Integrating Computational Thinking Through Wearable Technologies and Programmable E-Textiles

Introduction

Computational thinking is a problem-solving technique that has traditionally been employed by computer scientists to develop computer applications. However, computational thinking practices are now believed to be applicable to a variety of other fields (Google for Education, 2018), specifically those related to engineering and technology. Accordingly, the Advancing Excellence in P-12 Engineering Education (2018) project identified computational thinking as one of the core engineering concepts fundamental for setting a foundation for students to conduct the quantitative analyses that engineers and other related professionals perform. Likewise, the Committee for the Workshops on Computational Thinking advocates that computational thinking is necessary for people to develop efficient and automated physical design solutions as well as visualizations of design concepts and computational scientific models (NRC, 2011). These abilities, which also include thinking critically about complex problems, generating creative solutions, and communicating solutions effectively, are now considered necessary at all levels of scholarship.

While the demands in the computer science workforce continue to grow (Qian & Lehman, 2016), computational thinking skills are also considered valuable for multiple career fields (Kelleher, 2009). As a response to the demand, the interest in computer science education has been increasing, and introductory computer science courses have been developed for students at the elementary and secondary levels (Qian & Lehman, 2016). However, too few students are given the opportunity to develop computational thinking skills within engaging physical settings (Google & Gallup, 2016) provided through the hands-on and design-based learning environments afforded in engineering and technology classrooms. Therefore, this article will provide an example instructional activity for fostering computational thinking while also addressing core engineering concepts in electronics using programmable e-textiles (electronic textiles). Specifically, the instructional context of wearable technologies will be used to provide a physical connection to developing computational thinking skills and electrical engineering capabilities while also enhancing the rigor of engineering design and providing socially-connected relevance to learning.

Computational Thinking in Engineering

Computational thinking is a problem-solving technique that dissects complex problems and generates solutions that both humans and machines can understand (Aho, 2012). Everyone can possess the ability to apply computational thinking in any career field—one does not need to be a computer scientist (Wing, 2006). Typically, the computational thinking technique can be separated into four elements: (1) decomposition, (2) pattern recognition, (3) abstraction, and (4) formation of algorithms. Decomposition is the process of dissecting a problem into smaller more manageable tasks. Pattern recognition looks for solutions or similarities within problems. Abstraction ignores irrelevant data while solving problems. Finally, formation of algorithms is the creation of a step-by-step solution to be carried out by a computer program (BBC, 2018). These four elements are now considered essential skills to be taught across all grade levels for reasons including, setting a foundation for success in a technological society, increasing interest in the information...
technology professions, maintaining and enhancing U.S. economic competitiveness, supporting inquiry in other disciplines, and enabling personal empowerment (NRC, 2011c).

In particular, the importance of computational thinking practices has been stressed in engineering education as individuals in engineering fields regularly rely on computational models and automated systems as design solutions. Additionally, the Next Generation Science Standards lists computational thinking as one of the eight science and engineering practices (NGSS Lead States, 2013) and the Engineering in K–12 education report (NAE & NRC 2009) states computational and visualization tools should be used, as appropriate, to support engineering design, particularly at the high school level. Consequently, the Advancing Excellence in P-12 Engineering Education (2018) project established a engineering content taxonomy that included the practice of Quantitative Analysis with a core concept of Computational Thinking. This core concept is comprised of the following sub-concepts: (a) Programming and Algorithms, (b) Programming Languages, and (c) Software Design, Implementation, and Testing. In addition, a sample progression of learning is provided in Table 1 to help integrate computational thinking into future or existing engineering coursework as a means to (1) deepen students’ engineering design practices and (2) increase their abilities to produce optimized solutions to authentic problems.

### Table 1 Sample Progression of Learning in Engineering for Computational Thinking

<table>
<thead>
<tr>
<th>Dimension: Engineering Practices</th>
<th>Practice: Quantitative Analysis</th>
<th>Core Concept: Computational Thinking</th>
<th>Overview: Computational Thinking is important to the practice of Quantitative Analysis because engineers systematically analyze and develop algorithms and programs to develop or optimize solutions to design problems. In this area, students should learn how to design, develop, implement, and evaluate algorithms and programs for an engineering system.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4</td>
<td>I can successfully develop and implement algorithms and programs to solve an engineering design problem through the use of computational thinking.</td>
<td>Programming &amp; Algorithms (including flowcharting)</td>
<td>Programming (script programming languages)</td>
</tr>
<tr>
<td>Level 3</td>
<td>I can implement a program that incorporates a series of algorithms to develop my solution in its entirely. <em>(Advanced)</em></td>
<td>Level 3</td>
<td>I can write and evaluate programs using highly advanced techniques, such as writing external functions and calling them from a program. <em>(Advanced)</em></td>
</tr>
<tr>
<td>Level 2</td>
<td>I can write algorithms to develop a part of my solution and communicate the algorithms with flowcharts. <em>(Proficient)</em></td>
<td>Level 2</td>
<td>I can create programs using more advanced programming techniques, such as loops, conditional structures, and variables. <em>(Proficient)</em></td>
</tr>
<tr>
<td>Level 1</td>
<td>I can interpret a flowchart of designed system and describe how the system may work with what algorithms. <em>(Basic)</em></td>
<td>Level 1</td>
<td>I can develop basic programs using correct syntax and logical organization. <em>(Basic)</em></td>
</tr>
</tbody>
</table>

### Engineering Concepts Through Wearable Technology and Programmable E-Textiles

Wearable technologies are devices that can be worn to extend one’s capabilities to achieve some sort of task or meet a need.desire. Park and Jayaraman (2003) describe wearable technology examples as devices that enable more ‘hands free’ capabilities or devices that use interconnecting sensors to monitor a person’s health vitals. Popular wearable technology today includes: smartwatches, like Samsung’s Galaxy Gear or Apple’s iWatch; augmented reality headsets, like Google Glass; and virtual reality headsets, like the Oculus Rift.

While these wearable devices have become more physically flexible and adaptable to individuals, they are often viewed as rigid technologies. However, E-Textiles (electronic textiles) have provided a way for flexible circuits which can enable electronics to be more agile in the way they are used in society. E-textiles, also known as smart textiles or intelligent textiles, is a name for fabrics that are converted with electronics so they can transform, collect, and transmit data; store and transfer energy; and house small computers (Pailes-Friedman, 2016) while interacting with the environment or user (Stoppa & Chiolerio, 2014). These components can offer an engaging medium for designing and physically prototyping wearable and flexible
solutions to societal problems or creating novel products in relationship to a variety of fields such as fashion, medicine, and athletics. Particularly, the technologies of low power wireless communications, such as Bluetooth and Wi-Fi, and small vital sensors have advanced exponentially, reshaping how we use wearable technology and E-textiles in healthcare and preventive care (Suzuki, Tanaka, Minami, Yamada, Miyata, 2013). The wearable technology market is growing rapidly, and the Scalar Market Research firm, states that this market is expected to grow 18.9% from 2016 to 2021, more than doubling its revenue from roughly 29 billion dollars to 71 billion. This data emphasizes the need for more computational thinking-skilled employees in the workforce.

Wearable technology and programmable E-textiles can also provide authentic contexts for teaching important core concepts in engineering related to electronics and computer architecture. For example, the physical components of these technologies can address the sample progressions of learning provided in Tables 2 and 3.

Table 2 Sample Progression of Learning in Engineering for Electronics

<table>
<thead>
<tr>
<th>Level</th>
<th>Instrumentation</th>
<th>Gating</th>
<th>Integrated Circuits</th>
<th>Closed and Open Loop &amp; Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>I can successfully solve a design problem involving an electronic device.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>I can determine and justify the most appropriate measurements to take with the appropriate instrumentation for my circuit. (Advanced)</td>
<td>Level 3</td>
<td>I can simplify Boolean expressions and logic circuits to use the least number of gate ICs. (i.e., use K-maps, use Boolean algebra, draw multi-logic expression using one gate type, etc.). (Advanced)</td>
<td>Level 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>I can properly use the appropriate instrumentation to analyze my circuit. (Proficient)</td>
<td>Level 2</td>
<td>I can draw a logic circuit based on a given Boolean expression. (Proficient)</td>
<td>Level 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>I can identify different types of electronic instrumentation for circuit analysis (e.g. a volt meter or oscilloscope). (Basic)</td>
<td>Level 1</td>
<td>I can identify the difference between AND, OR, NAND, NOR, and Invertor gates, including drawing their logic tables. (Basic)</td>
<td>Level 1</td>
</tr>
</tbody>
</table>

Dimension: Engineering Knowledge
Core Concept: Electronics
Overview: Electronics are important to engineering literacy because engineers use and apply the principles of electronics as they create and troubleshoot technological solutions to design problems. In this area, students should learn how, why, and when to choose a certain type of electronic component or use the proper instrumentation based on the understanding of the basic structures of digital/analog electronics and electronic signals.
through literacy for all students.

wearable technologies and E-practices. Buchholz et al. (2014) focused on
influence high school students’ understanding of concepts, practices, and perceptions of computing. Furthermore, Kafai et al. learning activities with programmable and design activities can help them to understand concepts, make connections. Qiu et al. (2013) proposed a curriculum with programmable textiles and reported that the experience electronics and computer programming. Also, Kafai et al. (2014) explain that design activities with E-textiles can improve high school students’ comfort with, enjoyment of, and interest in working with electronics and programming. Also, Qiu et al. (2013) proposed a curriculum with programmable textiles and reported that the learning activities with programmable E-textiles can improve students’ comfort with, enjoyment of, and interest in working with electronics and programming. Also, Kafai et al. (2014) explain that design activities with E-textiles can influence high school students’ understanding of concepts, practices, and perceptions of computing. Furthermore, Buchholz et al. (2014) focused on the effectiveness of E-textiles toward enhancing girls interest in STEM activities and found that replacing the traditional circuitry toolkits with E-textiles can encourage more girls to participate in design practices. Therefore, the authors believe that aligning engineering with the socially relevant contexts provided through wearable technologies and E-textiles can help broaden participation in STEM fields and aid in achieving engineering literacy for all students. The lesson plan detailed in Tables 4, 5, and 6 provides a start for teaching engineering content through the context of wearable technologies.

Table 3 Sample Progression of Learning in Engineering for Computer Architecture

<table>
<thead>
<tr>
<th>Dimension: Engineering Knowledge</th>
<th>Core Concept: Computer Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview: Computer Architecture is important to engineering literacy because it allows engineers to design and optimize computer systems. In this area, students should learn what components constitute computer systems, how the components relate to another within the systems, and how to configure the components for desired performance.</td>
<td></td>
</tr>
<tr>
<td>Level 4</td>
<td>I can successfully solve a design problem involving a computer system.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computer Hardware</th>
<th>Computer Software</th>
<th>Processors &amp; Microprocessors</th>
<th>Interfacing</th>
<th>Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3</td>
<td>I can draw a basic block diagram of a full computer system and explain it. (Advanced)</td>
<td>I can determine and justify which type of software is needed for my design. (Advanced)</td>
<td>I can implement a given microprocessor/processor in a system of my own design. (Advanced)</td>
<td>I can determine and justify which type of memory is most appropriate for my design. (Advanced)</td>
</tr>
<tr>
<td>Level 2</td>
<td>I can explain the functions of each major hardware system within a computer. (Proficient)</td>
<td>I can explain the functions of different system software of a computer system. (Proficient)</td>
<td>I can explain how a given microprocessor/processor works. (Proficient)</td>
<td>I can explain the performance of different types of computer memory. (Proficient)</td>
</tr>
<tr>
<td>Level 1</td>
<td>I can identify the major systems in a computer (processor, memory, RAM, motherboard, fan). (Basic)</td>
<td>I can identify a variety of system software that can be included in a computer system. (Basic)</td>
<td>I can identify the characteristics (processing power, number of bits, etc.) of a given processor/microprocessor (Arduino, Raspberry Pi, etc.). (Basic)</td>
<td>I can identify a variety of memory types that can be included in a computer system. (ROM, RAM, etc.). (Basic)</td>
</tr>
</tbody>
</table>

Wearable Technologies: A Socially Relevant Context

In engineering education, there have been discussions that using programmable E-textiles in the classroom can help students to simultaneously develop making skills related to textiles (such as cutting, measuring, and stitching) and creative thinking while also providing connections to socially relevant contexts for learning in depth knowledge of electronic circuits and components (Davies & Hardy, 2016). For example, wearable technology contexts can highlight the influence engineering has on people and society while addressing many students’ desires to engage in fields that make a difference in people’s lives (e.g. healthcare, physical therapy, veterinary care, athletics, fashion, assistive technologies, or virtual reality). Additionally, these example can connect to the cultural backgrounds and communities in which the schools are located.

There have been several studies focused on employing E-textiles to provide opportunities for students to experience electronics and computer programming. Peppler and Glosson (2013) found that engaging children in E-textile design activities can help them to understand concepts around electricity, such as circuit analysis, current flow, polarity, and electrical connections. Qiu et al. (2013) proposed a curriculum with programmable textiles and reported that the learning activities with programmable E-textiles can improve students’ comfort with, enjoyment of, and interest in working with electronics and programming. Also, Kafai et al. (2014) explain that design activities with E-textiles can influence high school students’ understanding of concepts, practices, and perceptions of computing. Furthermore, Buchholz et al. (2014) focused on the effectiveness of E-textiles toward enhancing girls interest in STEM activities and found that replacing the traditional circuitry toolkits with E-textiles can encourage more girls to participate in design practices. Therefore, the authors believe that aligning engineering with the socially relevant contexts provided through wearable technologies and E-textiles can help broaden participation in STEM fields and aid in achieving engineering literacy for all students. The lesson plan detailed in Tables 4, 5, and 6 provides a start for teaching engineering content through the context of wearable technologies.

*Figure 2.* Student threading a sewing needle with conductive thread to make a wearable electronic device.

### Table 4 Wearable Technology Lesson Overview

**Lesson Purpose**: Students in this lesson will use E-textiles and computational thinking to complete an interactive wearable technology project. This lesson will serve to introduce students to the basics of programming and electronics while immersing them in the iterative prototyping of physical products. This lesson will explore the fundamentals of electronics and computer systems to develop a functional wearable technology product.

**Socially Relevant Context**: Wearable technologies and programmable E-textiles hold great potential for advancing toward solutions to grand engineering challenges such as improving health informatics and enhancing virtual reality. Many individuals have a phone or an electronic device of some kind that requires a power source. Relatedly, more advanced wearable devices can track fitness, connect to mobile devices, and perform other advanced functions. While these devices are far more flexible than the pre-existing technology, they are still often viewed as rigid. However, E-Tex tiles (electronic textiles) provide a way for soft and flexible circuitry which may enable electronics to be used in increasingly agile ways.

**Core & Sub Concepts in Engineering:**
- Computational Thinking
  - Programming and Algorithms
  - Programming Languages
- Electronics
  - Components
  - Integrated Circuits
  - Closed and Open Loop and Feedback (systems – system responses)
- Computer Architecture
  - Processors and Microprocessors
  - Interfacing

**Connected STEM Standards**:
- Standard for Technological Literacy 3
  - Benchmark H - Technological innovation often results when ideas, knowledge, or skills are shared within a technology, among technologies, or across other fields
- Standard for Technological Literacy 9
  - Benchmark J - Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.
  - Benchmark K - A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.
  - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- Next Generation Science Standard ETS1-3.
  - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

**Learning Objectives**:
- I can determine and justify which type of integrated circuits are most appropriate for my design.
- I can utilize a given microprocessor/processor in a system of my own design.
- I can develop programs using more advanced programming techniques, such as loops, conditional structures, and variables.
- I can determine and justify which components are needed hardware or software interfaces.
- I can explain the structures and control processes of closed, open, and feedback loops.
Driving Questions:
1. How can wearable technologies and E-textiles influence our daily lives?
2. What is computational thinking and how can we use it to solve design problems?
3. How can we enhance the flexibility of electronics devices to better adapt to living things?
4. How can computational thinking be applied to non-programming tasks?

Career Connections:
- Specific skills that students will learn include: computational thinking, programming, and systems thinking. These skills related to careers such as: Systems Engineer, Full Stack Developer, Computer Scientist, Manufacturing Engineer, Textile Industry Fashion Designer, Textiles Engineer/Manufacturer, and Electrical Engineering.

Table 5 Wearable Technology Lesson Plan

**Engage:** Sets the context for what the students will be learning in the lesson, as well as captures their interest in the topic by making learning relevant to their lives and community.

- Teacher will present the wearable technology tinkering activity “Complete the Simple Circuit.” Students are challenged to be the first to complete a circuit and light the LED using only the E-textile items listed below:

<table>
<thead>
<tr>
<th><strong>Materials Needed Per Student:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coin Cell Battery</td>
</tr>
<tr>
<td>Coin Cell Battery Holder</td>
</tr>
<tr>
<td>4” Conductive Thread</td>
</tr>
<tr>
<td>1 Sewable LED</td>
</tr>
</tbody>
</table>

- After 5 to 10 minutes – bring the class back together. If there are students who completed the challenge have those students explain how to solve it to the other students.

**Explore:** Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.

- Begin discussing the ever-growing popularity, necessity, and importance of wearable technology and E-textiles. Suggested talking points:
  - What is wearable technology?
  - What are some examples?
  - What are E-textiles?
  - Why are E-textiles and wearable technologies popular?

- Teacher will then present how an E-textile circuits functions.
  - A circuit is a path that electricity flows
  - In battery circuits, the positive and negative ends need to be connected
    - Complete circuit
    - If the circuit is broken – it won’t work
  - Some components need electricity to turn on
    - Lights/LEDs function when electricity flows through them
  - To turn off components – we can break the flow of electricity
    - Switches prevent the flow of electricity
    - To allow the electricity flow – turn on the switch
    - With push buttons – we must push the button to allow flow

- The students will now complete the exploration activity to create a flexible, light up emoji keychain. See Figure 3. This activity will give the students practice with sewing electrical circuits.

**Figure 3.** Exploration activity: Creating a flexible, light up emoji keychain

- To begin the exploration activity, have students gather into groups of two and handout the following materials:

<table>
<thead>
<tr>
<th><strong>Materials Needed Per Group</strong></th>
<th><strong>Available Part Number from Kitronik:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3” Circle of felt x 2</td>
<td>-</td>
</tr>
</tbody>
</table>
Students will then create a light up LED emoji keychain following the schematic below. *Note:* when using conductive thread separate strings need to be used between each sewing loop. Otherwise, it can short circuit the wiring (i.e. one string between cell holder and push button; another string between push button and LED).

- If students are having trouble with sewing, there are multiple short demonstration videos on YouTube they can look up and follow along with. There is also a helpful chart below to demonstrate a simple stitch.

**Materials Needed:**

<table>
<thead>
<tr>
<th>Sewable Miniature Coin Cell Holder</th>
<th>2718</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1220 3V Coin Cell, pack of 5</td>
<td>2269</td>
</tr>
<tr>
<td>Electro-Fashion, Conductive Thread, 6m</td>
<td>2727</td>
</tr>
<tr>
<td>Electro-Fashion, LED Board, White, pack of 10</td>
<td>2714</td>
</tr>
<tr>
<td>Electro-Fashion, Push Button Switch</td>
<td>2708</td>
</tr>
<tr>
<td>Needle Set, pack of 5</td>
<td>2741</td>
</tr>
<tr>
<td>Basic Sewing Thread</td>
<td></td>
</tr>
<tr>
<td>Keychain</td>
<td></td>
</tr>
</tbody>
</table>

**Engineer:** Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/refine a viable solution.

- Programming wearable technologies to solve a problem is an opportunity to develop computational thinking skills.
- Wearable technologies can interface with common devices such as Arduino microcontrollers, allowing students to build, code, and test solutions for real problems in their lives.
- In the engineering challenge of this lesson, students are introduced to the “ninja game.” This is a playground game where one player is trying to tag another’s hand, to knock that player out of the game. A video explaining how to play the game can be found at: (“How to play the Ninja hand game” link: https://www.youtube.com/watch?v=7F0p9ZlPH5A).
- Although commonly played, one problem with this game is that players often cheat and say their hand wasn’t touched. Therefore, the engineering activity challenges students to create a wearable item that would indicate when another player had scored a successful hit, to prevent cheating.
- An example step-by-step solution to this challenge is provided in Table 6.
- The following materials will be needed to complete this challenge.
Table 6 Example Solution to the Lesson’s Engineering Design Challenge

<table>
<thead>
<tr>
<th>Step 1: Design and Component Selection</th>
</tr>
</thead>
</table>
| A solution to the design challenge can be centered around the development of a wearable capacitive touch sensor. A capacitive touch sensor measures the change in capacitance along a part of a wire, where the “capacitor” exists in the space between the wire and another grounded object. Thus, a periodic signal is sent from one pin on a microcontroller, through a resistor, and another pin listens for that signal on the other side. If a grounded object is brought close to either side of the resistor, a slight capacitance is created, making an RC circuit that changes the signal as it passes through, in a way that can be measured by the microcontroller. Arduino has a great capacitive sensor library, for more information visit: \[http://playground.arduino.cc/Main/CapacitiveSensor?from=Main.CapSens\] The other piece of this step is selecting the components for the design. A small Arduino microcontroller was chosen, along with sewable LEDs, to be powered by a simple 9v battery. A long, fingerless glove was chosen to give ample room for securing.

Step 2: Initial Prototyping

Initial tests of the CapSense library functions were undertaken with an Arduino UNO. Simple code was written to test the Capacitive Sensor library, which was later re-used in the final design. Breadboard circuits were created. This was to test assumptions on proven hardware, which would prove to be helpful during the next step.

**Step 3: Prototype with Adafruit Trinket**

Adafruit’s Trinket microcontroller was selected for its small size and simplicity of operation. It was discovered at this step that the Capacitive Sensor Function did not work as expected. After some research into the implementation of the sensor, it was discovered through some tinkering that switching the send and receive pins from step 1 produced results consistent with what was desired. (e.g. the capacitive sensor wire needed to be on the send pin side of the resistor).

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**Step 4: Prototype Sensor**

The capacitive touch sensor itself, hardware-wise, is just a single conductive thread, sewn into a grid pattern on a separate piece of fabric. Conductive thread was chosen for its flexibility. The separate piece of fabric was needed such that the glove would insulate the wearer from setting off their own sensor. From here, initial sensitivity values were set in code.

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**Step 5: First Glove Prototype**

The capacitive touch sensor prototype was attached to the glove with non-conductive thread, and the sensor’s thread was carefully threaded back to attach to the microcontroller, such that it would not touch the inside of the glove. In this step, it was discovered that the thread is slick, and needs tied onto the microcontroller pins then carefully soldered. The heat from the iron can melt the thread, so direct contact needs to be avoided. The wire paths (conductive threads) were not the best in this first iteration, and hot glue was used to avoid shorts around the microcontroller. Also, an extra felt piece was added to cover the microcontroller, again to prevent accidental shorts or contact with the user.

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**Step 6: Refinement to Final Product**

Felt was selected to replace the fabric backing for the capacitive touch sensor for ease of use and improved aesthetics. It was discovered that without extra felt between the sensor grid and the glove, the user could trigger their own glove by flexing their hand. The overall layout was improved, and the process and workmanship was refined through the learning experience provided by creating the first prototypes. Hot glue was no longer needed around the microcontroller. The finished glove will blink several times when someone touches the felt pad on the back of the hand.

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