University of Nevada, Reno

# Microcontroller Educational Device (MED)

A thesis submitted in partial fulfillment
of the requirements for the degree of

Bachelor of Science in Mechanical Engineering

By

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We recommend that the thesis
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# Executive Summary

Deathstar Engineering took on the task of creating a microcontroller kit in the form of a portable demonstration. In the project proposal, the main objective was to teach microcontroller programming to users. The original sponsors of the project were interested in learning to program a variety of outputs for three controllers in particular: Arduino, Beaglebone, and Raspberry Pi. It was also intended that the product would need to be interactive and easy to use for beginners.

The product, designed by Deathstar Engineering, differentiates itself from the currently available choices by combining all of the different hardware programming interfaces into a single, easy to use system that will allow the user to experiment with several units, thus increasing the learning potential and value of the product. The product also mainly targets K-12 schools while keeping the design open and flexible to allow anyone who has an interest in programming microcontrollers to use the product. By creating the product in this way, it will fill a niche in the market that does not exist at this time. Fig. 1 shows the completed product, the Microcontroller Educational Device (MED).

Fig. 1: The completed MED

# Acknowledgements

First and foremost I would like to thank all members of my team for their contributions to this project and this paper. This includes Pedro Chavez, Zac Hudacko, Tyler Maggert, and Chandler McCunn. I would also like to thank my thesis advisor, Dr. Logan Yliniemi for stepping in and helping out. Finally, I would like to thank Fernley Elementary School, Fernley Intermediate School, and Fernley High School for their cooperation and help with the testing process.

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# Design Problem and Objectives

## Directive

Microcontrollers are growing in popularity due to their ease of use and versatility. They can automate many functions and as a result the ability to program these microcontrollers is becoming an increasingly valuable skill. Learning to program these devices is not easy. Finding a starting point to learning microcontrollers is challenging, and even choosing the right microcontroller to use and learn can be difficult. Deathstar Engineering's goal was to create a product that will simply and effectively teach multiple microcontroller platforms in order to simplify the starting point for those who want to use microcontrollers and help users get exposure to more than one microcontroller.

## Competition

Currently there are kits that exist that can teach users how to program and use microcontrollers. They come in a variety of forms such as the Arduino Starter Kit which includes multiple projects that can be built to use the Arduino controller. These projects include basic wiring components, instructions, and accessory parts. These kits can come in the form of briefcases, like the Duinokit, which creates a portable, storable, compact carrier for the parts. Similar products exist for other controllers such as the Raspberry Pi, and the Beaglebone.

## Market

Anyone who wants to learn about microcontrollers or wants to show others about them would enjoy this product. Deathstar Engineering plans to market this product to schools K-12 mainly, but will keep it open and flexible for anyone to use.

## Design Objectives

Since the market for the product is so wide in terms of demographics of users, objectives and goals were set in order to meet the needs of those potential customers. Table 1, the Product Requirement Specifications (PRS), summarizes the design objectives.

Some of the key targets were as follows. The product will: be compatible with three different microcontrollers (Arduino, Raspberry Pi, and Beaglebone), include at least two outputs (motors and lights), include at least two inputs (switches and dials), use interactive instructions to teach students how to program the microcontrollers, and be usable for ages 9 and up.

Table 1: Product Requirement Specifications (PRS)

| HID | Category | Requirement |
|---|---|---|
| 12.PRS.1.1 | Business | MED should not cost more than $200 to produce, not including cost of microcontrollers. |
| 12.PRS.1.2 | Business | MED will demonstrate three different microcontrollers; Arduino, Beaglebone, and Raspberry Pi. |
| 12.PRS.2.1 | Customer | Will be useable for students ages 9 and up or Academic grades 3 and up. |
| 12.PRS.3.1 | Product | Product will be smaller than 18”x12”x12”. |
| 12.PRS.3.2 | Product | Must be an effective tool in teaching students how a microcontroller works, as judged by a quiz. |
| 12.PRS.3.3 | Product | Must contain at-least two L.E.D.’s and one motor. |
| 12.PRS.3.4 | Product | Must weigh less than 10 lbs. |
| ~~12.PRS.4.1~~ | ~~Usability~~ | ~~Product will allow users to inspect and interact with the main wiring while any components are spinning.~~ DELETED |
| 12.PRS.4.2 | Usability | Users will be able to access switches and knobs while device is in use. |
| 12.PRS.4.3 | Usability | The instructions will allow an Instructor to completely setup, wire, and program the demonstration. |
| 12.PRS.5.1 | Material | All components will withstand impacts twice that of targeted motor speed. |
| 12.PRS.6.1 | Software | Directions will be interactive if internet access is available. |
| 12.PRS.6.2 | Software | All required software, and directions if needed, can be saved onto a single flash-drive. |
| 12.PRS.6.3 | Software | Instructions will be understandable to 2nd grade students. |
| 12.PRS.6.4 | Software | Working example codes will be available locally, as well as online. |
| 12.PRS.7.1 | Packaging | The Product must contain enough physical storage to accommodate all three microcontrollers. |
| 12.PRS.7.2 | Packaging | The Product must contain enough physical storage to accommodate enough spare electrical components to completely rebuild the main circuitry, twice. |
| 12.PRS.7.3 | Packaging | The product will be aesthetically pleasing, as judged by a survey. |
| ~~12.PRS.8.1~~ | ~~Labeling~~ | ~~All permanent electrical components should be clearly labeled, including polarity.~~ DELETED |
| 12.PRS.10.1 | Product Lifetime | The product will be usable for five years under normal use. |
| 12.PRS.11.1 | Safety | Any components will not spin fast enough to do unacceptable harm to user. |
| 12.PRS.11.2 | Safety | All electrical components will not have enough power to harm the user. |
| ~~12.PRS.11.3~~ | ~~Safety~~ | ~~All electrical components should not have enough power to harm the user, even under extreme conditions.~~ DELETED |

Closely related to the PRS is the Design Control Trace Matrix, which was used to track each of the design objectives over the course of the project. The DCTM can be found in the Design History File (DHF) in Appendix B.

# The Design

Based on all the assigned objectives a design for the product was created to achieve these objectives. Deathstar's design was designed to combine all three of the previously listed controllers into one portable unit. Combining all of the different hardware programming interfaces into a single, easy to use system would allow the user to experiment with several units, thus increasing the learning potential and value of the product. Fig. 2 shows a rendering of the concept design.

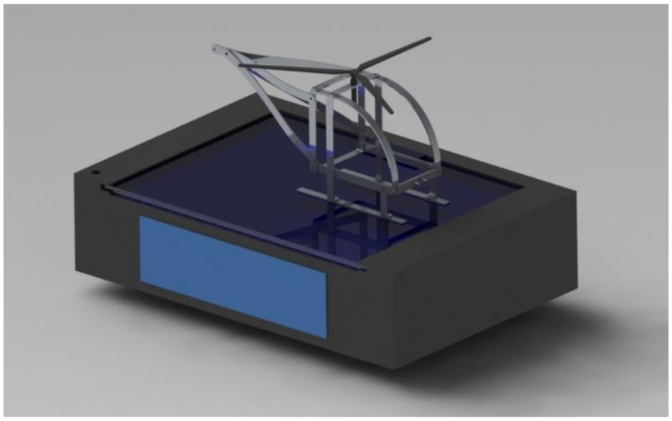

Fig. 2: Rendering of design

## Mechanical Design Description

To specify the design, the body of the base is made from plywood, with a sliding top panel made from acrylic. The demonstration—a toy shaped like a helicopter frame—is made from aluminum and is mounted on top of this acrylic. The helicopter will have a motor, lights, and a buzzer all wired into a plug. The front of the box contains a connector for the helicopter to plug into. It also contains a place to plug in each of the microcontrollers and various different inputs. Fig. 3 shows a wireframe drawing of the final design. All drawings can be found in the DHF in Appendix B.

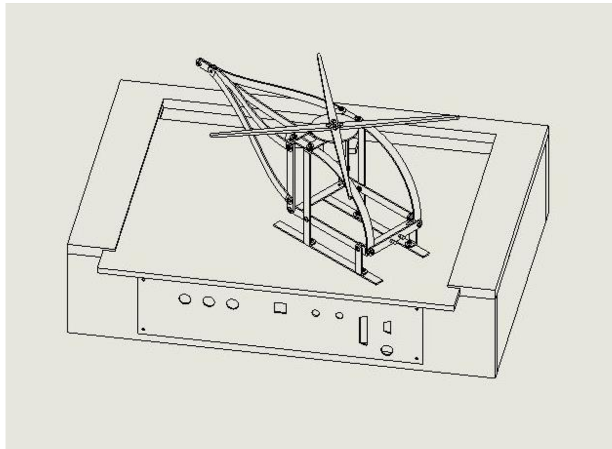

Fig.3: Final mechanical design

## Electrical Design Description

The product was designed so that all of the outputs would be powered through an external power supply. The circuits for each of these outputs were transistorized so the microcontrollers would have something to control. A shield was made to connect to each microcontroller which would interact with both the inputs and the outputs through the main board. Fig. 4 shows a wiring diagram of the main board. All electrical drawings can be found in the DHF in appendix B.

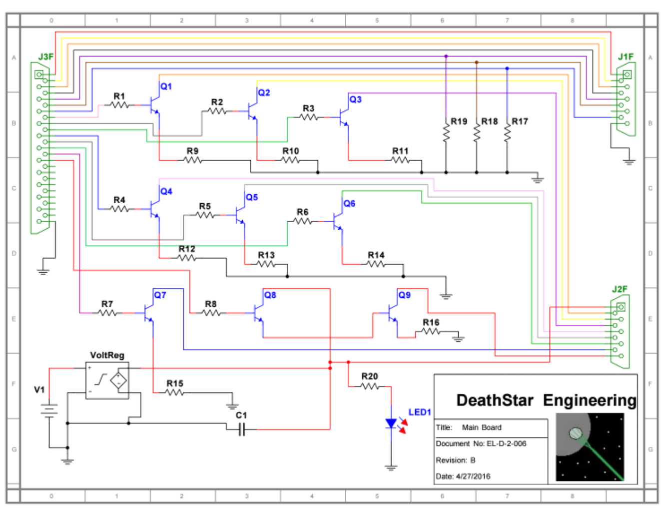


Fig. 4: Main Board

## Software Description

Interactive online instructions were created to guide students through the coding. They are designed to take the students through three steps: learn a concept, learn how that concept relates specifically to the microcontroller, and then learn how to incorporate it into the code. All required instructions and software were included onto a single flash drive. Print versions of all instructions can be found in Appendix B.

## Safety Concerns

There were two main safety concerns in the design; the first being the risk of electrical shock to the user, and the second being impact from the moving components. The risk of the first is minimal as the users don't interact with the wiring. The second is mitigated by selection of a low-power motor. A full Hazard Identification can be found in Appendix B.

## Manufacturing and Assembly Processes

The base components are cut on a table saw. They are assembled using dowels and adhesive. The acrylic top is cut and etched using a laser cutter. A shear is used to cut an aluminum sheet into strips. A mill and break are used to drill and bend those strips into the helicopter components. The components are fastened with machine screws. The propellers are 3D printed. Circuits are soldered into proper circuit boards and shields. Cables are attached to each shield and the helicopter components.

## Bill of Materials and Cost Analysis

Table 2 shows the full Bill of Materials for the design.

Table 2: Bill of Materials

| Item Number | Indent Level | Part Number | Description | Source | Quantity Required | UOM | Cost/ Unit |
|---|---|---|---|---|---|---|---|
| 1 | 0 | MD-0-001 | Microcontroller Educational Device (MED) | UNR Mfg | 1 | QTY | N/A |
| 2 | .1 | HE-1-001 | Helicopter | UNR Mfg | 1 | QTY | $20.15 |
| 4 | ..2 | HE-2-001 | Side support | UNR Mfg | 2 | QTY | N/A |
| 5 | ..2 | HE-2-002 | Horizontal long support | UNR Mfg | 2 | QTY | N/A |
| 6 | ..2 | HE-2-003 | Curved cab windshield | UNR Mfg | 2 | QTY | N/A |
| 7 | ..2 | HE-2-004 | Upper Tail | UNR Mfg | 2 | QTY | N/A |
| 8 | ..2 | HE-2-005 | Lower Tail | UNR Mfg | 2 | QTY | N/A |
| 9 | ..2 | HE-2-006 | Ski | UNR Mfg | 2 | QTY | N/A |
| 10 | ..2 | HE-2-007 | Ski support Short | UNR Mfg | 1 | QTY | N/A |
| 11 | ..2 | HE-2-008 | Ski Support Long | UNR Mfg | 1 | QTY | N/A |
| 12 | ..2 | HE-2-009 | Top bridge with motor hole | UNR Mfg | 1 | QTY | N/A |
| 13 | ..2 | HE-2-010 | Multi use support | UNR Mfg | 2 | QTY | N/A |
| 14 | ..2 | HE-2-011 | Vertical Support | UNR Mfg | 2 | QTY | N/A |
| 15 | ..2 | HE-2-012 | Machine Screws | McMaster | 28 | QTY | $0.02 |
| 16 | ..2 | HE-2-013 | Propeller | UNR DLM | 4 | QTY | $1.91 |
| 17 | ..2 | HE-2-014 | Set screw | McMaster | 2 | QTY | $0.06 |
| 18 | ..2 | HE-2-015 | Hex Nut | McMaster | 28 | QTY | $0.03 |
| 19 | ..2 | HE-2-016 | Hub | UNR Mfg | 1 | QTY | N/A |
| 20 | .1 | MC-1-001 | Microcontrollers | N/A | 1 | QTY | $114.95 |
| 21 | ..2 | MC-2-001 | Arduino | Arduino | 1 | QTY | $24.95 |
| 22 | ..2 | MC-2-002 | Beaglebone | Beaglebone | 1 | QTY | $55.00 |
| 23 | ..2 | MC-2-003 | Raspberry Pi | Raspberry Pi | 1 | QTY | $35.00 |
| 24 | .1 | BA-1-001 | Base | UNR Mfg | 1 | QTY | $14.25 |
| 25 | ..2 | BA-2-001 | Acrylic top | McMaster | 1 | QTY | $11.06 |
| 26 | ..2 | BA-2-002 | Plywood bottom | UNR Mfg | 1 | QTY | $1.31 |
| 27 | ..2 | BA-2-003 | Side panel | UNR Mfg | 2 | QTY | $0.31 |
| 28 | ..2 | BA-2-004 | Front panel | UNR Mfg | 1 | QTY | $0.33 |
| 29 | ..2 | BA-2-005 | Back panel | UNR Mfg | 1 | QTY | $0.50 |
| 30 | ..2 | BA-2-006 | Front Accessory Plate | McMaster | 1 | QTY | N/A |
| 31 | ..2 | BA-2-007 | Top Base Panel | UNR Mfg | 1 | QTY | $0.43 |
| 32 | .1 | EL-1-001 | Electronic Interface | UNR Mfg | 1 | QTY | $102.70 |
| 33 | ..2 | EL-2-001 | Arduino Prototyping Shield | DIYmall | 1 | QTY | $4.33 |
| 34 | ..2 | EL-2-002 | BeagleBone Black Proto Cape | LogicSupply | 1 | QTY | $7.95 |
| 35 | ..2 | EL-2-003 | Raspberry Pi 2 Hat – Prototype Board | JBtek | 1 | QTY | $7.95 |
| 36 | ..2 | EL-2-004 | Prototype | Veroboard | 1 | QTY | $8.30 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Universal Stripboard | | | | |
| 37 | ..2 | EL-2-005 | RGB LED – 4 pin | Gikfun | 2 | QTY | $0.17 |
| 38 | ..2 | EL-2-006 | 50 OHM resistor | Uxcell | 18 | QTY | $0.23 |
| 39 | ..2 | EL-2-007 | 1K OHM resistor | Radioshack | 12 | QTY | $0.30 |
| 40 | ..2 | EL-2-008 | 9 Conductor Wire | Stinger | 4 | Ft | $1.27 |
| 41 | ..2 | EL-2-009 | 9 pin D-sub Plug Male/Female Pair | Gino | 2 | QTY | $2.84 |
| 42 | ..2 | EL-2-010 | 25 pin D-Sub plug Male/Female Pair | Uxcell | 3 | QTY | $0.93 |
| 43 | ..2 | EL-2-011 | 6”x3”x2” Project Enclosure | RadioShack | 1 | QTY | $4.99 |
| 44 | ..2 | EL-2-012 | 10K OHM Potentiometer | Uxcell | 3 | QTY | $0.56 |
| 45 | ..2 | EL-2-013 | Potentiometer Control Knobs | Uxcell | 3 | QTY | $0.78 |
| 46 | ..2 | EL-2-014 | SPST mini toggle switch | Radioshack | 2 | QTY | $3.49 |
| 47 | ..2 | EL-2-015 | Momentary Push Button | Radioshack | 1 | QTY | $3.49 |
| 48 | ..2 | EL-2-016 | 2N2222 NPN Transistors | Jekewen | 8 | QTY | $0.07 |
| 49 | ..2 | EL-2-017 | 1.5 – 3V DC Hobby Motor | RadioShack | 1 | QTY | $3.49 |
| 50 | ..2 | EL-2-018 | 5V Continuous Buzzer | Amico | 1 | QTY | $0.89 |
| 51 | ..2 | EL-2-019 | Flash Drive | Walmart | 1 | QTY | $7.95 |
| 52 | ..2 | EL-2-020 | Transistor TIP42G | Radioshack | 1 | QTY | $1.99 |
| 53 | ..2 | EL-2-021 | 5 V regulator LM317T | Radioshack | 1 | QTY | $3.49 |
| 54 | ..2 | EL-2-022 | 100 microFarad ElectroLytic Cap | Radioshack | 1 | QTY | $1.49 |
| 55 | ..2 | EL-2-023 | Red LED with Holder | Radioshack | 1 | QTY | $1.50 |
| 56 | ..2 | EL-2-024 | Analog to Digital Converter MCP3008 | Adafruit | 1 | QTY | $3.75 |

# Proof of Concept

The proof of concept (or PoC) is a single demonstration using an Arduino to control a motor. The motor is attached to the propeller of a stationary toy helicopter in order to be more visually interesting. This is modeled after the educational demonstration, with only a motor output. Both a switch and a potentiometer are attached to the Arduino for use as inputs. All components are mounted to a semi-large portable plywood surface, similar to what will be the final mounting surface. Fig. 5 shows the design.

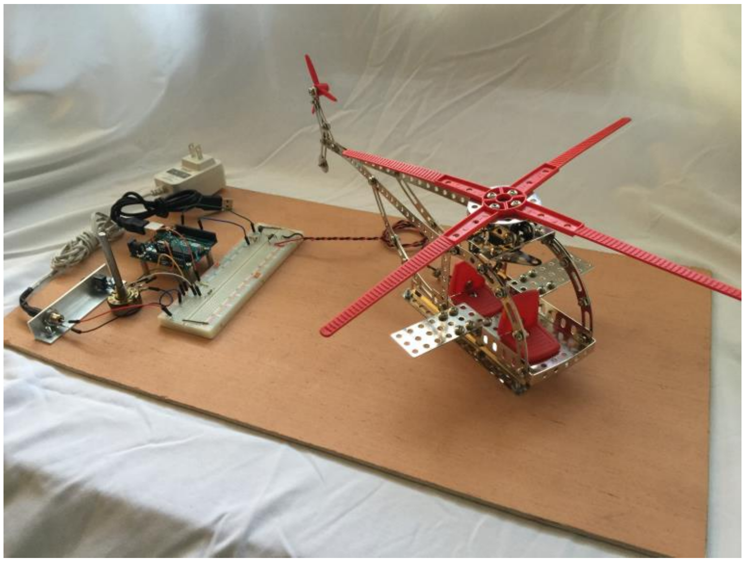

Fig. 5: The Proof of Concept

The instructions were created to guide the subjects through the coding process. These instructions were the same ones shown in Appendix B, but the students only completed the first sections. The instructions are interactive, and are designed to teach a concept, teach the syntax, and then check for understanding before telling the subjects what to do to accomplish the tasks. Two codes were provided: one powered the output, and the other simply read and displayed a value from the switch input. The instructions use these codes to get the subjects to be able to: turn on the motor, change the speed of the motor in the code, turn on and off the motor dependent on the state of the switch, and change the speed of the motor based on the position of the potentiometer.

This proof of concept was created to allow for the effectiveness of the planned demonstrations to be tested in an educational environment. It helped determine if the students who participate in the activity have fun, learn new things, and are challenged. Additionally, it will allow for each of these to be tested for specific age ranges, which helped determine which activities are too difficult or too easy for certain ages.

## Proof of Concept Engineering Analysis

One of the main concerns when designing the circuit for the motor control was the ability of the transistor to operate at the PWM, or pulse width modulation, frequency of the arduino. The arduino has a maximum PWM frequency of 976 Hz. The circuit was simulated in Multisim, where a Bode plot was generated to analyze the operating frequency of the selected PN2222 Transistor. This Bode plot can be found in Figure 6. We found that the transistor operated smoothly at frequencies above 1MHz.

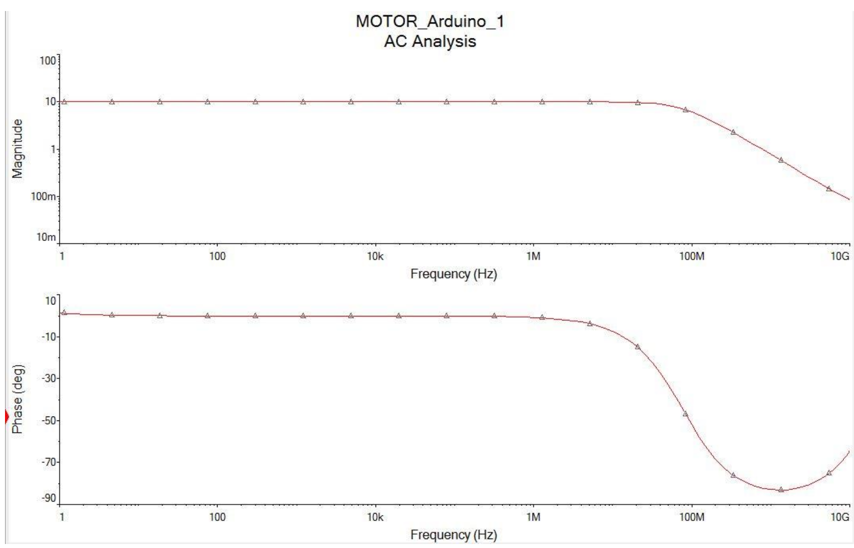


Fig. 6: Bode Plot showing that the PN2222 transistor operates smoothly at 978 Hz

## Proof of Concept Fabrication and Set Up

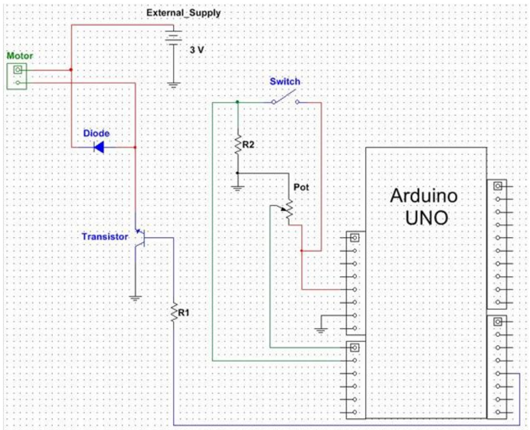

Fig. 7: Wiring diagram for the Proof of Concept

The toy helicopter was assembled using an ElTech construction set. The Arduino was attached to four standoffs with machine screws. The Arduino, breadboard, and toy helicopter were all screwed into a scrap piece of plywood. The helicopter motor and microcontroller were wired to the breadboard, following the wiring diagram in Figure 7. While it was previously thought that there would be some wiring for the students to complete, it was decided that the risk of a short circuit in the early testing phase was too great.

Table 3 shows the full bill of materials, along with the actual and as-built costs of the POC.

Table 3: Bill of Materials and Cost for the Proof of Concept

| Item | Price | Actual Cost | As-Built Cost |
|---|---|---|---|
| Aduino UNO | $24.95 | 0 | $24.95 |
| Metal Solar Helicopter Construction Kit | $90.54 | 0 | $90.54 |
| Electric Motor | $3.49 | 0 | $3.49 |
| Breadboard | $5.00 | 0 | $5.00 |
| 12in Jumper Wires | $7.95 | 0 | $7.95 |
| 6in Jumper Wires | $3.95 | 0 | $3.95 |
| 2'x4' Underlayment | $5.97 | 0 | $5.97 |
| **Total** | | 0 | $141.85 |

## Testing Methods

Since the proof of concept is interactive with the user, the demo was given to a set of test subjects. Observations were made while the subjects tested the demo to better determine the weaknesses in the design. A survey was also given to the subjects in order to get personal feedback on the demonstration design. Questions were targeted at determining understanding, difficulty, and interest. The full survey used in the first round of testing can be found in Appendix B, in the last page of the instructions.

## Results

At the time of writing, one round of testing has so far been completed. The tasks were attempted by two different groups of students: a group of three 10th graders and a group of four 4th graders. It should be noted that because of setup difficulties, the 10th graders only had about half an hour, while the 4th graders had 1 hour and 15 minutes to complete the activities. How far they got through the activity, as well as the predicted outcome, is shown in Table 4.

Table 4: Progress vs Expected Progress

| **Activities Completed** | Intro to Circuits | Intro to Coding | Running Motor | Changing Speed | Reading Switch | Switch /Motor | Variables | Map | Potentiometer /Motor |
|---|---|---|---|---|---|---|---|---|---|
| **10th Grade** | Completed | Completed | Completed | Completed | Completed | Completed | | | |
| | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete |
| **4th Grade** | Completed | Completed | Completed | Completed | Completed | Completed | Completed | Completed | Completed |
| | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | Expected to Complete | | | |

| | |
|---|---|
| (green) | Completed |
| (blue) | Expected to Complete |

The most important, and possibly most surprising result of the testing was that the fourth graders were able to complete the activity. For the most part, they were able to fully understand the content, and struggled with very few of the questions. This proves that students as young as 4th grade may be viable candidates for lessons such as this one. (However, the students we tested were likely well above average intelligence for their grade level.)

However, there were some difficulties with scalability. For the 4 elementary students, not all of them were able to see the screen with the instructions, so the instructions had to be read to them. This begs the question of how such an activity could be implemented on a classroom level. While there are several solutions, the best would depend on the number of students, the number of computers available to them, and other factors specific to the environment.

There was also a survey at the end. The actual wording used in the questions is available in Appendix B. Those questions were used to determine the amount of fun the students had, how difficult they found it, if they were interested in doing other similar activities, how much they learned, and if they understood the content. Each question had a low, medium, and high answer. The results are summarized in Table 5. Table 6 then shows the expected results for comparison.

Table 5: Results of the Survey

| Grade | Fun | Difficulty | Interest | Learning | Understanding |
|---|---|---|---|---|---|
| 10 | High | Medium | High | High | Medium |
| 4 | High | Low | High | Medium | High |

Table 6: Expected Results

| Grade | Fun | Difficulty | Interest | Learning | Understanding |
|---|---|---|---|---|---|
| 10 | High | Medium | Medium | High | Medium |
| 4 | High | High | High | High | Medium |

Both groups had fun and were interested in similar activities, which is slightly better than expected. The 4th graders understood more, were less challenged, and learned less than expected. The 10th graders answered as expected, except that they were slightly more interested.

### Impact on Final Design

In setting up the wiring, it was decided that the circuits were a bit complex and it was very possible for one of the subjects to create a short circuit. This solidified the decision that the final design will likely rely purely on pre-wired demonstrations. Otherwise, if loose components were going to be included, an easier way to create the circuits must have been devised.

Several shortcomings within the instructions were discovered that needed to be addressed. One example of this is the lack of description on how to upload a program to the Arduino. Additionally, it was decided that online instructions run the risk of being blocked by a school's network. Therefore, an offline option, but still electronic, would be preferred.

# Final Product

Fig. 8 shows a photograph of the final product. Fig. 9 shows all three microcontrollers and their custom shields, built to plug straight in to the front of the device.

Fig. 8: The completed MED

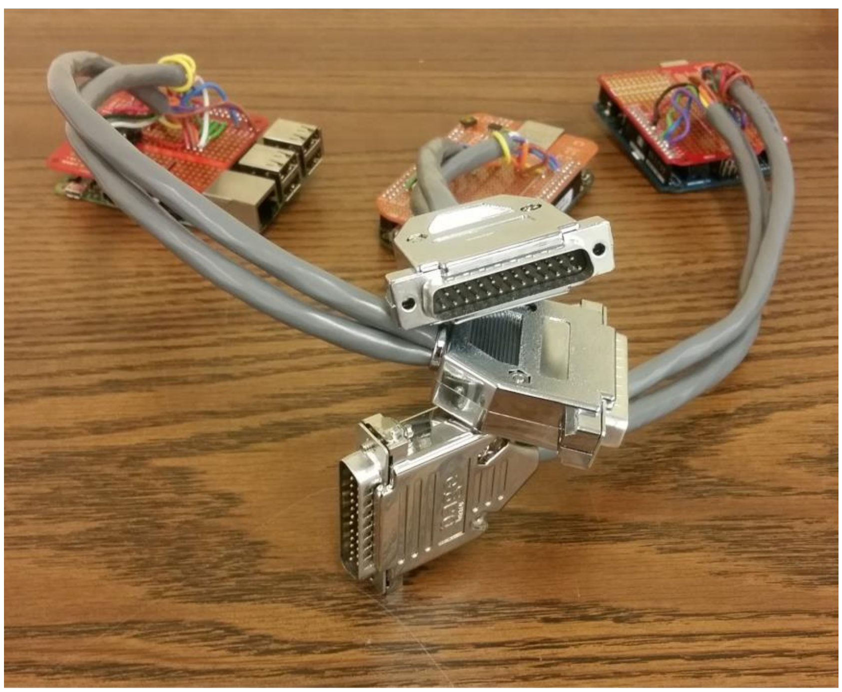

Fig. 9: Arduino, Raspberry Pi, and Beaglebone

# Conclusion

The current design has the potential to fulfil all of the requirements detailed in the PRS. All physical dimensions are within the required boundaries, and at 7.5 pounds it is well within the weight limit. It contains three different types of inputs and outputs. It properly interfaces with all three desired microcontrollers, and comes with interactive instructions for use. Based on the results from the proof of concept, the proficiency targets appear to be achievable. 9 and 10 year olds were able to complete the activities competently.

# Appendix A

PoC Results

Table A1 shows that raw data retrieved from the presenting the Arduino demonstrations to two groups of different students.

Table A1: Survey Results

| **Questions** | **4th Graders** | **10th Graders** |
|---|---|---|
| **Did you have fun?** | Yes. | Yes. |
| **Did you find this activity hard?** | No. | A Little. |
| **Would you do another activity like this?** | Yes. | Yes. |
| **Did you learn anything new?** | A few small things. | Lots! |
| **Were you able to understand what you were doing?** | Yes. | A little bit. |
| **What would make this more fun?** | Nothing. | The helicopter could fly. |

The complete wording of the survey can be found at the end of the instructions, shown in Appendix B.

# Appendix B

Design History File (DHF)