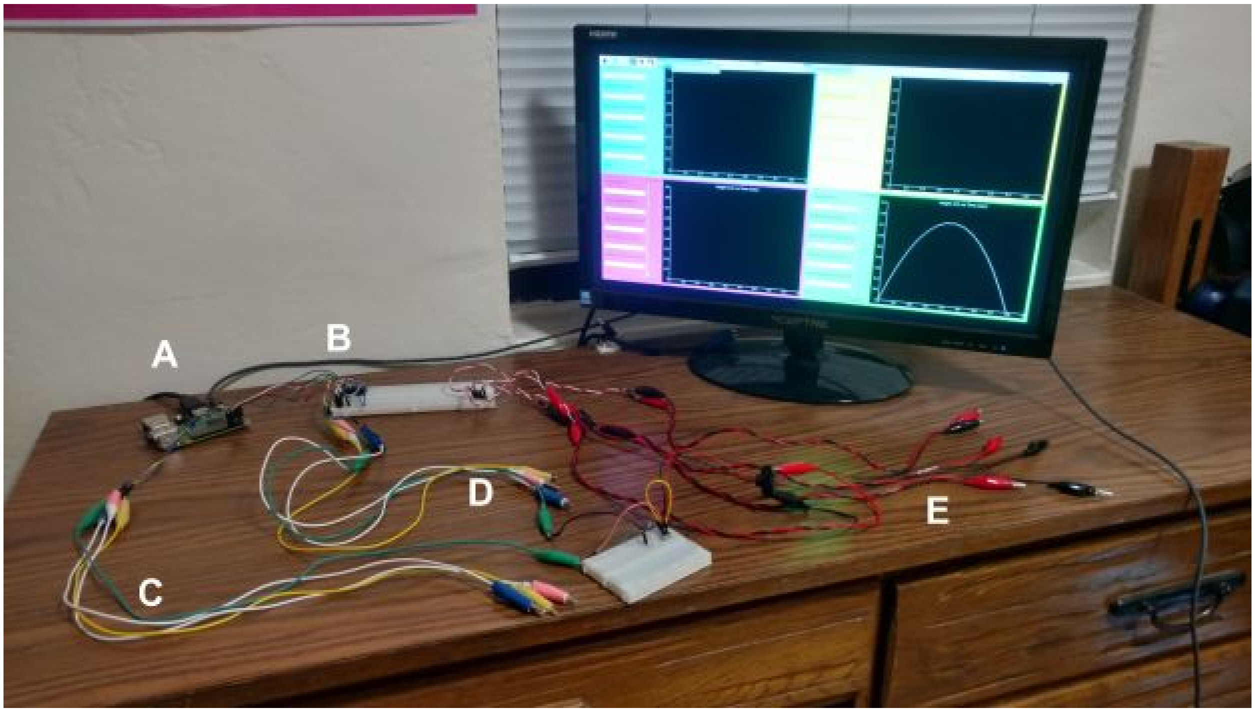


Figure 25: Projectile Motion Simulator and Circuitry Connected

To see the code used for the simulator please visit:
https://github.com/KyKyPi/SimulatedBallLauncher

User Feedback

Approach

In order to bring my product into a classroom, I needed to file paperwork with the Institutional Review Board (IRB) to ensure my methods were ethical. I started by contacting the principals of various schools which had done similar work with members of my committee team, Dr. Carberry, or Women In Science and Engineering (WISE). Since this project was designed for high school classes, I only reached out to high school principals. Once I had a signed letter of intent to participate from the principals, I was then able to reach out to teachers to gauge their interest. A few teachers actually contacted me because the principals had put out a notice about my project. Since this project is designed for math and science classes, I focused on contacting math and science teachers. Only one teacher ended up following through and continuing communication. Once I knew the school, teacher, and classes I would present to I had to fill out and submit the forms in Appendix F to the IRB. I also had to submit any materials which would be shown in the classroom including consent forms, surveys, presentations, lesson plans, and equation sheets. I was able to submit this information to the IRB, they asked for a few clarifications and quick edits, and once they were fixed I was approved to present in the classroom. Later on, I had to submit modifications to edit a few documents and provide training information for the rest of my thesis committee. These modifications were accepted quickly and with no complications.

The simulation and corresponding circuit kits were tested in four physics classrooms. The product was tested through a two-day lesson plan shown in Appendix A. The students were asked to complete surveys prior, during, and after the lesson to evaluate the students' opinions of the product shown in Appendices C, E, and F. The main focus of these surveys was to determine student interest and knowledge levels in math, physics, and/or engineering, student knowledge of specific engineering components and concepts, and student interest in pursuing engineering programs, courses, or degrees.

Participant information was collected through three surveys: a pre-activity survey, a during-activity survey, and a post-activity survey. The pre-activity survey was used to collect initial information about the participant such as gender, grade level, interest in mathematics, physics, and engineering, and knowledge level of various electrical engineering concepts and components. The during-activity survey was used as an activity worksheet. The students were provided with questions pertaining to the activity and space to do their calculations. The post-activity survey was used to collect information about the participant after the activity such as interest in mathematics, physics, and engineering, knowledge level of various electrical engineering concepts and components, and any general comments, concerns, or questions.

The surveys discussed above were created based on an example provided by one of my thesis committee members. The questions were developed based on this example and by thinking through the various sections of the lesson plan. These questions were then presented to my thesis committee for approval before submitting the surveys to the IRB.

Results

The student pre-activity survey started by collecting general information about the students. There were a total of 48 student participants. Forty-three of the students were juniors, four students were seniors, and one student was a sophomore. 54.2% of participants were male, 43.8% were female, and 2.8% identified as other. The participants were asked if they had family or close friends in STEM fields and if so their relation to the participant and their field. 51.1% of participants had close family or friends in STEM fields. Of these participants, 87.5% were encouraged to pursue similar fields. Another question in the pre-activity survey asked the students to list, if they had family or close friends in STEM fields, the relation and what field they are in. Figure 26 below shows a word cloud of the participants' family and friends in STEM and their fields.

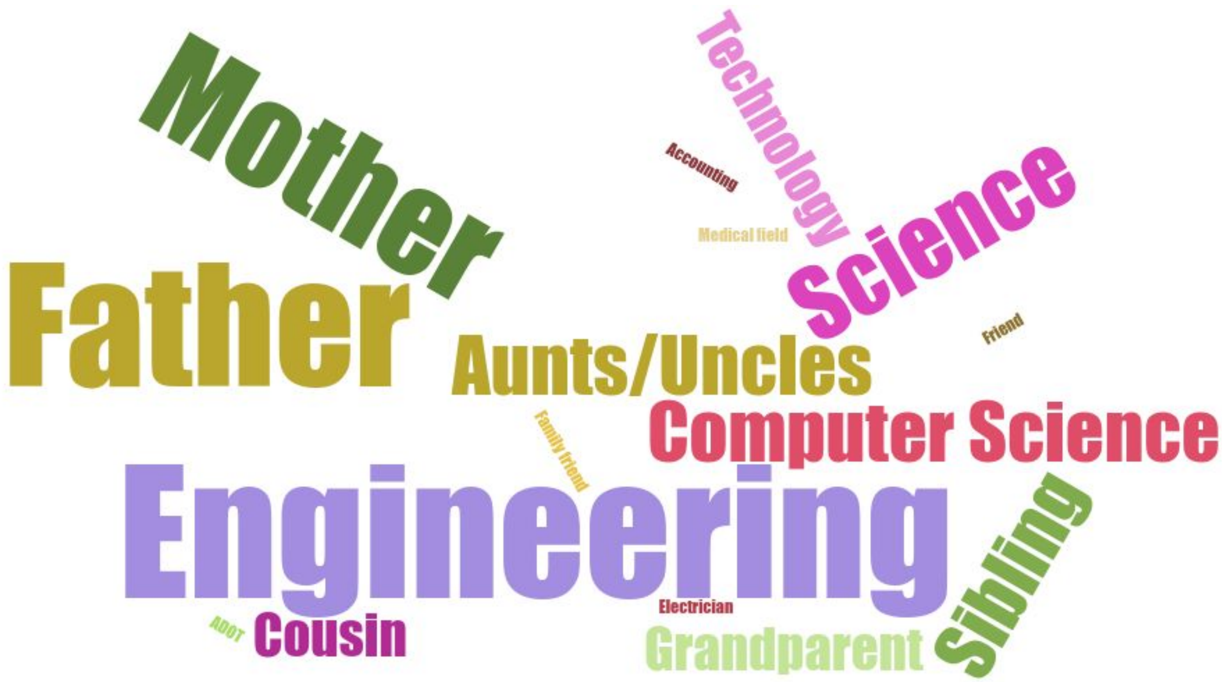


Figure 26: Participant family/friends in STEM and their fields

Figure 26 shows that, for the surveyed students, the most common family member in a STEM field was their fathers. Mothers were ranked second followed by aunts, uncles, and siblings. The most common STEM field of family members or close friends was engineering followed by computer science and science.

Overall, the majority of student participants enjoyed the activity. The first question of the student post-activity survey asked the students if they enjoyed the activity. The results for this questions are shown in Figure 27.

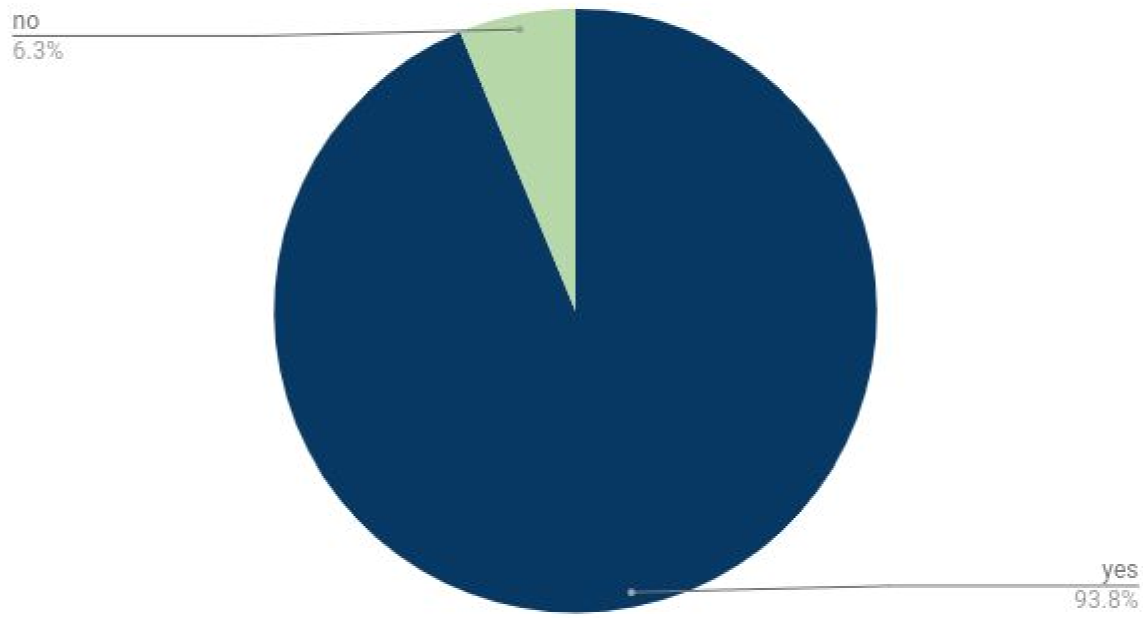


Figure 27: Percentage of students who enjoyed and did not enjoy the activity

As shown in the pie graph in Figure 27, 93.8% of students enjoyed the activity while only 6.3% of students did not enjoy the activity. Students were also asked why they did or did not enjoy the activity. The reasons students enjoyed the activity varied and are shown in the word cloud in Figure 28.

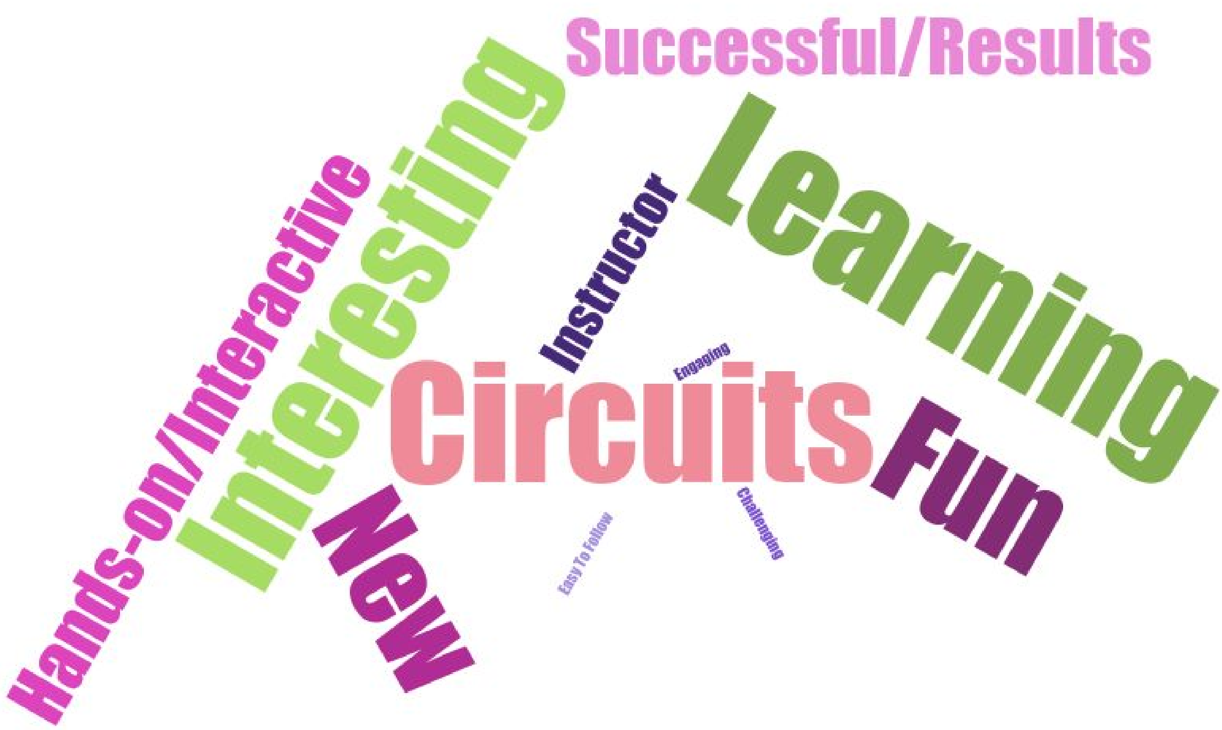


Figure 28: Why the students enjoyed the activity

Students enjoyed the activity because they were able to learn and were able to interact with circuits. Students also mentioned common words such as fun, new, interesting, hands-on, and interactive to describe why they enjoyed the activity. These buzz words can be used in future iterations and other lesson to help guide user focused product design. The explanation as to why some students did not enjoy the activity can also help guide future user focused product design. Figure 29 shows the reasons why 6.3% of students did not enjoy the activity.

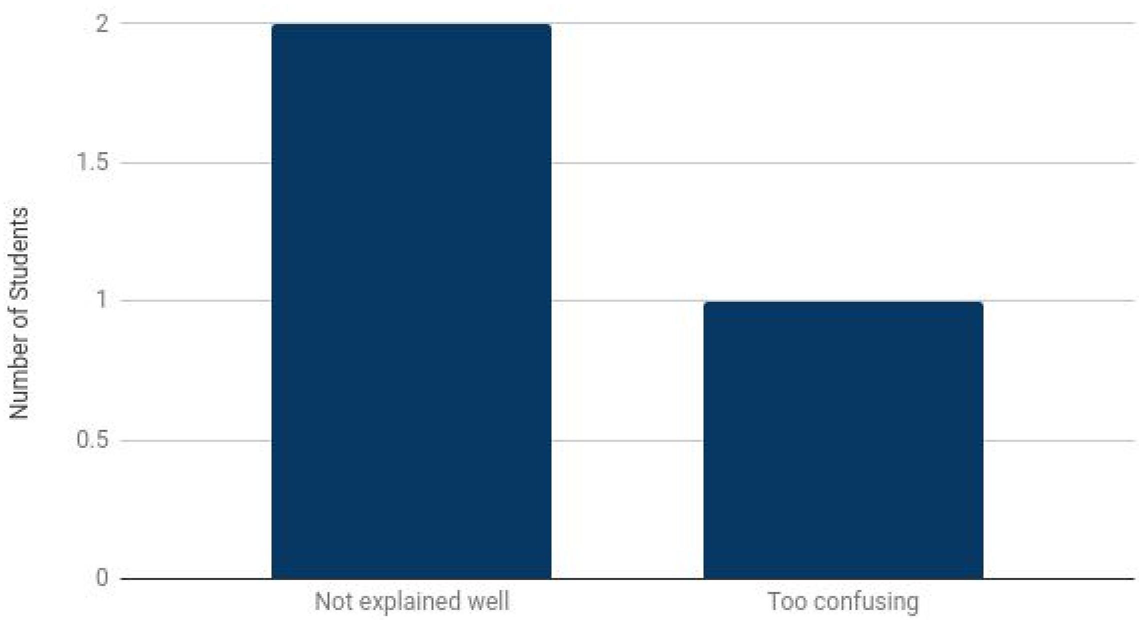


Figure 29: Why the students did not enjoy the activity

The few students who said they did not enjoy the activity said that the material was not explained well or was too confusing. In future iterations, slowing down the lesson and allowing increased time for questions would probably help to explain the content better and to reduce student confusion.

Interest Levels

Students were asked for their interest level pre and post activity to determine if this interdisciplinary activity could increase student interest in engineering, mathematics, or physics. Figure 30 shows the average student interest level prior to the activity and after the activity for math, physics, and engineering.

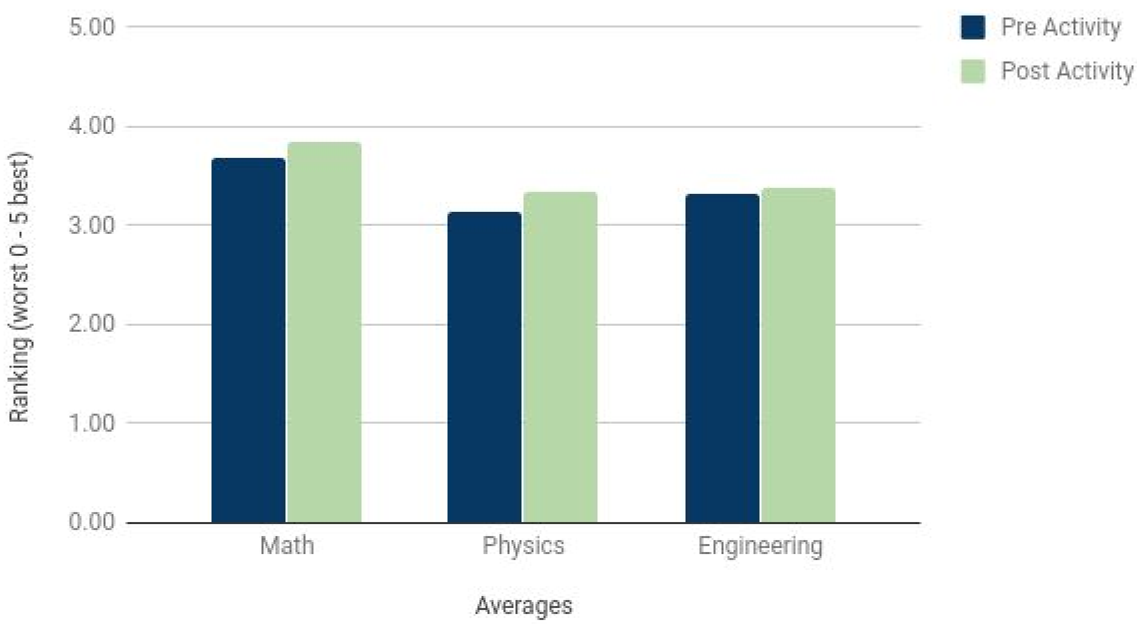


Figure 30: Participant interest in mathematics, physics, and engineering prior to and after the activity

As shown in Figure 30, the average interest in mathematics, physics, and engineering each increased slightly after participating in the lesson. Due to the sample size and reporting style it is not possible to definitively prove that the differences in reported interest levels were solely a result of the activity. In the post-activity survey, students were also asked to speculate as to why their interest increased or decreased after the activity. The word cloud in Figure 31 shows the keywords reported by the students.

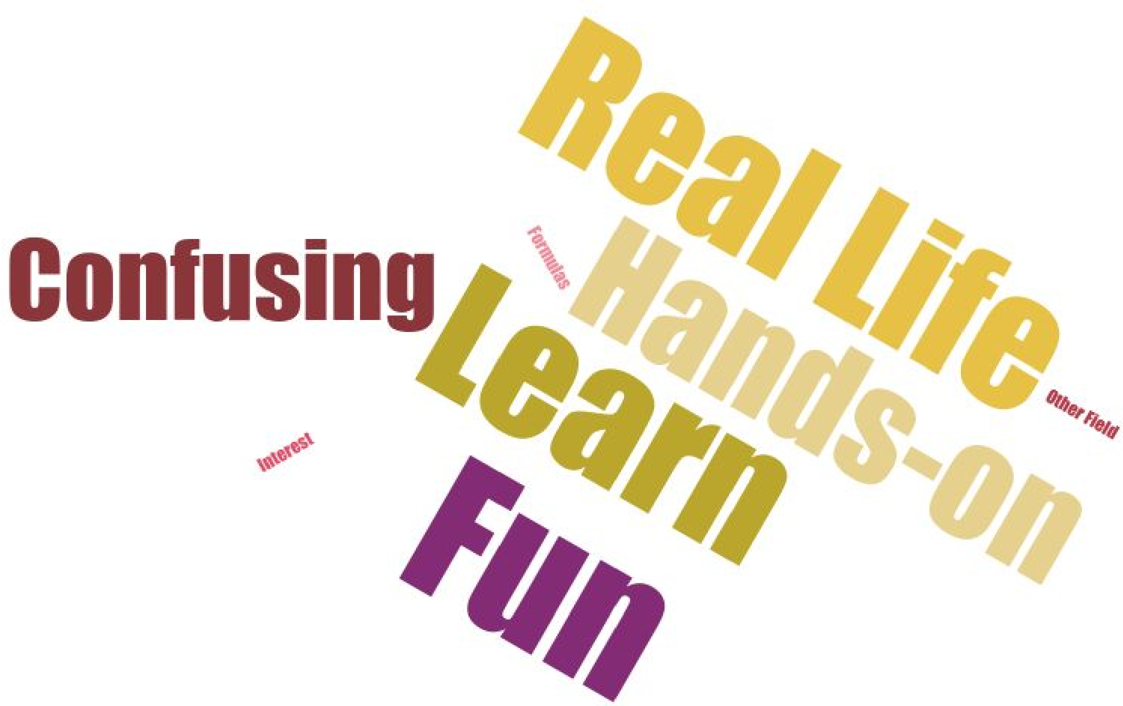


Figure 31: Why participant interest in mathematics, physics, and engineering increased or decreased

Many people commented saying that their interest remained similar to prior to the activity. Participants who felt their interest decreased expressed concern that the materials were too confusing. Those who increased their interest post-activity viewed the change to be due to learning new materials and the activity being fun, hands-on, and connected to real life applications.

Knowledge Levels

In the pre survey and post survey, students were asked to rank their knowledge of different concepts and components from zero to five (five being the highest knowledge level). This knowledge level was only collected through student's self reporting of knowledge. No assessment was completed to test actual student knowledge prior to or after the activity. Figure 32 shows the average student self-reported knowledge level prior to the activity and after the activity for math, physics, engineering, breadboards, batteries, switches, resistors, LEDs, motors, multimeters, voltage, current, and resistance.

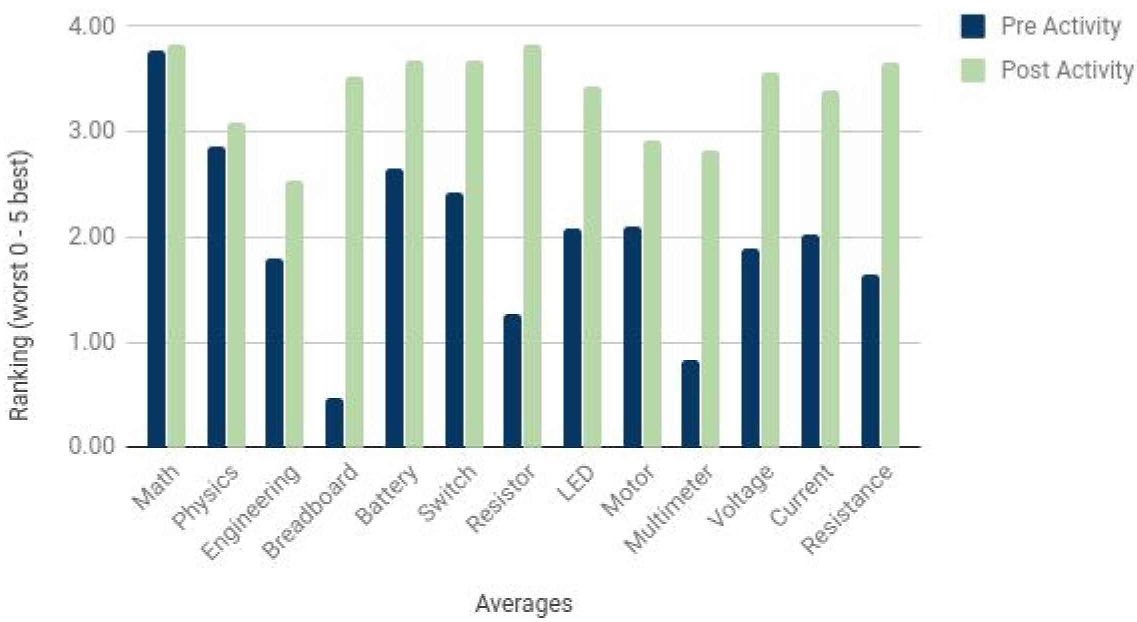


Figure 32: Participant perceived knowledge prior to and after the activity

Students ranked their average knowledge in mathematics, physics, and engineering higher than prior to the lesson. Perceived conceptual knowledge of voltage, current, and resistance also increased on average. Reported knowledge of breadboards and multimeters showed the greatest increase, however, all reported component knowledge increased post lesson. Breadboards and multimeters likely showed the greatest increase because the students may not of heard of them prior to the activity. The students also actively used the breadboard and multimeter in the lesson which could have increased their perceived knowledge levels. Due to the sample size and reporting style it is not possible to definitively prove that the differences in reported knowledge levels were solely a result of the activity. In the post-activity survey, students were also asked to speculate as to why their knowledge increased or decreased after the activity. The word cloud in Figure 33 shows the keywords reported by the students.

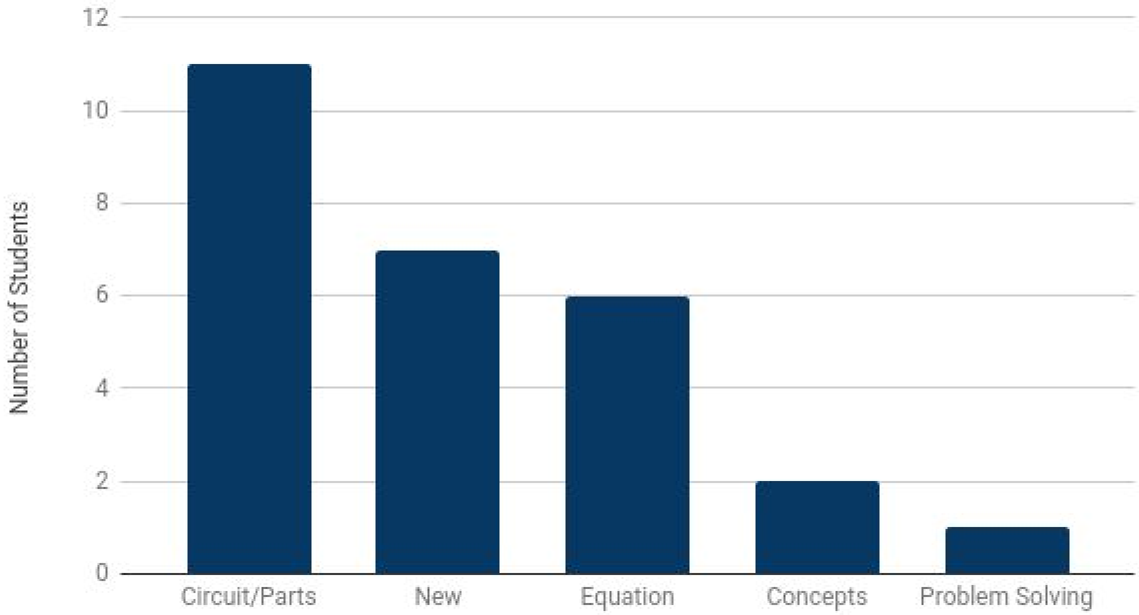


Figure 33: Participant reasons for increased knowledge

Participants ranked their knowledge higher post activity because they were able to work with various parts of the circuit, learned something new, and worked with various equations. They also reported higher knowledge levels because they worked with various concepts and used problem solving techniques.

Pursuing Engineering Interest

The main focus of this activity was to see if an interactive lesson could introduce high school students to electrical engineering and encourage them to seek already existing engineering programs, courses, or degrees. In the post-activity survey, students were asked, “Did this activity encourage you to look into signing up for engineering programs, courses, or degrees?” The results are illustrated in Figure 34.

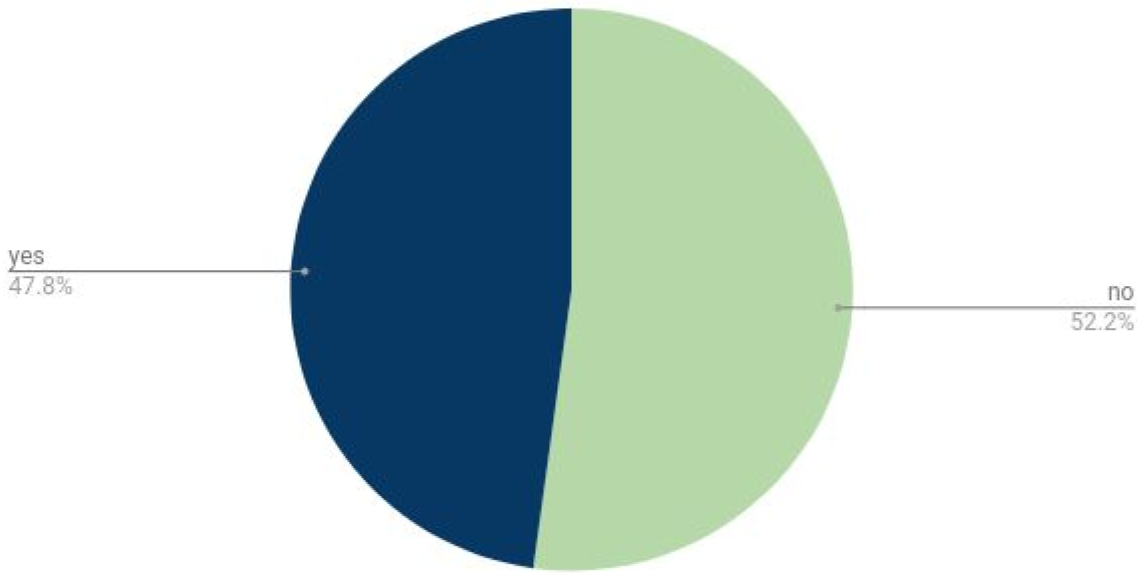


Figure 34: Percentage of students who were encourage to pursue further engineering opportunities

47.8% of the participants felt that the activity did encourage them to pursue further engineering opportunities. 52.2% of the participants felt that the activity did not encourage them to pursue further engineering opportunities. The students were also asked to explain why the activity did or did not encourage them to pursue engineering programs, courses, or degrees. The reasons why the activity did not encourage students to look into engineering opportunities is shown in Figure 35.

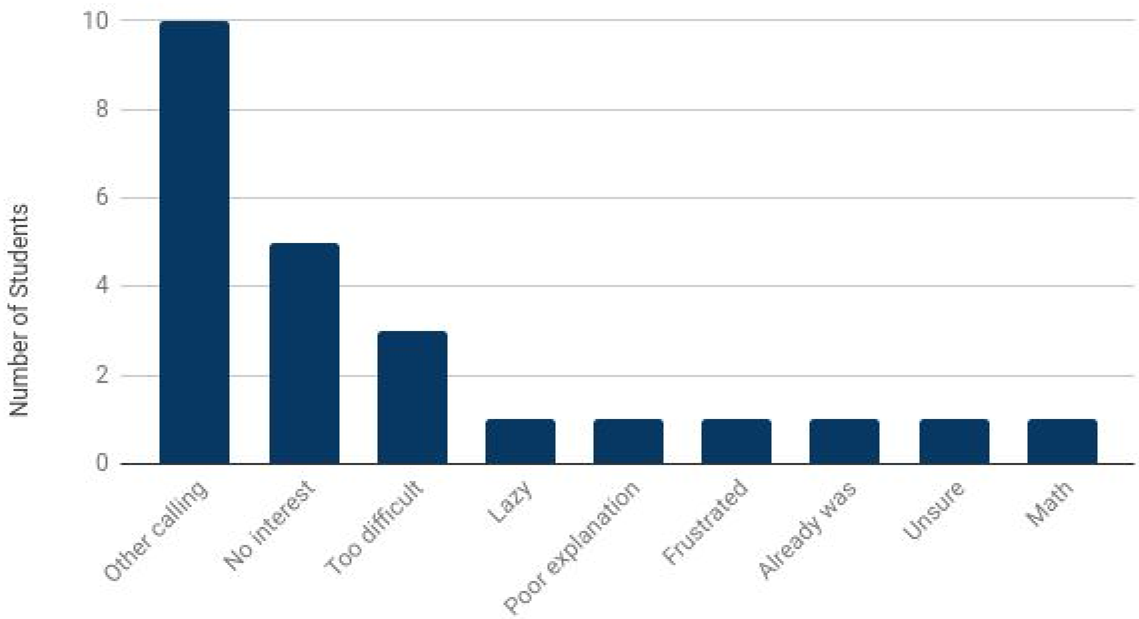


Figure 35: Participant reasons for not pursuing further engineering opportunities

The main reasons students did not feel encouraged to sign up for engineering opportunities was because they already had decided their career path, they were not interested in engineering, or it was too difficult. Since this lesson was presented to high school juniors and seniors, it is understandable that many of them would already have chosen a different calling or career path. In future iterations, this lesson would be presented to freshmen and sophomores to introduce the lesson prior to most students making their career decisions. The reasons why the activity did encourage students to look into engineering opportunities is shown in Figure 36.

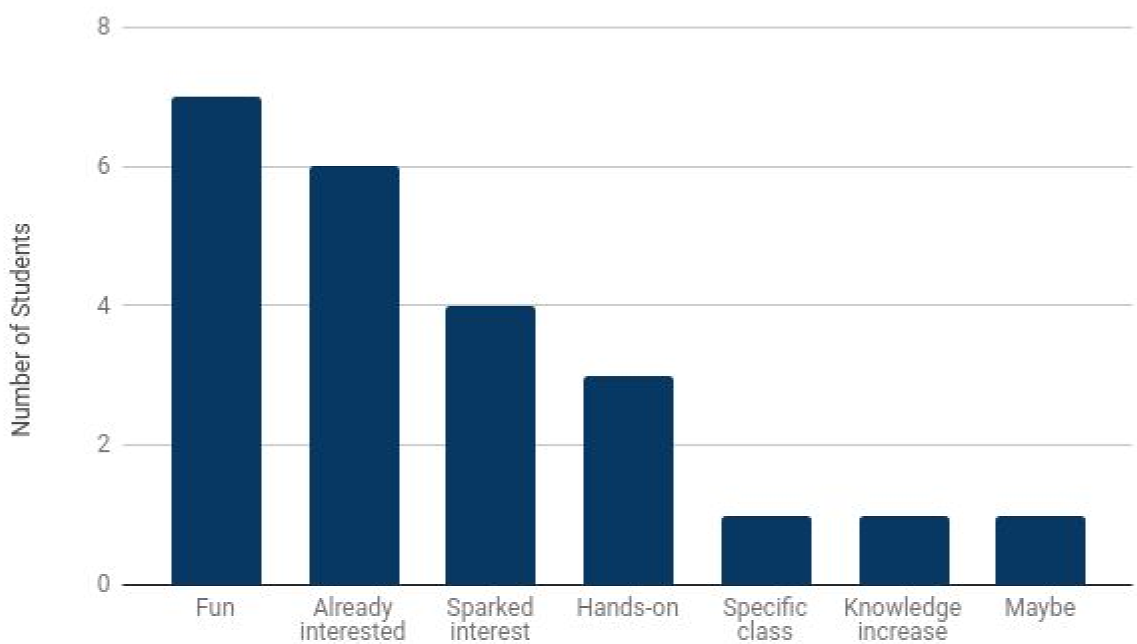


Figure 36: Participant reasons for pursuing further engineering opportunities

The participants who were encouraged believed the lesson sparked an interest in engineering because the activity was fun and hands-on. Others were already interested in engineering but still enjoyed the lesson to further their interest. The data displayed in Figure 34 was further broken down to show any differences between the activity's ability to encourage students to explore additional engineering opportunities if they had family or friends in STEM fields or if they did not.

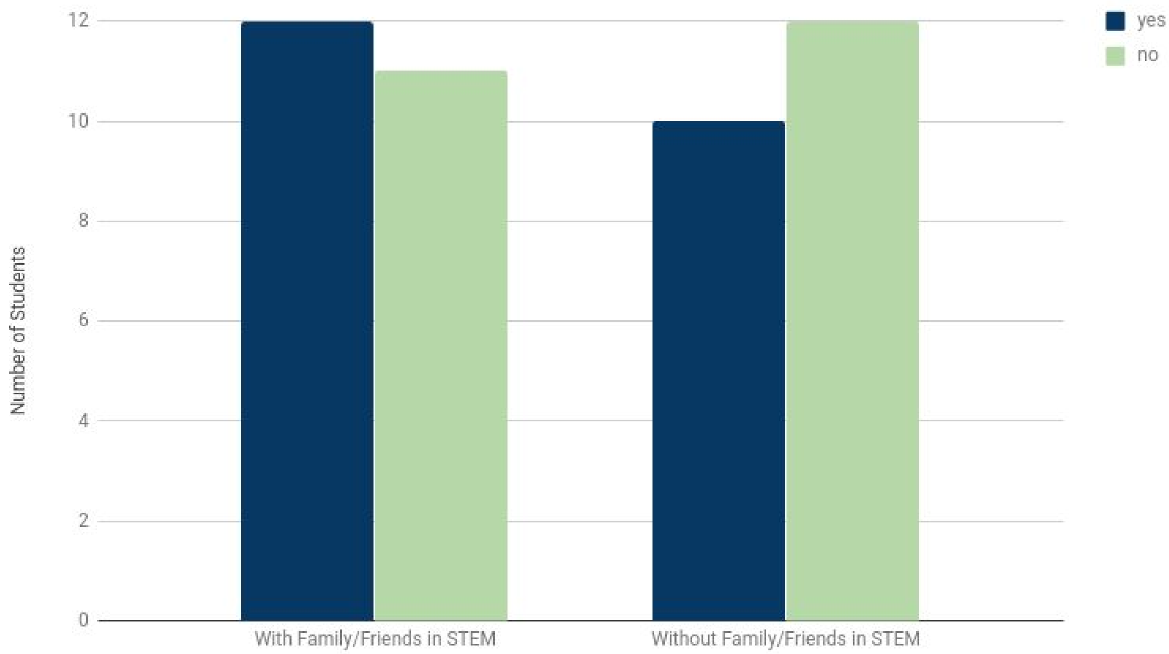


Figure 37: Number of participants encourage to pursue further engineering opportunities after the lesson depending on if they have family/friends in STEM fields

Of the participants without family or friends in STEM fields, 10 out of 22 were encouraged to pursue engineering opportunities after the lesson. This interest is less than those participants with family or friends in STEM, 12 out of 23 participants.

Teacher Feedback

All four classes were taught by the same teacher. This teacher greatly enjoyed the activity and felt like her students did too because the lesson used a different, hands-on approach. She perceived that her students learned the basics of the breadboard through connecting the components on the breadboard personally. The activity engaged her students by providing time to build and ask questions. Some suggestions the teacher gave were to provide a simplified version of the voltage divider equation to solve for the resistor value (R1). This saved time which students were able to use for questions and circuit building. The teacher saw the importance of giving step-by-step instructions for assembling the breadboard and following along with the equation sheet. This detailed approach helped decrease student confusion. The teacher observed that the students enjoyed working with the breadboard and seeing the immediate feedback and results from both the LED and the launch simulator. In future iterations, the teacher suggested giving further opportunities to answer questions during the introduction to the concepts and components. Due to class time constraints, this suggestion could not be incorporated during this iteration.

Reflection

The original outcome of this thesis was planned to be a journal article or conference paper to be published. I submitted files to IRB and resubmitted files when I received feedback suggesting edits or further information. The IRB process was stressful to ensure I provided all the information but their feedback was helpful and quick so the process was not postponed due to their responses. My original apprehension to submitting to the IRB was the possibility of submitting documentation which would be updated or unused later. Through this process, I realized it is better to submit early to IRB and then submit modifications rather than waiting until you have a final copy to submit. This will allow IRB to provide feedback sooner rather than later.

I was persuaded to pursue the ASEE conference by Dr. Carberry (my boss and past professor). He felt my project would be a good fit for the P-12 division. I discussed the idea with my thesis team and they agreed it could be a good fit. I submitted my abstract by the deadline the following week. I had never written an abstract before and was nervous to submit something so formal. A few weeks later, I found out that my abstract had been accepted. The rough draft of the paper was due the beginning of February so I planned to present my simulator in a high school in mid December to leave about a month and a half to evaluate the data and write the report.

In November, I decided to switch from the mechanical launcher to the simulator launcher. I was rushed to complete the simulator but was able to complete it before the end of the fall semester. I also completed the lesson plan, surveys, and presentation a week prior to when I planned to present in the high schools. Due to this timeline and the focus on the physical product, my thesis committee had less time to review the lesson plan. On December 3rd, I had worked all day to finalize the paperwork and sent it to my thesis team. I was so happy that I had finalized everything so I could present when I had intended to. However, I received the following feedback from one of my thesis professors:

> "I strongly suggest that you postpone teaching this lesson. … In my opinion, at the moment, you will need to do more work on lesson planning in order to represent yourself - and the ASU Engineering and Education Programs - well."

Needless to say, this feedback was not received well after significant dedication to completing the documentation, to the best of my ability, to meet the deadline. After lots of tears, I postponed the presentation and went back to work creating a more acceptable lesson plan.

I presented in four high school physics classes on January 10th and January 12th (the first week of school). Since it was the first week of school, I had to take off work to present on a Wednesday and Friday to avoid missing the first day of classes. Having a break between presentation days was not ideal because students needed to be refreshed of some material. Since it was also the first week of school for the high school, they happened to have shortened class periods on Wednesday. The teacher forgot about this detail, so I did not find out about this hurdle until the morning of the presentation. Despite the shortened classes, I was able to get through most of the information. The first two classes did not get as far, but the teacher was able to call them back during their study period to finish up the light dimming circuit. The last two classes did not need extra time because I was able to shorten the presentation time by providing the simplified voltage divider circuit equation. I had originally provided them with a version which solved for voltage which they would have to translate to solve for resistance. By providing the direct equation to solve for resistance, as suggested by the teacher, I was able to reduce the lesson time. I also provided detailed instructions on constructing the breadboard rather than providing images for the students to reference to complete their circuit. These step by step instructions decreased the amount of debug time needed. On Friday, was when I presented the simulator. This was the main time when I saw a difference between the AP and regular education classes. While going through the conversion equations, many of the AP students were able to follow along with the worksheet and my directions on the board. The regular education students need more direct instructions to complete the calculations. During the class presentations, one of the launch simulators did not work. I have not been able to determine the reason yet. Since one of the stations did not work, students had to stand in line longer to test their circuits with the simulator. During the polishing of the final prototype, I decided to incorporate alligator clips to increase the length and durability of the connection between the students' circuits and the simulator. This adaptation resulted in an additional requirement to teach the students how to use the alligator clips. Some students did not realize they were clips rather than plugs prior to demonstration. Since the wires were not directly labeled on the simulator, I had to hand the students the correct simulator wires for each connections. If time had permitted, I would have created an enclosure and further labels to help the simulator be more user friendly.

After presenting in the classrooms, I felt relieved and happy with my thesis. I felt that the presentations were successful and that the teacher and students enjoyed the activity. I then painstakingly entered all of the students' surveys into a spreadsheet to analyze. I created graphs and word clouds of the information to illustrate the survey results. By the time I had typed up and analyzed the survey information, it was the end of January. I had assumed that I would not be writing a conference paper as I had not written a research paper before and did not feel I could complete an acceptable draft prior to the deadline. I met with my director and he felt I could complete a rough draft by the deadline. So I wrote and submitted a conference paper rough draft in one weekend with no prior research paper experience. I knew that my submission was a rough draft and that I would receive feedback which I would need to edit my paper to reflect, but I did not expect the feedback I received.

The feedback I received from my thesis team was usually always supportive and optimistic to how the conference would accept my work. So when I got feedback discussing how much my research was lacking I was hurt. I felt like my thesis team had not prepared me. I had no research experience and had expected them to provide me with feedback to ensure I provided the conference with an acceptable research paper. Some of the feedback I received was as follows:

- "This paper lacks a thorough literature review and has serious methodology issues. The absence of a control group and thus parametric testing limits the research value of this study. Claims about the intervention's effectiveness are not support with appropriate evidence (descriptive data only, no comparison group)."
- "This paper documents a new experiment to be performed in high school to teach students about circuits and electrical engineering. I find the experiment trivial, and I do not completely understand the learning objective of the experiment. While the survey data suggests that students' enjoyed the activity, I do not think the survey questions accurately reflect the goals intended by the authors for their experiment or, perhaps, do not yield constructive answers to support a positive assessment of the quality of the experiment at achieving its goals. I also do not understand the difference in the figures for the LED and launch circuits. They seem repetitive, i.e. why do I need a physical picture of the breadboard and the schematic, and a circuit diagram. The paper also includes a number of typographic errors, including the fact that figures should not have titles if they have a caption below them and a poor use of references within the text and then the associated development of a bibliography."

- “The description of the module is certainly interesting, but how did you evaluate the effects (since that's in your title)? You need some methods and results in both the abstract and the paper.” “The presented approach is the basic principle behind every experiment is science and engineering labs. While the experiment is interesting for pre-college students, there are tons of similar experiments available in various sources. What may distinguish this manuscript is the evaluation of the impacts of the experiment(s) on short-term and particularly long-term interest of students in engineering.”

After hearing this feedback, I did not feel I could continue with the conference paper. The feedback did not just point out flaws in my paper as I expected but rather the research itself. I could not incorporate the feedback presented without redoing my experimental design and implementation. I would need to collect data on a classroom that did not complete the lesson to collect control group data and present to hundreds more students to gather large enough amounts of data to validate any of my claims. I did not have the time or resources to incorporate any of these aspects. After meeting with my thesis team, they agreed that most of this feedback was based on a very quantitative research approach which my research does not fit into. They thought that with some editing my research could fit in very well with the Resource/Curriculum Exchange category of the conference. Resource/Curriculum Exchange focuses more on the design of lessons and less on qualitative measures. However, despite this reassurance, I did not want to continue with the conference paper option. Barrett would not provide funds for me to present at the conference since I would graduate prior to the presentation date. I also wanted to focus more on my product (the simulator) which I felt was being disregarded when focusing on the research paper. So rather than focusing on developing a journal article or conference paper, I decided to write custom report which combines a mix between a blog post and an instructable. By switching to this writing method, I am able to focus more on communicating why I decided to pursue this product, what I designed, and how the user received my design. Despite being called an Honors Thesis, this was supposed to be a creative project. I feel that this paper provides the details of my creative project.

Lessons Learned

The biggest lesson I learned during this project is to have a vision and revisit the vision often. This project had an original vision to focus on electrical engineering, software engineering, and teaching. Throughout the idea creation processes, the project gained a mechanical engineering aspect. This additional aspect consumed considerable funds and time which could have been used to further advance the original vision. The mechanical component also distracted from designing for the customer. Originally, the design was to build small box launchers for each group of students. As the project progressed, the launcher got bigger and bulkier which would not be ideal for use or storage in a classroom. By revisiting the original vision, I was able to better align the product with my original goal and with the customer needs. This pivot to a simulator provided the customer with a more user-friendly product and me with a new found inspiration to continue working on the project after numerous setbacks and frustrations.

I learned in this project that when receiving feedback, I respond to the feedback. If someone suggests a change to my paper or project, I explain the reasoning for my process and result. If I think the feedback should be incorporated, I make a note to add the changes. If I do not think the feedback should be incorporated, I explain why I feel the feedback does not fit with my intentions for the paper or project. I found out that to others this approach makes them feel as though I am disregarding their feedback. In the future, rather than discussing the feedback in person, I will acknowledge their feedback and make note of it and decide to accept or deny the changes outside of meetings. This approach will make everyone feel that their feedback is being heard and considered. I have also been told, in this project, that my written feedback can be read as aggressive because I condense my sentences and make replies with counter statements to feedback. I will work on sounding less aggressive in written feedback by adding more questions rather than statements to my replies. I will also clarify that my replies are the start of a conversation to clarify why their feedback should or should not be included. For example, rather than writing “the reflection is in the section above”, I will write “Thank you for your feedback. I would like to start a discussion about what additional reflection you feel is needed in this report. I feel I have included reflection components in the section above and would like to clarify what components I may have missed”.

I learned in this process that it is not necessary to only follow one career path. Ever since I started college, I have been torn between continuing a career in engineering or returning to my original desire to be a teacher. Through this project, I realized that there are always opportunities to bridge the gap between professions to pursue a personal passion. This project has helped me realize my love for designing learning tools. My ultimate goal is to one day own my own business. This project has helped me realize I can combine my engineering degree and love of teaching to create a business based around designing learning tools for teachers. In the meantime, this project has also helped me focus my job searches. I have realized through this project that I enjoy working with the whole system rather than one small portion. So while I pursue creating my own business, I will use what I learned through this project to look for jobs at startup companies which will allow me to work with an entire product rather than designing or testings a small part without interaction with the product as a whole.

This project has also made me realize that I do not wish to pursue research in the future. From this experience, I have seen that research focuses more on the results and references rather than the process of creating a product or the product itself. Through feedback, I have found that I much prefer creating a product based on personal or customer ideas. I believe that a product can have value as long as there are even a few people who desire the product. This is something I found is missing in research. Without a substantial literature analysis as to why the product should be created, the research receives push back, not for the idea presented but because the idea was not discussed in articles prior to the current research. I understand that this may not be applicable to all research, but this has been what I have experienced in this process to cause me to refrain from pursuing research personally in the future.

Summary

In summary, I believe I found a market to introduce high school students to electrical engineering through their math and science courses. I brainstormed and researched various ideas prior to choosing a focus on parabolas through projectile motion. Sketches and physical prototypes were made of various designs before developing circuit kits and a ball projectile simulator. The kits and simulator were produced, and after receiving IRB approval, I presented a lesson plan containing the materials to four physics classes. I collected surveys during the presentations to evaluate the student and teacher enjoyment of the lesson and activity. This product was successful because it was found through user feedback to be enjoyable by the majority of the students and the teacher. In the consumer sample, the average student also increased interest and knowledge in math, physics, and engineering. Most students also reported that this interdisciplinary simulator and circuit kit also increased their interest in pursuing engineering programs, courses, and degrees. The original output of this thesis was designed to be a journal article or conference paper; however, through writing drafts and receiving feedback, it was found that a custom style report would better present the information to increase focus on the creative product designed. The completion of this product helped me to realize I do not want to pursue research, but I would like to pursue designing my own business around creating custom learning tools.

Future Work

In the future, further consumer studies would be done to collect further user feedback. Most of the students in this iteration were juniors or seniors. Ideally, future iterations would incorporate this product into freshman or sophomore level math classes to introduce the product to a larger audience with more time to decide on their courses and career prior to college. Further analysis of incorporating this product into a classroom with a teacher without prior knowledge of engineering topics, or in a high school with different funding could also provide further insight for innovating the product.

Future iterations of this lesson should include more time for presentation to allow for further explanation and questions to reduce student confusion. Future iterations of the product itself will include an enclosure and wire labels for easier use. The product should also be transferred from a Raspberry Pi 2 to a Raspberry Pi Zero W to reduce size and cost.

The lesson plan provided in Appendix A of this paper is the lesson plan used during the collection of user feedback. Since that time, I have received further edits to be incorporated to the lesson plan which would be taken into consideration in future testing. Some of these edits include further connections to specific mathematical, science, and engineering standards, specifying initial conditions and electrical components in the learning objectives, and clarifying which sections of my lesson focus on learning through deductive versus inductive reasoning.

Below is a list of the Arizona mathematical, science, and technology standards which correspond to the lesson in its current state or which the lesson could be adapted slightly to fit. These standards were analyzed prior to creating the lesson, but in future iterations of this lesson, the lesson plan would be adapted to better align with these standards.

Arizona's College and Career Ready Standards: Mathematics (*Arizona's College and Career Ready Standards: Mathematics,* 2013)

- Number and Quantity: Quantities
    - Reason quantitatively and use units to solve problems.
- Algebra: Seeing Structure in Expressions
    - Interpret the structure of expressions
    - Write expressions in equivalent forms to solve problems
- Algebra: Creating Equations
    - Create equations that describe numbers or relationships
- Algebra: Reasoning with Equations and Inequalities
    - Understand solving equations as a process of reasoning and explain the reasoning
    - Solve equations and inequalities in one variable.
    - Solve system of equations
    - Represent and solve equations and inequalities graphically
- Functions: Interpreting Functions
    - Interpret functions that arise in applications in terms of the context
- Functions: Building Functions
    - Build a function that models a relationship between two quantities
- Functions: Linear, Quadratic, and Exponential Models
    - Construct and compare linear, quadratic, and exponential models and solve problems
    - Interpret expressions for functions in terms of the situation they model

- Geometry: Expressing Geometric Properties with Equations
    - Translate between the geometric descriptions and the equation for a conic section
    - Use coordinates to prove simple geometric theorems algebraically
- Geometry: Modeling with Geometry
    - Apply geometric concepts in modeling situations

Science Standard Articulated By Grade Level: High School (*Science Standard Articulated By Grade Level: High School*, 2005)

- Inquiry Process
    - Observations Questions, and Hypotheses
    - Scientific Testing
    - Analysis, Conclusions, and Refinements
    - Communication
- Physical Science
    - Motions and Forces

Educational Technology Standard Articulated by Grade Level: 7th Grade to High School (*Educational Technology Standard Articulated by Grade Level: 7th Grade to High School,* 2009)

- Creativity and Innovation
    - Knowledge and Ideas
    - Models and Simulations
- Communication and Collaboration
    - Effective Communications and Digital Interactions
    - Digital Solutions
- Research and Information Literacy
    - Planning
- Critical Thinking, Problem Solving, and Decision Making
    - Exploring Solutions
- Technology Operations and Concepts
    - Applications
    - Problem Solving
    - Transfer of Knowledge

In future iterations of the lesson plan, I would make sure to specify the initial conditions and electrical components which were stated in the learning objectives. The initial conditions which were mentioned referred to the voltage supplied from a battery or power supply and the resistors chosen. The electrical components which the students learned the basic functionality of were breadboards, batteries, LEDs, resistors, multimeters, motors, wires, and switches.

In the current lesson plan, there are examples of both inductive and deductive reasoning. The first circuit the students create is a light dimming circuit. While making the circuit, the students calculated a range of resistance values which would work with their circuit. However, the students needed to use inductive reasoning to make a generalization about what increasing resistance would do to the brightness of the light. The students were able to observe different light brightness levels by testing different resistor values. The students then move to creating the simulator circuit. From the light dimming circuit, the students inducted that more resistance caused a dimmer light and less resistance created a brighter light. Through deductive reasoning students are now able to deduct that more resistance should create a shorter launch whereas less resistance should create a higher launch. Students were then able to test their hypothesis and observe the results of various resistor values in the simulator circuit. In future iterations of the lesson plan, these sections would be clearly labeled to indicate which style of reasoning the section focuses on. These labels will help the teacher structure the lesson and optimize the student learning through a combination of inductive and deductive reasoning components.

Hopefully, the work done in this creative project will influence and inspire me to design other learning tools and lessons. Ideally, future iterations will inspire me to create a business around custom learning tools.

References

Abbott, M., Warter-Perez, N., Kang, E., & Dong, J. (2012). Integrating Power Engineering Into Middle and High School Math Curriculums. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* San Antonio, TX.

Arizona Department of Education. (2005). *Science Standard Articulated By Grade Level: High School.* Retrieved from https://www.azed.gov/standards-practices/k-12standards/standards-science/

Arizona Department of Education. (2009). *Educational Technology Standard Articulated by Grade Level: 7th Grade to High School.* Retrieved from https://www.azed.gov/standards-practices/k-12standards/standards-educational-technology/

Arizona Department of Education. (2013). *Arizona's College and Career Ready Standards: Mathematics.* Retrieved from http://www.azed.gov/standards-practices/k-12standards/mathematics-standards/

Kotys-Schwartz, D., Sullivan, J., Yowell, J., & Zarske, M. (2005). Creative Engineering: Helping Ninth Grade Students Discover Engineering. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* Portland, OR.

Krause, S., Culbertson, R., & Carlson, M. (2008). Attitude Shifts in High School Math and Science Teacher Practice Through Connecting Math, Science, and Engineering in a Math Science Partnership: Project Pathways. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* Pittsburgh, PA.

Nathan, M., Tran, N., Phelps, A., & Prevost, A. (2008). The Structure of High School Academic and Pre-Engineering Curricula: Mathematics. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* Pittsburgh, PA.

Pelletier, M. & Chanley, P. (2007). Building Math Skills in Context: Integrating High School Mathematics with Engineering and Technology. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* Honolulu, HI.

Seidle, N. (n.d.). *Analog to Digital Conversion*. Retrieved from https://learn.sparkfun.com/tutorials/analog-to-digital-conversion/relating-adc-value-to-voltage

Sherburne-Michigan, M. (2017). Parents in STEM careers guide girls to 'hard science'. Retrieved March 21, 2018, from https://www.futurity.org/stem-careers-parents-girls-1638342/

Uysal, S., Yasar, S., Baker, D., Kurpius-Robinson, S., Krause, S., & Roberts, C. (2007). Inside the Classroom: Challenges to Teaching Engineering Design in High School. In proceedings of the *American Society for Engineering Education Annual Conference & Exposition.* Honolulu, HI.

Appendix A

Development and Evaluation of an Electrical Engineering and Math Curriculum Module for High School Students

Lesson Plan

Summary

Most students who enter engineering or other STEM fields come from families who work in those fields. There are STEM programs and classes for students who are interested in related fields, but the conundrum is that people need to be interested in order to pursue participation. This lesson plan and corresponding activity aim to increase student interest in engineering while solidifying students' understanding of projectile motion, parabolic equations and graphs, and basic mathematical calculations.

Students are asked to devise different methods of which they could launch a ball. The focus then adjusts to specifically electronic launch systems. First, they are introduced to various electrical engineering concepts and circuit components. They are then tasked with creating a light dimming circuit to calculate and demonstrate how different resistor values will create a different output voltage and thus a different brightness from the LED. This circuit is modified to attach to a simulated launch station. The student groups then test different resistor values with the launch height. They are tasked with the goal of determining the resistor value they need to reach a certain height and what height they will reach if they choose a specific resistor value.

Connections

The activity contains connections to electrical engineering, physics, and mathematics.

Electrical engineering is introduced through the creation of simple circuits. Circuit are used in items as simple as a ball launcher or automatic paper towel dispenser to the computer systems in NASA's spaceships.

Physics is introduced in this activity through projectile motion. Projectile motion is used in ball launching, missiles launching, or meteor travel.

Mathematics is incorporated in this activity through solving linear and quadratic equations and graphing quadratic equations. Quadratic equations are used in figuring out profits, calculating the area of a room, or finding the speed of a ball launch.

Pre-Req Knowledge

A basic knowledge of solving linear and quadratic equations. Familiarity with projectile motion.

Learning Objectives

After this activity, students should be able to:

- Understand the basic functionality of different electrical components.

- Determine the height of an object based on initial conditions.

Educational Standards (Arizona)

Mathematics

Mathematical Practices (MP)

Physics

Concept 1: Observations, Questions, and Hypotheses

Concept 2: Scientific Testing (Investigating and Modeling)

Technology

Strand 1: Creativity and Innovation

Strand 2: Communication and Collaboration

Strand 4: Critical Thinking, Problem Solving, and Decision Making

Materials List

For Launch Station:

1 - Projector

1- Raspberry Pi

1- Analog to Digital converter

1- HDMI cord

16 - Alligator clips

10 - Jumper wires

*All of the launch station components will be provided pre-assembled for this lesson. The Raspberry Pi will just need to be plugged into an outlet and the projector.

For Student Kit (for 3-4 students):

1- Multimeter

1 - Breadboard

1 - 9V battery

1 - Battery connector

1 - LEDs

3 - Jumper wires

1 - Switch

14 - Resistors

Introduction/Motivation

Everyone who has thrown a ball has dealt with projectile motion. However, physically throwing a ball is not the only way to create projectile motion.

In today's activity, we will explore one of the ways to electronically launch a ball. Using an electrical control circuit and mathematical calculations, we can calculate the required circuitry needed to launch the ball to a desired height.

Why is this important? Imagine you are trying to launch a rocket into space. It is important to overcome Earth's gravitational pull for a successful launch but it is also important to use as little fuel as possible to ensure enough is available for the rest of the flight. Calculations and electric circuits can help obtain this controlled launch.

Vocabulary/Definitions

Breadboard - A breadboard is used to hold and connect electrical components. Each horizontal line is connected and the vertical sections on the sides are connected.

Battery - A battery stores energy which can be used by other electrical components when connected in a circuit. There is one positive side and one negative side on a battery.

Switch - A switch will connect and disconnect a circuit. When the switch is in the open position, it breaks the circuit. When the switch is in the closed position, the circuit is once again connected allowing current to flow and the circuit to work.

Resistor - A resistor causes a voltage drop causing a decrease in current. Resistors are often used to prevent other components from receiving too much power and burning.

LED - An LED causes a voltage drop but uses that voltage drop to release light. You have to make sure you plug in a LED the correct direction or the LED will not light up. The longer leg needs to go to the positive side of the circuit.

Motor - A motor takes electrical energy and turns it into rotational motion.

Voltage - Voltage is the electrical potential between two points. Voltage is measured in Volts.

Current - Current is the measure of the flow of electrons and is measured in Amperes.

Resistance - Resistance is the opposition an object has to the flow of electrons. Resistance is measured in Ohms.

Procedure

Background

To effectively deliver this activity, it is necessary for the instructor to be familiar with the connections between the equations provided for voltage, current, resistance, angular velocity, linear velocity, maximum launch height, and total launch time.

Before the Activity

- Set up the simulated launch station by plugging in the Raspberry Pi power supply into the wall and the HDMI cord into the projector or monitor.
- Gather the student kits and ensure each kit has the required components.

- Print class copies of the pre-activity survey, during-activity survey, and post-activity survey.

<u>The Activity</u>

1. Write the learning targets on the board and introduce the activity through the targets

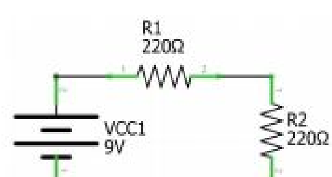
   What - Understand the basic functionality of the different electrical components.
   Determine the height of an object based on initial conditions.
   How - Create an electrical circuit to simulate a ball launch
   Why - To learn more about electrical engineering
2. Have the students break up into groups of 2-3 students. Assign a letter to each person in the groups A, B, C. Use these letters throughout the lesson to ensure everyone participates. Separate out tasks based on letter and ask for a thumbs up from different letters when a task is complete.
3. Have the students complete and turn in the pre-activity survey.
4. Think, Pair, Share: Ask students to write down different ways to launch a ball. Have the students discuss with other students near them. Then ask each group to share one idea with the class..
5. Introduce the idea of an electrically controlled launch, much like in the Introduction/Motivation section.
6. Think, Pair, Share: Ask students to write down different reasons why having a controllable launch is important. Have the students discuss with other students near them. Then ask each group to share one idea with the class..
7. Explain the overall flow for the class and reiterate the goal of the activity.
8. Pass out the kits. Have the students spread out their parts on their desk.
9. Introduce the definitions for the electrical components and concepts provided in the vocabulary/definitions section. As you introduce the components, have the students check to make sure their kit has all the necessary components. Use a water analogy to explain voltage, current, and resistance. Imagine you have a pipe with water flowing through it with certain current. Now, if part of the pipe was squeezed so it was smaller what would happen to the water current? The current would decrease because the water experience higher resistance from the tube. The same goes for electricity through a wire and resistor. The voltage drop across a resistor is shown with the difference in the amount of water on each side of the resistor or smaller pipe. For example, if 9 units of water were measured on the left and only 7 units were measured on the right, the drop would be 2 units. The same goes for voltage; 9 volts down to 7 volts would show a 2 volt drop across the resistor.
10. Introduce Ohm's Law to show the relationship between voltage, current, and resistance.

    Voltage (V) = Current (I) * Resistance (R)

    Provide examples like the following:

Current = 2 Amps	Resistance = 10 Ohms	V= (2 A)* (10 Ohms)	V = 20 Volts
Voltage = 5 Volts	Resistance = 1 Ohm	5 V = I * (1 Ohm)	I = 5 Amps

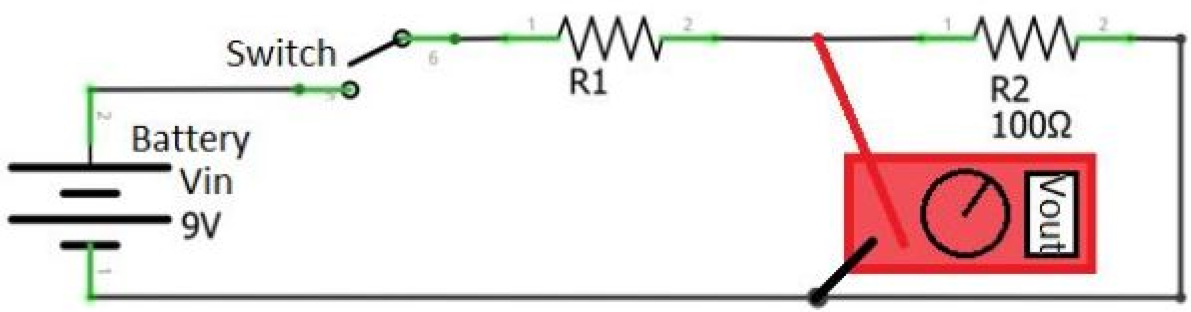
    * Trivia: Ohm's Law is called Ohm's law because Georg Ohm's research with resistors resulted in the founding of this relationship. The symbol for current (I), originates from the French phrase intensité de courant, (current intensity).



11. Introduce series resistor configurations.
    Series: Voltage drops
        Current is constant
        Resistance adds (RT = R1 + R2)
12. Introduce how to use a multimeter. This activity will only involve measuring voltage. So make sure the dial is turned to the 20 DCV section and the probes are plugged in as shown. The students will put one probe on each side of whatever component they wish to measure. Have each student measure the voltage of the battery.

13. Introduce the voltage divider circuit and equation.

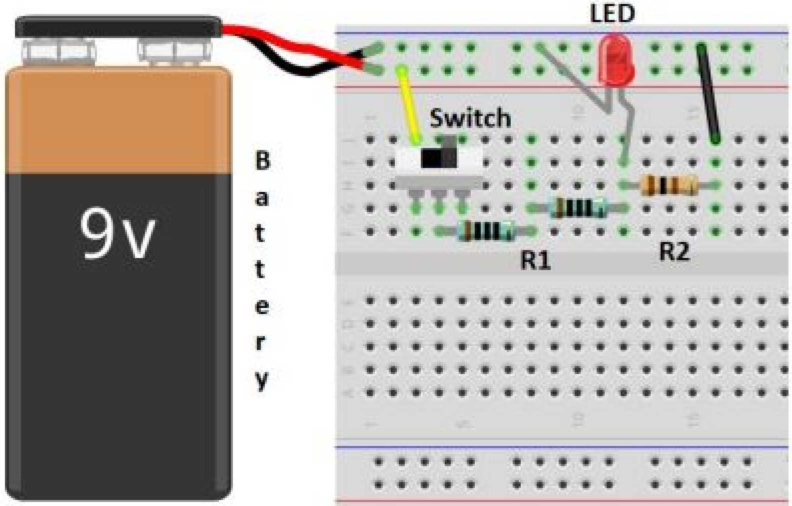
$$Vout = Vin * \frac{R2}{R1+R2}$$



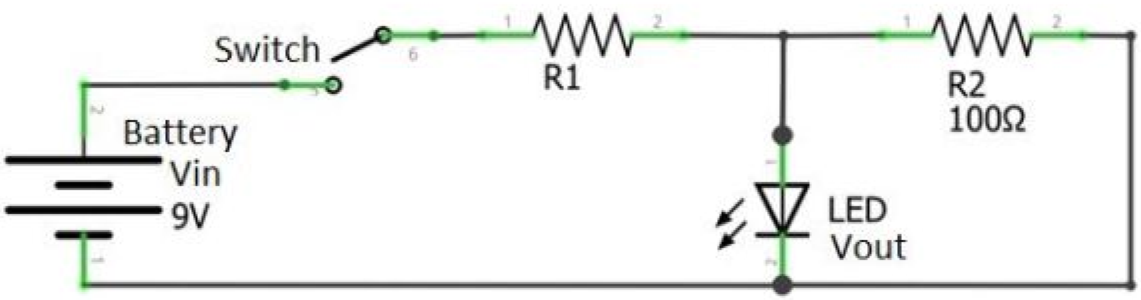
There will be a voltage drop across the first resistor. Based on the ratio between the resistance of R1 and R2 and the voltage of the battery, we can find the voltage which would be measured between the resistors. You can then put different components at this location to control the voltage provided to that component. This is where the LED will be connected and when the simulation will be connected.

14. Have the students construct the light dimming circuit as shown below. Don't have them plug in anything for R1 until calculations are completed. R1 is represented as 2 blue resistor so show how multiple resistors should be placed in series to get the correct value if needed.

Breadboard



Schematic



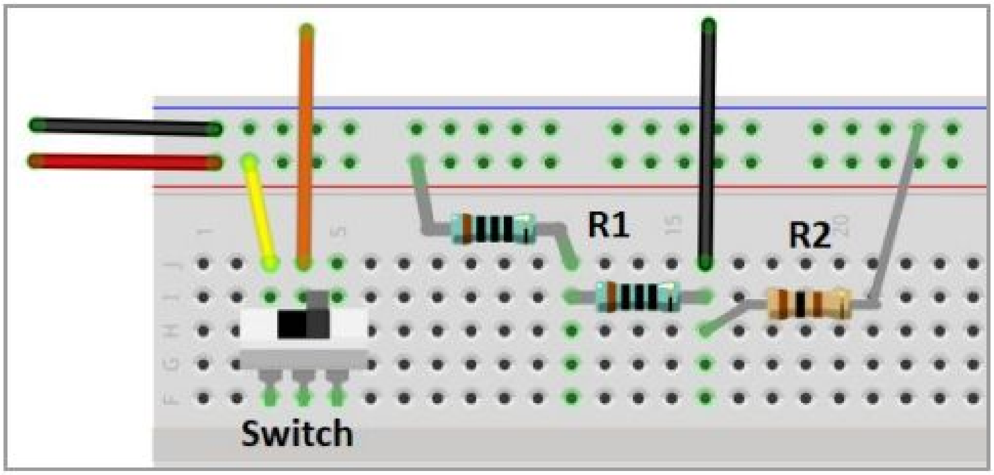
15. Have the students calculate the range for R1 for the light dimming circuit.

$$Vout = Vin * \frac{R2}{R1+R2}$$

    Vin = measured voltage of your battery
    R2 = 100 ohms
    Vout depends on the color LED you are using
    - Red/Yellow : 1.8 - 2.3 V
    - Blue/Green : 2.8 - 3.6 V

    Find the acceptable range for R1 by finding the value for R1 at max Vout and min Vout based on the LED you choose.
16. Have the students complete the Light Dimming portion of the During-Activity Survey.
17. Have the students construct the launch simulation circuit as shown. Don't have them plug in anything for R1 until calculations are completed.

Breadboard



Battery connector - from power and ground to simulator
Orange - from switch to simulator
Black - from resistors to simulator

18. Have the students calculate the range for R1 for the simulated circuit.

$$Vout = Vin * \frac{R2}{R1+R2}$$

Vin = power supplied from Raspberry Pi = 3.3V
R2 = 100 ohms
Vout range is 1.0V to 3.3V. Less than 1.0V will not supply enough voltage to launch a ball.
Find the acceptable range for R1 by finding the value for R1 which would create a max launch height and min launch height.

19. Pass out the equation sheets and go through a step by step example of all the calculations and an example launch simulation. If 3.3V is used for the supplied voltage, the answers should match those shown below:
    Voltage = 3.3V
    Angular velocity = 195.16 rad/s
    Initial velocity = 3.9 m/s
    Total time = 0.8 sec
    Final height = 0.78 m
20. Have the students complete the Launch Simulation portion of the During-Activity Survey. Make sure to provide copies of the equation sheet for this portion.
21. Collect the During-Activity Surveys and pass out the Post-Activity Surveys.
22. Collect the Post-Activity Surveys and organized kits.

Attachments

- Pre-Activity Survey
- During-Activity Survey
- Post-Activity Survey
- Equation Sheet

- Sample Presentation

Safety Issues

Students will be in contact with electrical components. The occurrence of mild shock from a 9V battery is possible.

Assessment

Pre-Activity Survey

The pre-activity survey collects information about the student and their knowledge of the material prior to the activity.

During-Activity Survey

The during-activity survey has the students record the voltage of their battery, the range of resistor values for R1, and the voltages measured across the LED for the light dimming circuit. The during-activity survey has the students record the voltage provided by the simulator and the range of resistor values for R1. The students then record their calculated and simulator measured values for the voltage, R1 value, angular velocity of the wheel, initial ball velocity, total launch time, and maximum launch height. The student is asked to record these values when they choose various resistor value settings.

Post-Activity Survey

The post-activity survey collects information about how the student's knowledge and opinions changed based on the lesson and activity.

Contributors

Kylee Burgess
Dr. Shawn Jordan
Dr. Sohum Sohoni
Dr. Barbara Kinach

Appendix B

Equation Sheet

Voltage → Motor Angular Velocity

Convert voltage to angular velocity of the motor using the following equation:

$$\omega = \frac{V}{A} + B$$

ω is angular velocity

V is voltage (volts)

A = 0.034 V·s/rad

B = 98.1 rad/s

A and B are constants composed of the following...

Torque, resistance of the motor, torque constant, and motor constant

However, since the motor is considered to be under constant load these values can be condensed into two constants A and B for simulation purposes.

Motor Angular Velocity → Initial Velocity of the Ball

Convert the angular velocity of the motor to the initial velocity of the ball using the following equation:

$$v_0 = \omega * r$$

ω is angular velocity

v_0 is initial velocity

r is the radius of the wheel = 0.02 m

* For this simulation, assume there is no loss during the transfer from angular to initial velocity

Initial Velocity of the Ball → Time to Height of Launch

Find the time it takes to reach the maximum height of the launch using the following equation:

$$v_f = v_0 - gt$$

g is gravitational constant = 9.81 m/s^2

t is time

v_0 is initial velocity

v_f is final velocity

Time to Height of Launch → Maximum Height of Launch

Find the maximum height of the launch from the time and the initial velocity using the following equation:

$$y_f = -\frac{1}{2}gt^2 + v_0 t + y_0$$

y_f is final height

y_0 is initial height

g is gravitational constant = 9.81 m/s^2

t is time

v_0 is initial velocity

Appendix C

Development and Evaluation of an Electrical Engineering and Mathematics Curriculum Module for High School Students

STUDENT PRE-ACTIVITY SURVEY

Prior to the Activity

1. What is your gender? (circle one)

   Male   Female   Other ____________   Prefer Not to Answer

2. What class is this survey taking place in? (circle one)

   Mathematics   Physics   Engineering

3. What grade level are you? (circle one)

   Freshman   Sophomore   Junior   Senior

4. Rank your interest in: (0 = none, 1 = low, 5 = high)

   a. Mathematics (circle one)   0   1   2   3   4   5

   b. Physics (circle one)   0   1   2   3   4   5

   c. Engineering (circle one)   0   1   2   3   4   5

5. Do you have any family members or close friends in the above fields or other STEM fields (Science, Technology, Engineering, or Mathematics)? (circle one)   Yes   No

6. If yes, what relation are they to you and what field are they in?

   ____

   ____

   ____

7. Do/did they encourage you to pursue STEM related fields? (circle one)   Yes   No

8. Rank your knowledge level in: (0 = none, 1 = low, 5 = high)

   a. Mathematics (circle one)   0   1   2   3   4   5

   b. Physics (circle one)   0   1   2   3   4   5

   c. Engineering (circle one)   0   1   2   3   4   5

9. BEFORE THE LESSON: Rank your knowledge of the following components/concepts: (circle one for each row) (0 = none, 1 = low, 5 = high)

a.	**Breadboard**	0	1	2	3	4	5
b.	**Battery**	0	1	2	3	4	5
c.	**Switch**	0	1	2	3	4	5
d.	**Resistor**	0	1	2	3	4	5
e.	**LED**	0	1	2	3	4	5
f.	**Motor**	0	1	2	3	4	5
g.	**Multimeter**	0	1	2	3	4	5
h.	**Voltage**	0	1	2	3	4	5
i.	**Current**	0	1	2	3	4	5
j.	**Resistance**	0	1	2	3	4	5

Appendix D

Development and Evaluation of an Electrical Engineering and Math Curriculum Module for High School Students

STUDENT DURING-ACTIVITY SURVEY

During the Activity

Light Dimming

1. What was the measured voltage of your battery?

   ____ volts

2. What was the resistance value for R1 using your measured Vin, 100 ohms for R2, and the maximum voltage for your LED for Vout. (Round up to the nearest ohm).
   ____ ohms

Show your work here:

3. What was the resistance value for R1 using your measured Vin, 100 ohms for R2, and the minimum voltage for your LED for Vout. (Round up to the nearest ohm).
   ____ ohms

Show your work here:

4. Predict, will a higher resistance or a lower resistance for R1 result in a dimmer light? (Circle one) Higher resistance Lower Resistance

5. Record the different resistor values you tried for R1 and the resulting voltage measured across the LED.

R1 Resistance (Ohms)	LED Voltage Measured (Volts)

6. Based on your measured values, does a higher resistance or a lower resistance for R1 result in a brighter light?
   (Circle one) Higher resistance Lower Resistance

7. Predict, will a higher resistance or a lower resistance for R1 result in a higher simulated launch?
   (Circle one) Higher resistance Lower Resistance

Launch Simulation

8. What voltage will be supplied to the circuit from the simulator?

   ____ volts

9. What resistance value for R1 would create the maximum output voltage to the simulation using the voltage from the simulator and 100 ohms for R2. (Round up to the nearest ohm).
   ____ ohms

Show your work here:

10. What resistance value for R1 would create the minimum output voltage to the simulation using the voltage from the simulator and 100 ohms for R2. (Round up to the nearest ohm).
    ____ ohms

Show your work here:

11. Choose a value for resistor 1 and calculate the height the ball will reach. Then plug in the correct resistor and record the values from the simulation. (Round to 2 decimal places)

	Calculated	Measured from Simulator
R1 Value chosen (ohm)		
Voltage chosen (volts)		
Angular velocity of motor (rad/s)		
Initial ball velocity (m/s)		
Total launch time (sec)		
Launch height (m)		

Include a rough sketch of the graph from the simulator. Make sure to label your axis.

12. Choose a value for resistor 1 and calculate the height the ball will reach. Then plug in the correct resistor and record the values from the simulation. (Round to 2 decimal places)

	Calculated	Measured from Simulator
R1 Value chosen (ohm)		
Voltage chosen (volts)		
Angular velocity of motor (rad/s)		
Initial ball velocity (m/s)		
Total launch time (sec)		
Launch height (m)		

Include a rough sketch of the graph from the simulator. Make sure to label your axis.

Appendix E

Development and Evaluation of an Electrical Engineering and Math Curriculum Module for High School Students

STUDENT POST-ACTIVITY SURVEY

After the Activity

1. Did you enjoy the activity? (circle one) Yes No

   Why? ____

2. AFTER THE LESSON: Rank your knowledge of the following components/concepts: (circle one for each row) (0 = none, 1 = low, 5 = high)

a.	**Breadboard**	0	1	2	3	4	5
b.	**Battery**	0	1	2	3	4	5
c.	**Switch**	0	1	2	3	4	5
d.	**Resistor**	0	1	2	3	4	5
e.	**LED**	0	1	2	3	4	5
f.	**Motor**	0	1	2	3	4	5
g.	**Multimeter**	0	1	2	3	4	5
h.	**Voltage**	0	1	2	3	4	5
i.	**Current**	0	1	2	3	4	5
j.	**Resistance**	0	1	2	3	4	5

3. Rank your interest in: (0 = none, 1 = low, 5 = high)

a.	Mathematics (circle one)	0	1	2	3	4	5
b.	Physics (circle one)	0	1	2	3	4	5
c.	Engineering (circle one)	0	1	2	3	4	5

   Did your interest in mathematics, physics, or engineering increase or decrease? If so, why?

   ____

   ____

4. Rank your knowledge level in: (0 = none, 1 = low, 5 = high)

   a. Mathematics (circle one) 0 1 2 3 4 5

   b. Physics (circle one) 0 1 2 3 4 5

   c. Engineering (circle one) 0 1 2 3 4 5

   Do you feel your knowledge level in any of these subjects increased or decreased? If so, why?

   ____

   ____

   ____

5. Did this activity encourage you to look into signing up for engineering programs, courses, or degrees? (circle one) Yes No

   Why?

   ____

   ____

   ____

6. Did this activity help you understand how mathematics is used in real-life engineering situations? (circle one) Yes No

   Why?

   ____

   ____

   ____

Appendix F

ASU Knowledge Enterprise Development

ARIZONA STATE UNIVERSITY

SOCIAL BEHAVIORAL INSTRUCTIONS AND TEMPLATE		
NUMBER	DATE	PAGE
HRP-503a	12/15/2017	1 of 4

Instructions and Notes:

- Depending on the nature of what you are doing, some sections may not be applicable to your research. If so, mark as "NA".
- When you write a protocol, keep an electronic copy. You will need a copy if it is necessary to make changes.

1 Protocol Title

Include the full protocol title: Development and Evaluation of an Electrical Engineering and Mathematics Curriculum Module for High School Students

2 Background and Objectives

Provide the scientific or scholarly background for, rationale for, and significance of the research based on the existing literature and how will it add to existing knowledge.

- Describe the purpose of the study.
- Describe any relevant preliminary data or case studies.
- Describe any past studies that are in conjunction to this study.

Most students who enter engineering or other STEM fields come from families who work in those fields. There are STEM programs and classes for students who are interested in related fields, but the conundrum is that people need to be interested in order to pursue participation. The goal of this study was to introduce engineering concepts in a required high school mathematics class to reveal and investigate the ways in which engineering concepts can be successfully introduced to a larger populace to increase interest in engineering programs, courses, and degrees. A lesson plan and corresponding materials - including circuit kits, a simulated ball launching station, and a graphical display - were made to accomplish this goal.

Throughout the lesson students were asked to (1) use given materials to accomplish a goal, (2) predict outcomes based on conceptual understanding and mathematical calculations, (3) test predictions, and (4) record and analyze results. The students first created a simple circuit to understand the circuit components and gather general electrical engineering knowledge. A simple light dimmer circuit allowed students to understand electrical concepts before applying the circuit to simulated launch a station. The students were then asked to predict the time and height of a ball launched with various settings of their motor control circuit. The students were able to test their theories with the launcher test set up and collect a parabolic height versus time graph. Based on the measured graph, the students were able to record their results and compare calculated values to measured values.

The results of the study provide a foundation for determining successful ways to increase student interest in engineering while developing hands-on concept modeling in mathematics classrooms. Additionally, this lesson serves as a model for other researchers or teachers to develop lesson plans with interdisciplinary connections to engineering.

There are no past studies that are in conjunction to this study and no relevant preliminary data or case studies.

3 Data Use

Describe how the data will be used. Examples include:

- Dissertation, Thesis, Undergraduate honors project
- Publication/journal article, conferences/presentations
- Results released to agency or organization
- Results released to participants/parents
- Results released to employer or school
- Other (describe)

The data will be used for my undergraduate honors project/thesis. However, part of my honors thesis is to write a journal article or conference paper to be published. The defense for my honors thesis will be a draft of the paper to be published. I have currently applied to the 2018 ASEE Annual Conference & Exposition.

4 Inclusion and Exclusion Criteria

Describe the criteria that define who will be included or excluded in your final study sample. If you are conducting data analysis only describe what is included in the dataset you propose to use.

Indicate specifically whether you will target or exclude each of the following special populations:

- Minors (individuals who are under the age of 18)
- Adults who are unable to consent
- Pregnant women
- Prisoners
- Native Americans
- Undocumented individuals

I will be collecting survey data from high school students and high school teachers of the classes I visit. High school students who are under 18 will be required to submit a parent signed document before their data can be included in the study.

5 Number of Participants

Indicate the total number of participants to be recruited and enrolled: ~130

6 Recruitment Methods

- Describe who will be doing the recruitment of participants.
- Describe when, where, and how potential participants will be identified and recruited.
- Describe and attach materials that will be used to recruit participants (attach documents or recruitment script with the application).

I sent an email to the principals of schools in the area. If they were interested, I received a signed letter of intent from the principal. The principals forwarded my email to their teachers. Interested teachers then reached out to me. I asked for some information about their class. The email sent to the principals and to the teachers have been attached. To recruit the students, I will ask the teachers to send home parent consent and student assent forms. This lesson will be done during class time, but is optional, students who are not participating in the research will be allowed to listen to the lecture portions of the activity and participate in discussion but will not be permitted to touch the simulation or electrical components.

7 Procedures Involved

Describe all research procedures being performed, who will facilitate the procedures, and when they will be performed. Describe procedures including:

- The duration of time participants will spend in each research activity.
- The period or span of time for the collection of data, and any long term follow up.
- Surveys or questionnaires that will be administered (Attach all surveys, interview questions, scripts, data collection forms, and instructions for participants to the online application).
- Interventions and sessions (Attach supplemental materials to the online application).
- Lab procedures and tests and related instructions to participants.
- Video or audio recordings of participants.
- Previously collected data sets that that will be analyzed and identify the data source (Attach data use agreement(s) to the online application).

The duration of the research activity will be a 90 minute class period or two 45/55 minute class periods depending of the class structure. There will be no long term follow up. Teacher surveys, student surveys, and presentation materials are attached. There will be no interventions and sessions, video or audio recordings, or previously collected data.

8 Compensation or Credit

- Describe the amount and timing of any compensation or credit to participants.
- Identify the source of the funds to compensate participants
- Justify that the amount given to participants is reasonable.
- If participants are receiving course credit for participating in research, alternative assignments need to be put in place to avoid coercion.

No compensation or credit will be provided to participants. Participation is solely for learning purposes.

9 Risk to Participants

List the reasonably foreseeable risks, discomforts, or inconveniences related to participation in the research. Consider physical, psychological, social, legal, and economic risks.

The teachers will be giving up class time which could be viewed as an inconvenience. Students will be in contact with electrical components. The possibility of mild shock from a 9V battery is possible. To mitigate this risk, avoid shorting the two terminals of the battery. Also, make sure to disconnect the battery before connecting or disconnecting the circuit.

10 Potential Benefits to Participants

Realistically describe the potential benefits that individual participants may experience from taking part in the research. Indicate if there is no direct benefit. Do **not** include benefits to society or others.

The possible benefits for teachers are an enhanced knowledge and understanding of (1) electrical equations for teaching, (2) physics equations for teaching, (3) how students learn STEM concepts, and (4) effective activities for developing lesson plans with interdisciplinary connections to engineering. Although there may be no direct benefit to students, the possible benefit of participation is an increased interest in engineering, mathematics, and physics, enhanced problem-solving and spatial-reasoning ability, and potentially stronger understanding of previously taught concepts.

11 Privacy and Confidentiality

Describe the steps that will be taken to protect subjects' privacy interests. "Privacy interest" refers to a person's desire to place limits on with whom they interact or to whom they provide personal information. Click here for additional guidance on ASU Data Storage Guidelines.

Describe the following measures to ensure the confidentiality of data:

- Who will have access to the data?
- Where and how data will be stored (e.g. ASU secure server, ASU cloud storage, filing cabinets, etc.)?
- How long the data will be stored?
- Describe the steps that will be taken to secure the data during storage, use, and transmission. (e.g., training, authorization of access, password protection, encryption, physical controls, certificates of confidentiality, and separation of identifiers and data, etc.).
- If applicable, how will audio or video recordings will be managed and secured. Add the duration of time these recordings will be kept.
- If applicable, how will the consent, assent, and/or parental permission forms be secured. These forms should separate from the rest of the study data. Add the duration of time these forms will be kept.
- If applicable, describe how data will be linked or tracked (e.g. masterlist, contact list, reproducible participant ID, randomized ID, etc.).

If your study has previously collected data sets, describe who will be responsible for data security and monitoring.

All surveys which are collected will not contain names and will remain anonymous. Each student will be given a number which they will write on each survey submitted. This way all three surveys can be linked together by number. Paper versions of the data will be collected and stored in a locked filing cabinet. Consent forms will be kept in a separate folder in the filing cabinet. All forms will be kept for 2 years before being properly shredded for disposal. The only people with access to the information will be Kylee Burgess, Shawn Jordan, Sohum Sohoni, and Barbara Kinach.

12 Consent Process

Describe the process and procedures process you will use to obtain consent. Include a description of:

- Who will be responsible for consenting participants?
- Where will the consent process take place?
- How will consent be obtained?
- If participants who do not speak English will be enrolled, describe the process to ensure that the oral and/or written information provided to those participants will be in that language. Indicate the language that will be used by those obtaining consent. Translated consent forms should be submitted after the English is approved.

Consent and parent permission forms will be provided to the students by the teachers prior to the activity. They will be expected to submit completed forms to their teacher before the activity. The teacher will submit the completed forms to me on the day of the activity. Teacher consent forms will be sent through email and collected along with the student forms on the day of the activity. Student, parent, and teacher consent forms are attached.

13 Training

Provide the date(s) the members of the research team have completed the CITI training for human participants. This training must be taken within the last 4 years. Additional information can be found at: Training.

Kylee Burgess – September 19th, 2015
Shawn Jordan – May 6, 2015