Design for Wearable Interactivity

Yaling Liu / Wei Wang / Stephen Eick
Georgia Institute of Technology
yaling.liu@design.gatech.edu / wei.wang@design.gatech.edu / stephen.eick@gatech.edu

INTRODUCTION

Interactive products and wearable technologies have become prominent in the field of Industrial Design (ID). ID education has adapted to this shift by integrating information and communication technologies (ICTs), human-computer interaction (HCI), and interactive product design criteria into the ID curricula. The design of wearable technologies also requires the ID student to master working with the constraints of the human body while incorporating form factors, enabling technologies, and interaction modalities (Wang, Bryan-Kinns & Yan, 2015) into their design process.

This paper presents a summary and analysis of a short-term workshop founded on the "learning by making" strategy (Rollins, 2013). The workshop saw students design "Circuit T-shirts" with interactive features. The students participating in the workshop had little prior experience with interactive technologies. They explored conductive and soft materials, designed an interactive gesture with a graphical circuit on a T-shirt, presented the final product in a runway format, and accompanied their presentation with a short video. This paper summarizes student design outcomes by analyzing their interview responses together with assessment by the authors during and after the workshop.

COURSE OVERVIEW

To give undergraduate ID students earlier exposure to interactive technologies, the course "Introduction to Smart Product Design" (ISPD) was introduced in the newly-redesigned undergraduate Industrial Design curriculum at the School of Industrial Design, Georgia Institute of Technology (Budd & Wang, 2017). Compared with existing interactive technology design courses (Martin et al., 2012; Hartmann & Wright, 2013; Corno & Russis, 2017), ISPD was deliberately targeted to sophomore year ID students. This placement within the curriculum ensured the students already had exposure to the history and fundamentals of industrial design prior to dealing with the transdisciplinary complexities of interactive technologies. ISPD was taught in conjunction with two complementary courses, "User-Centered Methods" and "Human Factors in Industrial Design." This horizontal format allowed students to explore different interactive technologies from a human-centered perspective.

The first six weeks of ISPD concentrated on the fundamentals of digital electronics and programming through a series of Arduino-centric exercises. Two short projects, Smart Product Critique and Future Sensor, helped students gain a better understanding of off-the-shelf interactive products and sensor functionality. The Circuit T-shirt Workshop was launched to anchor and evaluate their knowledge of digital electronics. The workshop experience culminated in the assignment to design and create an innovative and functional interactive product.

CIRCUIT T-SHIRT WORKSHOP

THE BRIEF

The workshop aimed to explore natural human gestures, study human body movements, and create a simple interaction on a wearable product we refer to as a "Circuit T-shirt." The design materials included the following:

- Non-conductive soft materials: The T-shirt (100% preshrunk cotton Gildan G644 Adult Softstyle® 4.5 oz.) is one of the most common garments in a person's closet. Its softness, workability, and strength qualify it for this workshop. The color black was chosen to maximize the visual impact of the copper tape and LED lights. The medium weight of 4.5 oz. provides strength to affix materials to the T-shirt. This particular T-shirt had long sleeves, allowing student to explore the use of forearms in this workshop.
- Conductive materials: ¼" copper foil tape, 3V coin cell battery, LEDs, and through-hole resistors are common beginner circuit elements in the interactive design field. These materials were selected to allow the students to prototype and validate their idea with speed.

Students were required to use copper foil tape as a "paintbrush" to design a graphic on the T-shirt. The graphic was required to contain at least one complete circuit. At least one LED light would serve as the output device upon receiving the input of a gesture interaction or body movement. The ultimate goal of the Circuit T-shirt was to communicate a story of a unique interaction.

THE METHOD AND THE PROCESS

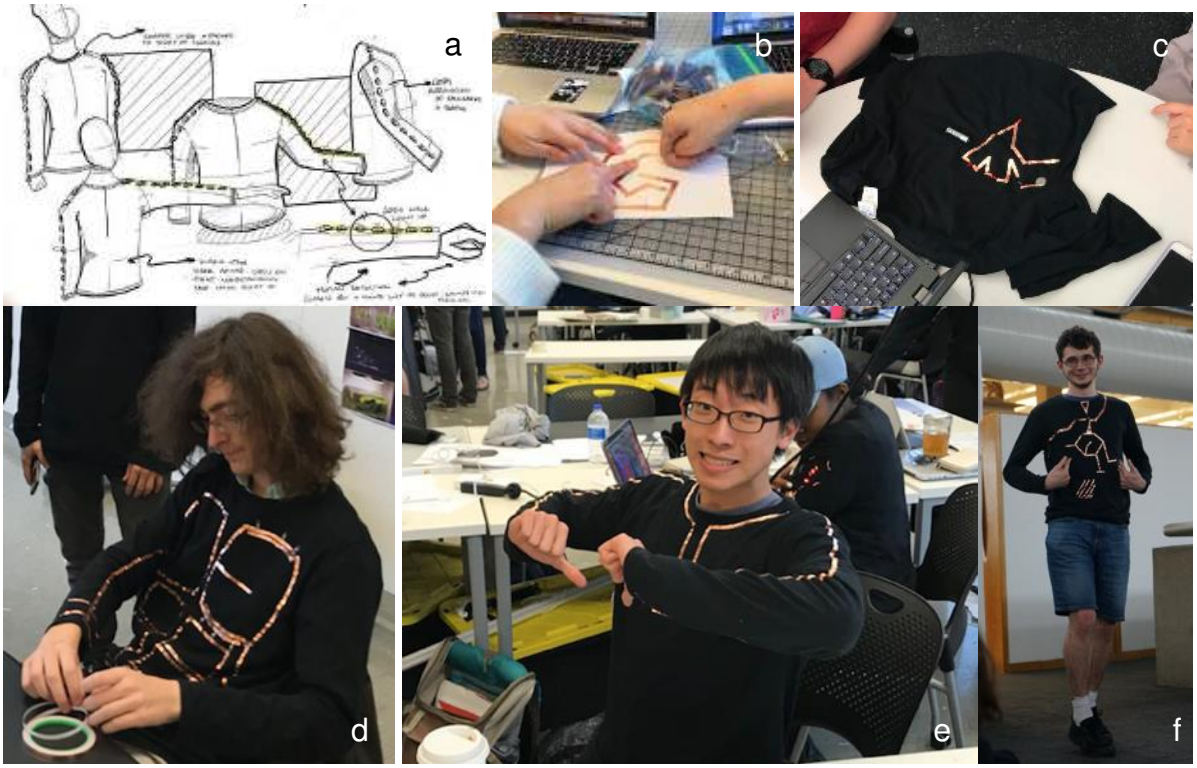

Figure 1. Circuit T-shirt workshop process

In a short-term intensive process, the workshop was conducted in one week with three phases:

Phase 1: Brainstorming and concept development

Students were encouraged to freely brainstorm and develop their concept in gestures and body movements by playing the game Charades with each other, then sketch out concepts. The specific steps include the following:

- Step 1.1: First encounter with the materials
- Step 1.2: Brainstorming in gestures and body movements through Charades.
- Step 1.3: Concept sketches (Figure 1a)

At the end of phase 1, every student presented three concept proposals for a graphic design with circuit layout and gesture/body interaction. Each proposal was presented on one 11x17 (tabloid size) sketch. After approval from the instructors, the final concept was selected and moved to the prototyping stage.

Phase 2: Prototyping

The prototyping in Phase 2 is a novel learning experience for ID students. Compared with 3D modeling and printing phases in the traditional product design process, prototyping wearable interactivity is an agile iteration to transfer a circuit sketch from paper to soft materials. It required students to develop their hands-on capabilities and creativity to explore the constraints of the materials, electricity and body's interactivity. Steps include the following:

- Step 2.1: Circuit sketch on paper (Figure 1b)
- Step 2.2: Circuit sketch transferring to soft materials (Figure 1c)
- Step 2.3: On body making (Figure 1d)
- Step 2.4: On body testing (Figure 1e)
- Step 2.5: A working prototype

At the end of phase 2, every student was expected to have a functional Circuit T-shirt.

Phase 3: Presentation

To encourage engagement from the students, the final presentation included a video demonstration and a catwalk show. The video, rather than being focused on technical aspects, was designed to give students the opportunity to craft a story around their design. The live presentation method from fashion design was a novel experience for ID students, helping them consider the dynamic effects beyond the still model of their creation. Each student would walk to the end of the catwalk, stop, and demonstrate their T-shirt. The presentation phase includes the following steps:

- Step 3.1: Storytelling through a one-minute video
- Step 3.2: A runway show of how the interaction works (Figure 1f)

THE OUTCOMES AND OBSERVATION

36 students (n = 36) each constructed an interactive T-shirt design. In their presentations, each student demonstrated their designs on a runway walk. They narrated their design story with a video presentation (shown in Figure 2). After the presentations, the students were asked for *in-situ* feedback and reflection on the success of the workshop. Student responses centered on evaluating the viability of the overall process, assessment of working with conductive and soft materials, and the effectiveness of their body gesture solution to their designs. The feedback session was documented with video and researchers'

observation notes. The instructors also conducted a focus group and then applied the data to analyze the workshop's outcomes. Additionally, an online survey was sent to each student at the beginning of each workshop phase to track their learning process. These surveys were constructed with questions to assess understanding of human-centered design approaches, knowledge about wearable products, and experience in working with soft conductive materials. The information was measured on a scale from 0 to 5. Participation in this survey was voluntary, and 11 students (n = 11) participated in all survey sections.

Figure 2. The final presentation

DISCUSSION

The workshop aimed to build a fundamental understanding of human-centered design and interactive wearables by creating gestures or body movements to visually communicate information using LEDs. The workshop also served as an introduction to conductive materials commonly used when prototyping an interactive wearable. After the workshop, 75% of students felt more comfortable working with the soft conductive materials. One student remarked that they enjoyed being able to explore the electronics they were taught in a fun setting. After the workshop, students also mentioned they had a better understanding of how to build circuits with copper tape. Through the design process, it also appeared evident the students discovered that the conductive material itself could be used as an aesthetic element in their T-shirts (or in other designs as well).

This section summarizes the key findings and reflections of the workshop: gesture design with body movement and working with conductive and soft materials.

GESTURE DESIGN WITH BODY MOVEMENT

Gesture is becoming the next big thing in Design (IDEO, 2018). In this workshop, the gesture could be defined as a movement of part of the body, especially a hand or the head, to express an idea or narrate meaning (Oxford Dictionaries, 2018). From the outcomes of the workshop, two major categories of gestural action emerged: *natural gestures* and *specialized gestures*.

Natural gestures

A natural gesture is delivered in an effortless way as one of the common human actions. The observed natural gestures from the workshop were the following:

Figure 3. One finger pressing (the left), one palm pressing (the middle), and two fingers pressing (the right)

Figure 4. One arm in contact with the body (the left), crossed arms movement (the middle), and the LEDs on the back (in the right)

- One finger pressing: use of the index fingertip to press on a specific area of the circuit. (Figure 3 the left)
- One finger stroking: use of an index finger to stroke a specific path.
- Two fingers pressing: use of two fingers to press on two specific areas of the circuit. (Figure 3 the right)
- Palms pressing: use of one of one palm to press a larger area of the circuit on the upper body (Figure 3 the middle) or use two palms to complete the circuit placement on the upper body.
- One arm and the upper body: use one arm to contact a larger area of the upper body. (Figure 4 the left)
- Two arms: both of the arms in contact with a specific area to complete the circuit.
- Crossed arms: crossed arms over the chest to connect the circuit (Figure 4 the middle and the right). The circuits are either on the arms only or on both of the arms and the upper body.

Specialized Gestures

A specialized gesture is designed to express a defined motion. Examples like:

- “Cactus” (Figure 5 the left): This student used the shape of a cactus to express the gesture of one arm bent into an L shape and the other arm touching the side of the upper body with the elbow in order to activate the LEDs lights on the T-shirt.

- “The point and the judge”: (Figure 5 the right): This student designed a gesture that emphasized the motion of power in which one arm was positioned under the shoulder and moved toward the middle of the upper back in order to connect the circuit; the other arm remained forward with two fingers bent.

Figure 5. Specialized gesture: cactus (the left) and the point and the judge (the right)

In the workshop, the circuits were driven by gestural motion design. The outcomes of the complete electronic circuit fell into two areas: *single-person circuit* and *two-person circuit*.

Single-person circuit

A full circuit is completed by a gesture from one person. An example is shown in Figure 6: the individual would touch at one of five points on her arm to complete the circuit.

Figure 6. Single person circuit

Two-person circuit

A full circuit is completed by two persons. For example:

- Fluttering motion: The circuit is completed when one individual embraced and activated the sectional circuits on another person’s arm.
- Arm wrestling (shown in Figure 7): The incomplete circuit is used to determine the winner of an arm wrestling match. Two individuals arm wrestle; the motion by the winner of lowering the opponent’s wrist to the table signals an LED graphic on the shirt.

Figure 7. The LEDs were on while wrestling (in the left), and the winner turned off the lights (in the right).

Most students acknowledged that gesture design was one of the first vital issues they considered in starting their projects. One student even said that selecting the interaction method must start with the gesture because it drove the direction of the story that went with the graphic on the T-shirt. Another student noted that it was important to think about a form with gestures, e.g. where should the switches go so they were not mistakenly triggered. The workshop also helped students consider using gesture design in other consumer product lines. For example, one student mentioned that they learned why there were not as many products with gesture interaction on the market; because everyone used different gestures, it was difficult to design for everyone.

WORKING WITH CONDUCTIVE AND SOFT MATERIAL

Textiles are flexible materials consisting of a network of natural or artificial fibers (Merriam-Webster, 2011). They have been widely used in specific design fields, like Fashion Design and Housewares. This workshop provided an opportunity for students to work with a knitted fabric, which afforded flexibility and stretch. In working with flexible textiles, the students encountered four issues they had to design around fabric properties, T-shirt sizing, selection of an area of interaction, and the properties of the copper tape.

The fabric mattered.

Although the students were comfortable in working with the T-shirt fabric, they did not anticipate how stretchy the T-shirt would be. Moving an arm could affect any circuitry placed on the shoulder or arm as the shirt stretched and twisted. As a result, a number of issues were encountered with designs which placed main circuit elements on the shoulders and arms.

The sizing mattered.

The fit of the T-shirt also played a vital role in the effectiveness of the gesture. Students who wore a T-shirt too large for their body had difficulty getting their gesture to work reliably because the T-shirt floated on their body and the contact was not secure. Those students wearing tighter-fitting T-shirts had noticeably more effective gestures. It is evident that fit is a crucial design consideration in wearable technologies.

The area mattered.

Another challenge students encountered was placing the point of interaction on their body in a reliable location. Many students selected to place their points of interaction at an easily-touchable point such as on forearms or their chest. However, some students had complex gestures and subsequent interactions, making for unconventional and challenging points of contact. For example, one pair of students designed their point of contact as their conjoined sides as they embraced each other. Another student had a

handheld object which, when touching a particular point on their shirt, would cause the shirt to illuminate. It required careful considerations of where and how to place a point of interaction to close the electrical circuit.

The copper tape mattered.

Copper foil tape is one of the most accessible conductive materials on the market. Copper tape is a thin strip of copper with one side coated with a mild adhesive. It is economical, customizable, and amenable to rapid prototyping and design iteration. Students encountered the following characteristics of copper tape as they were designing their projects:

- Conductivity is generally lower on the adhesive side than the non-adhesive side.
- The tape is more rigid than the T-shirt.
- The adhesive side is sticky.
- Creating curved lines with copper tape is difficult.
- Connections become more reliable by stacking layers.
- A shirt → LED pin → copper tape stack is not reliable because the mild adhesive is not strong enough to reliably hold the thin metal LED pin and conduct electricity. A shirt → copper tape → LED pin → copper tape stack created significantly more reliable connections.

Soft materials like textiles are not typically used for fabrication in electronic-based assignments in Industrial Design projects. One student remarked that the material choice was important. For example, understanding of soft materials versus rigid materials that could not flow with movements became critical. This student found a solution to the dilemma by focusing on the prototyping phase. Another student remarked how designing a wearable interactive product forced the designer to consider the ease with which the product could break. For this student, focused design thinking to arrive at solutions was important. Another student said that it was tricky to transfer a 2D design sketch onto a 3D on-body T-shirt. On-body making and testing was the critical juncture in transferring ID thinking with 2D sketches to the new design requirements of 3D space. As shown in Table 1, the significant changes happened from the transition from phase 2 to phase 3. At the completion of the assignment, most students self-measured their knowledge of working with soft conductive materials as moderate to high. They remarked on how much more comfortable they had become in working with soft conductive materials as a result of this workshop.

Knowledge level	0 beginner	1	2	3	4	5 expert
In the beginning of Phase 1 (*n = 11*)	*45.5%*	*0*	*36.3%*	*18.2%*	*0*	*0*
In the beginning of Phase 2 (*n = 11*)	*27.3%*	*45.5%*	*18.2%*	*9%*	*0*	*0*
In the beginning of Phase 3 (*n = 11*)	*9%*	*18.2%*	*18.2%*	*27.3%*	*27.3%*	*0*
In the end of presentation (*n = 30*)	*0*	*3.3%*	*50%*	*23.4%*	*20%*	*3.3%*

Table 1: Poll responses in different phases for the question “Please score your knowledge of working with soft conductive materials”

CONCLUSION

In this paper, the authors reviewed the outcomes of the Circuit T-shirt Workshop which had been tested with undergraduate students to assess their teaching strategies and discussed how to teach undergraduate ID students to design wearable and interactive objects with two learning challenges: 1) gesture design and 2) working with conductive and soft materials. Though the workshop was short and intensive, the outcomes and survey results demonstrated the "learning by making" model is an efficient and effective approach in helping students understand the inherent constraints in wearable design and create diverse gesture design with various bodily movements. Using copper tape on the T-shirts presented significant challenges in the prototyping process. Switching to conductive fabric tape or conductive thread will be considered for future workshops.

Designing a wearable object with interactivity is a challenging but productive experience for Industrial Design students because it requires knowledge of the human body, physical motion analysis, understanding of electronics, experimentation with wearable materials, and other learning experiences. It is our conclusion that the Circuit T-shirt workshop, summarized in this study, was a valuable teaching protocol for an Industrial Design curriculum.

ACKNOWLEDGMENTS

We wish to acknowledge Joyce Medina, all students in class of 2020, colleagues in industrial design education, and peer reviewers of this paper. The research is sponsored by Georgia Tech Faculty Development Grant and School of Industrial Design.

REFERENCES

Budd, J., & Wang, W. (2017). Industrial Design Education: Taming Technology to Enhance User Experience. *Archives of Design Research (ADR)*, 30 (3), 17-27.

Corno, F., & De Russis, L. (2017). Training engineers for the ambient intelligence challenge. *IEEE Transactions on Education*, *60*(1), 40-49.

Fallman, D. (2008). The interaction design research triangle of design practice, design studies, and design exploration. *Design Issues*, *24*(3), 4-18.

Hartmann, B., & Wright, P. K. (2013). Designing bespoke interactive devices. *Computer*, *46*(8), 85-89.

IDEO (2018). Why Gesture is the Next Big Thing in Design, https://www.ideo.com/blog/why-gesture-is-the-next-big-thing-in-design. Retrieved at April 25th, 2018

Martin, T., Coupey, E., McNair, L., Dorsa, E., Forsyth, J., Kim, S., & Kemnitzer, R. (2012). An interdisciplinary design course for pervasive computing. *IEEE Pervasive Computing*, *11*(1), 80-83.

Merriam-Webster. (2011). https://www.merriam-webster.com/dictionary/textile. Archived from the original on 2011-11-09. Retrieved 2018-04-25

Oxford Dictionaries. (2018). https://en.oxforddictionaries.com/definition/gesture. Retrieved 2018-04-25

Rollins, A. (2013). Learning by Making: Embedding Hands-on Experience for Industrial Design Education. In *IDSA Eastman Education Symposium 2013*

Wang, W. Bryan-kinns, N. & Yan, Q. (2015). The Design Space and The Shifting Trigger in Wearable Product Development. In the Proceeding of *International Design Congress: Eeum Design Connects*. pp. 206-210.

the Proceeding of *International Design Congress: Eeum Design Connects*. pp. 206-210.