Exquisite Circuits: Collaborative Electronics Design through Drawing Games

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ABSTRACT

We present *Exquisite Circuits*, a novel collaborative circuit design approach that remixes the surrealist *Exquisite Corpse* drawing game for paper circuits. In this pictorial, five participants played the game and documented their design, fabrication, and thought processes during gameplay. From these results, we contribute lessons learned on how game elements like surprise, ambiguous goals, and shared responsibility open new ways of thinking about the expressive and collaborative design of technology. *Exquisite Circuits,* through paper circuitry's hybrid of aesthetic and functional design affordances, helped reveal tensions between arts and technology cultures and approaches. We invite educators, designers, and technology creators to try their own variations of the *Exquisite Circuits* and share their results with the creative technology community.

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INTRODUCTION

Electronics design is typically a problem-solving pursuit driven by the rules of physical and material logic, often in search of functionality (“does it work?”) and efficiency (“for how long?”). In an attempt to depart from these focusing forces, we look to the opposite: the illogical and the ephemeral. Taking a “disruptive improvisations” approach [2], we look to the *Exquisite Corpse* drawing game for inspiration as a methodology to integrate surprise and randomness into collaborative creation [7, 9, 25, 27]. We extend this game by translating its analog drawings into electronics through paper circuits, creating a new game that we call *Exquisite Circuits*.

Unlike the wire and breadboard approach of traditional circuit design, paper circuits use craft materials like conductive paints and copper tapes on paper to enable circuit design with aesthetics and artistic expression in mind [6, 16, 18, 21]. This approach not only augments the interactive possibilities of paper [28], it also turns interaction and computation into a friendly material with which to craft [18]. With its low cost, off-the-shelf availability and accessibility through familiar materials, paper circuits has grown in popularity among hobbyists, researchers and educators alike [13, 15, 26]. Through *Exquisite Circuits*, we open space to explore paper circuits beyond material techniques to the creative processes and experiences that this medium may uniquely enable. Through this, we hope to achieve new ways of thinking about the expressive and collaborative design of technology.

This pictorial journeys our pilot game of *Exquisite Circuits* in which we closely document our collective design, fabrication and thought processes. In doing so, we began to uncover how applying the improvisational approach of the Surrealists to circuitry design and fabrication opens new possibilities for co-creation. We share our early reactions and from the experience, lessons learned about the paper circuit medium, its impact on our own views of technology design, and directions for future tool designers. We conclude with various ways to play *Exquisite Circuits* as a provocation for readers to extend this new approach.

The Exquisite Corpse Reborn

One quiet night in 1925, a group of Surrealists played classic game of *Consequences*: players took turns adding words to a structured narrative, folding the paper to hide their contribution. At the end of each round, the paper was unfolded to reveal the full story.

The game suddenly took a turn when one player announced a new rule: "Just write anything." Out of this newly unlocked freedom came their first nonsense line: "**The exquisite corpse ... will drink the new wine.**"

From there, the artists tried playing with drawings instead of words. Players drew a section and then folded the paper so that only a few lines could be seen at the edges of the section. The next player could continue the drawing by extending these lines, but without knowing what previous players drew. Thus the *Exquisite Corpse* was born [3, 12].

Breton, N. Eluard, Hugo, P. Eluard. *Exquisite Corpse* [c. 1930] © TateCC-BY-NC-ND 3.0 [4]

The players were enthralled. In hiding and then colliding their individual freeform drawings, they found a mechanism to **disrupt the overbearing logic and order of their conscious minds** by randomly generating works as a collective.

> "Violent surprise provoked our admiration and sparked an insatiable passion for new images... We were at once recipients of and contributors to the joy of witnessing the sudden appearance of creatures none of us had foreseen, but which we ourselves had nonetheless created."
>
> ***- Simone Kahn [12]***
> *Surrealist Artist, c. 1925*

Part of the charm was the game's lightness: it was playful, humorous, unpredictable and unprecious. "Don't forget—the wastebasket had a role in all this," noted artist Simone Kahn [12]. The materials were fast and ephemeral; anyone at any skill level could play by simply writing or sketching without the possibility—and thus without the pressure—of producing anything in particular.

That the *Exquisite Corpse* so smoothly translated from words to visuals indicates its power as not just a game, but also a methodology [9, 25, 27]. Its success inspires us to ask: can we push the *Exquisite Corpse* beyond the verbal and graphic dimensions into the electric and computational planes?

For this, we return to paper circuitry. As a lightweight design medium [10], paper circuits allow us to retain the quick, handmade and aesthetically diverse affordances of the original drawing game while augmenting them with the interactive capabilities of electronics. Coupling the accessibility of paper circuits with the *Exquisite Corpse* serves as a potential entryway for players from varying backgrounds and skill levels to collaborate in creating expressive hardware together [5, 21, 22], just as the original game allowed artists of all backgrounds to play together and achieve artworks not possible alone. In the rest of this pictorial, we explore what it means when the *Exquisite Corpse* becomes an *Exquisite Circuit*.

Design Tools

Our pilot game of *Exquisite Circuits* took place remotely across three time zones using three digital collaboration tools: Zoom, Google Docs, and Circuit Sketcher.

Circuit Sketcher (www.circuitsketcher.com) is a browser-based circuit design tool we are developing for paper circuit design more broadly. Our activity centers around players generating ideas and building off of each other's designs, so we chose to use a shared lightweight tool that we designed to make circuit layout more like sketching. Circuit Sketcher uses a paint-style canvas where users can place circuit components and traces as well as import images to design from. In contrast to technical features often found in existing circuit design software [16, 24], we opted for a simpler interface, where users can:

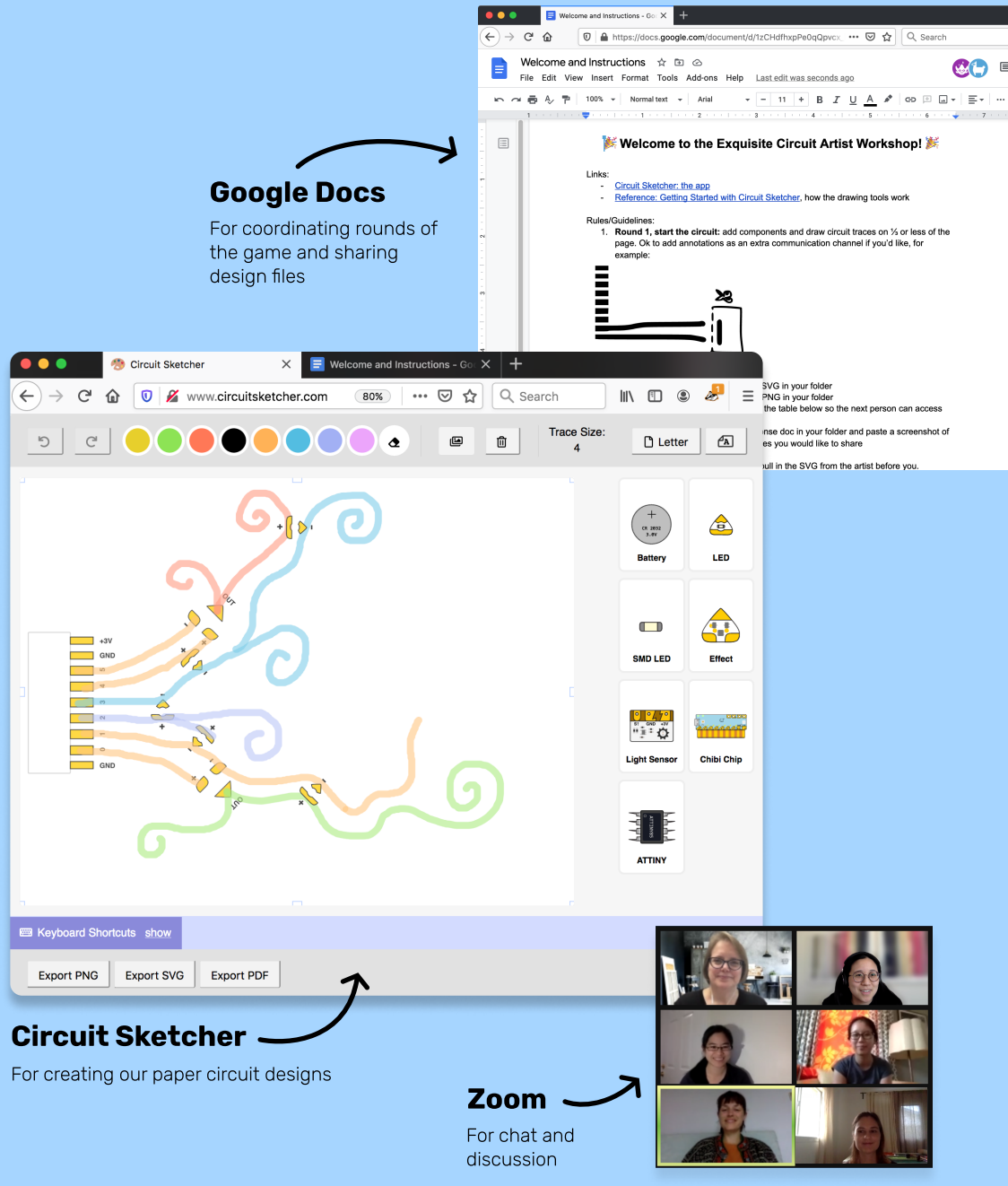
Stamp footprints for common circuit components, including coin batteries, Chibitronics Circuit Stickers and a programmable microcontroller [23]. The parts can be moved but not resized to ensure that footprints match physical component dimensions for fabrication.

Draw connections between footprints, supporting multiple colors to distinguish between traces. Default trace widths match standard copper tape sizes used in paper circuits.

Import images as a reference for circuit design or decorative background.

Export designs as PDF or PNG image templates for printing and handcrafting, or as SVG files for digital fabrication on vinyl cutters.

Circuit Sketcher was used in service of our activity, with players passing off in-progress designs in a shared Google Doc between rounds and importing these images into the software to continue. Our goal in this pictorial is not to evaluate the Circuit Sketcher tool itself [11, 14, 19], but use it as a platform to enable us to observe the collaborative circuit building process that emerged from our *Exquisite Circuits* game.



How We Played

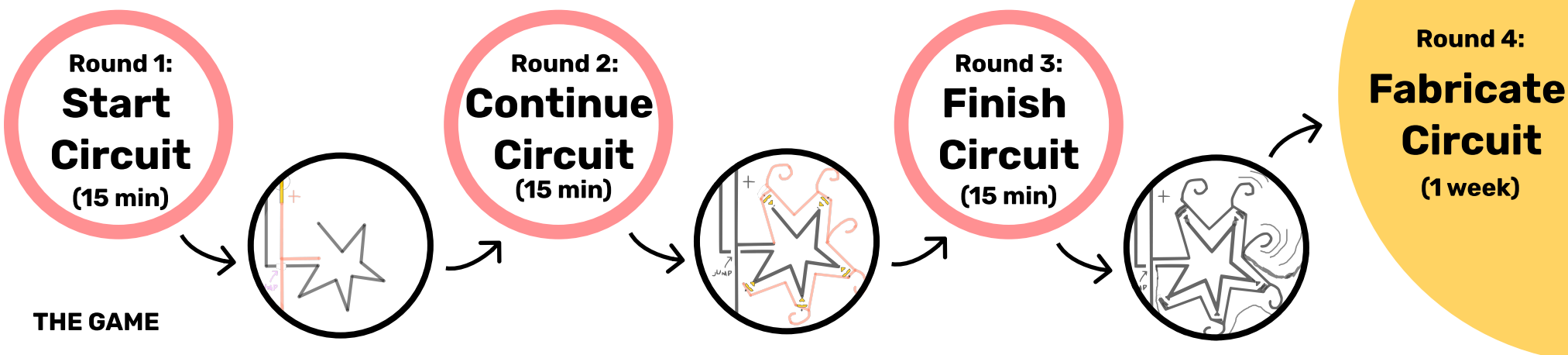
PARTICIPANTS AND METHODOLOGY

For our pilot game of *Exquisite Circuits*, we took an autobiographical design approach [8, 17]. Three of the authors co-designed the Circuit Sketcher software and developed the initial game idea; three additional authors participated in playing the game; all were involved as researchers in making sense of the results and designing future variations.

In this pictorial, we describe the results of an initial game of *Exquisite Circuits* that took place between 5 players, all authors on this paper. One of the co-designers of the game did not participate in the game itself due to time zone challenges, but joined for the results analysis and discussion.

All participants had prior experience in designing and fabricating paper circuits, and all but two had previously used the Circuit Sketcher software. Collectively, the group represented practitioners and researchers working at the intersection of technology, art, and education. While the electronics skill level among the group was high, all participants situated themselves in various stances of resistance or tension vis a vis dominant engineering practices, perspectives informed in part by our own experiences as minoritized participants in STEM fields and/or with marginalization of our other interests and values (art, craft, activism, "bricolage" practices [29], community-centered and culturally sustaining approaches [1, 20]).

Our personal motivations (or "authentic needs") [8] for playing included a) expanding the boundaries of our own practices through collaboration, b) experientially exploring new possibilities for intertwined technology and art processes, especially ones which might surprise us, c) surfacing the "hidden skills" needed to support more multi-faceted and creative approaches to working with technology, and d) bringing back ideas to our tool design practices, classrooms or communities in support of more equitable and inclusive engineering education.



THE GAME

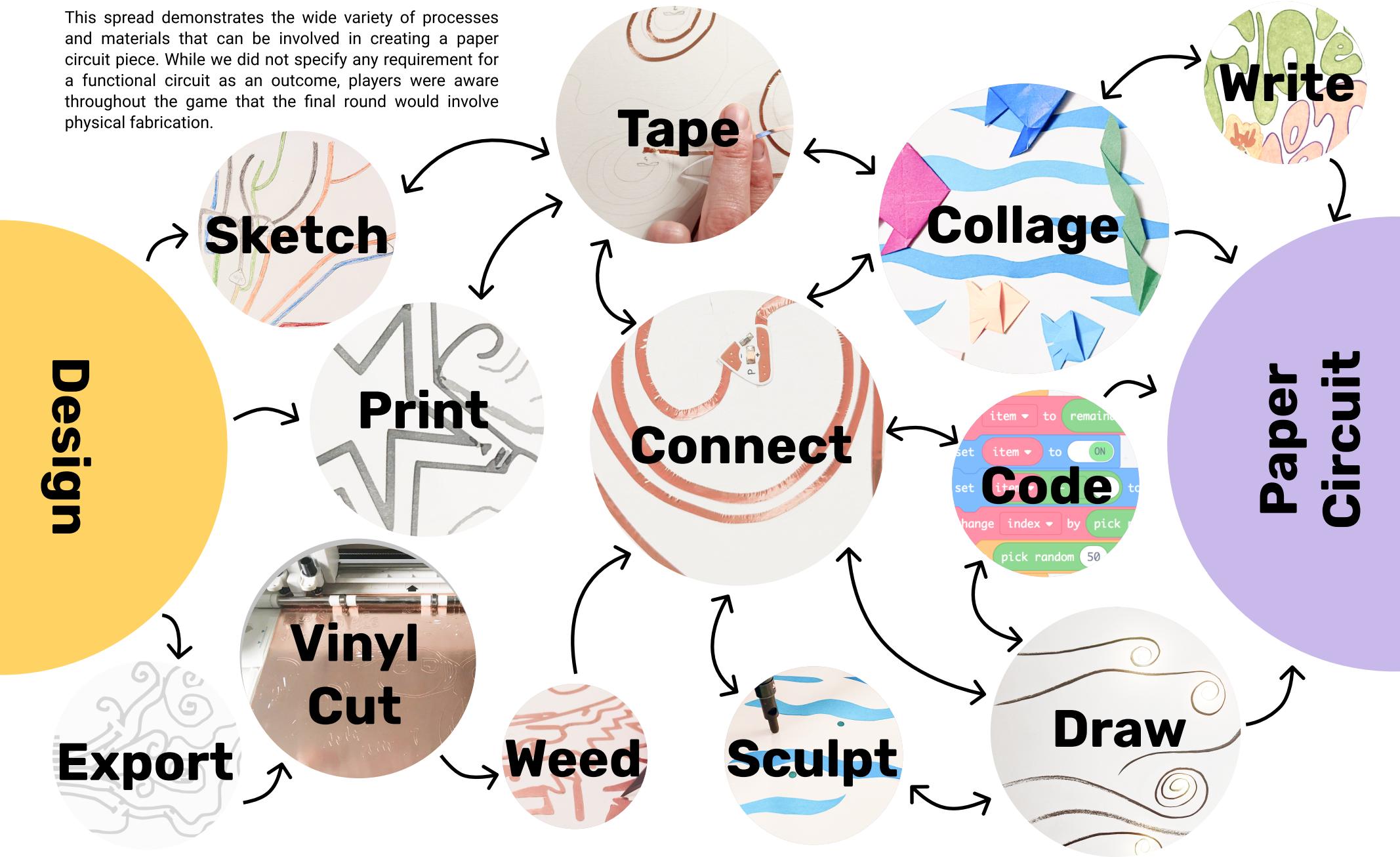
The first three rounds of *Exquisite Circuits* took place over an hour-long Zoom workshop that began with a tutorial on using the Circuit Sketcher software. In each round, players had 15 minutes to design their part of the circuit before exporting their design (including any previous players' designs) as an image for the next player to import and continue.

In these rounds, we captured snapshots of the digital designs at each stage and solicited reflections about each player's design intentions. Players responded to open-ended questions like "How did you choose your visual style?" and, "What is your intended function for the circuit (if any)?" via an individual Google Doc, which was not shared with other players during the game.

In the fourth and final round, players had one week to fabricate the circuit (see pg. 5) using materials and tools of their choice and with the freedom to debug and modify circuits and add any desired artistic elements. Once all final designs were fabricated and documented, we shared the images and collectively reviewed our outputs and experiences.

Paper Circuit Fabrication

This spread demonstrates the wide variety of processes and materials that can be involved in creating a paper circuit piece. While we did not specify any requirement for a functional circuit as an outcome, players were aware throughout the game that the final round would involve physical fabrication.

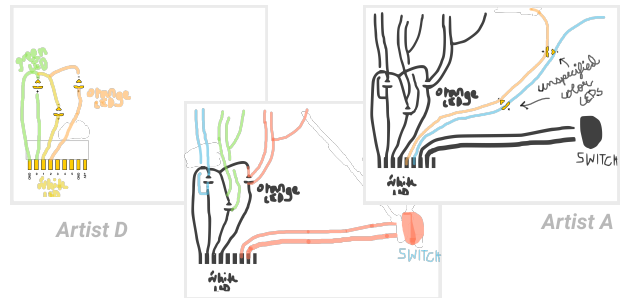


Exquisite Circuits Creations

These are the circuit designs and fabricated artifacts generated from each round. Some artists added drawings and overlays to the digital design, while others more directly translated the output from the activity. Two circuits were fabricated with a vinyl cutter and three were handmade with copper tape.

In the three case studies that follow, we share the roles of collaboration, ambiguity, and trust in the artists' processes from idea formation to fabrication.

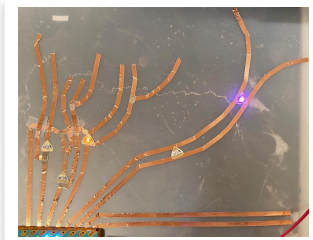
BRANCHING KELP



Artist D

Artist A

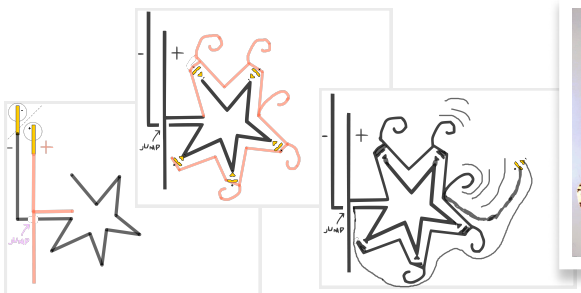
Artist E



Artist B

DANCING STAR

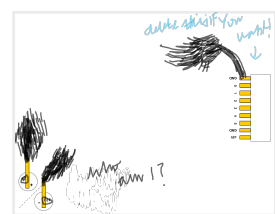
Artist B



Artist A

Artist C

Artist D

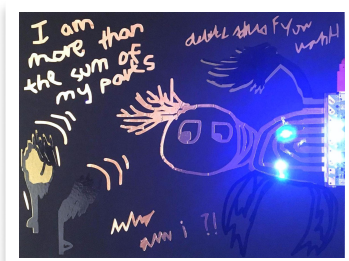


Artist C

Artist E

Artist D

WHO AM I?



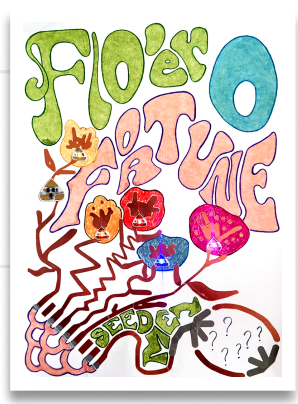
Artist A

FLO'ER O FORTUNE

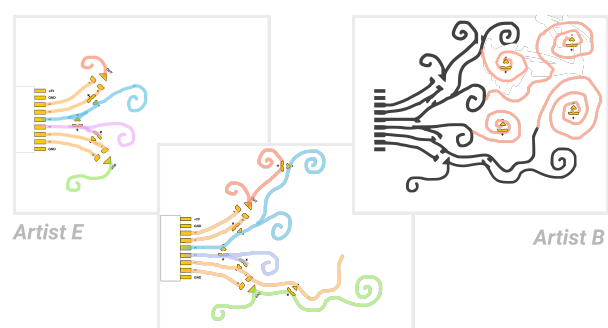
Artist B

Artist C

Artist D



Artist E



Artist E

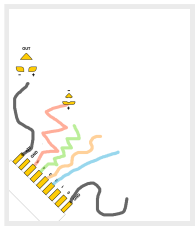
Artist A

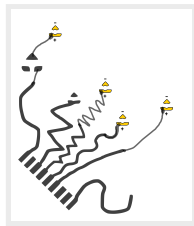
Artist B

SPARKLING SWIRLS

Artist C

Drawing Across Planes





Much of the creative process in *Exquisite Circuits* was driven by the inherent ambiguity of what a line can represent in a paper circuit. Every stroke can be read across several planes: **graphical** (illustrated elements), **electrical** (connecting components in a circuit), **verbal** (as process annotations or text in the final piece) and **material** (copper traces to be fabricated).

All artists began their first round by laying out at least one functional element (e.g. components and traces) on the electrical plane. These elements were then open to interpretation and consideration by subsequent artists across any of the planes. Abstract graphical lines grew into nature-inspired themes such as stars, flowers, and seaweed. Functional elements appeared in the layout as parts footprints and in the lines themselves. Text annotations served various functions from providing design intent, such as marking power and ground nodes, to serving as creative prompts. The shapes of lines affected ease of fabrication.

With so many dimensions to consider, many artists noted a struggle between making the circuit work and freedom to visually and conceptually improvise. This led to a sort of creative conversation where functional considerations were passed on to subsequent players.

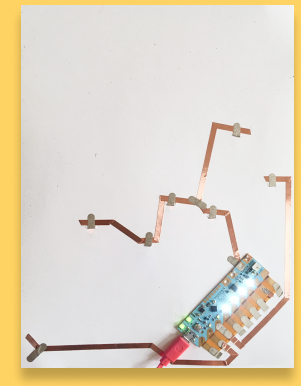
> "I was at first thinking about the needs of the circuit, to make sure there were ways to connect + and - appropriately, but then realized that those problems can be solved later. I was hitting a creative block. So then I focused on the lines and their forms, to bring about a visual of whimsy."
>
> ***- Round 1 Artist***

FLO'ER O FORTUNE

In the words of the fabricating artist, this piece represents a "fortune telling" flower bed. To plant the seed, viewers **draw or write in the seed area and then scribble over it to close the circuit**. An LED flower is then randomly chosen to fade in and out. Erasing the seed area opens the circuit for the next question.

Starting the design, the first artist initially focused on laying down the groundwork for a functional circuit by drawing the power and ground leads. However, after hitting a "creative block," she shifted her focus to create whimsical, decorative lines. These squiggles were later re-interpreted as vines, which bloomed into leaves and flowers drawn by the third and fourth artists. Through this process, the electrical traces were collaboratively transformed into expressive elements, both computationally and graphically.

Notably, the first artist passed along the question of how to connect the ground trace to the next artists. This connection was ultimately created by the final artist that fabricated the circuit who, in an effort to preserve the original look of the file, placed the ground trace on the back of the page and literally created a new plane in the process.



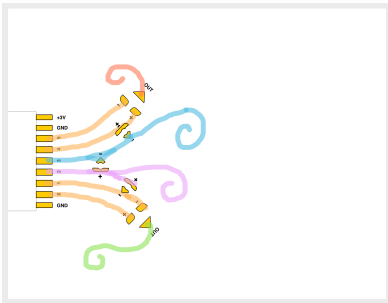
Creative Conversation

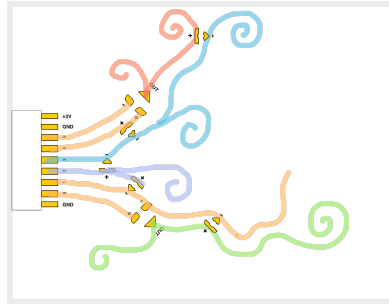
Throughout the *Exquisite Circuits* game, players carefully negotiated and communicated with the artists that came before and after.

Players were attentive to leaving creative invitations for the next artist by literally leaving blank space on the canvas, creating verbal prompts, leaving incomplete circuits, or drawing evocative shapes like swirls and squiggles for others to finish.

While not all ideas were taken up by later artists, for the most part subsequent players were careful to honor and preserve prior artists' work, for example by avoiding erasing where possible. In fabricating, several artists wrote of efforts to keep true to the "spirit" of the circuit drawing they were given, while translating it to a physical, functioning circuit.

> "It looks like she turned up the knobs on the spirals! Making the circuit work required double the traces, thus doubling the spirals themselves. The circuit became a heightened version of itself."
>
> ***- Round 1 Artist***





SPARKLING SWIRLS

What began as a series of decorative curving traces from the microcontroller continued thematically across rounds of the game. In this way, each player stylistically preserved the aesthetics of the design while adding additional lights, ultimately creating a programmed piece where the LEDs fade in and out in an illustrated overlay.

While all the artists continued the stylistic theme of the piece, their approaches to the circuitry differed. The first two artists drew functional circuitry, whereas the third artist took a more flexible approach, adding LEDs to spiral curves without separate power and ground connections.

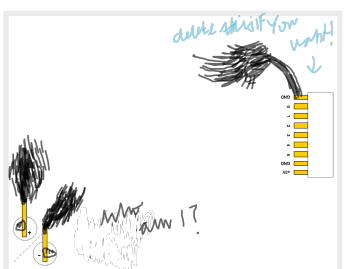
To create a functional circuit congruent with the existing shapes, the fabricating artist used both pencil drawing and digital design tools to sketch out the connections. Then she laid out the curves by hand using thin strips of copper tape with soldered intersections. Along the way, she used a multimeter to troubleshoot connections. Fabrication of this piece exemplified a fluidity of process between artistic and technical thinking, between digital tools and precise handwork.

Breaking the Rules

As the game progressed, artists began to discover that **"someone else can take care of the tech,"** freeing them up to explore other dimensions. One artist described this as "throw[ing] out the math part of it so I can focus on the art of it." In later rounds we observed ungrounded circuitry, components in nonfunctional positions, and other intentionally unfinished designs.

Artists were not just reserving room for others to create, but actually leaving bits hanging or even broken as they pursued sparks of inspiration on other planes. Setting up puzzles for others to resolve, should they choose to do so, created a collaborative freedom from one person to the next and evidenced a kind of trust: people could share the task of making things work.

> "I loved working on this thread...every turn was a strong tug in a particular direction, from fanciful beasts to circuit-breaking doodles to text and finally to circuit rebuilding and computational randomness. I had no idea where the next step after mine was going."
>
> ***- Round 3 Artist***



WHO AM I?

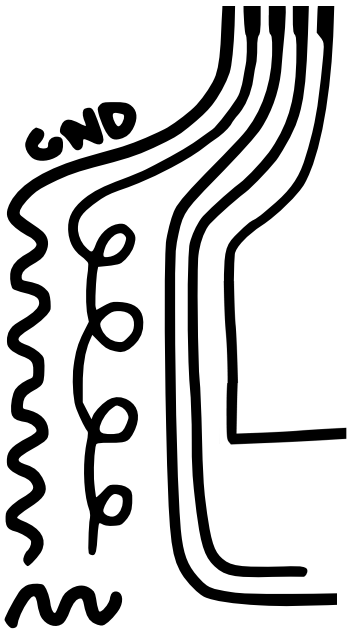
This piece originally emerged from scribbles on the page meant to evoke sketchmarks one might make in a notebook, representing "little shoes and furry faun legs." The first artist's provocative statement "Who am I?" ultimately led players to move in the direction of storytelling and character creation.

In the second round, the artist's child participated by **drawing a rainbow**, in the process shorting the circuit into a single non-functional unit.

While the second player worried that the shorted rainbow had "messed up" the work for future artists, the third artist actually found freedom and epiphany in the short: "That all the pins were shorted together helped me focus less on function and more on a playful image that contributed to the story." The broken circuit reminded the third artist that it was possible to depart from considering the logic of the circuitry. Levity and mischief brought out positive surprise in the game.

This artist departed from the circuitry altogether and instead drew imagery and wrote prose in response to the prompt from the first artist. The next and last artist in this group enjoyed the challenge of taking the merged circuit and making it work, starting from a collection of creative and evocative forms, and untangling it in a freeform way toward functionality. Making the circuitry work while maintaining the integrity of the design became a stimulating technical and artistic puzzle.

Emergent Themes



PROCESS FLUIDITY

The many dimensions in which to create and interpret lines in paper circuits (e.g. aesthetic, functional, material, spatial) appeared to give players more room to explore and problem solve. This open space created a sense of fluidity and freedom from the constraints of the functional or material aspect of the circuit. The software tool further provided a means for players to sketch, "doodle," and erase without the need to immediately produce functional electronics.

COOPERATION

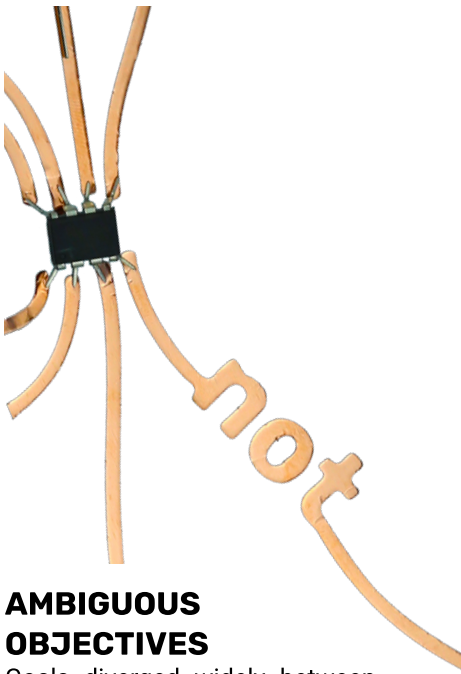
A sense of trust and care emerged as an unwritten social rule of the game. Players described efforts to preserve the work of previous artists while reserving creative space for future artists to come. This generated a dynamic where players negotiated, however indirectly, with other players. Creating designs that could be fabricated became a shared responsibility, and there was an element of care between artists to respect, plan for (or at least engage with) other players through the design itself. This became a kind of unspoken (though sometimes written, via a few scribbled annotations) dialogue between makers.

SURPRISE

With each round, new artists took full creative control, and marks inevitably changed in form, function and meaning. As a result, the *Exquisite Circuits* process generated designs and artifacts that could not have been predicted from prior rounds and would not have been created by any player alone.

SHARED RESPONSIBILITY

When artists ran into technical issues without immediate solutions, they decided they could trust subsequent players to identify and resolve these open technical challenges. This relieved artists from the urgency of problem solving, giving them greater freedom in which to play and push boundaries.



AMBIGUOUS OBJECTIVES

Goals diverged widely between artists, and "broken" circuits turned out not to be a barrier but instead invitations for creative contribution. Even if "problems" remained unsolved, the round could still be a success if players completed the process of the game. While most of us seemed inclined to make a working circuit, there was no explicit requirement or pressure to make anything function as part of the rules of the game. This inclination speaks to our own assumptions, which evolved as the game progressed.

Reflections

Our pilot game of *Exquisite Circuits* helped reveal new dynamics to the circuit design and making process. The following reflections share our own experience and transformations as a result of playing. Tensions and limitations that arose inspired us to create the spectrum of game variations on page 12.

Preciousness and Playfulness
Our game departed from the rules of *Exquisite Corpse* in part due to the fabrication step. This led to contrasting timescales across different stages of the process, from 15-minute rounds on a digital canvas to 1-week efforts to realize the design in physical form. Working solo, with physical materials and a week's time to plan a coherent piece, participants were necessarily more careful and less improvisational compared to when drawing their designs in software. As players invested time and effort in planning and making their piece, the results also naturally became more precious. While it did result in interesting finished pieces, the fabrication stage of our game moved away from the lightweight, collaborative, and ad hoc nature of the original Exquisite Corpse game.

It may be possible to consider fabrication as a separate stage of the experience, in which the ideas generated in the improvisational game space are then applied to an artist's more formal work. This would align with prior uses of Exquisite Corpse-inspired activities as a creativity support tool [7, 9, 25]. Or, as in the variations on the next page, one might shift the fabrication activity towards one that is faster-paced, more collaborative, and less precious.

Expanding Participation
The original Exquisite Corpse games had artists and nonartists drawing together: anyone could participate if they could make a mark on paper. In fact, diversity in players added creative fuel to the game. With Exquisite Circuits we aimed for a similarly universal accessibility. However, because this was a pilot game, we chose players who are experienced paper circuit practitioners to test our basic game dynamics, and thus we were not able to actually test how approacheable the game is for players of diverse skill levels.

In a group with matched skill levels, we found that our trust in each others abilities to "fix" non-functioning traces enabled us to move more fluidly between technological and aesthetic considerations. However, our prior experience also may have limited the scope of what we could imagine, as we saw when a player's young child contributed a few lines. This process may flow differently among players with more varied skills levels and backgrounds; other creative dynamics, frictions, and possibilities might emerge.

Disrupting Hierarchies
As educators, tool designers, and practitioners, we shared an interest in exploring new dynamics for hybrid technology and art making. Our experience is that these often exist in asymmetrical relations of power in which technical skills, analytical ways of thinking, and efficiency are valued over ambiguous, expressive, or non-linear approaches, and in which the cultivation of trust and care are often overlooked.

In contrast to technology-first approaches to design, *Exquisite Circuits* afforded opportunities to share, trust, question, and explore together without an endpoint or goal. Rather than a strict hierarchy between arts and technology, artistic and analytical approaches were more equally distributed through the structure of the game. Productive tensions emerged as we grappled with the open endedness of the goal ("does a circuit have to work?"). Ultimately, the creative experience was centered not around aesthetics or technology, but on the nonverbal collaborative conversation that took place around them.

CONCLUSION

The *Exquisite Circuits* game format created a space for collaboratively navigating the graphical and functional dimensions of creating paper circuits, resulting in a set of creations that combined the unique skillsets of our participating artists, ranging from origami to storytelling to digital fabrication. The collaborative rules of the game brought conversation and elements of suprise to the circuit building process, and enabled different backgrounds to come together and share the responsibilty of technical crafts.

The game is a container for breaking rules, where any line can be turned into a trace, and therefore we could design our exquisite circuits without feeling locked into strict functionality; we could share technical questions, choose to work across multiple dimensions or one at a time, trusting in the next artists, or caring for the previous, using our own intuitions to interpret and re-imagine the meaning of the shared design. This provided freedom to work spontaneously and to play with free association of shape and line.

We invite artists, educators and technology creators to try out our *Exquisite Circuits* variations to test and extend this playful approach to collaborative design.

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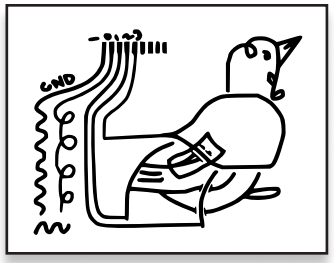
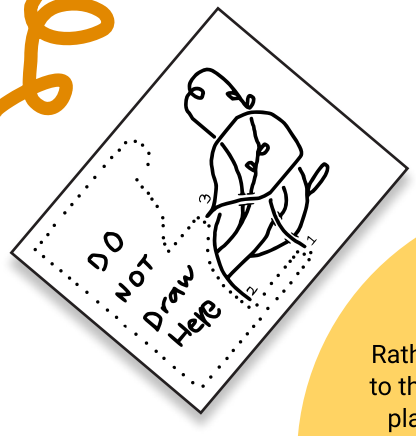
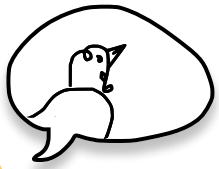
Variations







Telephone
The first player draws a circuit. The second player verbally describes that circuit. The third player adds drawn lines to what they imagine is the first circuit based on the verbal description. The fourth player verbally describes this circuit, and so on.

Randomness
Invite a bystander to contribute a few lines! Close your eyes while drawing! What other elements of external randomness or unexpected variation might be introduced?

Expand Participation
Perhaps not all players need prior experience with circuits! What happens with a group of really mixed creative backgrounds?

Hidden Information
Rather than showing the full circuit to the next player, only the previous player's changes are passed. To avoid new circuits overlapping with "hidden" circuits, drawing can proceed across a folded-over page, or players can use annotations to describe areas that should not be drawn over.

Play with Time
How long do players have to draw? To fabricate? What ideas might come out in a high-speed round?

All Cards Out
Players can see the full circuit that came before. Verbal annotations are allowed

Share out!
To share your games and see what others are making, use the tag **#exquisitecircuits**

Varying Tools, Co-Presence, and Media
Digital tools and video chat allowed us to play *Exquisite Circuits* with artists across the world during a global pandemic. Your game could be played in person, remotely, asychronously or together, using all digital or all analog tools (how about mailing letters?) An in-person host could gather all the fabrication materials, or invite guests to bring their favorite tools and materials to the party for a materials mashup.

Starting Points
Give players a printout with a starting point, such as a battery holder or microcontroller footprint

The design space of *Exquisite Circuits* affords many options for variation, each of which might open new possibilities for different audiences. We invite you to try these design experiments!

Adjust Creative Resistance by dialing the rules up and down

What constraints and boundaries are helpful? How much freedom?

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