# Apples and Oranges: Comparing Crafty Sonic Circuits for Electronics Education

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## ABSTRACT

The Apple Amp and Orange Synth are solderless craft-based sonic teaching circuits developed to support a remote STEAM summer camp for 8 - 11 year old girls. In this paper, we use autoethnographic reflection and thematic analysis to compare and contrast the functionality and pedagogical applications of these two circuits. We explore how the circuits could facilitate complementary approaches to electronics education by pairing more and less predictable sonic outcomes. We further consider how the circuits and scaffolding activities might be redesigned to better align with goals of constructivist and constructionist learning environments.

## CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; **Education**.

## KEYWORDS

STEAM; education; e-textiles; craft

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## 1 INTRODUCTION

The Apple Amp and Orange Synth are two craft-based solderless sonic teaching circuits developed to support remote STEAM education for the Girls Electronic Arts Retreat (GEAR)[3] of the Technology in Music and Related Arts Department [10] at Oberlin College and Conservatory [9].

These and other GEAR projects intersect art, sound, and technology and prioritize accessibility and the authentic integration of art and STEM disciplines. We use arts and crafts to elucidate the tools, theories, and applied creative practice of music technology. To improve our projects' accessibility, we replace less familiar, more opaque tools–such as breadboards that hide conductive connections–with craft-based alternatives that make underlying technologies more visible or tangible. To support integrated learning, GEAR projects embed sound, listening, and creative musical play in paper circuits in order to support Gaver's ludic design framework that 'promote[s] curiosity and exploration' [17] in learning. Others working at the intersection of education and musical interface design have explored the potential of the application of ludic design in musical contexts [16] and we aim to build on this framework for a younger audience.

The Apple Amp and Orange Synth are two recent complementary GEAR projects that help to illustrate our broader pedagogical approach. Made from custom-cut copper tape traces, vinyl stickers, electronic components, and craft foam or Styrofoam, the circuits share the same underlying design, but differ significantly in functionality and pedagogical applications. The Apple Amp is a simple circuit that behaves as expected, creating a predictable outcome whereas the introduction of a screen-printed conductive ink component in the Orange Synth creates unanticipated but interesting sonic results. In this paper, we compare and contrast these circuits' technical frameworks, their pedagogical affordances and constraints, and consider implications for future pedagogical circuit design.


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## 2 BACKGROUND

Electronics are commonly learned in school-based physics courses or through DIY projects with popular microcontrollers like the Arduino [2]. However, novel models for teaching and learning electronics are increasingly common. For example, Jie Qi's Chibitronics, a collection of commercially-available circuit stickers, teach circuit building through paper circuits [21] and Nicolas Collins's book, Handmade Electronic Music, provides an introduction to electronics through DIY sound-generating circuits [11]. These creative approaches often emphasize learning through experimentation over rote theoretical study and aim to reach non-traditional audiences. For example, in several studies, Leah Buechley has found that women and girls were more inclined to create computing projects that employ familiar crafting skill sets [6].

While many e-textile projects use LEDs as their primary actuators, musicians and artists like Jess Rowland [22], Afroditi Psarra [20], Rebecca Stewart [23], and others [24] [25] [12] have combined craft and sound-based approaches to create new e-textile and paper circuit musical instruments. Our Apple Amp and Orange Synth are therefore situated at the nexus of several interwoven disciplines: STEAM education, e-textiles, electronics, music technology, and sound art. Inspired by Beuchley's work and related research, we take this approach in an effort to foster enthusiasm for STEAM disciplines in our target population (8-11 year old girls).

## 3 METHODOLOGY

Our analysis of the Apple Amp and Orange synth emerged as part of a broader effort to examine lesson plans and projects developed for the first two iterations of GEAR, held in person in 2019 and remotely in 2020 [4]. Through this process we determined that these teaching circuits merited further discussion given their potential to support a range of pedagogical approaches and different forms of knowledge acquisition (factual, conceptual, procedural, and metacognitive) [14].

In this paper, we use autoethnographic reflection, a qualitative research framework, to describe, analyze, and critique the pedagogical affordances and constraints of the Apple Amp and Orange Synth. Autoethnographic practices have been used in other educational studies [18]. While autoethnography often explores cultural and personal themes, we apply it here instead as a first step in defining an iterative design research framework [8] to help shape subsequent project iterations. Autoethnographic reflection felt pertinent as it afforded the authors an opportunity to reflect on personal experiences with iterative design process and the learning that took place through the development of GEAR projects.

To evaluate our teaching circuits, we built a dataset using methodologies aligned with established autoethnographic practices [7]. We collected our own written reflections, videos of "interactive introspection," exploring memories and shared experiences of design processes, and kept a shared digital folder documenting our design processes. Finally, using thematic analysis [5] we synthesized findings across datasets. This process helped to identify connections between the Apple Amp and Orange Synth, given the inherent similarities in their design. We provide an overview and analysis of each circuit, discuss outcomes of our reflective process, and explore potential improvements and future research.

# 4 CIRCUITS - DESCRIPTION, ANALYSIS, & CRITIQUE

## 4.1 Overview

The Apple Amp and Orange Synth provide an introduction to electronics and circuit building for children ages 8 and up with adult supervision. The circuits were deployed as part of a remote camp experience; apart from several scaffolding activities we designed for the camp, our circuits assume no prior experience with electronics and require no special tools for assembly. We prioritized visibility of circuit design and made conductive traces an aesthetic feature. We created instructional videos and featured detailed circuit illustrations in an accompanying Zine. We packaged electronic components secured in the correct locations atop these illustrations so participants could easily identify components (fig, 1, second from right). Prior to building the Apple Amp and Orange Synth circuits, participants complete introductory activities including building a simple LED paper circuit, competing in a remote 'resistor race,' and creating a stop motion 'circuit circus' video, among others. These activities introduce the different electronic components used in these circuits as well as technical concepts including electrons, electrical current, circuits, and conductivity. They also provide an opportunity for participants to practice circuit building skills in preparation for assembling the Apple Amp and Orange Synth.

## 4.2 The Apple Amp and Orange Synth

The Apple Amp is a simple hobby amplifier built around an LM386 chip [13] using the schematic found in Nic Collins's Handmade Electronic Music (fig. 1, right). It is a solderless battery-powered amplifier designed in the shape of an apple. The circuit is made out of copper tape traces, a custom vinyl sticker substrate, and electronic components (figure 1, left). A clear vinyl sticker with a printed circuit illustration may be laid over the circuit to assist in assembly and insulate traces (fig. 1, second from left). Before circuit assembly, the Apple Amp circuit sticker trace is affixed to a large piece of Styrofoam. A small piezo disc is attached to the apple on the Styrofoam using push pins and copper tape. The Styrofoam piece provides a useful substrate for embedding components into the copper traces and securing their position on the circuit. Participants can also affix found objects to this Styrofoam; objects are touch-activated and amplified via the Apple Amp creating a musical instrument that we dubbed the 'Styrofonium.'

The Orange Synth is a dual purpose touch-sensitive solderless synthesizer and electromagnetic circuit sniffer. It is an adaptation of the LM386 hobby amplifier circuit used in the Apple Amp, built with copper tape, craft foam, and a custom screen printed conductive ink coil that doubles as a variable resistor (fig. 2, right). The screen printed sensor undermines the stability of the original LM386 amp design, causing the hacked circuit to function as a lo-fi tactile synth (fig. 3). In addition, the circuit is highly sensitive to electromagnetic interference and is great for 'Electrical Walks' where a participant uses a pickup coil and amplifier (or an Orange Synth) to listen to hidden electromagnetic fields in their environment [15]. To play the Orange Synth, a player uses one hand to move a conductive "straw" across the traces of the screen printed coil, and the other hand to touch parts of the circuitry, creating new electrical connections. The interface has no traditional "interface" parts, like buttons or knobs.

## 4.3 Analysis

The Apple Amp and Styrofonium projects work together to blend STEM and art learning objectives. The first part of the Apple Amp activity—building the circuit itself—focuses on STEM learning and affords little room for experimentation. We introduce technical concepts like transduction, amplification, and audio signal routing (inputs/outputs) and reinforce the names and functionality of different electronic components. Experimentation is highly encouraged in the second part of this activity, as participants construct and play their own Styrofonia using the Styrofoam substrate and found objects. Through play and creative experimentation, participants can learn about the sounds different objects make when amplified and about the way the substrate conducts sound vibrations from affixed objects to the piezo disc. Given the proximity of the speaker (embedded in the apple amp) and the contact microphone (affixed to a large resonant surface), it is possible to unintentionally trigger a feedback loop, creating an additional opportunity for a semi-impromptu exploration of feedback from technical and creative perspectives.

The Orange Synth's copper traces feature minor cosmetic changes from the Apple Amp to fit the "Orange" theme. The input section is also modified: the Apple Amp's volume potentiometer has been replaced by a screen printed sensor. Made out of conductive ink, paper, and a paper 'straw' that functions as the potentiometer's 'wiper.' This DIY component displays the inner working of a potentiometer for pedagogical purposes. However, since the potentiometer is

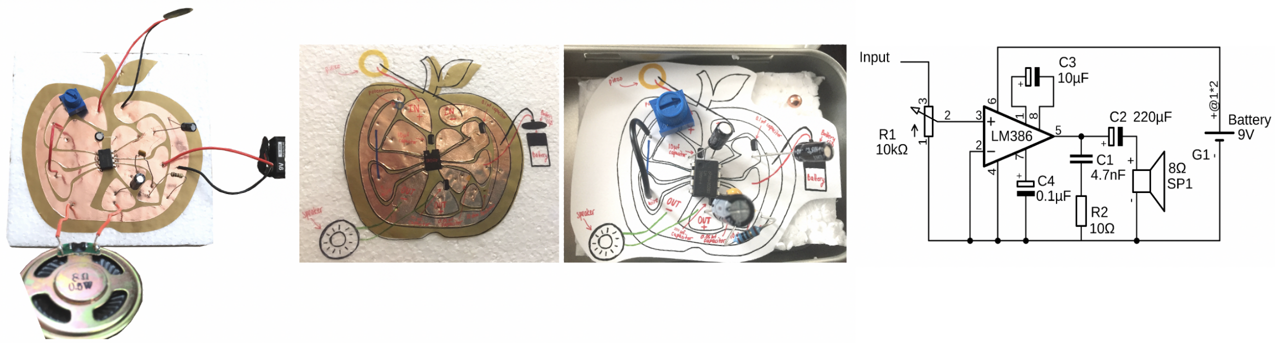


**Figure 1: The Apple Amp (left). A clear vinyl circuit illustration overlay to assist with circuit building (middle left). A tin with components placed atop a circuit illustration (middle right). The circuit is based on the LM386 amplifier (right). C3 fixes the amp’s gain at 200, so volume is adjusted by scaling the input signal with R1.**

**Figure 2: The Orange Synth (left, 1-2). A screen-printing process is employed to craft the conductive ink coil.**

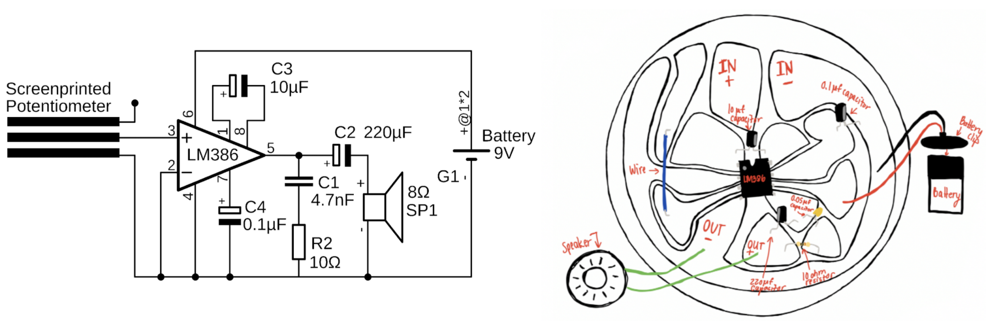


**Figure 3: The Orange Synth’s circuitry is identical to the Apple Amp, but substitutes screen-printed conductive ink traces for R1. These traces are connected directly to the LM386’s input, and any electrical coupling between the screen printed sensor and the output capacitors C1 and C2 creates feedback oscillations.**

connected to the amplifier’s input, it also becomes an antenna for receiving and amplifying ambient electromagnetic signals. And, when a human is inserted between the amplifier’s output and its input, they create a positive feedback network. Since the human body has both capacitive and resistive properties, the feedback loop has a resonant frequency, and turns the circuit into an oscillator.

Since the feedback loop contains so many variables (the pressure the human exerts on the contacts; the body’s conductivity; the position of fingers on the conductive traces; the ambient physical and electromagnetic conditions; etc.) this oscillator is very unstable. So, while the circuit design and assembly process for the orange synth does not afford much room for variation, the erratic behavior of the orange synth offers opportunities for experimentation, circuit probing, and play that can foster discussion and facilitate learning. For example, by inviting students to describe what types of probing yield the most interesting (to their ears) sonic results and to hypothesize the reasons for the circuit's behavior in response to their probing.

### 4.4 Discussion

Despite theoretical similarities, the Orange Synth and the Apple Amp invite different interactions and exemplify different electrical concepts. The Apple Amp's interface is simple, clearly defined, uses uniform components and behaves predictably. This makes the Apple Amp a useful teaching tool for demonstrating concepts like amplification and transduction: producing specific effects for demonstration is simple, and for more advanced courses, deconstructing the circuit is straightforward. The Orange Synth, on the other hand, is unpredictable, and its behaviors are difficult to model and to explain; a thorough explanation would introduce concepts that go beyond elementary electronics education. However, the circuit's instability and the sheer range of sounds it can produce promote electronics learning through experimentation. This contrasts with the predictable behavior and straightforward pedagogy of the Apple Amp.

Furthermore, the Apple Amp's interface consists only of a knob for adjusting volume, and a piezo disc for generating sounds. By touching the Apple Amp's circuitry in just the right way, a person could make it behave less predictably, like the Orange Synth, but the Apple Amp's interface does not encourage that kind of experimentation. The Orange Synth lacks clearly-defined interface components, meaning participants have to probe the circuitry, introducing complex variables that provoke equally complex sounds.

The Apple Amp and Orange Synth both demonstrate potential as tools supporting a constructivist learning environment since participants develop their understanding of circuit design and function by building their own devices [1]. Potential revisions to the projects' build processes that could better integrate these projects into a constructivist learning environment are outlined in our critique. However, the creative experimentation fostered by these teaching circuits–particularly the Apple Amp's Styrofonium activity–balances "spontaneous and natural direction on the one side, and the intentional" decision making on the other. In so doing, the activity puts into practice the pedagogy of play to support a hands-on, interactive learning environment [26]. The contrasting features of the Apple Amp and Orange Synth highlight the pedagogical potential of an interface design continuum including familiar and predictable models alongside novel, unpredictable approaches. This continuum supports complementary pedagogies: clear-cut demonstrations with straightforward explanations, on the one hand, and learning through experiments with unstable designs, on the other. With additional scaffolding activities, musical play and experimentation, and the introduction of discussion, reflection, and iterative design, we believe that these projects could effectively support different modes of knowledge acquisition, including factual, conceptual, procedural, and/or metacognitive learning [14]. Ultimately, we aim to explore this possibility and to investigate whether teaching circuits that navigate between complementary pedagogies can improve electronics education.

## 5 CRITIQUE

Simple adjustments to the Apple Amp and Orange Synth designs might improve learning outcomes through closer alignment to constructivist principles. For example, while the Apple Amp circuit assembly requires troubleshooting, extensive step-by-step guides and documentation leave little room for experimentation. Encouraging participants to interact with the circuit in different ways, exchange electronic components, or modify its design could provide a more thorough electronics introduction. Participants could also use different circuit inputs and outputs, exchanging the piezo disk or conductive ink coil for a homemade synth, or routing the circuits' outputs through paper speakers. The circuits could also be adapted to support multiple inputs and outputs in order to allow for the panning and mixing of sounds. Further experimentation could be encouraged in relation to the Apple Amp's Styrofonium activity: the amp could be affixed to alternate substrates to generate discussions about the role of the substrate material in shaping the resulting sonic behaviors. Potential adaptations to the Orange Synth design are explored below as avenues for future research.

## 6 FUTURE RESEARCH

Our primary goals for future research include the implementation of systemic evaluation of the Apple Amp and Orange Synth for their pedagogical affordances and constraints, and for their potential in attracting underrepresented audiences to electronics learning. We intend to explore the teaching affordances of the stable, predictable design of the Apple Amp versus the less predictable behaviors of the Orange Synth. We would like to develop kits with a variety of different circuit building activities using different materials – including paper craft, e-textiles, and breadboards – and devise assessments to interpret the effectiveness of the projects using several criteria including their aesthetic appeal, educational potential, durability, environmental impact, design flexibility, support activities, and continued use. We also intend to revise existing circuits and develop new projects to foster authentic STEM and arts integration [19] by increasing opportunities for creative experimentation. For example, a new iteration of the orange synth might invite participants to make their own collection of screen-printed potentiometer designs, listen to sonic outcomes, and revise designs based on what they hear.

## 7 CONCLUSION

The Orange Synth and Apple Amp are sonic teaching circuits based on a growing area of research at the intersection of craft, sound, and technology. In this paper, we have explored these closely related circuits to consider the different interface affordances created by the slightest of circuit variations. We shared our approach of using craft to make conductive traces aesthetically pleasing to pique the interest of our participants and to assist with STEM learning outcomes and have demonstrated how creative experimentation can lead to unstable circuits that support both technical and creative learning outcomes. Through our reflective process, we recognized the value of interface design itself as a tool for creative experimentation and technical learning; this understanding will inform our future sonic teaching circuit designs.

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