23 PROJECTS + DIGITAL FABRICATION ROUNDUP 2025

Make:

Ingenious New Lasers, CNCs, and 3D Printers Recommended and Reviewed

CELEBRATING MAKERS AND THEIR INCREDIBLE DIY PROJECTS

20th Anniversary Issue

Two decades of wacky, wonderful contraptions

+

Secret Combo Lock Circuit

Heat Gun Coffee Roaster

Vintage Pinball Rescue

Handheld CNC Router

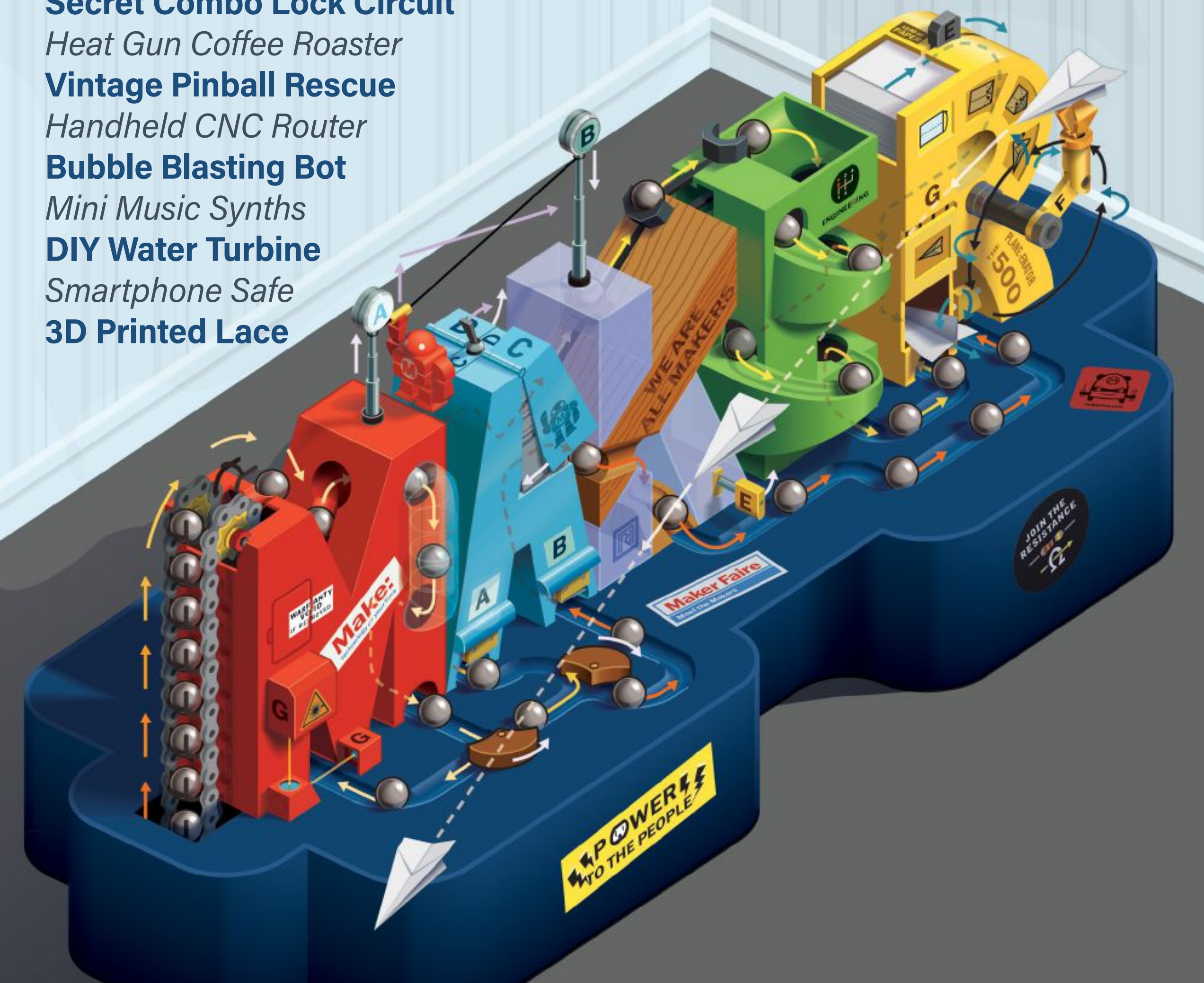
Bubble Blasting Bot

Mini Music Synths

DIY Water Turbine

Smartphone Safe

3D Printed Lace

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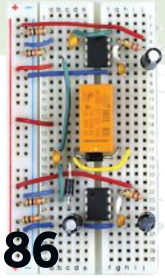
ON THE COVER:
For our 20th anniversary we're celebrating makers and their ingenious gadgets and contraptions, with a Rube Goldberg-esque paper airplane launcher.

Illustration: Rob Nance



WonderLab, Erin Winick Anthony, Adobe Stock WhoopWhoops, xTool, Cocoa Press, Keith Hammond, Brigitte Kock, Larry Cotton, Charles Platt, Lee Wilkins

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> —*Mister Jalopy*

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Make: Community

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What's your favorite memory of Make:?

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Eugene, Oregon
(Cover illustration)
When [Creative Director] Juliann Brown asked if I wanted to do the R2-D2 illustration for Vol. 50, the only reply was *Toot toot*!

Larry Cotton
New Bern, North Carolina
(Wobble Disk Coffee Roaster)
The thrill of publishing over 30 of my articles over the years, 11 of which were co-authored by Phil Bowie.

Cameron Chaney
San Francisco, California
(Get Your Bearings)
Meeting Maker Faire pioneers and hearing stories of the event's wild, uninhibited beginnings.

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Community Round

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A thank you from Dale Dougherty and Make: Community

We truly appreciate all those who joined Make: Community and made a financial commitment to become investors in our future. Below is a list of those who supported our community fundraising campaign on Wefunder as of November 15, 2024. The community raise is still open at wefunder.com/make. Join us and we will add your name in our next issue.

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FROM THE EDITOR'S DESK

MAKE: MAGAZINE AT 20

It's been an amazing 20 years, and we couldn't have made this magazine what it is without you, our readers. And we mean that literally!* Make:** ***authors are often **Make:** ***readers first! It's your kind words and dedication — and creative projects — that keep us going. —The Editors***

I've subscribed to *Make:* since issue #1. Attended all the Maker Faires at The Henry Ford in Dearborn, Michigan. It's been life changing. I want to help keep this space alive so everyone can find their inner maker! *—Brian Smith*

I have been a subscriber since nearly the first issue and love the community and innovation that *Make:* highlights. *—Jared Siirila*

A longtime reader who believes in the maker movement and the good it can bring. I want to help ensure *Make:* is there to keep leading the charge for years to come. *—Davin Desborough*

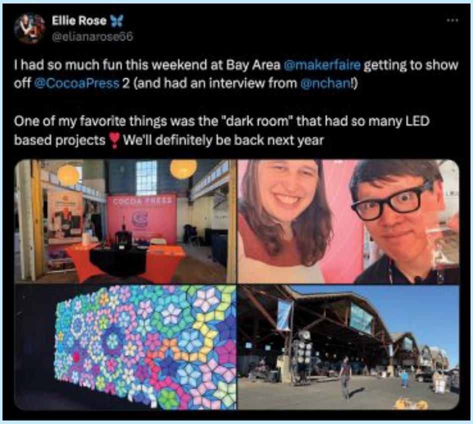
I'm the inventor of OpenCat robots. I first published my project on the Make Community site and got lots of traffic. My Nybble cat was once featured on the *Make:* magazine cover. All that networking helped me continue my career that brings more advanced robot pets to the general public. *—Rongzhong Li*

Make: has had a major impact on my career path and me actually building my ideas. Open Source communities have been instrumental in my continued learning, and made it easy to enable others when they have motivation but lack the technical know-how. Without *Make:* I would not have changed the direction of my work, and I would not be me. *—Aaron Zidichouski*

The culture of making is core to who I am and the world I want to live in. I love your magazine, events, and ethos. We need more of it and I am excited to participate in keeping it going. *—Connor MacNulty*

MAKER FAIRE ON SOCIAL MEDIA

Maker Faire Bay Area was back with a vengeance in 2024, and it was one of our best shows yet. Start planning for MFBA 2025 now or find a Faire near you at makerfaire.com.



A Magazine, a Movement By and For Makers

by Dale Dougherty, President of Make: Community

It's a rare thing to start a magazine and see it survive for 20 years. It's even rarer that a magazine would become a catalyst for a community and a movement, based on a set of ideas:

- **It's part of human nature to make things. It's who we are at our best.**
- **We are all makers, but not everyone realizes they have the gift.**
- **Look at the many physical and digital tools for making things.**
- **Makers create all kinds of things for work and play, from the serious to the silly.**
- **We foster a kind and generous community that welcomes all.**

One of the questions I've been asked, and it's awkward for me, is "How did you create the maker movement?" I usually start by saying that I didn't create it. I started a magazine to show the amazing projects that people make, and I called our readers *makers*. I created Maker Faire to bring makers together to showcase their projects for a broader audience. I thought that was the best way for others to see themselves as makers and join in. I did those things with intention but I didn't know where it would lead. *Make:* had the good fortune to find more and more people who read this magazine, go to Maker Faire, and work on projects of their own. Because so many embraced the word *maker* and made it their own, and because they sought a connection to other makers — all of us created a movement.

Makers have always existed. I am appropriately humbled when I meet someone who says they were a maker before maker was a thing. Popular magazines similar to *Make:* once existed in a similar trim size — for example, *Popular Science*, *Popular Mechanics*, and *Popular Electronics*. Their day seemed to pass when kits for building computers gave way to manufactured personal computers.

We wondered if a new generation would enjoy making things and find that it was worth the time and effort — also because it was so much fun.

The magazine got started in 2005 before Arduino and Raspberry Pi, before MakerBot and Prusa, before Tinkercad and Fusion 360 and many others. Soon, however, new software came along that made it easier to make things and new hardware came that was a lot more affordable. This democratization of technology made the tools of production available to more people and gave them new capabilities. It created new opportunities. However, it wasn't the tools alone — we were excited to see what projects were possible with the new technology. We also wanted to see more young people have the opportunity to become makers.

The first issue of *Make:* featured Prof. Neil Gershenfeld, the founder of Fab Labs, and a column by Tim O'Reilly of O'Reilly Media who gave this magazine the green light. From its beginning, *Make:* was a magazine by and for makers and it still reflects their interests and capabilities. All 20 years of projects, all contributed by makers, are the heart and soul of the magazine. Makers are ordinary people who have developed special talents that surprise and delight us. My own life is richer for having met so many makers everywhere in the world, which would never have happened but for this magazine.

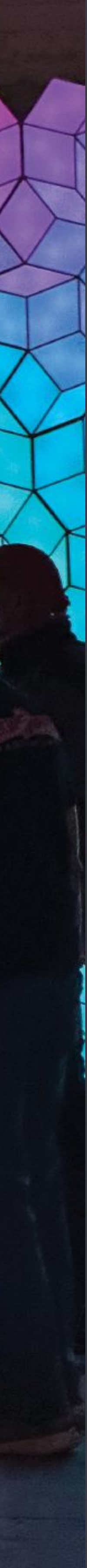
Our editorial team, Keith, David, Craig, and Sam, like many before them, are wranglers of makers who occasionally crack the whip to get things in order. Juliann, our creative director, snaps her fingers to create the magical layouts that make DIY projects look even better.

Together, they shape what's in your hands today, a rare and remarkable product that reflects the dreams and doings of a creative community. All of us at *Make:* are grateful for all of you — makers past, present, and future.

MADE ON EARTH

Amazing builds from around the globe

Know a project that would be perfect for Made on Earth?
Let us know: *editor@makezine.com*



IT REALLY TILES THE ROOM TOGETHER

CHUCKSOMMERVILLE.COM

If you've ever watched the Times Square Ball drop on New Year's Eve with its many LED lights and patterns, you've seen the work of **Chuck Sommerville**, a longtime game designer and LED artist based in Folsom, California. His *Penrose Tile Wall* is accessible throughout the year, and has exhibited at Burning Man and last year at Maker Faire Bay Area.

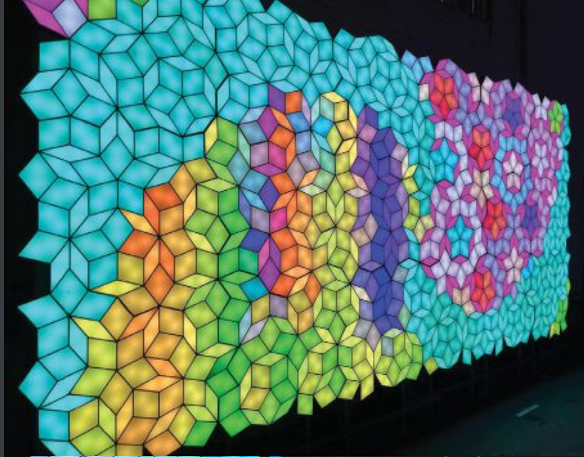
Measuring 18×9 feet, each of its 900 diamond-shaped "cells" contains two lighting modules with three 12V LEDs each. The "backplane" wall itself is mounted to a steel Unistrut framework. Sommerville crafted the 18-piece backplane out of melamine with the help of a team of friends. They used a CNC machine to cut the holes for the LED modules, the slots for the cell dividers, and the dividers themselves out of melamine as well to maximize the light output. Finally, they used a fabric found in stretched fabric ceilings as an outer diffusing cover glued on top.

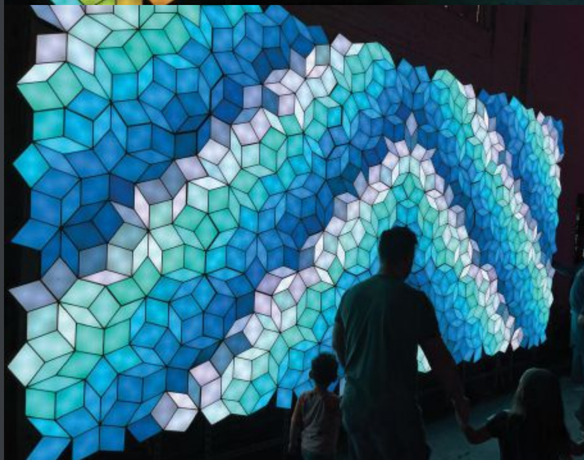
To animate the LEDs, Somerville primarily uses the game development engine Unity 3D for modeling and developing the animation content; the patterns displayed by the Penrose tilings are quite literally infinite. "The animations are generated in real time mostly using math. I also spend a lot of time studying the geometry of whatever piece I'm working on to bring that beauty of that natural form out. For the tile wall, I created a database with lots of information about each tile, such as position, shape, orientation, a list of neighbor tiles, and what interesting shapes the tile is a part of."

For those interested in beginning their own journey with LED art, Sommerville warns that his work is unlike most mainstream animation. "It's not a playback system like used in lighting your house with Christmas lights. All the animations are generated in code in real time. Since I used Unity, I write in C#. If you want to get started with something a little more entry level, check out a product called Pixelblaze. It allows you to create new animations in code using something like JavaScript."

You can see more of Sommerville's work by following him on Facebook and YouTube at @ChuckSommerville. —*Marshall Piros*

Sari Singerman, Keith Hammond





MASTER OF THE MICRO ARTS

INSTAGRAM.COM/GATTEMVENKATESH_ARTIST

Gattem Venkatesh is known the world over for his beautiful sculptures at the micro level. What began as a hobby has exploded into a phenomenon all its own, and his artworks have inspired countless children and adults alike to search within themselves and create their own works of art.

Venkatesh is best known for his intricate miniature sculptures carved on the tips of pencils, chalk, bangles, toothpicks, and other materials — over 500 works and counting. He won the Guinness World Record title for the world's smallest toothpick carving of the Empire State Building, was honored in India's *Limca Book of Records* for the tiniest ship model, and was awarded the National Youth Award (India) for his social work teaching art and science to more than 24,000 students at over 80 schools.

Venkatesh also holds a bachelor's degree in architecture and completed his master's in urban planning in 2021 at New York Institute of Technology, but art is where his heart lives. That's what has driven him to create his unique works, ever since he was a young student in Chinadoddigallu village in Andhra Pradesh, India. During a vacation after high school when he was 14, Venkatesh created a miniature model of the Hindu god Lord Ganesha out of boredom. His parents took notice and encouraged him to continue developing his art form, and that's where his journey began.

Venkatesh creates his miniatures using surgical blades, cutters, and injection needles to carve out the minutest of details, each giving definition and form. He regularly collaborates with architects and engineers, painters and sculptors, and even fashion designers. It's easy to see these relationships in the pieces he carves, with each evolving as his talent and style progress. *—Cabe Atwell*

Gattem Venkatesh

MAKING CONNECTIONS WITH GLASS

MOZEART.COM

When **Chris Mosley** was in elementary school, he was the kid who was always behind in his work. While other students dutifully read in class, he got in trouble for drawing because he was more interested in creating his own stories than reading someone else's.

Fast-forward to today, and the creativity that got him in trouble as a kid now enables him to flourish as an artist, flameworking and blowing glass in his studio in Santa Cruz, California.

Mosley's **Social Networking Project** is an interactive artwork, where passersby hold glass rods wherever they'd like on an ever-growing sculpture. Mosley then fuses them into place with a torch, connecting the glass rods in a technique called "networking" (see what he did there?).

"I was doing glass demos, and noticed everyone was bored," said Mosley. "I could tell they thought, 'Cool, glass. OK. I'm moving on.' So I wondered how I could get people to engage, and it just came to me: Why don't I let them be a part of this?"

The results are unique glass sculptures that reflect the imaginations of their participants, as audience members choose how and where to connect their rod to those of their fellow creators. These newfound artistic collaborators become part of the project themselves, as their personalities influence how they evolve the glistening spiderweb of glass. But not all are willing artists — at least at first.

"Kids are stoked — they don't even know what's happening, but they see fire and they're ready to make something," said Mosley. "But a lot of adults are very standoffish; you can see they're interested but hesitant. I think they have a fear of being embarrassed, of not understanding or getting it wrong. But there is no 'wrong' here."

While most people geometrically connect the rods from point to point, some people curve or bend their rods with the help of Mosley's torch. "When people are ready, their minds kind of free up and their reservations leave, and they open themselves to the experience. That's what I was hoping for, to go on a journey together and build this thing while not thinking about anything else."
—Kevin Toyama

Mozeart

A young girl gets ready to press the buttons of the Brilliance Bottler.

Making Mayor Clayton's WONDERLAB

CREATING A WHIMSICAL MAKERSPACE FOR "WISH" KIDS

Written by Christie Miga

CHRISTIE MIGA is an Atlanta-born experiential educator, artist, and innovator. With degrees in studio art and history, she taught in the classroom for over 16 years and now works as manager of experiential education at Give Kids The World Village.

The entrance to Mayor Clayton's WonderLab.


Evan and Christie Miga and Ian Cole worked on the WonderLab from concept through construction.

"Dad, I don't want to go to trick-or-treating, I want to stay in the WonderLab!"

When I overheard an 11-year-old say these words, I knew we'd made something special with Mayor Clayton's WonderLab. Brooklee, the incredible kid who said these words, was on her Make-A-Wish trip to Central Florida with her family and staying on the property at Give Kids The World Village, an 89-acre storybook resort where children with critical illnesses and their families spend weeklong, cost-free vacations. Brooklee was visiting from Utah, and her parents explained that she asked to visit the WonderLab every day of their vacation; she couldn't wait to try all the daily activities. By the end of their vacation, the volunteers and I cheered as soon as she entered the building.

Mayor Clayton's WonderLab, our six-room STEAM activity center, opened in July 2024 and the response has been incredible, with many stories like Brooklee's — faces lighting up with excitement and a sense of accomplishment. Parents have shared that their children loved the activities so much, they plan to re-create them at home. Perhaps most impressively, even teenagers have stayed engaged for hours.

DESIGNING THE WONDERLAB

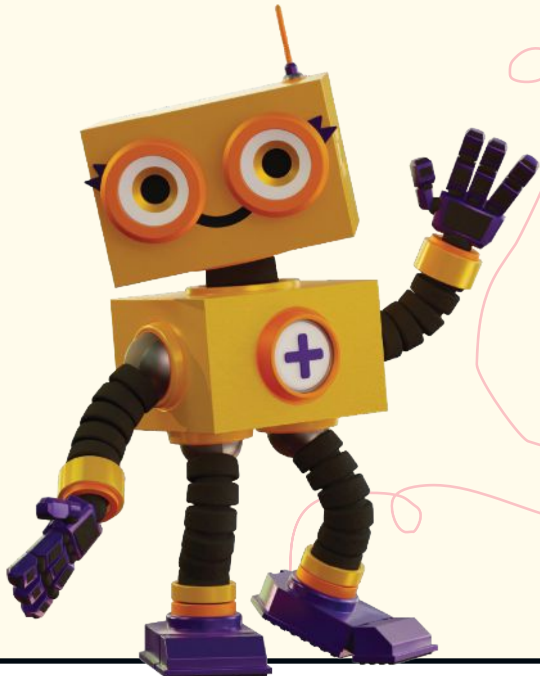
The vision for a makerspace at Give Kids The World came from Ian Cole, their chief innovation officer (and producer of Maker Faire Orlando!). In 2020, he brought my husband, Evan — a brilliant designer — and me, an experiential educator, on board to design the space. Together, the three of us made the key decisions that ultimately brought the WonderLab to life.

Give Kids The World Village already had an impressive list of venues on property like a castle, movie theater, ice cream shop, and rides, to name a few. And every night, families return from Orlando's theme parks to a themed party at the Village, including a popular Halloween bash on Monday evenings, hence Brooklee's trick-or-treating comment.

In that larger context, we wanted to design an experience for vacationing tweens/teens in an environment that is both beautifully themed and adaptable, all while adding to the mission of inspiring hope for wish families. To bring all this to life, we were also given a building that would need extensive renovation.

The challenge in designing the WonderLab was to figure out how to design a space that was flexible and attractive, childlike but not childish, and neither overstimulating nor boring. We had to find a balance that felt cool to teens but didn't distract from the activities.

We created a compelling narrative to act as the foundation for all the decisions to come.



Give Kids The World, Christie Miga

Mayor Clayton (the Village's 6-foot mayor bunny) has met a lot of kids over the years and knows they have a lot of creativity! He realized they need a place to share it at the Village. He called on his friends the Wonderbots (Wonder, Imagination, and Possibility) to help him build his vision of a creative space to explore. They agreed and got right to work on the project converting an old building to a new lab filled with robotic inventions. One such invention is the Brilliance Bottler. This machine collects creative brilliance and converts it to usable power for the lab. So, every time a kid has an idea, they help keep the lights on!

Once we decided on the story, the design elements began to fall into place. Evan gave the lab a look of "childlike sci-fi" filled with a bright color palette and design elements from the Wonderbot world. Additionally, he decided natural wood should be incorporated throughout. This acts as a place for the eye to rest from color; we decided to show the end grain of the wood so kids could see how everything was made. I like to think of it as "practical whimsy."

Miga Me LLC, Christie Miga

An early concept rendering of the Brilliance Bottler.

EXPERIENTIAL EDUCATION

While Evan focused on the design (the look and feel), I dedicated myself to the functionality. In my 16 years of teaching, I had little experience with STEAM/STEM; I was a history, art, and literature teacher. In fact, when I was hired to design the WonderLab activities, I was taken aback. How can I create activities around a topic I'm not very experienced with?

The answer: Learn as much as I could from people smarter than me and put my experiential learning background to good use. Experiential education (EE) creates learning experiences that have meaning; the focus is not solely the experience itself, but the reflection on the experience that provides the deepest learning. There are gigantic books on the subject, but I'm going to narrow it down to the three main EE points we utilize in the lab: curiosity, inclusion, and process.

- Curiosity *rules* in the WonderLab. Our facilitators are trained to express genuine curiosity with participants. This can happen in many ways, including asking questions to arrive at an outcome, being open to outcomes other than the intended ones, and promoting "redos" to try things multiple times. This creative intentionality creates a collaborative environment between the learners and facilitators, an exchange of information instead of the traditional one-way transfer of information.
- Inclusion is important in any creative space, but especially at the Village where we serve children from around the world with many different needs. All guests are greeted when they arrive at the lab with an original animatronics show and invitation to explore the space. Every day has a variety of activities, and every room has a facilitator welcoming

guests. We have worked to eliminate barriers like accessibility and apprehension. Feeling included gives the kids confidence to try ideas and the WonderLab is an environment for all because everyone belongs.

- At the WonderLab we strive to enjoy the process over the product. If a child falls in love with a process, they will want to explore all the possibilities within it. We enable experience, so the process is enjoyable and easy to build upon in subsequent creations. This allows space for kids and facilitators to collaborate, ask questions, and be curious. It's a bonus that the products are fantastic too!

I've mentioned our facilitators quite a lot. Every one of our incredible facilitators are volunteers and they are the heart of operations at the WonderLab, and the Village overall. Give Kids The World Village needs between 1,500 and 1,800 volunteer shifts filled each week to operate at full capacity; these include roles such as serving ice cream, operating rides, or serving food. When we were planning for the new WonderLab volunteers, it was clear the roles were going to be unique. We needed folks who could comfortably engage with kids in learning experiences, often with multiple kids at once. Even more, we needed to be able to train any of the volunteers to teach any of the activities while finding their groove in experiential facilitation. I am thrilled our training techniques have proved successful with these challenges and the community growing in the WonderLab is an inclusive and experiential one. In fact, we create the same environment for facilitators as the one they create for the guests.

ACTIVATE AND CAPTIVATE

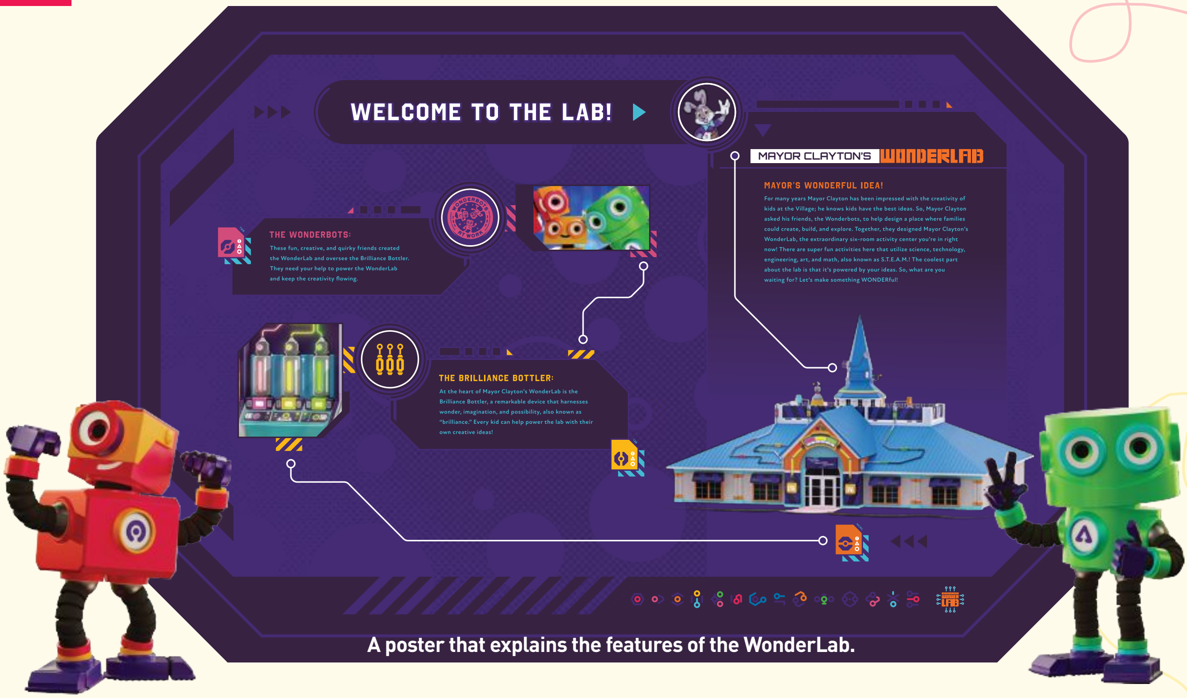
Choosing captivating activities for the WonderLab was crucial. Our families are on vacation, so it was essential to create a fun and exciting space that truly felt worth their time. Through prototyping early activities, naturally WonderLab standards emerged. These standards would act as filters for every activity to pass through to be a WonderLab activity. Here are those standards:

1. **Activities must be hands-on.** An active work environment encourages participants to engage, chat, work together, and laugh.
2. **Screen-based activities must have a physical component/payoff.** One example is our animatronics activity. Kids use computers for this, but the excitement comes from watching the motors move the animatronic body parts, not the screens. The screens are merely a tool.
3. **Each activity must encompass at least two STEAM pillars.** I wanted kids to see how the STEAM elements (science, tech, engineering, arts, math) easily interact and are used together.

EVEN THE TEENS

A few weeks ago, a family of three teenagers walked through the WonderLab doors. One of them had dark hair covering their face, walking behind the rest of the family, and was clearly not sure about the bright, colorful space they had just entered. I observed as they took notice of the animatronic welcoming them into the lab, and I figured it was a good sign. As they walked through the rooms, deciding where to land, I noticed a glimmer of interest in our circuitry activity. I watched as the facilitator in the room welcomed them in and showed an example of how easy it was to make a noise or light machine. Quietly, they took some pieces and parts to work on at a station. When I returned 15 minutes later, they had built an entire keyboard circuit and were playing music for the volunteer! It was incredible to see the smile appear behind the hair.

Opening day crew. Our facilitators are all volunteers.



A poster that explains the features of the WonderLab.

4. **Activities must be adaptable for various ages, abilities, and interests.** Everyone should get a chance to learn, imagine, and wonder. We work tirelessly in the WonderLab to give all kids a memorable experience.
5. **Activities must have a mix of learning and exploring/experimenting.** It's important for kids to know they can go further with any activity, whether it's staying in the WonderLab for 2 hours to complete a goal or taking information home to re-create the activity there. No activity has a hard start or end to it.
6. **Low stakes, nothing intimidating.** We want to inspire curiosity. Activity introductions should be simple, engaging, and easy to start. If kids can't find success in a few minutes, they may not continue. I wanted kids to benefit quickly, within 10–15 minutes, with the potential to experiment for hours.
7. **Activities must be volunteer-run.** Give Kids The World Village runs on volunteer help, so volunteers need to be trained frequently. If the activities are complex, it would scare volunteers away and be too complicated for most kids to engage.
8. **Create choice.** Kids and adults like to have choices, so we put choice into the activities: colors, storylines, circuitry challenges, paper airplane designs, etc. Also, there's an assortment of activities, four or five each day.
9. **Theming creates cohesion.** Giving activities solid theming and/or design creates a strong brand, but they're also more effective when everything is cohesive and organized.

Accessibility and flexibility were important concerns for the space. We knew there would be a large population of wheelchairs in the space, so we thought carefully about counter height, table height, and mobility. Furniture layouts would change with each activity's needs. For this, we created rolling workstations that nested into countertops so we could double the work space when busy or put tables away for needed floorspace. Our fabrication company worked with us to determine the right materials to be sanitized and hold up over time.

Also, the building we were renovating had all of one closet for storage — which would not work for an activity center. Evan and I built as much storage as possible into the plans so materials could be put away out of sight to reduce visual noise and overstimulation. As we walk through the lab today, we often say it feels like we are walking through our 3D renders!

Above is the actual Volts & Bolts Studio; below is the concept design.

The Wonderbots welcome new guests.

An animatronic version of Mayor Clayton greets everyone inside.

Miga Me LLC, Christie Miga

WELCOME TO THE WONDERLAB

Let's take a tour of the WonderLab spaces.

Exterior: As families walk up to the WonderLab, they see robotic inventions, tubes, pipes, and a giant meter covering the building. At the entryway, they pass by our three robot mascots known as the Wonderbots (our WonderLab builders) and under a banner welcoming all makers, inventors, and creators!

Lab Access: The first room that guests enter greets them with beautiful backlit posters illustrating the WonderLab story, spacey Lego creations floating in a star field overhead, and an animatronic of Mayor Clayton. This space welcomes families and primes them with curiosity while transitioning between the outside world and the WonderLab creation spaces.

The Hub: The Hub is directly in the center of the building and connects all rooms. As a natural space for wayfinding, room names and daily activities are labeled here. Additionally, our "WonderLab TV" plays a compilation of process videos including watercolor painting, claymation, stop motion, and digital art. But the main feature here is the Brilliance Bottler, a Wonderbot-created machine that converts wonder, imagination, and possibility into power for the building. Your awesome ideas keep our lab up and running!

Test & Try Lab: This room is for facilitation activities that allow for iteration such as printmaking, robot obstacle courses, paper airplane research, and circuitry machine building. This room also features two Garner Holt Education Through Imagination animatronics that kids get to puppet and record animatronic shows.

Tech 101: Tech 101 is a facilitation room that emphasizes the mix of art and tech. The activities here include 3D printing, stop-motion and green-screen video making, weaving on 3D-printed looms, and button making. We showcase five of our 3D printers here and all kinds of awesome prints to inspire guests.

Volts & Bolts Studio: Since we are down the street from world-class theme parks, including animatronics in the WonderLab mix was a no-brainer! This hands-on exhibit shows guests how raw materials are turned into parts for animatronic tiki birds, and how those animatronics are programmed. To illustrate it all, we have a laser cutter, vacuum former, mini CNC machine, and more 3D printers. This experience was made possible by the generosity of Garner Holt Productions and Garner Holt Education Through Imagination.

Even while I was writing this article in my WonderLab office, I heard a parent say, "This place is cool; look at all the details!" How awesome is that? Beyond the look, story, and activities of the WonderLab, the root of everything we do at Give Kids The World Village is to provide hope to children with critical illnesses. We believe happiness inspires hope, and this is true in the WonderLab.

We want the enthusiasm of the WonderLab to go home with them. For many Wish families, consistent school time or clubs can be difficult. Kids may miss science fairs, robotics clubs, or art classes. The WonderLab works to fill those gaps so kids can think about making cool stuff in the future. We provide families with resources to create our activities at home, gift to them 3D-printed tools, and share a vlog series that shows how the WonderLab was built.

The Hub features the Brilliance Bottler.

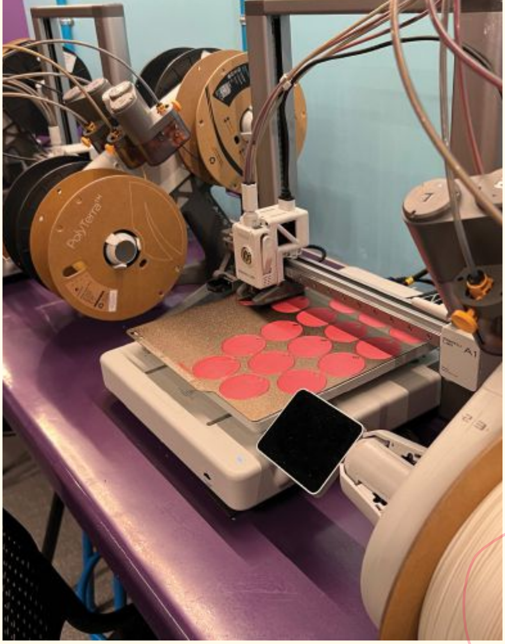
When we started, it was almost unimaginable to me that a child would not only leave a theme park early, but also willingly pass up a chance to collect loads of free Halloween candy — all to create stop-motion videos in the WonderLab. It's incredibly fulfilling to see our design work be realized in a wonderful space that welcomes kids every day.

Keep up with the WonderLab on their vlog: youtu.be/Pco_KOOlZkU

Christie Miga, Give Kids The World

The Test & Try Lab with its work tables nested underneath the counter.

The Tech 101 room has many creative options.

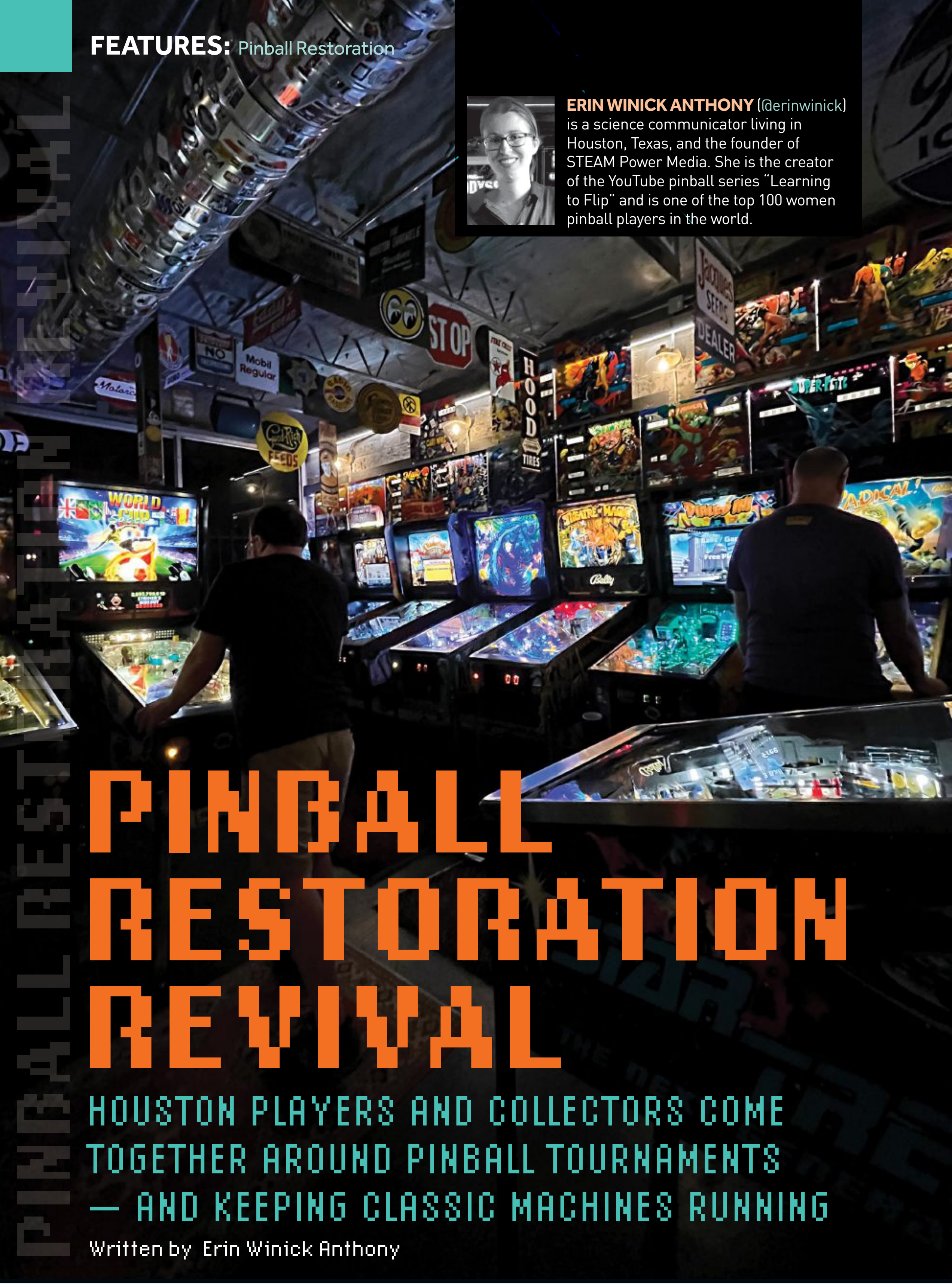


Five 3D printers are available in Tech 101.

Controlling the animatronic figure with a MIDI controller.

Weaving a bracelet on a 3D-printed loom.

Evan and Christie Miga came to Maker Faire Orlando 2019 dressed in robot costumes of their own creation.



ERIN WINICK ANTHONY (@erinwinick) is a science communicator living in Houston, Texas, and the founder of STEAM Power Media. She is the creator of the YouTube pinball series "Learning to Flip" and is one of the top 100 women pinball players in the world.

PINBALL RESTORATION REVIVAL

PINBALL RESTORATION REVIVAL

HOUSTON PLAYERS AND COLLECTORS COME TOGETHER AROUND PINBALL TOURNAMENTS — AND KEEPING CLASSIC MACHINES RUNNING

Written by Erin Winick Anthony

Though it's commonly associated with dinging bells and chimes in the 1960s, and electronic whirring and beeps in the 1980s, the pinball machine has entered a new era of popularity.

These physical, electromechanical games entered a rough patch during the influx of video games in the 1990s. But in 2023, *The Economist* reported that sales of new machines by pinball's biggest manufacturer, Stern, rose by 15–20% every year since 2008. Pinball tournaments and community events are booming too, with thousands being held each year.

Part of this resurgence in the pinball business can strangely be credited to the Covid-19 pandemic. While it hurt arcades, barcades, and the social aspects of pinball, it increased demand for home buyers. People who were staying home during lockdown found joy in owning their own machines. This expanded the market, creating customers for new machines but also increasing demand (and prices) for old machines from the original heyday of pinball. This in turn created a need for more people to learn to repair machines.

As a competitive pinball player myself, and a proud science and tech nerd (I worked as a science communicator for NASA), I've been fascinated to learn about pinball restoration from the experts.

THE RISE OF SPACE CITY PINBALL

Chicago has long been the undisputed hub of pinball; many of the largest machine manufacturers, present and past, are located there, and the competitive scene is strong. But with the rise in pinball's popularity, large pinball communities have popped up all around the world. Each of these communities requires its own local repair and restoration heroes. Pinball machines are designed to be played thousands of times, but between getting beat on during serious competition and reluctantly used as drink tables in bars, many decades-old machines can present some strange repair challenges.

Houston, Texas, is one of those new pinball hubs that has arisen over the past five years. The sprawling city easily has five or more tournaments every week, and hosts the annual Houston Arcade and Pinball Expo. There are dozens of public arcades and bars hosting machines, but the city is also home to a number of private collectors.

A hub for much of the Houston pinball community has formed around one of those collectors: Tim Hood. Tim and his wife Christine own more than 200 pinball games, including some strange and unique machines that he has had shipped from Europe. Hood is one member of the close-knit group that call themselves the Wormhole Five: Tim and Christine, Jamie and Genine Burchell, and John Speights. During the pandemic they founded Wormhole, a private pinball club where the group could get together safely in their own Covid social bubble.

Wormhole has grown way beyond that and is now open to the public for three pinball tournaments a month, which they stream on Twitch. The tournaments give an opportunity for the Wormhole Five to share a couple dozen of their impressive, oddball collection of machines with the community.

The Wormhole pinball club. Co-founder Tim Hood is the one with the long white hair on the right (top).

Erin Winick Anthony

John Speights looks for the next machine to work on restoring in the Vault.

Erin Winick Anthony

Speights opens *Halley Comet* and lifts its playfield to inspect it for the first time.

Some of those are brand new, but many are vintage machines that require months of work behind the scenes from a dedicated team to get them ready for their Wormhole debut.

PICKING A MACHINE TO RESTORE

On a hot Houston summer day, I met Wormhole manager John Speights at the Vault, the Hoods' storehouse of vintage pinball games. Speights has some of his games stored inside as well.

Tucked away on a side road in the Houston Heights, the Vault holds rows of folded-up pinball machines. Some were previously fixed up for Wormhole, others are currently being restored, and many more, shipped over from Europe and around the USA, are yet to be opened.

Plastic sheeting still envelops many of the games including *Bike Race* (1992), *Punk!* (1982), and Capcom's *Pinball Magic* (1995). Many are modern solid-state games, with a few classic electromechanical machines splashed in. Today's the day that two of those packed-up machines get opened to begin their restoration process in the hopes of making it into Wormhole.

"Of the around 60 European games Tim's gotten, we've only opened 10," Speights said. "It's hard to keep up, in a great way."

The first step is to cut off the plastic ties keeping the folded-up games secure for transport and storage. From looking at the side Speights could tell one of the games is *Halley Comet*, a solid state manufactured in 1986 by Juegos Populares in Spain, but the other was hard to identify solely from the side art.

To figure out the height of legs needed, Speights measured existing machines that were at a comfortable play height. He went digging in the stack of pinball machine legs in the corner and emerged with 31½" legs. (After testing, he'd return for ½" shorter legs to perfect the play feel.)

With legs bolted on and the game standing, it was time to unfold the machines' back boxes. With some help from some others working in the Vault, Speights got them open and attached any unplugged cables. The mystery game was revealed to be *Olympus*, another Juegos Populares game of the same era with muscular Olympian gods featured on the back glass. Speights went into inspection mode on both machines and took notes that he'd text to Brian Foytik, Wormhole's primary technician.

"I've learned that about 95% of pinball repair is observation," Speights said. "The game quits working, and you're like, 'Oh no, I have no idea how to fix this.' But in reality, if you take a moment, slide the glass off, lift the playfield up, look at the area that's not working, you're like, 'Oh, it's this thing that came off.' A wire came loose or the spring is off. It's things that you can observe and say, 'Okay, I can fix that.' It's become less intimidating to me through watching people like Brian and seeing how he works on things."

Upon lifting the playfields, both *Olympus* and *Halley Comet* showed oxidation, rust, and dirt on the metal switches inside, indicating they may have been housed near water. Speights checked for board and battery corrosion and looked for any glaring problems like hanging cords, snapping some pictures of the boards to send to Foytik.

"Brian isn't going to like this," he said, looking at the oxidation inside.

But with the thumbs-up from Foytik to turn them on to see what happens, he found a transformer to allow him to plug them in, as they both had European style plugs.

As he flicked the power switch to *Halley Comet*, lights and sound immediately came from the machine. The music sounded a bit strange, kind of like a blown-out speaker, but the game did seem to turn on.

"Anytime that we open a game up like that, we don't know how long it's been wrapped up. Maybe a month, maybe 17 years, we don't know," Speights said. "The fact that the game booted, we are 90% of the way there."

Speights manually added a few credits onto the game using a lever inside the coin door, and hit the start button for a first test game.

There were some other obvious issues with *Halley Comet* — the plunger to launch the ball not being lined up, a drop target not going down, and some bulbs burnt out — but for the most part Speights was ready to pass this project off to Foytik as the next game to restore.

"Without Brian Foytik, the pinball community in the Houston area would not be near what it is, because he keeps a lot of these games alive that other people don't know how to do," Speights said. "He provides so much and he doesn't ask for anything in return. He does it purely out of his love of pinball repair and seeing these games play."

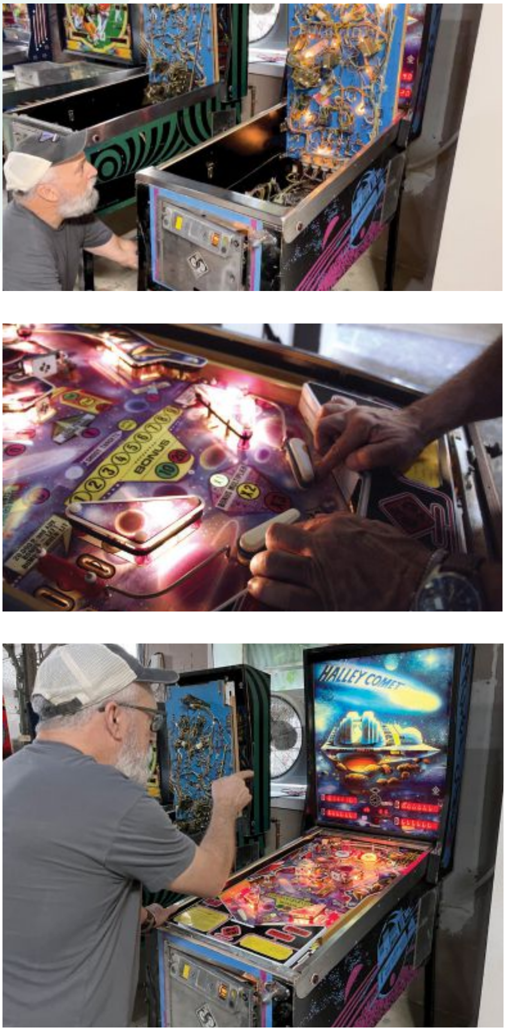
GETTING A PINBALL MACHINE TOURNAMENT READY

A few nights later, I returned to the Vault with Foytik as he did his own inspection of *Halley Comet* and started the restoration process.

"This is what they would probably call a working project," Foytik said. "It still needs some minor stuff done to the boards, like to change the electrolytic capacitors. Since they're older, they will fail and they'll leak out as well," he explained. "That will bring it back up to like a newish condition."

Foytik grew up around repair work. His dad, Clarence, was skilled at fixing everything from jukeboxes to pinball machines, but Foytik didn't get interested in repairing pinball machines himself until after purchasing his first one, a *Twilight Zone*, in 2008.

"I wanted to learn and try to get some repair skills like he had," Foytik recalled. "It was just



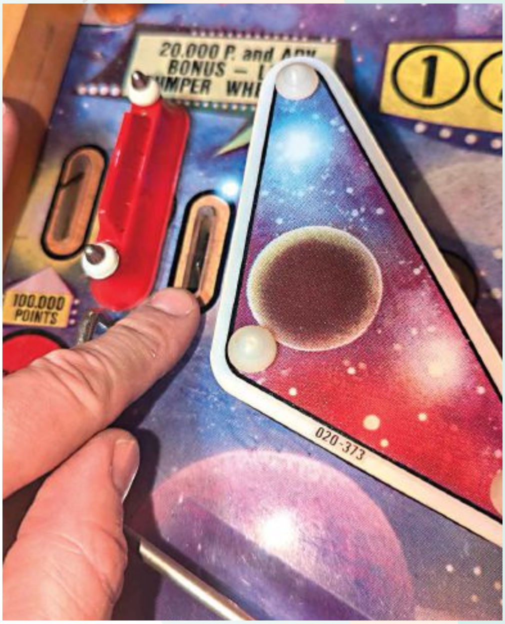
Speights powers up *Halley Comet* to test lights and sound, then inspects flippers before a first test play.

amazing all the kinds of stuff that he worked on: tractors, engines, vehicles. He could fix almost anything electronic around the house. That's what I want to try to get into and get as good as he was."

Foytik got into supporting Wormhole and the Houston pinball community through another pair of Houston repair icons, the Dronets, who run UpKick Pinball. If you've got a big project, Elizabeth and David Dronet are who you reach out to first, and you send it to their house to be "UpKicked." Foytik found joy in working on some of their projects.

"I was working on Tim's games for at least for

Brian Foytik inspects the switches on the underside of the *Halley Comet* playfield, at the Vault. The flipper solenoids, green, can be seen here as well.



Erin Winick Anthony, Brian Foytik

A roll switch's leaf switch beneath the playfield (left) wasn't triggering and had to be bent back into shape.

10 months before he even knew I was working on them," Foytik said. Now he leads the charge restoring Wormhole's games in the Vault, as well as still working on his own personal projects.

With toolboxes at the ready and a magnetic light attached to the side of the *Halley Comet* machine, it was time to get started. First up on today's repair docket: the plunger was so loose and off center that it couldn't launch the ball to the top of the machine. This was an easy fix, using a screwdriver to relocate and tighten the plunger so that it would hit right in the center of the ball as it sits in the shooter lane. Being just a little off center can drastically change the plunger's power.

The start button was also getting stuck, making the game start over right away when a game finished, and automatically adding extra players. This was fixed by just cleaning around the button and adjusting the switch a little bit that was right behind it.

Next was taking a look at individual switches on the underside of the playfield. Pinball machines of the solid-state era use numerous leaf switches that can be pressed by the ball to record points and send other signals. A few of this machine's drop target switches needed cleaning. Foytik used a Flexstone file to do this, a small non-conductive file that he could run through the switch to take off any dirt and buildup. Many repair techs use an emery board or even just a business card for the same task.

Other switches needed closer attention, their metal contacts under the playfield loosened or tightened with needlenose pliers. Foytik would reach one arm around to the back of the lifted-up playfield and run his hand along the switches as he adjusted them. He was checking that the switch would fully depress and pop back up like it would need to if a ball ran over it.

Thankfully all the solenoid coils powering the flippers and bumpers seemed to be in decent condition, but Foytik did notice that one flipper appeared more powerful than the other. Rather than just swap the underpowered coil, he decided it would be worth it to track down two working coils to swap them on both flippers.

"If you just swap one, then the one that felt more powerful before will likely feel underpowered," Foytik explained.

Many of the small insert lamps that light up shots on the playfield were burnt out or dim. Using some rubbing alcohol and a paper towel, he cleaned debris buildup off the plastic inserts, and then did some quick swaps of the bulbs for fresh LED lights.

Now it was time to take on the game's weird crackling sound. One of the most convenient things you can have when fixing a pinball machine is another version of that game. And just by Foytik's luck, Hood had purchased a second, worse-condition *Halley Comet* whose soundboard could be swapped into the first machine. This second machine was much worse for wear with spiderwebs galore, floppy flippers, and missing parts. But the soundboard was intact.

With a quick unscrewing and screwing of a few bolts, the soundboard was swapped. Upon booting the game back up, the sound was a bit better, but still had some of the crackling noise.

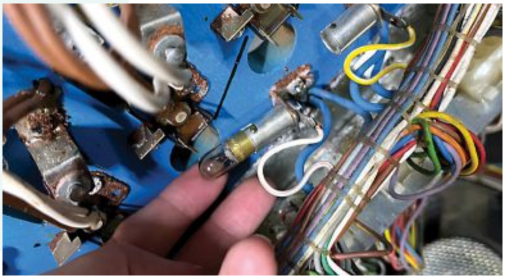
Now Foytik decided to bring the circuit boards home to take a closer look, do some soldering, and swap out the capacitors. The only major hangup seemed to be that he couldn't figure out how to get the game to change from five to three balls. Machines like this often have a setting to enable the change, but this one didn't seem to work. And knowing how good Wormhole's tournament players are, giving them five balls would make the games last way too long.

"Sometimes you find a small problem that you think is hard which ends up being easy. But other times you end up overthinking it and making it hard," Foytik said. "So sometimes, if I have trouble, I usually leave it for another day."

Although the game is getting close to being fixed up, it still needs a switches-and-lights test run to check on those last few switches that don't seem to be triggering when a ball rolls over them. Some of the springs also need to be swapped on the few plastic drop targets that aren't responding very strongly when they are supposed to pop down and back up.

The final steps to finishing any pinball restoration project are swapping out any of the older rubber pieces on the game that look close to breaking for new ones, giving the playfield a good cleaning and waxing, and finally doing some last play testing.

"It needs test plays — you need to hit all the switches again and again and again," Speights said. "You're sending electrical signals through these transistors from resistors that may not



Some the vintage lamps in *Halley Comet* were swapped out for fresh LEDs.

Foytik pulls the soundboard out of a donor *Halley Comet* machine to swap it into the one being restored.

have received electricity in a long time. A lot of times they'll fail, and then boom, another issue comes up. We have to trace it back, replace that resistor, and you're back in business — until the next thing comes up."

Wormhole isn't going for aesthetic perfection with their games, but they are dedicated to getting the mechanics up and running properly.

"There are probably going to be more beautiful specimens out there of each individual game that we have here," Speights said, "but we want ours to play 100% and for you to be able to experience the game play as it was intended."

- To read more about Wormhole's tournaments and repair crew, read the extended version of this article at makezine.com/go/pinball-restoration.
- Check out the International Flipper Pinball Association (ifpapinball.com) to find a pinball community or repair classes near you, and explore Pinball Map (pinballmap.com) for a crowdsourced map of all the pinball machines in your area.

Back to the Beginning

THE TEAM THAT MADE THE FIRST *MAKE:* MAGAZINE

Written by Dale Dougherty

The OG Team

MARK FRAUENFELDER: Mark was the first editor for *Make:* magazine. He had worked at *Wired* and was a founder of *Boing Boing*. Today, he's research director at a nonprofit think tank called Institute for the Future, and they're in Palo Alto, California.

DAVID ALBERTSON: David came up with the design and format for *Make:* magazine. He is a graphic designer who has his own firm, Albertson Design in San Francisco.

SHAWN CONNALLY: Shawn was the managing editor for *Make:*, working with Mark as well as copy editors and designers to produce the magazine. Today, she divides her time between Occidental, California, and New Mexico. She is a master gardener.

PAUL SPINRAD: Paul was an early contributor to *Make:* and then joined the team as an editor. Today, he's a technical writer at Broadcom.

KEITH HAMMOND: Keith is the editor-in-chief of *Make.* He started as a copy editor on early issues of *Make:* before managing the projects section.

I had the opportunity to bring back together members of the first team who helped develop *Make:* magazine, taking an idea I had and turning it into something real and tangible. I am grateful for all that they did.

DALE: Mark, when I first talked to you about a new magazine I wanted to start, you were in Rarotonga in the Cook Islands.

MARK: I was there with my two young daughters and [wife] Carla. You had been doing the *Hacks* series of books at O'Reilly and you wanted to do a general-interest "recreational technology" magazine.

DALE: I had no experience publishing a magazine, but I had connected to John Battelle. He knew you from *Wired*.

MARK: About four months later, I came back from Rarotonga and I flew out to meet you with John. I was really excited about it. You asked about a designer and I had always been a huge admirer of David Alberston's work.

So then, Dale and David and I met, and you said, let's make a prototype. So that was several weekends — and weeks — up at David's in his studio, putting stuff on the wall. We didn't have a name for the magazine and I was pushing foolishly for the name *Geek*. You of course came up with the great name *Make*, which was perfect.


DOZENS OF HACKS AND HOW-TOS FOR YOUR GEAR
Premiere Issue!
Make:
technology on your time
181 pages of D.I.Y. technology
How to Make a Magnetic Stripe Card Reader
AERIAL PHOTOGRAPHY NOW WITH KITES!
BUILD YOUR OWN KITE RIG USING THE PLANS INSIDE!
Backyard Monorails
XM Radio Hacks
iPod Tricks
Blogging Made Simple
50
84
96
106
REAL-LIFE REVIEWS OF USEFUL GADGETS!
O'REILLY

And then adding the colon to it was just, like, the brilliance of that — *what* are you going to make?

DALE: My original idea was *Hacks* magazine. I told my kids, and they didn't get the word *hack*. It meant nothing to them.

As an editor at O'Reilly, I recalled a book we had published about a Unix utility, *Managing Projects with GNU Make*. I wanted the magazine to be about projects, how to build things. The **make** utility was used to run a bunch of commands to compile a program. I didn't care if anyone knew that connection, but I loved the word *make* because it was a verb for doing something.

DAVID: Mark, I remember when we were here in my little office, just how much fun it was. Dale, you had shared with me old *Popular Mechanics* magazines. I loved those. They're so beautifully done and they were so sincere. And so when we talked about this being like a shop manual, I really got excited about that.

SHAWN: I had a 3-year-old at home. Dale said, come in, I have this crazy idea. He would never call it crazy; I called it crazy to do this stuff. But I thought it was a pretty interesting idea.

DALE: Your role, Shawn, was managing editor, which is really bringing all the different pieces together. Paul, you came on after the first issue.

PAUL: I used to work at *Wired* but not at the same time that Mark did; yet we knew a lot of folks in common. I'd taken some time off to write a book about VJing, about live video performance, which I was super into. I pinged Mark looking for work and he said I'm starting this magazine. Do you want to write these two short pieces? There was one about this guy in Fremont who had built in his backyard a monorail. I love that stuff.

DALE: We have a photo of a puppy in the monorail that captures your interest immediately.

PAUL: Totally. The puppy monorail!

DALE: Keith is our current editor-in-chief.

KEITH: I had just moved to Sebastopol ... like, why is there a magazine in this little town? And so I came in and met the magazine team that had been pulled together, right after the first issue succeeded. You guys were like, Oh, we have to really do this now!

It's fussy work, scientific notations and abbreviations, conventions and nomenclature and dimensions ... it's really fussy.

DAVID: It was a big part of selecting the typeface for the magazine. We had character sets that allowed for inline fractions and that had all the mathematical symbols, so we could keep them uniform with the whole look of the magazine.

KEITH: On top of that, it has to actually work! The

Make:
technology on your time™
Volume 01

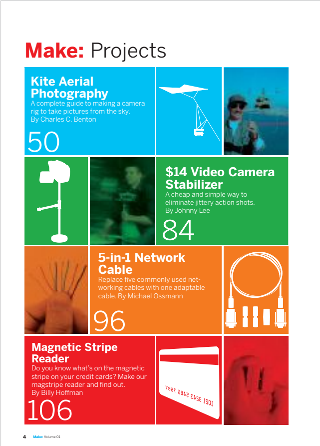
22
The feral robot dogs are coming to a Superfund site near you.

The Wright brothers made better bicycle seats than airplanes. It's time to revisit the grooved saddle.

38

ON THE COVER
Photographer Emily Nathan captures Cris Benton rigging his kite camera before a test run. Make one yourself with his instructions on page 50. The kite shown is a Cody historical reproduction, made by Logo Kites Drachen GmbH of Hamburg, Germany. Available exclusively from Gomberg Kite Productions International, www.gombergkites.com.

2 Make: Volume 01



Make: Projects

4 Make: Volume 01

Volume 01

162
Even if you've never picked up a soldering iron, MAKE's primer will have you connecting components in short order.

Why is this man screaming? Because his mechanical pong machine has broken yet again.
158

DIY

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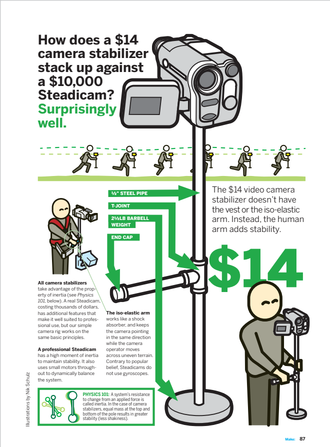
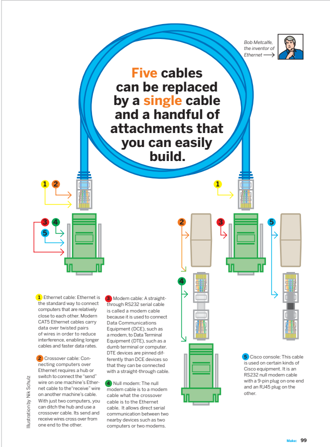
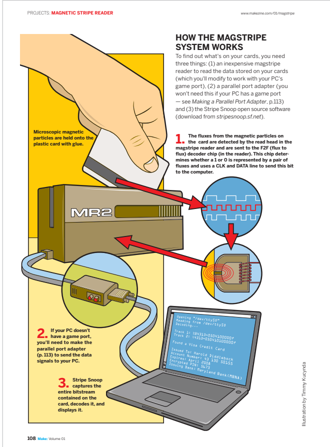
6 Make: Volume 01

DNA OF *MAKE:*, EST. 2005: Delightful makers, DIY projects, open source technology, hacks and how-to skills.







WORTH 1,000 PHOTOS: Infographics, exploded illustrations, and cutaway diagrams show you how it really works.

part number has to be the right part number; the length of the screw has to be right, or it won't fit.

PAUL: And it's in print!

DALE: David, one of the things I'm really proud of is the design of *Make:* and it has stood the test of time. We've had other designers follow David but he laid the foundation. We took a category that often didn't have much design, either it was grungy or just plain, the equivalent of Courier font.

DAVID: I didn't have to pitch it too hard; it was great to have you guys as collaborators to push things along. It was really worth the effort because we wanted those pages to look great.

DALE: David, you had a particular vision, and I trusted that. We didn't do a hundred variations. You were pretty close from the beginning.

DAVID: I really wanted this to stand out, to not look like a typical techie manual, and I wanted — your vision, Dale, of this thing being for, like, dads and kids, that kind of age range — I wanted kids to look at it and say, this is exciting. It's not just the gear.

DALE: A lot of the computer magazines were based on classes of gear, mobile phones or laptops or PCs or Macs. They were overly business focused — plain, straightforward. I wanted making to be fun and playful. That's one of the reasons people do it.

Mark, you have a great sense of what's cool. I think it's honed in *Boing Boing*, and I don't mean affected cool but authentic and genuine, something original that you haven't seen before — like, someone actually did that!

MARK: That's always been my thing. Like when *Wired* hired me to do their review section, and also they had a section called Fetish, which was new gadgets and things like that, and it was just tapping into my natural interest for interesting new things out there that intrigued me.

DALE: But Mark, you actually have a degree in mechanical engineering.

MARK: I do.

DALE: I think the secret touch you had, and I see it in places like Japan, like our Maker Faire Tokyo, it's combining pop culture or the sense of what's popular or cool with technology.

DAVID: I remember when Mark said, OK, we got a scoop! The big scoop was that there are a bunch of students in Hong Kong who were going to like the local Pizza Hut. They had architected the salad bar so that they could maximize a single bowl by building platforms out of carrot sticks. I love that Mark was like, We got it! We're going to be the first ones to get that out there.

DALE: One of the things that we tried to do was have illustrations for the projects.

KEITH: The exploded diagram or cutaway for that big opening illustration for major projects — it sets this context for how the whole thing works. It was not a boring diagram, it was beautifully illustrated with a lot of character.

DALE: Again, that's a connection to those old *Popular Mechanics* that had wonderful line art. It did something that photographs don't do the same way. It was clear and easy to understand.

MARK: We made a connection to Roy Doty who was the fantastic "Wordless Workshop" illustrator for *Popular Science* and *Popular Mechanics*. He was in his mid-80s doing illustrations for us. He was such a great bridge, and a thrill to work with.

DALE: The first issue had four major projects. I think they were a pretty good reflection of what *Make:* wanted to be. One was the mag stripe reader by Billy Hoffman, which was a hack. How do you know what's on that mag stripe on a credit card or a hotel room key? And then Johnny Lee's $14 Steadicam. It had a weight at the bottom of a pipe and a bracket to hold a camera.

We had a challenge to figure out what was going to be on the cover. What would be the most different and inspiring project we could find? We found Cris Benton, a professor of architecture at UC Berkeley who was putting cameras up in the air hanging from a kite. He was flying them at 200 feet so he could get different views of buildings.

Our goal was to share the instructions of how to build something and not hand-wave over the process. Cris had many different camera rigs but the one he made for the magazine was a harness made with popsicle sticks and it was designed for a disposable camera.

MARK: It had the Silly Putty viscous timer. Cris made this project for us especially, because we said: "Your rigs are expensive. Can you do a low-cost version?" The shutter mechanism was a little film canister with Silly Putty inside and a rubber band. You wound it up in the Silly Putty, but it was super viscous. So the little lever that pressed the shutter button …

DAVID: It was a toothpick with rubber bands.

MARK: It took 3 minutes to finally hit the shutter, but it was enough time to deploy that kite and get it up to altitude.

DALE: It was a Rube Goldberg kind of contraption.

MARK: That first project makes you realize how long ago this was. Now there's just so many other options with Bluetooth and all that stuff.

DALE: Cris was also using a Canon camera and he was able to hack the firmware in to do the same kind of thing, getting a delay. I've found it fascinating that we covered hacking consumer technology to make it do something that you want it to do, but it wasn't really made to do.

PAUL: There's something very subversive about DIY and doing things you're not supposed to. The design of *Make:* was very approachable and appealing. It was not anti-establishment in any way. It was very direct and clear. That's what made it so subversive.

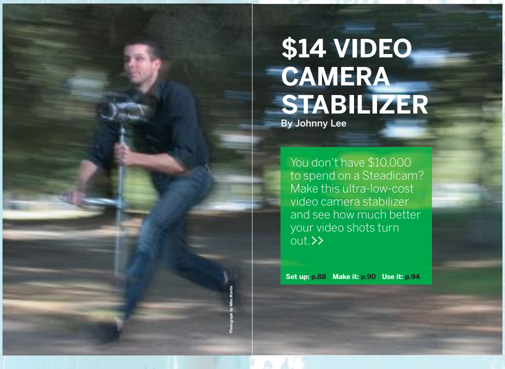
DALE: One of the questions I got early on was, why are you doing a print magazine? There was something about it being tangible that really appealed to me. This was a magazine about objects and we wanted to create the magazine as an object about those objects. I hoped people would want to collect them and hold on to them.

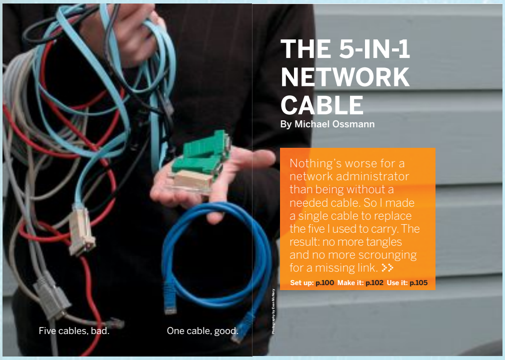
DAVID: I think we were all aware that it was comfort food for some people too, like the people who would have a subscription to *Martha Stewart Living* and they never make a recipe.

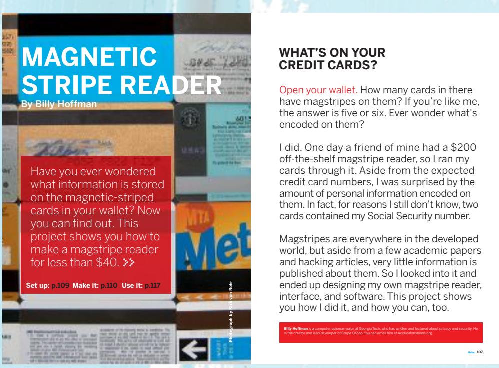
They just felt really good about going through the pages and looking at the pictures and the elaborateness of some of these little projects. We heard from some readers: I comb through every issue, I make maybe one project a year.

DALE: I also heard from people who said "I grew up reading magazines like *Popular Electronics* and that's how I learned about technology. I read it under the covers at night with a flashlight." We're filling people's head with ideas for things, and

VOLUME 01 MAJOR PROJECTS







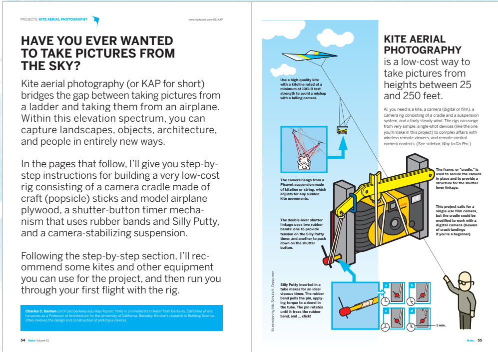
Where are they now?

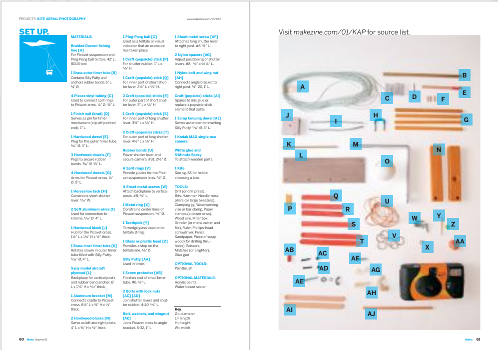
- **CRIS BENTON, Berkeley, California, writes:** Like *Make:* I find myself 20 years older and this places me in the state of contented retirement. I continue to play around with KAP, using low level photographs in sustained, longitudinal projects to document and understand landscapes of interest. My South Bay Salt Pond work led to exhibits at the Exploratorium and to *Saltscapes*, a book with Heyday Press. Another KAP project documents the coastal defenses of San Francisco Bay. These days I am splitting my time between grandkids, camping, and travel but still get a kite up now and then. flickr.com/photos/kap_cris

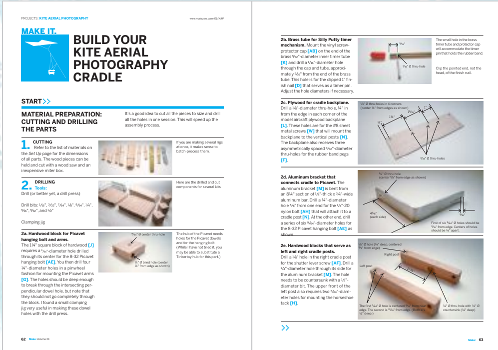
- **JOHNNY LEE, Redmond, Washington, writes:** I am working on AI experiences for wearable devices like AR glasses. Very "buzzwordy," I know. Previously, I developed spatial computing technology for Google, and did a short stint in robotics. The $14 camera stabilizer was my first real exposure to the power of the maker community. Being included in the premier issue of *Make:* is still a badge of honor ... I even got to ride the coattails of the magazine when it was included in the Cooper Hewitt Smithsonian Design Museum Triennial in 2006. It definitely encouraged me to continue making other projects accessible to the community such as my Wii-remote hacks and funding the Adafruit OpenKinect prize.

- **MIKE OSSMAN, Evergreen, Colorado:** Mike writes and designs open source products at GreatScottGadgets.com, which he calls an "effort to put exciting, new tools into the hands of innovative people" — notably the HackRF One software defined radio (SDR) transceiver featured in *Make:* Volumes 84 and 87.

- **BILLY HOFFMAN, Atlanta, Georgia, writes:** Writing for that first issue of *Make:* was not only rewarding but also very validating: there existed other people, like me, that were obsessively curious with how things worked, and with building things. In early 2005, I was about to graduate from college. I had been active in the hacking/2600 scene, but working with *Make:* and O'Reilly helped me see there was a much broader appeal. Since *Make:*, I've made a career of figuring out how things work, as a researcher, founder, and then CTO at a series of computer security and web performance startups. Nowadays I do my making with my daughter, who loves to download, modify, and print models on her 3D printer. In her eyes, hackers are people who know how to mod *Minecraft*!







SHOW AND TELL: Overview illustrations, materials lists, and step-by-step instructions lead to a successful build.

then their own ideas emerge and they then know how to do it because they saw someone else do something like it.

KEITH: Now that's all in your bag of tricks. And it demystifies technology, what's under the hood. It's not a magic black box from some big company. It's just technology — you can figure out how it works and you can point it in a new direction.

PAUL: I remember it was like the peak period for magazines going out of business. It was so funny, working for *Make:* while reading that so-and-so is going out of business. I kept thinking, there is an exception here.

KEITH: We somehow started a magazine right when all the other magazines were going off a cliff. And it only got worse. But we were like Wile E. Coyote. We just went out over the cliff and just kept going. We're still going.

DALE: I like that image. I didn't know if we'd get any advertising. So we had a higher cover price than most magazines. Tim O'Reilly said, when people pay for something, they value it.

KEITH: I think reader-supported publications are the ones that have kept bumping along steadily.

DALE: Mark, you mentioned our first project, kite aerial photography, was long, over 30 pages in print. We had to back up the release of the first issue because of the complexity of it. One thing that distinguishes *Make:* is how we provided detailed step-by-step instructions for projects.

DAVID: It's recipe building. We really worked on that and kept trying to hone it so that we had a templated way to lay out projects in a sequence. I worried that the material would come across as extraordinarily dense and impenetrable. What we wanted was something that people can look at and go, OK, I can handle this. It gives them the confidence that they can understand it all. All of us worked really hard to make sure the instructions were really as simple as they can be.

DALE: Editors had two challenges. One was working with some authors who are not naturally writers. Second, often they're not very good at describing their own work in a way that other people can follow the instructions, without knowing the same background information. They had to think how someone else would be able to do what they do.

KEITH: This is what led to the Make Labs engineering interns building and testing projects to see if this stuff would really work. Especially mechanical contraptions like the Stirling engine confused. And that's the editorial back-and-forth with the author. We started improving the projects also for photography.

DAVID: And we built a guide for authors for taking their own photographs. We tried to make that into its own how-to to make it really easy for them.

DALE: There's such authenticity to a photo that a maker takes of their project, often it's in their workshop or their garage. I always preferred that to our own studio shoots.

PAUL: Another part of David's design was the photo of the materials at the very beginning, a sort of establishing shot of all the materials. You see how it makes the project so tangible and less intimidating. You're setting the stage: This is what you start with.

DALE: Mark, I really enjoyed meeting the makers as people. They didn't fit into the traditional categories of artists or even technologists and or scientists and others. It was fun to find out, often this is a side project or something that they just did. You never asked a maker, why'd you do that? It was more like, we're happy that they did it.

DAVID: There was such a folk art kind of component to a lot of these things — the makers and how unique they were.

DALE: These encounters with people led me to thinking about Maker Faire as an event — to bring all these makers together for the public to meet them and talk to them about their projects.

SHAWN: I still remember the first time I saw an ad that used the word *maker* after we started the magazine. Dale pretty much created this word and this movement and now I get every week, an ad or an email about makers. I think we created a word and a movement, as you say.

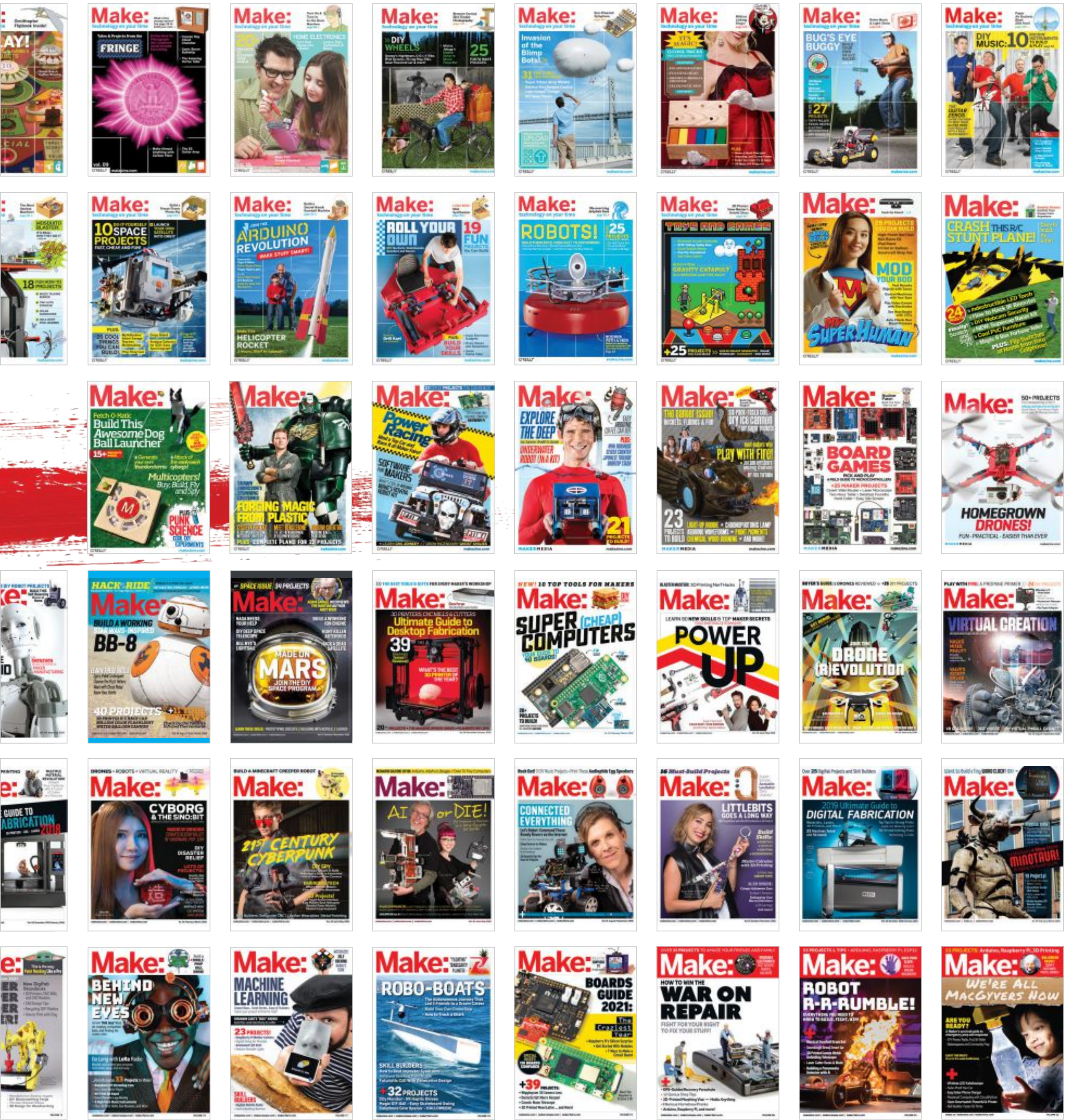
DALE: The word *maker* served a purpose of connecting people that had different interests and different things they like to do but they were all makers. Maker Faire was just an umbrella for all kinds of different people who make things and they can all talk about their projects and regardless, they can say "I'm a maker."

SHAWN: The word *maker*, like you said, you put it in the first issue and now 20 years later, everyone just uses it as a noun in a way that really no one did 20 years ago. I find that fascinating and really something for all of us to be proud of.

YOU CAN DO IT: "Howtoons" presented kid-friendly DIY projects in a comic-book format.

Dale Dougherty is the founder of *Make:* and Maker Faire, and the president of Make: Community.

For the Makers...

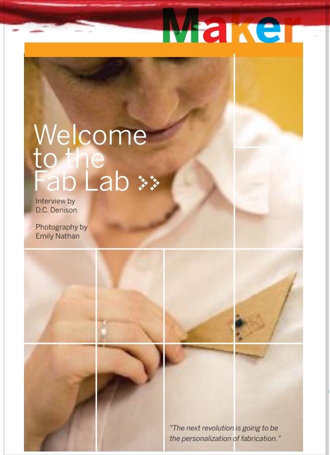


Collect Them All!

From our original digest size in 2005, to full size in 2014 and back again in 2019, *Make:* has delivered a beautiful, project-packed, book-like publication that's worth keeping. Thank you for reading! We hope all of these are on your shelf; if not, explore makershed.com/collections/back-issues or get complete digital archive access at make.co/join.

The Band Began to Play

Written by Neil Gershenfeld

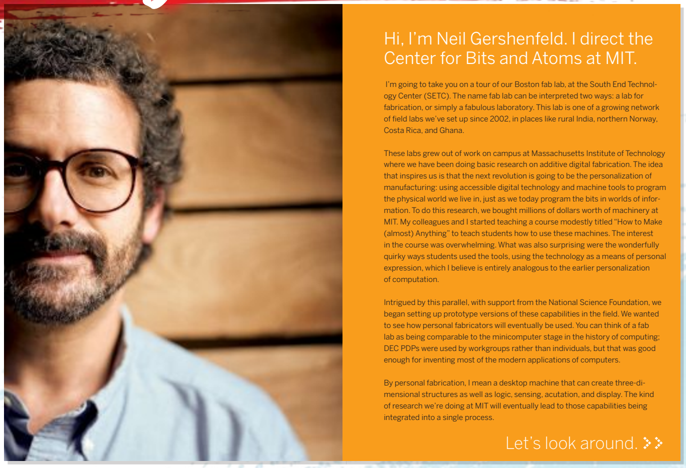

Make:

Welcome to the Fab Lab >>

Interview by D.C. Denison

Photography by Emily Nathan

"The next revolution is going to be the personalization of fabrication."


Hi, I'm Neil Gershenfeld. I direct the Center for Bits and Atoms at MIT.

I'm going to take you on a tour of our Boston fab lab, at the South End Technology Center (SETC). The name fab lab can be interpreted two ways: a lab for fabrication, or simply a fabulous laboratory. This lab is one of a growing network of field labs we've set up since 2002, in places like rural India, northern Norway, Costa Rica, and Ghana.

These labs grew out of work on campus at Massachusetts Institute of Technology where we have been doing basic research on additive digital fabrication. The idea that inspires us is that the next revolution is going to be the personalization of manufacturing: using accessible digital technology and machine tools to program the physical world we live in, just as we today program the bits in worlds of information. To do this research, we bought millions of dollars worth of machinery at MIT. My colleagues and I started teaching a course modestly titled "How to Make (almost) Anything" to teach students how to use these machines. The interest in the course was overwhelming. What was also surprising were the wonderfully quirky ways students used the tools, using the technology as a means of personal expression, which I believe is entirely analogous to the earlier personalization of computation.

Intrigued by this parallel, with support from the National Science Foundation, we began setting up prototype versions of these capabilities in the field. We wanted to see how personal fabricators will eventually be used. You can think of a fab lab as being comparable to the minicomputer stage in the history of computing; DEC PDPs were used by workgroups rather than individuals, but that was good enough for inventing most of the modern applications of computers.

By personal fabrication, I mean a desktop machine that can create three-dimensional structures as well as logic, sensing, acutation, and display. The kind of research we're doing at MIT will eventually lead to those capabilities being integrated into a single process.

Let's look around. >>

FAB LAB FOUNDER LOOKS BACK AND TO THE FUTURE

It was 20 years ago today ... that Dale Dougherty (not Sgt. Pepper) came to play. I'm proud now to have been the first interview in *Make:*, although I was puzzled at the time. I'd been making things all my life, but didn't get why that act warranted capitalization, or a magazine, or becoming a noun+verb+adjective. Rereading the interview now, I'd give myself a C for vision, a B for technology, and an A for people.

Vision

In the interview I mentioned some of the places fab labs had spread to, but didn't note that each was inspired by another lab opening. That led to exponential growth (as measured by the fablabs.io portal); there are now around 3,000 fab labs in 150 countries; that's 11.5 doublings over 20 years, a pace that is comparable to Moore's Law for digital technologies. That trend has come to be called Lass's Law, after Sherry Lassiter, who leads the Fab Foundation (more on that shortly).

Gordon Moore's prescient 1965 article that articulated what became Moore's Law, "Cramming More Components onto Integrated Circuits," got almost everything right, but missed two important things. The first was duration — he projected 10 years of doubling; it actually began to roll off after 50 years. And he foresaw the positive impacts of digital scaling, but he (along with most everyone else) didn't anticipate the associated spread of spam, fake news, and income inequality, resulting in consequences we've spent years reacting to.

The *Make:* interview ends by mentioning my upcoming book *Fab*, which in 2007 celebrated the emerging parallel between personal computing and personal fabrication. It wasn't until my next book, *Designing Reality*, in 2017 that I addressed the technological roadmap for 50 years of scaling the performance of digital fabrication, and along with my brothers Joel and Alan looked at how to address barriers and risks now rather than waiting for them to manifest (an updated version will be coming out as an audiobook).

Prof. NEIL GERSHENFELD is the director of MIT's Center for Bits and Atoms, where his unique laboratory is breaking down boundaries between the digital and physical worlds. He's the founder of a global network of around 3,000 fab labs in 150 countries, chairs the Fab Foundation, and leads the Fab Academy.

In retrospect, the technological part of that scaling has been the easy part. Much harder has been building the organizational capacity to keep up with it, because empowering anyone to make anything, anywhere, challenges the historical boundaries between work and play, education and industry, formal and informal settings.

To keep up, we've had to create a Fab Academy for hands-on technical training (fabacademy.org) which grew into Academany, aka the Academy of Almost Anything (academany.org) after geneticist George Church and colleagues used the platform for a Bio Academy; a Fab City initiative for cities to produce what they consume (fab.city) which began as a 40-year countdown to urban self-sufficiency in Barcelona when Vicente Guallart was the city planner); and a Fab Foundation (fabfoundation.org) that's dedicated to supporting the growth of the fab lab network and its programs, regional capacity-building, the social impact of technology innovation, and my favorite annual event, the FABx gathering that's rotated among sites around the world.

With the subsequent proliferation of hacker spaces, makerspaces, super labs, mini labs, bio labs ... a single count is no longer meaningful as it was in the early days of standardized fab labs. We'll continue to track the scaling of digital fabrication, but what really matters is its impact, which is why all of these programs are now focused on measuring outcomes.

Technology

The $25k fab lab inventory that I described grew to $100k by the end of what I've called the fab 1.0 era of purchasing fab labs. A major addition in response to demand was large-format machining, for making things from furniture up to houses. And at the time of the interview 3D printing was too expensive, proprietary, and immature to include; thanks to pioneers from Adrian Bowyer to Bre Pettis to Josef Prusa to Max Lobovsky it's now become affordable, reliable, and useful.

In the interview I suggested a fab lab might eventually be able to make another lab. This fab 2.0 era has matured much faster than I expected at the time; machines and their builders including Daniele Ingrassia's Open Lab Starter Kit, Jens Dyvik's Fabricatable Machines family, Jake Read's Clank, and Nadya Peek's Jubilee are sharing open designs for machines that can compete with their commercial predecessors, while also sharing benefits that include teaching skills, creating work, and easing repair, customization, and reuse.

The democratization of "machines making machines" is leading to both more and less expensive labs. More expensive, through million-dollar-scale super fab labs with more advanced tools able to replace supply chains for many of the components that go into those machines. And less expensive, through few-thousand-dollar minilabs based on commoditized production from open designs. It's also expanding the scope of capabilities, including fab labs making bio labs, and an Open Metrology initiative that developed with the National Institute of Standards and Technology to expand access to advanced scientific measurements.

The biggest technological omission in the 2005 interview is what my lab (MIT's Center for Bits and Atoms, or CBA) has spent the most time on since — the distinction between analog additive and subtractive processes and what I've called the fab 3.0 stage of discrete digital assemblers, and the fab 4.0 stage of machines and materials merging in self-assembly. CBA has since shown how the robotic assembly of functional building blocks can lead to record-setting material properties, and be used for making everything from cars to boats to planes to space structures. We're studying the nanoscale boundary where bricks effectively become quantum, and are developing assemblers that can assemble themselves from the parts that they're assembling. This recursion is at the heart of my 50-year digital fabrication scaling roadmap, and is the experimental realization of John von Neumann and Alan Turing's theoretical models of life.

People

I found the most prescient part of the interview to be what seemed almost incidental at the time — the people that appear in the article.

Neil Gershenfeld addressing the audience at the FAB24 conference in Puebla, Mexico, in August 2024.

Grace Gershenfeld

One of the TAs I mentioned for my course *How to Make (Almost) Anything*, Raffi Krikorian, went on to create the computing infrastructure at Twitter, then rebooted computing for the DNC, and is now the Emerson Collective's chief technology officer. Another, Manu Prakash, has become a pioneer in frugal innovation, famous for (among many other things) his 50-cent microscope that's been distributed in the millions. One of the students, Amon Millner, co-invented the Scratch programming language that's been used by millions of kids; another, Ayah Bdeir, created the littleBits electronics building blocks that have had a transformative impact on STEAM education.

I appreciated all of these people at the time, but didn't foresee what their impact would be. Something similar followed at scale in the fab lab network; through it, countless remarkable people have become change agents: Abu Adam, Adam Stone, Adrián Torres, Adriana Cabrera, Anastasia Pistofidou, Aristarco Cortes, Bas Withagen, Beno Juarez, Blair Evans, Cecilia Raspanti, Chirag Sharma, Daniele Ingrassia, Duaa AlAali, Enrico Bassi, Felicity Mecha, Fiore Basile, Frosti Gíslason, Haakon Karlsen, Henk Buursen, Jani Ylioja, Jean-michel Molenaar, Jens Dyvik, Jogin Francis, Krisjanis Rijnieks, Srinath Kalbag, Kamau Gachigi, Katie Rast, Luciana Asinari, Luciano Betoldi, Mel King, Nadine Tuhaimer, Namgyal Gyaltshen, Nancy Wu, Norella Coronell, Nuria Robles, Pradnya Shindekar, Quentin Bolsée, Rahul Rajan, Rico Kanthatham, Santi Fuentemilla, Saverio Silli, Sibu Saman, Tomás Díez, Ujjwal Deep Dahal, Vaneza Caycho, and Youka Watanabe are just a sample. The social engineering that makes this possible for them has proved to be more significant than the technological engineering.

What began as an outreach project turned into inreach — more knowledge has come from the network than has gone out to it. The greatest opportunity I see at the intersection of digital communication, computation, and fabrication is tapping our greatest wasted natural resource: the underused brainpower of the planet. That's why the newest projects I'm involved in are building on all of this fab lab infrastructure to create a distributed incubator (distinc.academany.org) and a platform to teach 21st-century vocational skills (futures.academany.org).

For *Make:*'s 40th anniversary it's easy to predict that the "almost" will be dropped from *How to Make (Almost) Anything*, and that the metaphor of "bits to atoms" will become literal. What's harder to predict, but even more exciting to shape, are the seeds being planted today for the future of how we'll live, learn, work, and play.

Triumph of the Makers

THE FUTURE IS HERE

Written by Tim O'Reilly

Twenty years ago, I wrote a column called "News from the Future" for the first issue of *Make:* magazine. I based it on the notion from science-fiction writer William Gibson that "The future is here. It's just not evenly distributed yet." Makers, hackers, hobbyists, and enthusiasts, I argued, are living in a future that we will all one day catch up to. The list of projects from early issues of *Make:* did indeed bring momentous news from the future. Drones, anyone? Ubiquitous wireless networking? Autonomous vehicles? Earth sensing? Biohacking?

Shoebox-sized satellites are now launched by the thousands from reusable launch rockets built by private companies. We increasingly get our internet, and soon, our phone service, from space. Elon Musk, the world's richest man, has built his fortune on hardware innovation. Autonomous taxis are prowling the streets of San Francisco. Ukrainian naval drones have sunk Russian warships and driven their navy from the Black Sea. Homemade drones costing hundreds of dollars, often still assembled by hobbyists, are taking out multi-million-dollar Russian tanks. Artificial intelligences — not just humans — are hungry for new physical and energy infrastructure. Vast new solar and wind farms, and even nuclear — and perhaps fusion — power plants are coming on stream.

In today's news from the future, the need for maker expertise has never been greater. The great challenges of the 21st century — climate change, pandemics, rising energy demands from artificial intelligence, crumbling 20th-century infrastructure, vast geopolitical power shifts, mass migrations, and more — will not be solved by consumer internet applications, or even cutting-edge AI. They require engagement with the physical world. Inside every one of these challenges is an opportunity. But to talk of opportunity and the fever dreams of investors looking for their next big score is to miss the point. The purest explorations of new possibilities don't just come from those looking to profit from them, but from those who are pursuing the new out of curiosity and the sheer joy of exploration.

To those motivations, we must add courage and the urgent spur of necessity. A recent story in the *Kyiv Post* about drone warfare in Ukraine (kyivpost.com/post/44112) highlights how important grassroots makers are to the defense of the country in its war for national survival:

> *"In order to feed the inexhaustible demand for drones, Ukraine churns out hundreds of them every day in shops, garages, mini-factories, and even individual apartments across the country. There is no central planning. ... Civic action groups gather money [for] other civic action groups that build drones. Every once in a while, people decide the best way they can contribute to the war effort is to build some drones themselves."*

I hope that isn't news from a dark future coming to more of the world, but it may well be. In any case, self-sufficiency, the ability to take things apart and put them back together, perhaps in a new way, reusing old devices to solve new problems, building new mechanical and electronic "bodies" to house artificial intelligence or extend human reach and perception — these are going to be essential skills for the future.

So don't listen to people who tell you that the future belongs to kids who learn how to use AI better than their peers. Everyone is going to learn to use AI, just as everyone learns to use a smartphone today. But only some people will also still know how to get their hands dirty.

Make: is your home if you want to be one of those.

Peter Adams / Faces of Open Source

TIM O'REILLY is the founder, CEO, and chairman of O'Reilly Media. Tim gave the go-ahead for Dale Dougherty to develop *Make:* magazine (and Maker Faire) while working at O'Reilly.

MATT STULTZ is head of community for Cocoa Press, a contributing editor of *Make:*, and longtime wrangler of our Digital Fabrication Shootouts.

Loving These Lasers

POWER'S UP, PRICES ARE DOWN — TIME TO ADD A NEW TOOL TO YOUR SHOP!

Written by Matt Stultz

Matt Stultz, Adobe Stock-Juhku

We've often focused our Digital Fabrication issues on 3D printers, but with this year feeling like more of a transition year for the 3D printing industry, we wanted to give a little more focus to another great tool in the digi-fab world: lasers!

In the past, laser cutters and engravers were out of reach for most individual makers, but not any longer. Today, lasers are better, faster, more capable, and of course cheaper than ever before. Depending on your needs, there is a laser out there for you and hopefully this issue of *Make:* will help you add a new tool to your workshop.

Why a Laser?

Why should you get a laser, when you already have a 3D printer?

- **Speed.** They're fast. It's for good reason that in the early days of desktop 3D printing, companies like MakerBot, Ultimaker, and Printrbot turned to lasers for their production. Designs that would take hours to print out with a 3D printer can be designed to be cut out of flat sheets of wood or acrylic and assembled like puzzle pieces in a matter of minutes.
- **Materials selection.** We all have a sensibility about what materials are used in products, and the plastics that 3D printers produce are often perceived as cheap or low quality — whereas materials like wood and glass are seen as luxurious or classic.
- **Marking and customization.** Lasers are a great solution for modifying existing objects and materials. If you want to personalize your oh-so-popular Stanley mug (or Big Dumb Cup as *SNL* put it), then a laser, especially with a rotary attachment, is a perfect option. Wood, glass, plastics, metals, stone, and many other materials can all be etched depending on the type of laser you have.

CO_2, Diodes, or Fiber?

Looking for your first laser? The hardest choice is which type you should purchase. Typically you'll need to choose between ***CO_2***, ***diode***, and ***fiber*** lasers, but each kind has its pluses and minuses to it. Let's try to sort this out as best as we can.

CO_2 LASERS

Think of a CO_2 laser as being something like a neon sign: when energy is applied to gases trapped in a tube, the gas molecules get excited and emit light. CO_2 lasers use a combination of carbon dioxide (hence the name), nitrogen, and helium to produce an infrared light that is focused out the end of the tube. The excitation energy can come from high-voltage direct current (DC), or high-intensity radio frequencies (RF).

CO_2 lasers tend to be large and bulky, requiring a decent amount of climate-controlled space to keep them. They need to be cooled, either by water in the case of DC-excited glass tube lasers, or by air in the case of RF-excited metal tube lasers. Either way, the room can't be too hot because the laser won't stay cool, or too cold because the water might freeze. I've had quite "fun" times helping a friend and neighbor lower a big CO_2 laser into their basement after they discovered their garage wasn't warm enough here in our Maine winters.

If you are looking to cut and engrave a wide range of materials, this is where CO_2 lasers really stand out. Wood, leather, acrylic, rubber, fabrics, foams, paper, and plastics can all be cut with CO_2 lasers, and the same list plus glass, stone, ceramics, and coated metals can be etched (see "What Cuts What?" on page 45).

DIODE LASERS

Diode lasers take advantage of the advancements in solid-state laser technology brought on by media players like Blu-ray drives. While blue laser diodes are the most common, a growing number of machines from companies like xTool and Acmer (Figure A) are now offering lasers with both blue and IR diodes in them, increasing

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the number of materials these machines can cut and etch.

The big advantages of diodes is that their solid-state lasers don't require the same cooling and therefore storage conditions, making them smaller, lighter, and much cheaper. Many of the diode lasers on the market are what we refer to as "open gantry" lasers — typically just a motion system, a controller, and the diode housing with no enclosure. While often the cheapest option, we strongly suggest avoiding these unless you plan on putting them in an enclosure yourself. The risk of stray laser light is not worth the cost savings (see "Don't Fry an Eye" on page 44).

Diode lasers can cut many of the same materials as a CO_2 laser with the exception of light-colored or transparent acrylics that do not absorb the diode's laser light.

Unfortunately the cost savings come with a downside: Most diode lasers are underpowered at 10–20 watts compared to the typical 40W+ of their CO_2 counterparts. Some manufacturers are combating this by stacking multiple diodes together inside the housing to create higher power but this often comes at the cost of an increased spot size, making them less suitable for high-quality etches.

FIBER LASERS

If metals are your target, you want a fiber laser. Fiber lasers derive their light from a doped fiber optic cable where the laser is excited directly inside the fiber.

These lasers are capable of etching metals such as steel, aluminum, copper, brass, gold, silver, and titanium. Deep etchings can be achieved using multiple passes, making incredible, almost 3D creations. Even with lower-power fiber lasers you can cut thin metals, and with multiple passes you might be able to cut thicker sheets — but possibly without the finish you would hope from a laser cut.

The big downside of fiber lasers is that they really are only suitable for metals and fail to cut many other materials (I tried cardboard just to see what would happen and it did literally nothing to the sheet). Prices are dropping and good fiber lasers are now getting within the budget reach of motivated makers.

What About Galvo Lasers?

Galvo (***galvanometer***) refers to the motion system that delivers the laser beam, not the source of the light like a diode or CO_2 laser. Most lasers use an XY gantry like those found on 3D printers or CNC routers. Galvo lasers use wiggling mirrors to direct the light instead, like the lasers used at concerts or planetariums for light shows, so they're even faster — but typically lower power.

Lasers for Makers in 2025

If you're still with me, you're probably considering a laser of your own. Here's what I'm watching in the maker/hobbyist market this year:

GLOWFORGE

In the past your options were to buy an expensive RF laser, import a questionable CO_2 laser from overseas, or buy a Glowforge. Those days are gone. Glowforge unfortunately has proven accurate many users' fears about their cloud-based machine control. They are hiding basic features behind paywalls and even forcing users of their newer machines to subscribe to cut anything more than the most basic model.

THUNDER LASER

Thunder has begun creating significantly lower-cost RF-based CO_2 lasers with their 30W **Bolt** line. While we haven't formally tested them, I've had a little hands-on time with one of their units and have friends who love them. Hopefully in the future I can get more time with one to give my full opinion, but if you're in the market right now, I think a Bolt could be a safe decision (Figure **B**).

AEON LASER

If you need something larger, sometimes getting a big laser into your home can be an issue. Aeon's Mira Pro line of CO_2 lasers offer a great balance between cutting size and still being able to pass through a standard-sized house door. Again, I've had limited time with these but would love to add a **Mira Pro 9** to my arsenal of tools (Figure **C**).

Acmer, Thunder Laser, Aeon Laser, EM-Smart, xTool

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Color marking metal with an EM-Smart fiber laser.

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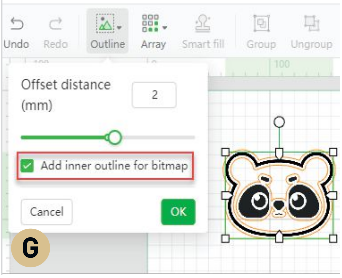

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EM-SMART

EM-Smart (Figure D) is making fiber lasers that are beginning to be affordable to many makers and makerspaces, coming in cheaper than a new 3D printer a few years ago. You can read my review of the **EM-Smart One** on page 126.

XTOOL

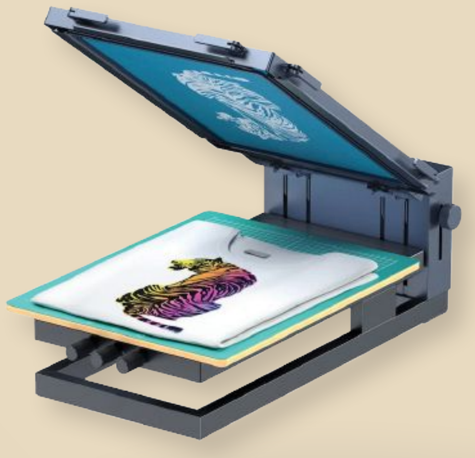
In my opinion the real standout in the industry right now is xTool. They are creating an entire ecosystem of incredible lasers and products that help support them. From their **S1** diode laser cutter (see our review in *Make:* Volume 89, page 123, makezine.com/go/xtool-s1) and **P2** CO_2 laser cutter (reviewed on page 123 of this issue) to their **F1** dual blue and IR diode laser engraver (reviewed on page 124), and everything in between, xTool seems to be looking to build a laser for every need. They're even creating crazy combinations of tools like their **M1 Ultra** that incorporates a diode laser, craft cutter, and inkjet printer all in one. I'm particularly excited about the **F1 Ultra** (Figures E and F) that combines a blue diode and a fiber laser into one galvo-based machine.

The thing that really sets xTool apart, though, is their software. They have created an easy-to-use, high-quality software package called **xTool Creative Space** (Figure G) to control their machines, but unlike a Glowforge, you are not trapped in that ecosystem. Other third-party software packages will still run on xTool's G-code-based machines.

This is just a small sampling of what we're seeing in the laser world right now, and we are excited to see what-all comes next. Follow along as we bring more laser content to you in future issues and at makezine.com.

Laser Silkscreens!

Looking for cool things to do with your laser? xTool's screen printing system replaces the traditional screen making process with a laser-etched screen.



Don't Fry an Eye

PROTECT YOUR VISION FROM LASER TOOLS

Written by Ryan Priore

Thorlabs; OSHA

Thorlabs certified laser safety glasses illustrating the three pieces of OSHA-mandated information:
1. Defined laser wavelengths of intended use;
2. Optical density at defined laser wavelengths;
3. Visible light transmission.

The same powerful laser beams that enable digital fabrication tools also pose significant risks to the eyesight of any living creature in the vicinity of the tool, if proper safety precautions are not employed. Laser radiation, even in small doses, can cause severe and permanent eye damage as well as burns to the skin (Figure A), whether viewed directly or reflected off other surfaces.

When operating a laser, you are responsible for the safety of those around you:

- Make informed laser purchases from **reputable vendors**.
- **Know the classification** of your laser cutter/engraver. Most are Class IV — rated as Severe eye and skin hazard.
- Follow all **engineering and administrative controls** for your laser cutter/engraver. These may include warning signs, laser-blocking enclosures, safety interlocks to prevent operation while the enclosure is open, etc.
- **Know the wavelength** of your laser, for example:
  Blue diode: 455nm
  IR diode: 1,064nm
  CO_2: 10,600nm or 10.6μm
- Protect your eyes by purchasing **certified laser safety glasses** for any Class II or greater laser for everyone potentially in the Nominal Optical Hazard Distance (NOHD). Do not trust inexpensive or included laser safety glasses.
- **Keep rooms brightly lit** to ensure that pupils are not dilated.
- **Do not wear jewelry** while using or servicing the laser.
- **Never look into a laser beam** or specular reflected laser beam.
- **Keep your head above beam height.**

To learn all about laser eye safety, how to calculate the optical hazard distance, how to choose the correct eye protection that meets ANSI standards, and more, refer to my complete article online at makezine.com/go/laser-eye-safety. Safeguard your vision while working with laser tooling so you can unleash your creative potential. Pew, pew, pew!

RYAN PRIORE, PH.D. is a technology manager for Thorlabs based in Wexford, Pennsylvania. He's an experienced spectroscopist, digital fabricator, and a veteran of *Make:*'s original digi-fab shootouts.

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LASER TOOL	SPECTRAL DOMAIN	EYE DAMAGE	SKIN DAMAGE
Diode laser	Visible (400–780nm)	Photochemical and photothermal retinal injury	Photosensitive reactions or skin burn
Fiber laser	Infrared A (780–1,400nm)	Cataract or retinal burn	Skin burn
CO_2 laser	Infrared C (3,000nm–1,000 μm)	Corneal burn	Skin burn

What Cuts What?

THREE LASER TYPES AND WHICH MATERIALS THEY CAN HANDLE

Written by Matt Stultz

One of the most important parts about deciding to purchase a new laser cutter/engraver is knowing what materials that laser can cut and engrave. Here's a basic table to help you decide what will work best for your needs.

Laser Cutting and Engraving Material Compatibility

MATERIAL	BLUE DIODE LASER	CO_2 LASER	FIBER LASER
Wood	Cuts & engraves (thin, up to ~3mm)	Cuts & engraves (thicker cuts, up to ~20mm)	Engraves only
Acrylic (clear)	Cannot cut/engrave	Cuts & engraves	Cannot cut/engrave
Acrylic (colored)	Cuts & engraves (dark colors)	Cuts & engraves	Cannot cut/engrave
Leather	Cuts & engraves (thin)	Cuts & engraves	Engraves only
Fabric/textiles	Cuts & engraves	Cuts & engraves	Cannot cut/engrave
Paper/cardboard	Cuts & engraves	Cuts & engraves	Cannot cut/engrave
Plastics	Engraves some (dark plastics)	Cuts & engraves (depending on type)	Engraves certain types
Transparent plastics	Cannot cut/engrave	Cannot cut; engraves some (requires additives)	Cannot cut/engrave
Stone/slate	Engraves	Engraves	Engraves
Metal (bare)	Cannot cut/engrave	Cannot cut; engraves some (via marking agents)	Cuts thin metals & engraves
Metal (anodized)	Engraves	Engraves	Cuts thin metals & engraves
Metal (coated)	Engraves	Engraves	Cuts thin metals & engraves
Rubber	Engraves	Cuts & engraves	Engraves
Foam	Cuts & engraves (thin)	Cuts & engraves	Cannot cut/engrave
Ceramics	Cannot cut/engrave	Engraves (surface marking)	Engraves (limited marking)
Glass	Cannot cut/engrave	Engraves (frosted effect)	Engraves (via marking agents)

Upping Their Game

HEATED CHAMBERS, TOOL CHANGERS, DUAL EXTRUDERS — FILAMENT 3D PRINTERS ARE INNOVATING, SPARKED BY COMPETITION AND BY THE OPEN SOURCE COMMUNITY

Written by Chris Yohe

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CHRIS YOHE is a CTO by day, digi-fab daemon by night, *Make:* Digi-Fab Shootout alum, and 3DPPGH co-founder in Pittsburgh, Pennsylvania. A city set on a hill cannot be hidden — let your light shine!

Adobe Stock–Juhku, printer photos courtesy of manufacturers

Our first 3D printer shootout, comparing 15 machines in 2012, headlined the *Make: Ultimate Guide to 3D Printing*.

When *Make:* started its original 3D Printer Shootout in 2012, the landscape was drastically different. A Digital Fabrication issue like this one, including laser cutters and CNCs, wasn't even a thought! We were focused on the tiny, emerging market of affordable 3D printers.

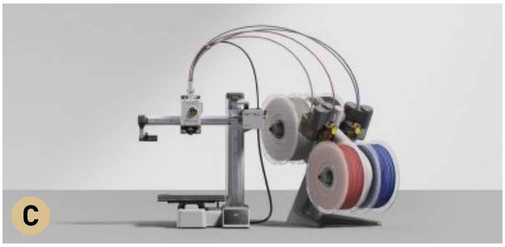
Since then we've seen enormous growth and waves of change, and the latest may be the biggest yet. When Bambu surged onto the market in 2022 a sea change began in desktop 3D printing — call it the 3D printer shakeout. As the market continues to shift to keep up, we both marvel at the possibilities in the present and wonder who is next.

The Rise of Bambu

Bambu Lab launched in 2022 with an incredibly successful Kickstarter for their **X1** printer (Figure A), but the most impressive thing was that they delivered! While failed digi-fab Kickstarter campaigns are littered around the internet like filament scraps from multicolored prints, Bambu gave the public what they promised and the public was ready and waiting. By looking at what the open source community was doing, and packaging it in an incredibly user-friendly package, they had a hit. Finally, here was a machine that nailed the 3D printing experience, not just for seasoned veterans but for uncles, aunts, grandparents, and kids of almost all ages.

On top of a quick and easy setup, the real magic was the **Automatic Material System (AMS)**. While multi-filament printers had been on the market for a decade, this was one of the first for non-experimenters, especially at a consumer-friendly price point. Bambu took multi-extrusion and the speedy Core-XY motion system that had become all the rage, and married them in a single sleek box that anyone could use for a price most could afford. The question was what would come next?

As we've seen, Bambu continues to give the people turnkey printers, and at even more attractive prices, first with the launch of the **P1P** — a more affordable, smaller Core-XY machine — followed by the fully enclosed and slightly sleeker **P1S**. Next came the **A1** (Figure B) and **A1 Mini** (Figure C), incredibly affordable printers that rival anything in their price class, especially with the level of form and finish they provide, and the same dependable user experience and software that users came to expect from Bambu.



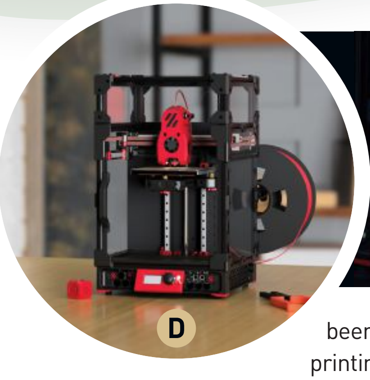
Completing the package, Bambu's cloud offering allows you to easily send prints to your printers from anywhere, and their model repository ensures that you never have to look far for ideas. Bambu truly became the Easy Button of 3D printing — to this day it's an easy recommendation for someone looking for a simple way to get started printing.

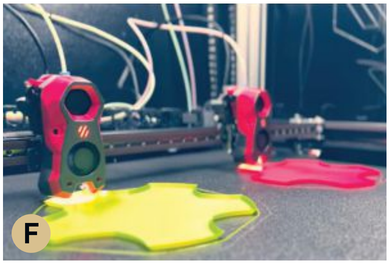
DEEPER DIVE

- **X1 Carbon review:** *Make:* Volume 87, page 122, makezine.com/go/bambu-x1c
- **A1 review:** Volume 88, page 125, makezine.com/go/bambu-a1
- **A1 Mini review:** Volume 89, page 122, makezine.com/go/bambu-a1-mini

Open Source Innovators

But while Bambu has invigorated a wide swath of the market, they're not the only option — far from it. Look no further than where they took inspiration: the open source community that has





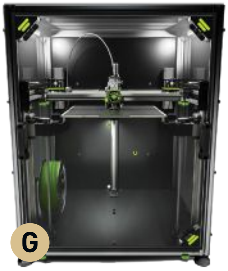
been the lifeblood of the 3D printing hobby for two decades now. While some love their sleek, sterile, injection-molded stylings, the world is still ripe with homemade, industrial, hand-crafted designs — and even these are way ahead in aesthetics compared to their counterparts of a few years back.

Certainly one of Bambu's inspirations was the fervor for Core-XY printers, and no community exemplified that zest more than the **Voron Design** crew. While Bambu was proprietary from the get-go, Voron has open source in their soul, blazing through their 8th anniversary this year. Helping to bring many crowd favorite printers to the masses, from the **V0** (Figure D) to the **Trident** (Figure E), they've grown into one of the main names you hear in 3D printing, no small feat for a small group of engineers looking to just share their ideas with the world. While we wait anxiously for the new large-format **Phoenix**, their first ***independent dual extruder (IDEX)*** printer (Figure F), to appear later this year, they also have other new additions: a fresh version of their **ERCF** multi-material system came hopping onto the scene in 2024, and they've even announced the **Cascade**, a new CNC mill.

DEEPER DIVE

- **Interview with Voron creator Maks Zolin:** makezine.com/go/story-of-voron

Rat Rig also has years of experience bringing clever open source designs to hardcore home users. They too have updated their lineup, coming forth with their **V-Core 4** (Figure G), supporting not only Core-XY but also hybrid and IDEX modes in a wide range of customizable sizes. Rat Rig has a new mill on the way as well, as they also seem keen to expand beyond 3D printing. This seems to be a recurring theme; good or bad, at least it's in capable hands in these camps.



Prusa Ups the Ante

Prusa Research is a rock-solid mainstay that has continued to strive to improve 3D printing with seemingly endless iterative improvements, large and small. The **Prusa XL** (Figure H) certainly earned that large moniker, as one of the first large-format ***tool changers*** — machines with swappable extruders — delivered for regular end users and not just as a niche experimental setup. With numerous improvements in firmware and a few subtle hardware tweaks, the XL has grown into a formidable multi-material, large-format workhorse. The **MK4** (Figure I) has grown

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alongside it, with continued improvements, which we got a chance to test drive with the **MK4S** — see our review on page 122 of this issue.

DEEPER DIVE

- **Prusa XL review:** *Make:* Volume 88, page 124, makezine.com/go/prusa-xl
- **Prusa MK4 review:** Volume 86, page 122, makezine.com/go/prusa-mk4

While Prusa continues to show that they too have a few tricks up their sleeve, recent years have heard a growing call to replace the aging i3 platform the MK4 machines are based on. With the XL we got a peek, and with the **Core One** (Figure J) we have the answer. One of the first hobbyist machines launching with a true ***temperature-controlled chamber,*** the Core One is the Core-XY machine we've been expecting from Prusa since the rise of Voron. Taking the Nextruder and advancements in software, firmware, and print profiles honed judiciously in the past few years, the rigid and enclosed Core One boasts a larger print volume than the MK4 with plenty of sleek, catchy eye candy.

The only thing it doesn't seem to have is the trusty open source label. With the entrance of the Core One we see the exit of open source hardware for this particular model, although when dealing with the complex, tight-tolerance CoreXY assemblies you see in this model that's almost to be expected.

On a positive note, the software and firmware remain open source, and the machine itself, like other Prusas, is hackable and moddable — it's even available as an upgrade path from the MK4S. Sold assembled or in kit format, this machine will go head to head with Bambu's flagships and will try and up the ante as it releases into the wild in Q1. It's exciting to see new designs coming out of the old standard and we look forward to seeing the results in the wild.

Coming in Hot!

The Core One from Prusa wasn't released in time to review in this issue, but it's not the only new hotness. **Bambu** is being tight-lipped about their upcoming offerings — a rumored **H2D** heated-chamber dual-extruder printer and **AMS 2 Pro** multi-material module — that we hope to know more about by the time this issue hits the newsstands. Stay tuned to makezine.com for more updates from Bambu, Prusa, and others.

Adobe Stock-Juhku, printer photos courtesy of manufacturers


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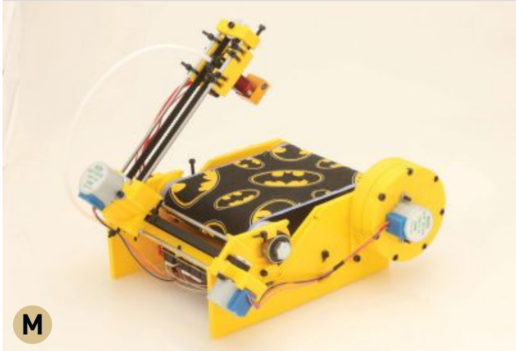
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Old Reliables

All the while, the old standards keep chugging along and releasing new machines. While you may not hear their name as much, **Creality** is still cranking out functional printers: their **K1C** enclosed Core-XY is perfectly serviceable, and the **K2** (Figure K) with its multi-material capabilities shares the sleek sensibilities we've seen elsewhere. Certainly if imitation is the sincerest form of flattery, Creality has been flattering a lot of folks, and to great reward. Don't forget **Ender** either. They continue to update and release new models as well.

Similarly, **Sovol** and other value brands continue to update and release new machines. Certainly these can be perfectly fine printers but nothing here is truly moving the needle at the moment. How long till they too release heated-chamber models? 2025 will tell!

DEEPER DIVE

- **K1C review:** *Make:* Volume 89, page 123, makezine.com/go/creality-k1c

Fun New Flavors

One thing that is moving that needle is the creativity of our great community. From the fun and portable **Positron** (Figure L) printing upside down, to the neverending **Baby Belt** (Figure M) printing to infinity, and even the delicious **Cocoa Press** (Figure N) printing chocolate (see page 52), there's no stopping the variety this community will create. We don't have room here to cover all these bright spots of inspiration and amusement (though we will tell you about the man who's bringing many of them to you in kit form — Jason from LDO Motors — on the following page), but you will see more of them in the future!

DEEPER DIVE

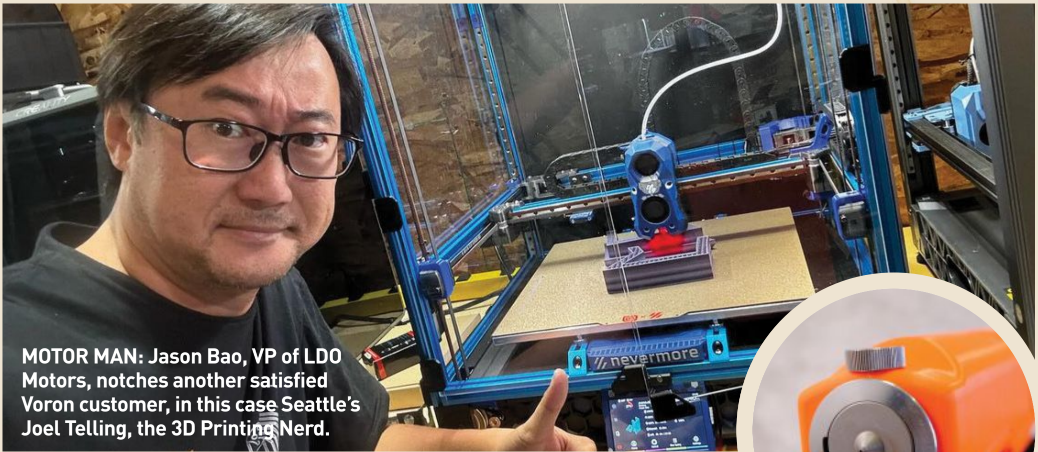
- **Interview with Cocoa Press creator Ellie Weinstein:** turn to page 52 of this issue
- **Interview with Baby Belt creator Rob Mink:** youtu.be/6IQrY-1wsfU

Adobe Stock–Juhku, printer photos courtesy of manufacturers

LDO Inside!

THE SECRET SAUCE FOR INNOVATIVE 3D PRINTERS, CNCS, AND KITS

Written by Matt Stultz



Jason Bao

MOTOR MAN: Jason Bao, VP of LDO Motors, notches another satisfied Voron customer, in this case Seattle's Joel Telling, the 3D Printing Nerd.

HOT COCOA: Custom chocolate-extruding hot end parts are produced by LDO for Cocoa Press.

What do Voron, Cocoa Press, Positron, Millennium Machines, LulzBot, Formlabs, and Prusa all have in common? They all use the same supplier to help bring their machines to market: LDO Motors.

Finding all the parts you need to build a 3D printer can be a trick, but finding enough to bring that printer to market can be a nightmare. LDO manufactures motors and other components for digital fabrication machines, and if they don't have a part that's needed, they'll help find a manufacturer or supplier who does. LDO's team becomes your own private shoppers to the magical world of the Shenzhen electronics markets. This helps small companies get access to parts and processes that would be hard to muster without sending team members to China.

A great example of the power of this approach is the Voron project. Voron is a team of designers working together to bring open source 3D printers to market. They've become the favorites of the builder community over the past few years. But Voron doesn't manufacture or sell anything! Instead, Voron licenses LDO to create kits based on Voron designs and offer those kits for sale through resellers. The Voron team never touches these kits — all sourcing and manufacturing is handled solely by LDO.

Cocoa Press, where I work, has some unique components that can't just be purchased off the shelf. That's not a problem for LDO; with just an email of CAD drawings, the LDO team arranges for those custom parts to be machined.

So how did LDO find themselves as the go-to supplier for desktop digital fabrication companies?

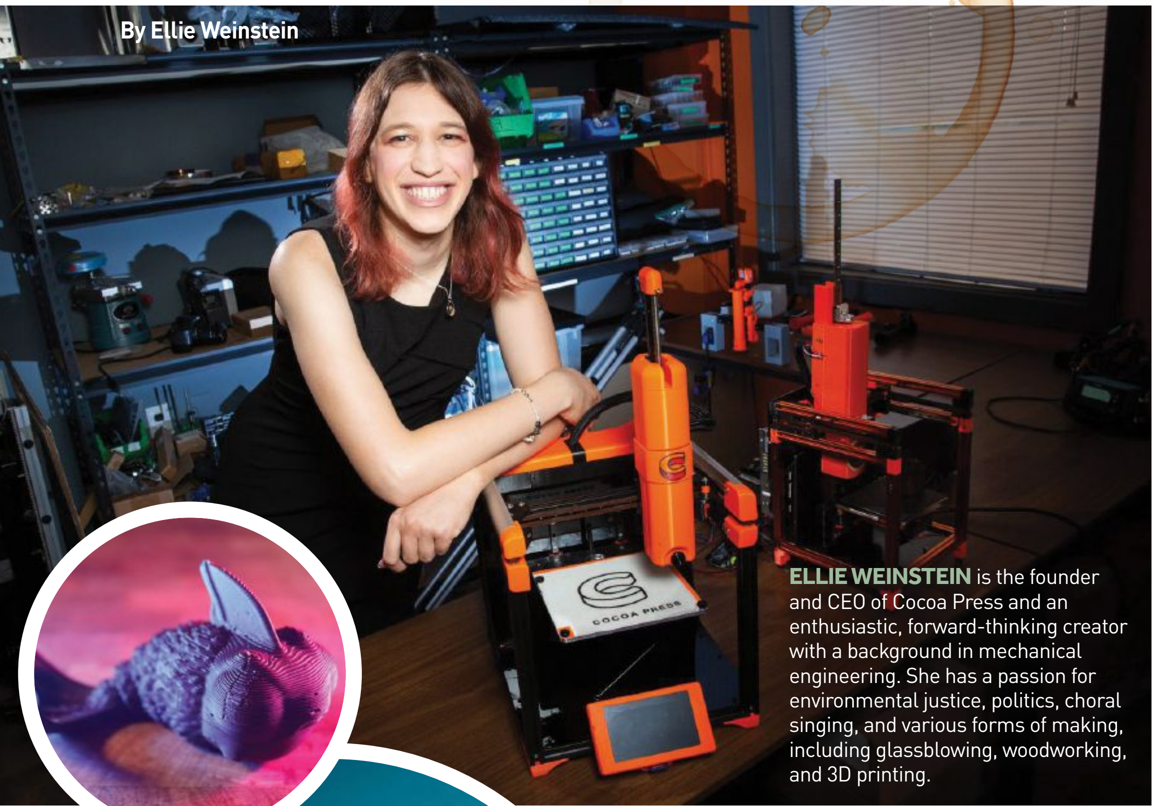
For years, attendees to RepRap fests have found themselves in front of a table covered in a variety of motors, staring into the smiling face of Jason Bao, VP of LDO Motors. Jason has always been happy to answer questions and engage with the community, sharing his knowledge along the way. While the rest of the LDO team is back in Shenzhen, Jason lives in Southern California so he can easily interact with American makers and break down the language barrier that often comes with working with foreign suppliers.

The next time you go to fire up your favorite printer, take a look at the motors. You may find that you are part of the LDO club too.

10 Years On:

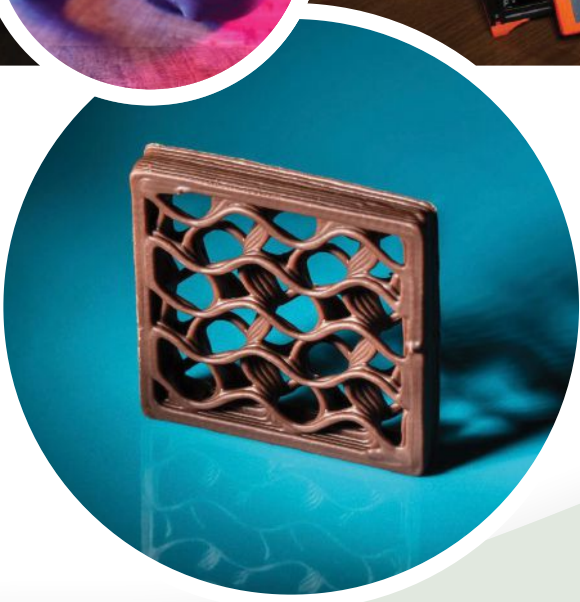
CREATING A 3D PRINTER THAT PRINTS CHOCOLATE

By Ellie Weinstein



ELLIE WEINSTEIN is the founder and CEO of Cocoa Press and an enthusiastic, forward-thinking creator with a background in mechanical engineering. She has a passion for environmental justice, politics, choral singing, and various forms of making, including glassblowing, woodworking, and 3D printing.

Leslie Barbaro/Penn Engineering, Cocoa Press



Developing a 3D printer that prints chocolate was an idea Ellie Weinstein had in high school, and she worked on various prototypes while at Penn studying mechanical engineering. After graduating, Ellie decided to turn her prototype into a manufacturable product and start Cocoa Press as a company. —Dale Dougherty

I launched the first Cocoa Press printer in the fall of 2020 and it was just an absolute failure from every perspective — everything from the product not working well, shipping being difficult, having to raise the price, etc. Just a bad product/market fit overall. That was one of several times that Cocoa Press almost shut down.

I said, "Let's become our own customer." We spent the next year and a half selling chocolate and sold tens of thousands of dollars of custom chocolate. I realized where 3D printing really makes sense. I had some chocolate equipment that I used to make blank bars and then we'd 3D print text on top of them. Ninety second print. I sold thousands and thousands of personalized chocolate bars. However, I didn't want to be a chocolate shop. I wanted to do the hardware because that's what I'm interested in. I wasn't interested in running a company that didn't interest me.

I looked at all of the 3D printers out there and decided to work with an existing manufacturer and just add our own extruder. The gantry system on our printer worked badly and what worked well were the chocolate-making parts. I found a 3D printer company and started working with them but they folded. Then I checked out the Voron printer — an open source 3D printing group. I loved the V0, the small printer. We made a prototype using a V0, brought it to the Midwest RepRap Festival, and met the team. Afterwards, I got an email from Maks Zolin, the founder of the Voron project, and he said, "Hey, let's make your printer, but good." Unfortunately he came down with Covid-19 from that event, but he had the most productive Covid you've ever seen anyone have. He just redesigned the whole machine, which became the printer we started selling last year. I'm forever grateful for Maks.

We worked with LDO [Motors] who had made some parts for the original printer, but really saved us by making a custom extruder motor. We moved from air pressure back to a stepper motor-driven system. That was a huge game changer. LDO made about 75 percent of the parts for our kits. They would send the boxes to us and we would put in the rest of the other stuff at our office.

When I launched the kit for pre-sale, I was hoping for 50 pre-orders in the first two weeks. I got 50 in the first 24 hours, and I hit a hundred. At that point, I finally felt confident enough to hire someone to help me.

We started shipping in October 2023. Suddenly we had to figure out how to make enough chocolate here. I wanted to outsource it, but chocolate shops are not used to making

cylindrical, air bubble-free, seam-free chocolates, with very high tolerances because they're used in our system almost as a mechanical seal. The printer comes with 20 of our Cocoa Cores.

We started shipping machines and the coolest part was — I made the machine but I didn't know what it could do. People have figured out how to do manual color swaps to do multicolor things, which we're now making easier with our new machine. Someone bought it for their wedding to make their own wedding favors because it was going to be cheaper than [buying] wedding favors, and then they had a chocolate printer at the end of it.

From the outside, it looked almost like Cocoa Press was an overnight success but I've worked on it for a decade now, and also it's always looked like it was going well from the outside. That was something I always struggled with. How do I be optimistic, but also be genuine? It wasn't going well a lot of the time.

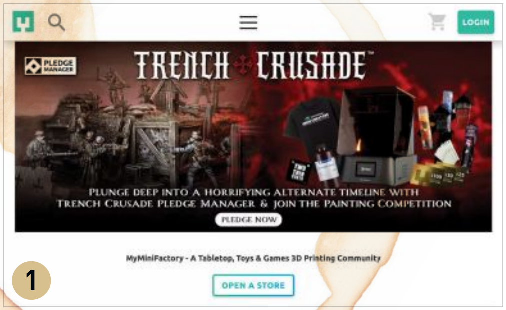
I almost feel like we operate somewhere between the startup and the small business model. I'm not trying to grow to be 100 people. I'm not looking for VC money anymore. I just want this to be able to sustain itself, and grow a little bit, for sure. I am really excited about shipping Cocoa Press 2 in 2025.

This article is excerpted from a longer conversation between Ellie Weinstein and Dale Dougherty. Enjoy it online at makezine.com/go/3d-printing-chocolate.

Sharing Is Caring

ONCE FREE, 3D FILE SHARING SITES NOW HELP DESIGNERS GET PAID

Written by Matt Stultz



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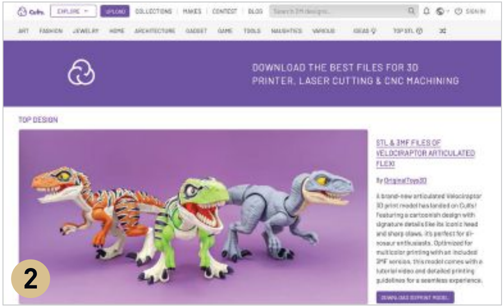

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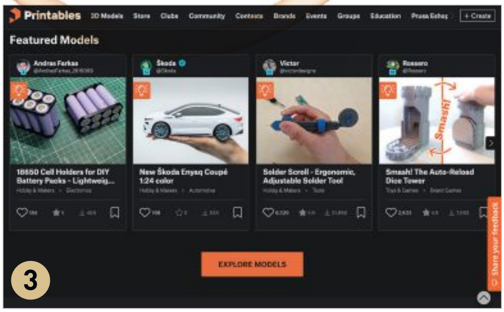

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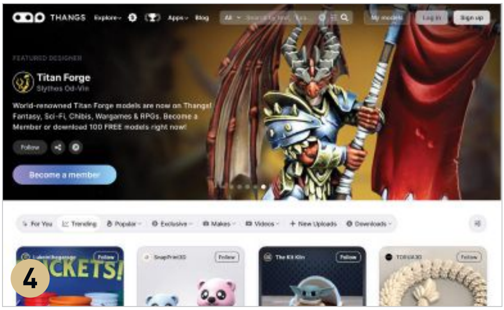

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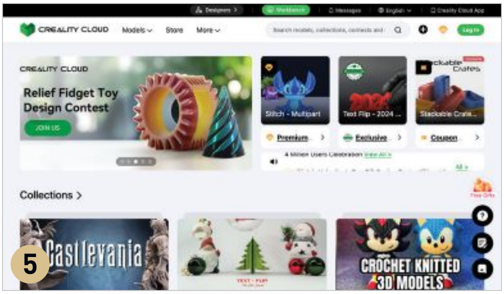

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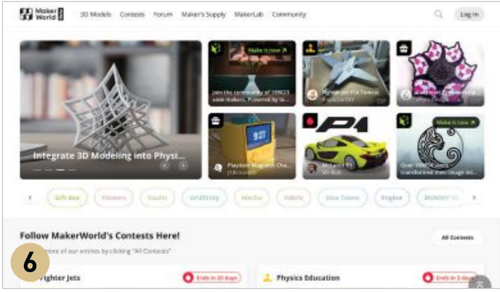

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In 2008, Zach "Hoeken" Smith decided he needed a better way to share digital files with his fellow NYC Resistor hackerspace members and other friends, for use with their laser cutter, CNC machines, and brand new RepRap 3D printers. So Zach created **Thingiverse**, and when he cofounded MakerBot with fellow NYC Resistor members Adam Mayer and Bre Pettis the following year, Thingiverse was folded into the company, eventually focusing almost solely on 3D printing files. Thingiverse grew quickly, with the community contributing millions of free and open designs, giving back to the open source ethos that permeated the early days of 3D printing.

Ten years later though, Thingiverse had fallen into a state of disrepair, opening a door for other sites to come into the market — and oh, how they have come.

(Full disclosure before I continue: I worked on Thingiverse as a developer from 2011–2012 and then on the Prusa team helping build up Printables from 2019–2023.)

Pioneers of Paid

MyMiniFactory (Figure 1) and **Cults3D** (Figure 2) launched in 2013 and 2014 respectively. MyMiniFactory quickly found a following with the tabletop gaming miniatures market, allowing those seeking minifigs for their next *D&D* campaign to cut through the clutter that was becoming Thingiverse. Cults found another way to set themselves apart: They offered paid models.

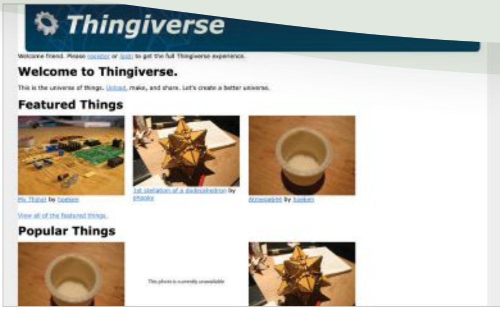
In the early days of desktop 3D printing, you had two options: build a RepRap printer from parts you obtained yourself, or buy an open source kit for a machine like an Ultimaker or a MakerBot Cupcake. Many of the files being uploaded to sharing sites were modifications for the printers themselves, and companies often relied on the user base to help them figure out how to do it better. File sharing was seen as giving back to the open source community.

This culture of sharing fueled the hobbyists who were excited to see their work adopted by the community, but made it hard for professional designers to find a home for their work. Cults opening up sales finally gave designers a place to monetize their models while still connecting to the 3D printing community, and by 2018, MyMiniFactory had joined Cults in selling models.

The New Crowd

The last 5 years have seen an explosion of new file sharing platforms, starting with the launch of **Printables** (Figure 3), known as PrusaPrints from 2019–2022, then **Thangs** (Figure 4), **Creality Cloud** (Figure 5), and **MakerWorld** (Figure 6) from Bambu — with only Thangs being independent from a manufacturer of 3D printers. (As I wrote this article, Thangs was acquired by Shapeways to host their community platform.) While Printables and Thangs started out as entirely free, they too, along with Creality Cloud and MakerWorld, joined the crowd of sites that offered paid models.

There are two primary ways that these sites are selling models: pay for each model as you go, or buy a membership/subscription. Patreon has been a popular way for designers to share their work, but with its changing fees and policies, the "patron" model was ripe to find a new home that



Thingiverse in 2008.

Thingiverse in 2025.

fit file sharing better. Now Printables (with Clubs) and MyMiniFactory (with Tribes) both offer the option to subscribe to your favorite designer to receive access to their exclusive models.

To keep it interesting, the king and original file sharing site is making a comeback. With the merger of MakerBot and UltiMaker, Thingiverse is getting new upgrades and maintenance. They still have the largest collection of models and the name recognition; time will tell if the updates have come too late to keep them on top.

Where to Upload?

So where should you share? Depends what you're looking to get out of it. If you want to make some extra cash, Cults and MyMiniFactory are probably your best bets as they're the most clear on model sales. If you're looking to simply share your files, Thingiverse and Printables are good choices with large audiences. If you own a Creality or Bambu, or are creating files specifically for those printers, then their sites likely make the most sense.

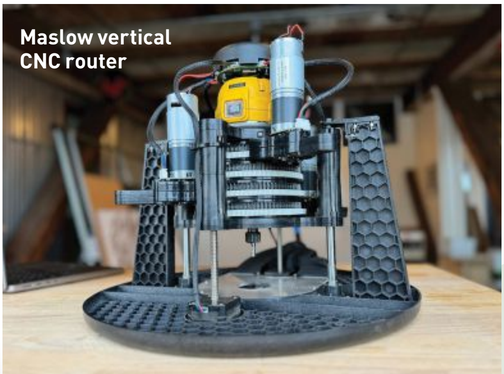
The debate arises, though: How do we balance the sharing spirit of the desktop 3D printing community with benefiting model creators for their work? I believe the best answer has yet to be found. What do you think? We'd love to hear from you at makezine.com/go/discord.

Carving New Paths

NEW AND NOTABLE CNC GEAR WE'RE EXCITED ABOUT FOR 2025

Written by Matt Stultz

Matt Stultz



Maslow vertical CNC router

Browsing this issue you'll read all about 3D printers and lasers that are the darlings of the maker world. Personally though, my favorite tool in my collection is my CNC router.

CNC means Computer Numerical Control, so technically a 3D printer or laser cutter is a CNC machine too — but typically when we talk about CNCs, we're talking about two tools. A ***CNC router*** is typically designed for cutting materials like wood and plastic; some even use the same hand routers attached to them that a woodworker would use to say, add a roundover to a board. A ***CNC mill*** is typically designed for cutting harder materials like metals; they tend to be more rigidly constructed but have smaller working areas.

While last year was slow for releases of CNC gear, there are a few exceptions we're excited about in 2025.

Maslow Vertical CNC Router

maslowcnc.com

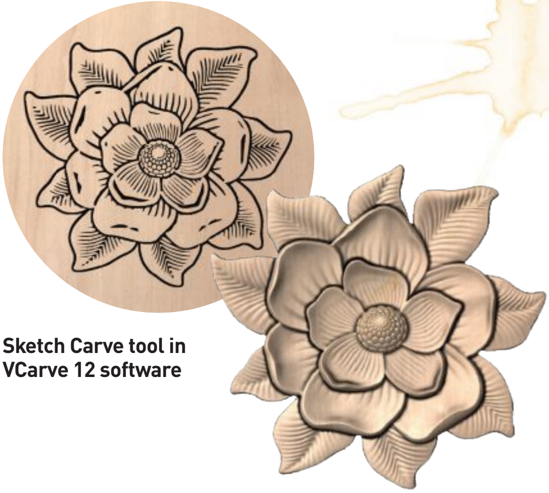
Maslow has a unique approach to dealing with the largest problem with CNC routers: the large amount of space they take up in your workshop! With most CNC routers, if you want to cut parts out of a full 4'×8' sheet of plywood, you need a machine that's around 5'×10' — practically the size of a car in your garage. Maslow flips the machine on its side with the router dangling down, so you can place it against a wall, taking only a few feet of space into the room. We caught up with the Maslow team at Maker Faire Bay Area where they showed off exciting changes they'd brought to the **Maslow 4**, then they gave us one more surprise — a Kickstarter for a new improved **Maslow 4.1**. It's still in production — we'll get one for review as soon as possible.


Milo V1.5 desktop CNC mill

Milo V1.5 Desktop CNC Mill

millennium-machines.com

A good, sturdy desktop-sized CNC mill is hard to come by, and they're usually made from heavy cast materials to make them rigid. Millennium Machines took a few pages from the Voron playbook and created the **Millennium Mill**, which LDO Motors then turned into the **Milo kit** (docs.ldomotors.com/en/milo/cncresellers). The Milo uses aluminum extrusion for rigidity, and 3D-printed parts to bring the whole thing together. Old-school machinists may scoff at the idea of a CNC mill that uses 3D-printed parts but the initial reviews show this to be a very functional machine. This kit is quite the build, so if you need a mill to get work done right away, this likely isn't your best option. But if you want to really get to know how your CNC works, building a Milo could be a fun experience. We have a kit in hand; watch for our review up soon at makezine.com.


Sketch Carve tool in VCarve 12 software

VCarve 12 CAM Software

vectric.com/products/vcarve

I think the most exciting new thing in the CNC world isn't a machine at all — it's software. When preparing a job to be cut on your CNC machine, you need to convert your design into the G-code instructions the machine understands, using CAM software like the popular VCarve family. Vectric released **VCarve 12** in mid-2024 and it brings some really amazing new functionality. There are two features I'm most excited about:

The **Sketch Carve tool** allows you to take a 2D image or 3D model, and with just a couple clicks create a detailed V-bit carving. This process used to require lots of time to create vector art that would even begin to work right, and to manually set up the job to create the carving. Now with VCarve 12, you can simply import a JPG or PNG image, autotrace it with the tool, and your carve is set up. Expect to see a boom of CNC artwork on sites like Etsy!

The new **Inlay tool** takes the popular process of inlaying a contrasting color of wood into a carving to make it stand out, and halves the work needed to set up the job while also improving the quality of the final output. In the past, you needed to set up a V-bit job to cut out the pocket for the inlay and a separate job to cut out the material that will go into that pocket. If you didn't set up both jobs perfectly, your inlay wouldn't fit. The new Inlay tool in VCarve 12 sets up both jobs at once, with perfect tolerances.

If you picked up a CNC this year, share your projects with us on Instagram @makemagazine!

Get Your Bearings

BUILD A HANDHELD CNC ROUTER THAT AUTOMATICALLY KEEPS YOUR CUTS ON TRACK

Written by Cameron Chaney

Cameron Chaney

CAMERON CHANEY is a mechanical engineer, tinkerer, and maker of things. He is particularly intrigued by human-robotic interaction, and surfing.

Compass is a DIY handheld CNC router designed to make CNC machining more accessible. Unlike traditional CNCs that move a cutting tool within a fixed workspace, Compass relies on you to guide the device around your workpiece. As you move it, it automatically adjusts the cutting tool to stay on the programmed design path, enabling accurate, large-scale cuts with a much smaller device.

This is all accomplished using optical flow mouse sensors to track the position of the device, and a leadscrew-driven gantry to adjust the tool. The brains are a Teensy 4.1 microcontroller.

Why a Handheld CNC?

The concept of a handheld CNC machine may seem a little backwards at first. CNC machines are big hunks of metal and motors, with spinning blades to cut things with. How and why would I ever put one of these into my hands?

When you think about it, though, it makes sense. CNC is a technology that helps you bring a design in your head to life in the real world, with the help of a computer to automate the fabrication. This is awesome — until you realize that a standard entry-level CNC machine can cost thousands of dollars and take up an entire room. This leaves many of us enthusiastic makers to rely on more traditional methods of shaping wood and metal, using cheaper hand tools like jigsaws and handheld routers. These are affordable, small, and portable, but they require a lifetime of learned skills and expertise — and usually stable hands — to bring an idea to reality.

A handheld CNC combines the computer precision of CNC technology with the flexibility and cost of standard hand tools. You control it like you would a standard handheld router, moving it roughly along your design, but now it's able to auto-correct to cut your design perfectly. Using the same workflow to get a design from computer to CNC machine, you simply upload your toolpath, set your origin on your workpiece, and move the device where it tells you to. The UI screen on the front of the device will show you exactly where to move the router, and alert you if you're going too far off track. Compass does the rest, leaving you with a beautiful cut and a sleek CNC machine that can fit in your suitcase or on your shelf.

TIME REQUIRED: A Few Weekends

DIFFICULTY: Moderate/Difficult

COST: $500–$700

MATERIALS:

- **Dremel 3000 rotary tool**
- **Optical flow mouse sensors, PMW3360 (4)** with lenses
- **Teensy 4.1 microcontroller**
- **Stepper motors, NEMA 17 (2)** Amazon B0B93HTR87
- **Stepper driver boardss (2)** BigTreeTech TMC2209 V1.3
- **Compass motherboard PCB** see the GitHub repo at github.com/camchaney/handheld-cnc
- **Compass sensor PCBs (4)** see GitHub repo
- **Leadscrews, 8mm (2)** cut from 300mm stock
- **Leadscrew nuts, 8mm (4)**
- **Flex couplers (2)**
- **Linear bearings (10)**
- **Pillow bearings (2)**
- **Smooth rods, 8mm (2)** cut from 600mm stock
- **Power supply, 24V**
- **Locking LED power button, 24V**
- **Rotary encoder/pushbutton** with knob
- **UI screen, Waveshare 1.28" round color LCD**
- **Momentary pushbuttons, 16mm, 3A 250V (2)**
- **Limit switches (2)** for endstops
- **Aluminum sheet, ¼" thick** for the base plate
- **3D-printed parts** for frame, handles, Z carriage, Dremel mount, etc. See GitHub repo.
- **Various cables, header pins, wire, nuts, bolts, etc.**

TOOLS:

- **3D printer**
- **Soldering iron and solder**
- **Allen wrenches: 1.5mm, 2.5mm, and 6mm**
- **Screwdriver**
- **Deburring tool**
- **Thread taps: M3 and M8**

Origin of Compass

Makers and making — having some vessel for unleashing my creativity, working with my hands — have been a big part of my life, from making skateboards with my dad in my garage when I was 8 to practically living in the makerspace for four years at my university. I created Compass because I wanted to make a device that could lower the barrier to entry to making, and give more people this channel to unleash their creativity.

3D printing and CNC machining are great, but they can feel very foreign to people who aren't

A

already familiar with engineering, computers, and electronics. There's a disconnect between the user and what they're creating. These are amazing technologies that allow you to push a button and have your creation made before you, but you can lose the "maker" in the process. There's nothing tangible to grasp onto and feel like, "I'm making something right now!"

Handheld CNC routers bring this tangible interface back to digital fabrication, allowing the user to really feel like they're a part of the fabrication process while also lowering the barrier to entry of woodworking. People with shaky hands, or a condition like Parkinson's, don't have to count themselves out from creating beautiful handmade things.

My goal with Compass is to make CNC machining more accessible to woodworkers, and make woodworking more accessible to everyone. I found a piece of my identity in discovering makerspaces, digital fabrication, and woodworking tools. I want to help others experience that same sense of belonging, creativity, and freedom.

Where Am I? Solving for XY

The hardest part of this project by far was figuring out how to get the robot to know where it is. I brainstormed a ton of different ways to do it — including string potentiometers, ToF beacons, cameras, following a drawn line, or even driving itself around on wheels — but decided on using the same technology that a computer mouse uses to track its movement in space. This was the simplest solution and the cheapest to implement. No setup required, no external beacons, and the user still plays a part in the movement of the device.

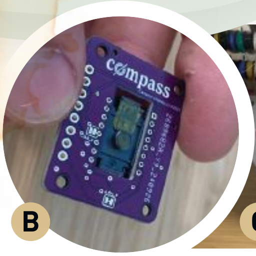
I spent the next month or so dissecting a bunch of mice, figuring out how to connect them to my microcontroller and get readings from them (Figure A). Once I verified that this would work, I found a breakout PCB for a nice gaming mouse sensor, ordered four of those, and started the challenge of how to transform all that data to a position and orientation estimate of the router. Luckily I had taken a class in ***rigid body kinematics*** the year before, which was exactly what I needed to do this.

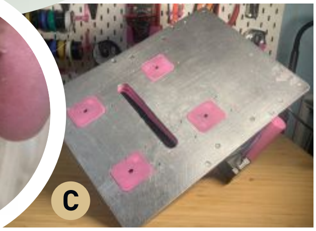
Once I got the sensing working, I constructed the device and went to test it with a pen instead of a cutting spindle. This definitely did not work on the first try! I finally got it to draw just a simple straight line, and I was elated. Once I actually used it to cut something, the feeling was euphoric. It was just a little sine wave in corkboard, but the feeling of having this robot moving and reacting to my motion, while the Dremel was spinning at 35,000rpm to cut the material and make my design, was really second to none.

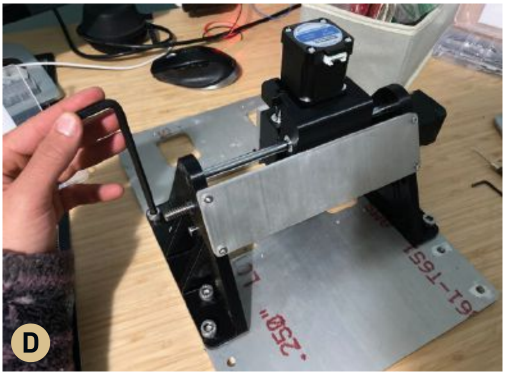
Four Eyes Good

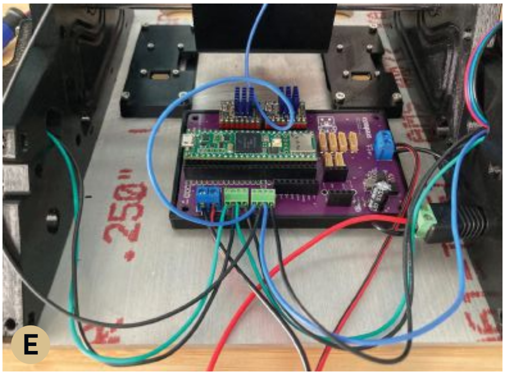
The crux of this project is how Compass figures out where it is on the workpiece, by using four optical flow sensors (Figure B) on the bottom of the device (Figure C). These are small cameras which constantly watch the surface and detect whether it moves or not, and by how much. A computer mouse has one sensor; by adding a second sensor, we're able to detect rotation as well. Using simple rigid body dynamics, we can estimate precisely where Compass is in space and how it's oriented. Using four sensors gives us multiple ways to calculate these position-orientation values, making the system more robust by adding redundancy and error correction.

This sensing technology accomplishes the same concept as Shaper's Origin router, without the need for computer vision or proprietary fiducial tape. You just set Compass down on your workpiece and you're good to go, with no setup or









Cameron Chaney, Keith Hammond

workpiece mapping needed.

Each of these sensing methods have their benefits and drawbacks. Shaper's technology is absolute positioning, whereas Compass' is relative. This means that with Compass, over a long enough run, the sensor readings will begin to drift. This can be problematic for big cuts if not prepared properly, but there are a few ways to counteract it. Drift is minimized by the aforementioned redundancy of sensors, as well as by using top-of-the-line, high-precision, highly sensitive gaming mouse sensors. To reduce error stack-up, we start off with as accurate a reading as possible for each time step. We can also predict, based on surface quality readings, how soon the drift will exceed a desired threshold. This can be used to prompt the user to simply re-home the device after long intervals, pausing the cut when necessary and keeping track of where to resume the design from. A simple 3D-printed corner bracket does the trick for device homing.

Build Your Own

Most of the physical components of Compass are 3D printed to ease manufacturing and to allow DIYers to build their own more easily. Assembling your own handheld CNC router is pretty simple. Once you have all the parts, it's like an adult Lego set: all the pieces come together with three Allen wrenches, a screwdriver, and minimal soldering. (I hope to make it "no soldering" with new PCBs.)

You build the spindle mount first, plopping in the linear bearings, leadscrews, smooth rods, and stepper motor. Then everything else mounts to the aluminum base, with the spindle mount sliding nicely onto the X axis' smooth rod gantry (Figure D). A few more screws for the motors, sensors, and handles, and then all that's left is to route the wires, which all snap in with connectors or go into screw terminals (Figure E). Once assembled, the device needs to go through a simple calibration and then you're good to go!

Open Source

All the designs and firmware for this project are open sourced, so anyone can make a Compass and modify it as they see fit. If you want to put a laser on it, be my guest! Go online to github.com/camchaney/handheld-cnc for the full build instructions, code, 3D files, and BOM. Make your own for about $500, or buy a kit from my website compassrouter.com/make for a little more, and get CNC technology in your hands.

Upcycle a Printer

TRANSFORM THAT OLD 3D PRINTER INTO A COOL NEW CNC TOOL

Written by Dom Dominici

Another year, another new 3D printer in the workshop. Maybe you got a fancy new one for Christmas or just couldn't pass up a smoking deal. Now you have an extra printer collecting dust. It's slow and the print quality is lacking, so what can you do with it? Why not try one of these awesome project ideas and turn your outdated 3D printer into a whole new tool for your collection!

Recreator3D Filament Maker

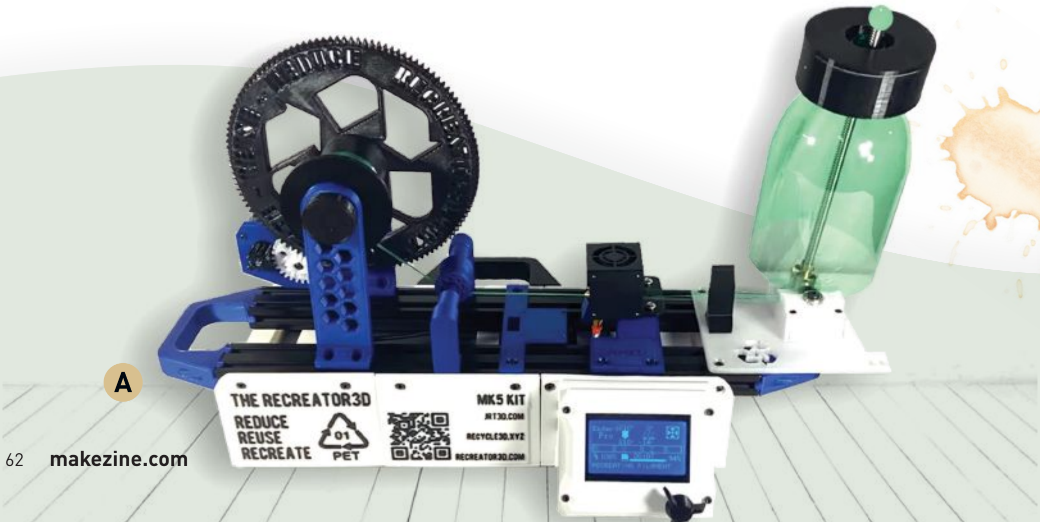
recreator3d.com

I was introduced to Josh Taylor and the Recreator3D back in fall 2022 at the East Coast RepRap Festival (now called 3D Printopia). You may have seen this handy project at other maker events, or here in *Make:* (Volume 88, page 52). Not only do you get to save your old printer from becoming yet more e-waste, but you also get a handy tool to recycle plastic bottles into printer filament via a process called ***pultrusion***. Instead of extruding through a hot end, this handy machine pulls recycled bottles through a drilled-out hot end and onto a collection wheel to create coils of PET (not PETG!) filament. If you've got the urge to take plastic bottle recycling into your own hands, this is the project for you.

There are multiple versions and mods for the project driven by not only Josh, but the thriving community behind him. The Recreator3D MK5 for instance originally focused on using new or recovered parts of Ender 3 printers, but now there's a more universal MK5 kit (Figure A). Meanwhile the MK3 Lite is a more compact but still full-featured version of the machine. If you haven't checked it out yet, I highly recommend it (even if you don't plan to build the machine yourself). If you do decide to build a Recreator3D, be sure to jump on their Discord server, where the welcoming community will help you get up and running in no time.

CNC Hot Wire Foam Cutter

While hand tools are both vital and efficient, you can't beat the precision of a CNC machine. For example, a hot wire cutter can be an amazing tool, but accuracy is hard, even for experienced makers with the steadiest of hands. By attaching the hot wire to a CNC, the cuts become amazingly smooth, as many RC plane makers can attest. Peter Ryseck on YouTube has done just that,



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using a $99 3D printer (youtu.be/YAMKeaMLssk). He's not the only one.

On the RCGroups forum, Mario Peralta shared his build (rcgroups.com/forums/showthread.php?4193855) of a 4-axis hot wire cutter (Figure B) based on the machine developed by Keith Howlette, as documented on his site and ebook (rckeith.co.uk). Keith's machine is large but still utilizes NEMA17 motors and electronics from 3D printers. Mario used the same electronics as Keith but decided on a smaller footprint for his design.

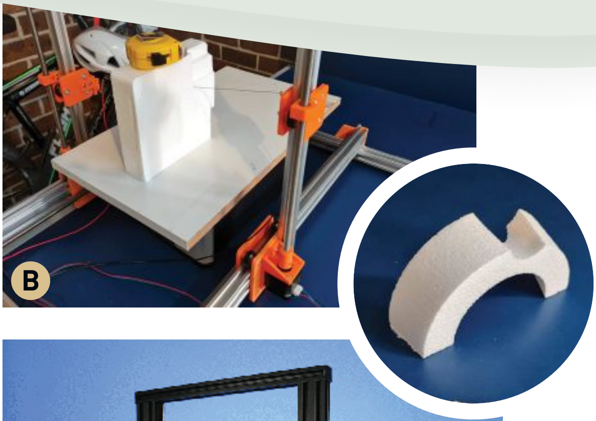
Powercore Wire EDM Cutter

rackrobo.io

As desktop CNC machines became more prevalent, it was only a matter of time before we saw some more advanced technologies implemented. One of these technologies is ***electrical discharge machining***, or ***EDM*** for short. EDM is a cutting process where electrical discharges (or sparks) erode a conductive material between two electrodes submerged in a dielectric fluid that controls the sparks. Back in April 2023, Rack Robotics took this concept and launched the Powercore over on Kickstarter (Figure C). Later that year they fulfilled those orders for the Powercore (and related accessories) to get you up and running with a version of the tech called ***wire EDM***.

Wire EDM operates almost like a hot wire cutter (Figures D and E), but instead of foam, wire EDM can precision cut metals and other conductive materials. While Rack Robotics only shared plans to convert an Ender 3, there are more mounting plates and CAD files available on their GitHub (github.com/Rack-Robotics) and Printables (printables.com/@RackRobotics0_631255) pages, so you can turn nearly any motion system or 3D printer into a precision EDM cutting tool.

At press time, Rack Robotics was working to re-engineer parts of the Powercore V2 and ship an updated version in Q1 2025 with their next batch of preorders. They have been working on some great updates within Danger Klipper that will allow 4-axis motion and speed control to increase reliability. I wouldn't be surprised if we end up with a Powercore V2.5 or V3 in the spring



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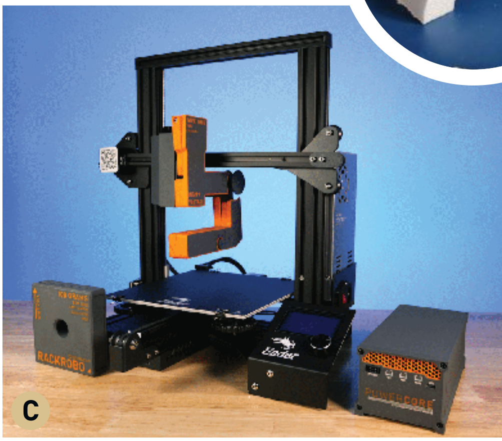

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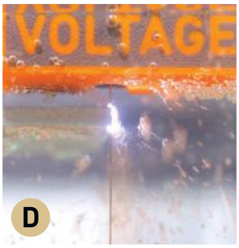

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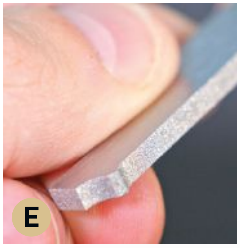


E

Adobe Stock-Juhku, Recreator3D, Mario Peralta, Rack Robotics

and I can't wait to see it in action.

These are just three of the many things you can do to breathe life into your old printers and hardware. People turn these machines into pen plotters, laser engravers, or even kinetic artworks. What will you do with your old printers? We'd love to hear about it and maybe feature you in *Make:*! Find us at mastodon.social/@makemagazine or join the discussion in Discord (makezine.com/go/discord).

DOM DOMINICI is a maker and avid 3D printing enthusiast in Orange County, California. He is the founder of the 3DPOC meetup and one of the producers of Maker Faire Orange County. @geektoybox

Written and photographed by Brigitte Kock

3D-Printed Lace Fabric

How to 3D print lace — with zero 3D modeling skills required

BRIGITTE KOCK (@variableseams) is a London-based modular fashion designer and educator, teaching how to create 3D-printed wearables at home. From concept to finished product, she shows you how to 3D print TPU fabric, create modular pieces, and combine 3D printing techniques for unique results using affordable methods.

Over the years, I've identified nine different ways to 3D print fabrics. In this article, I'm thrilled to share one with you: the ***lace method***. If you've ever wanted to create intricate, detailed textiles that would take forever by hand, this technique is for you. Best of all, you just need a bit of 2D graphics know-how and access to vector software. I typically use Adobe Illustrator, but for this article, I'll walk you through the steps using Affinity Designer's free 6-month trial to keep things as accessible as possible.

One of the most exciting things about 3D printing is how it allows us to create designs that would normally be complex or costly, with almost no waste — and all from the comfort of home. The lace method shows how even a basic home 3D printer can open up new creative possibilities. Whether you're into fashion, accessories, or just love exploring new techniques, this approach is a game-changer.

By the end of this article, you'll know how to turn a simple 2D lace pattern into a 3D printable fabric file. It's a perfect project if you're ready to push beyond the usual slicer infill patterns but not quite ready to dive headfirst into full 3D modeling.

So, grab your computer (and maybe your coffee mug), fire up your software, and let's get started!

CREATE YOUR 3D-PRINTED LACE FABRIC

Before you begin, you might like to see my overview video at youtu.be/oUdoEHYluiU.

1. FIND YOUR LACE DESIGN

First, decide whether to create your own lace design or use an existing one. If you're curious about designing your own, you can explore five DIY methods in my course at variableseams.com. Whichever route you choose, ensure that your file meets the criteria outlined in this step. For beginners, I recommend starting with a pre-designed pattern like the one I used, from PatternWorldShop on Etsy (Figure A).

When choosing a lace design file, here's what to watch out for:

- **Avoid floating bits and spirals** if you're 3D printing the entire lace without any fabric underneath — anything floating will detach, and spirals will flop without support.
- **Ensure consistent lace thickness** for even tension across the fabric.
- **Pick "seamless" patterns** so you can extend designs without visible joins.
- **Choose files meant for laser or vinyl cutters** (*.dfx* or *.eps* format) to avoid issues like open or duplicate lines and make editing in vector software easier.

TIME REQUIRED: A Saturday

DIFFICULTY: Intermediate

COST: $10–$15

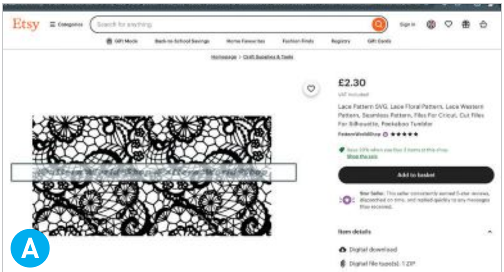
MATERIALS

TPU filament, 80A–95A hardness on the Shore A hardness scale. You'll use about 10g for this fabric swatch, or about 300g for a whole bucket hat.

TOOLS

» **3D printer**
» **Computer with:**
- **Vector software** such as Adobe Illustrator, Affinity Designer (free trial), or GIMP (free)
- **3D design software** such as Tinkercad (free)
- **Slicer software** such as Cura (free)

» **Scraper (optional)** helpful to remove TPU cleanly from the printer bed
» **Pliers (optional)** for the modular connections



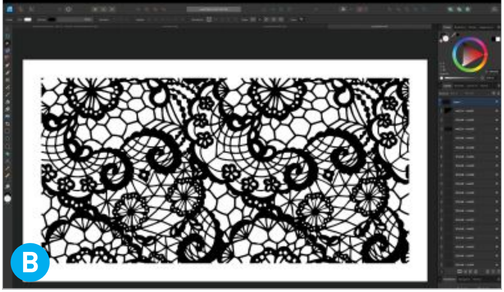
TIP: Looking to explore free options? Sign up for Adobe Stock's free trial. You'll get ten EPS downloads, and it's a handy way to gather some high-quality patterns.

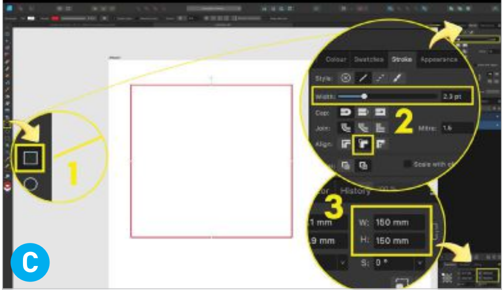
2. CREATE YOUR FABRIC SHAPE

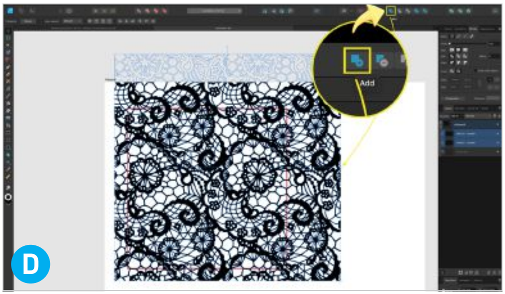
By the end of this section, you'll have a black-and-transparent SVG file of your lace fabric design ready to go. Here are the detailed steps:

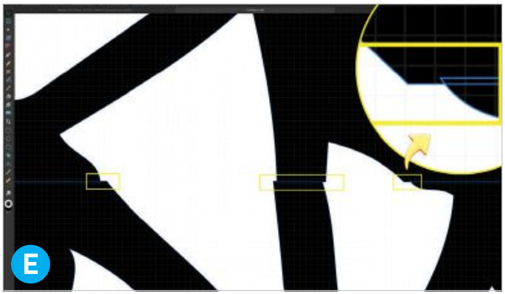
2a. Open your lace file

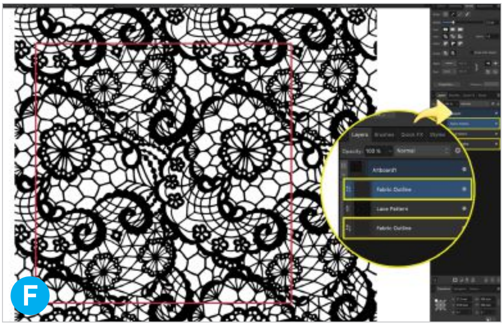
Start by importing your lace design into your 2D

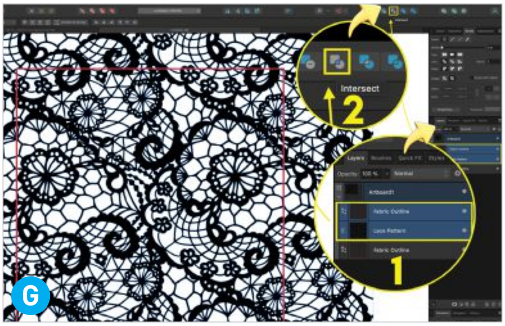












vector software — in my case, Affinity Designer (Figure B).

2b. Create your fabric outline
Start a new project and draw the fabric outline you want to 3D print. For this test I'm keeping it simple, drawing a 150mm×150mm square using the rectangle tool and a 0.8mm stroke weight. To make it stand out, use a contrasting color like red (Figure C).

2c. Position your lace design
Copy and paste your lace design onto your canvas within the fabric outline. If it doesn't cover the whole area, use the Add tool to merge multiple lace patterns into one larger, seamless version (Figure D).

Even if your design is labeled "seamless," zoom in and you may spot minor imperfections (Figure E). Don't worry, they won't show when it's 3D printed.

PRO TIP: Avoid duplicate lines (which can cause errors) by slightly overlapping your lace patterns. For a smoother process, add a 0.4mm stroke to your lace, expand it into a shape, and merge all shapes (see Step 2f). This ensures that even the thinnest lines are thick enough to print, and eliminates most file error issues.

2d. Duplicate the fabric outline
Duplicate your fabric outline and align it perfectly with the first outline, creating a layer order of outline-lace-outline (Figure F).

2e. Trim the lace to fit
Select both the lace pattern and the fabric outline, and use the Intersect button (top toolbar again) to trim off any lace that sits outside your fabric shape (Figure G).

2f. Clean up lace outline (optional)
If you want to 3D print open edges, delete the second fabric outline and skip to the next step.

But if you're like me and prefer a clean border, merge the second outline with the lace. Start by converting the outline into a shape using Layer → Expand Stroke, then combine it with the lace using the Add tool (Figure H). Voilà — your 2D lace fabric design is ready (Figure I)!

2g. Export as SVG

Switch from Designer Persona to Export Persona in the top left corner to reveal the Export Options. Select your lace (without the canvas), set the background to transparent, and export as an SVG file. Your lace design is now ready to be transformed into a 3D model (Figure J).

3. TURN YOUR FABRIC SHAPE INTO A 3D MODEL

In this step, we'll take that 2D lace design and turn it into a 3D model — no fancy 3D modeling skills needed. Cue big smirk. We'll be using Tinkercad, a free 3D modeling software. You can find it at tinkercad.com.

3a. Set up your workspace

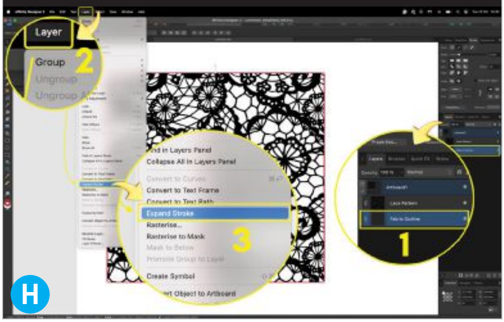
Create a new 3D model to open up Tinkercad's workspace. Go to Settings in the bottom-right corner and adjust the size to match your 3D printer's build plate (for me, that's 300mm× 300mm). This ensures that your design will fit when it's time to print it (Figure K).

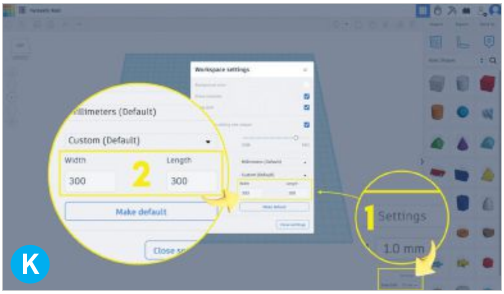
3b. Import your lace design

Now import your *.svg* lace file — but before clicking Import, double-check that your dimensions match the original 2D vector image. For example, my design was 150.8mm, but Tinkercad somehow enlarged it to 425.2mm (Figure L). No idea why!

If your design has a unique shape, you can find the exact width and height in Affinity Designer, under the Transform tab (Figure M on the following page).

TIP: Scaling your design later in the Tinkercad workspace can mess with the height settings, so make sure you have the correct width and height here.





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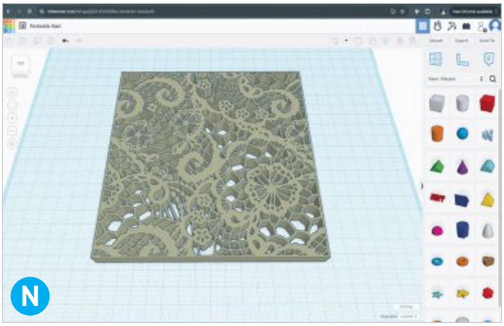
If your lace is detailed, give it time to load — 5 minutes isn't unusual (Figure N)! If it takes longer than 15 minutes, there may be an issue with duplicate or intersecting lines in your SVG file. Since Tinkercad doesn't provide error messages, you'll need to check your 2D design for issues.



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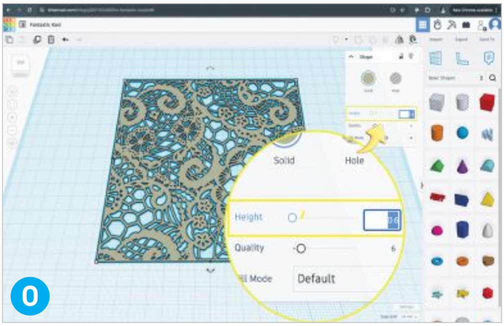
3c. Set the height of your lace

Select the lace shape and a pop-up will let you adjust the height. For 3D printing fabric, I set it to 0.6mm, which gives three layers at the standard 0.2mm layer height — the sweet spot for flexibility and strength. For finer lace, try 1.0mm or 1.2mm. Again, it may take a few minutes for Tinkercad to process (Figure O).



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3d. Export your 3D model

When you're happy with the design, export it as an STL file. And that's it! You've created a complex 3D model in just a few minutes — no advanced skills needed.

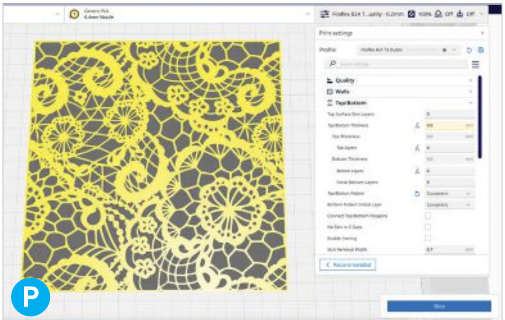
4. SLICE YOUR LACE 3D MODEL

In this step, we'll slice the 3D model and convert it into a file format your 3D printer can understand.

4a. Load your lace into a slicer

Open your lace model in slicer software (Figure P). I personally use Cura (free) because of its user-friendly interface, but there are plenty of great options out there.

If it's your first time using a slicer, make sure your 3D printer and settings are configured for the material you're printing with. If you need help with this, check out my other YouTube videos for more guidance.



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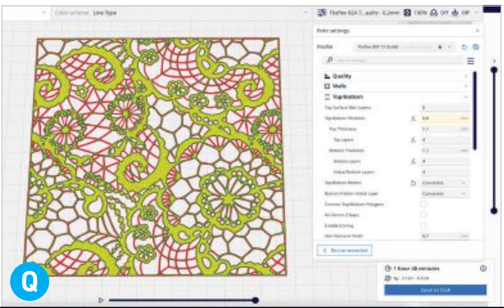
4b. Adjust the print settings

Set the Infill Density to 80% or higher, and for the Infill Pattern choose Lines. For lace designs, I recommend using Concentric for the Top/Bottom Pattern (Figure Q).



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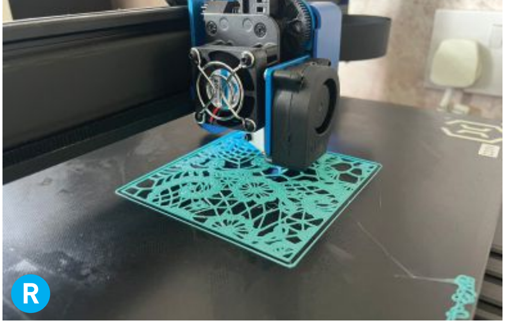
TIP: There's a bug in Cura where it sometimes doesn't recognize the holes in the lace; this tends to resolve itself when you set the Wall Line Count to 2. If that doesn't work, you might try an alternative slicer, like PrusaSlicer.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S

4c. Slice and export as G-code
Once you've tweaked your settings, slice your design and export it as a *.gcode* file.

5. 3D PRINT YOUR CUSTOM LACE FABRIC

Finally, it's time to bring your 3D lace design into the physical realm! I recommend picking a TPU filament that's not too flexible, between 90A–95A, if this is your first time 3D printing with TPU (thermoplastic polyurethane). A lower Shore hardness (70A–80A) will be more textile-like but is much more challenging to 3D print.

5a. Send your G-code to the printer
Transfer the file to your 3D printer. Once it's loaded, keep a close eye on the first layer to ensure all your settings are correct and the filament adheres properly to the build plate. If anything's off, stop the print and tweak the settings from Step 4 (Figure R).

5b. Remove your finished lace
When the print is complete, carefully remove your 3D-printed lace (Figure S). And yes, it's time for a well-deserved celebration — you've done it!

TIP: If you're impatient like me, you might be tempted to pull your lace off before the printer has even finished homing to its start position — but doing so can lead to permanent deformation, like curling. Hold off until the bed cools down to room temperature, and your print will come off much smoother — and without warping!

WEAR IT: MAKING 3D-PRINTED LACE GARMENTS

Now that you've mastered this technique, the real question is: What will you make with it? If you're looking for a fun starter project (rather than printing square samples over and over), I've got just the thing — a cute 3D-printed lace bucket hat! By the end of the day, you could be wearing it to dinner.

I've also used this technique for corsets and other garments, so feel free to get creative with your own designs. If you need a little more guidance or want to dive into a bigger project, I've got an online course packed with detailed instructions, plus bucket hat files customized to your size. Check it out at stan.store/variableseams for all the details!

Wobble Disk Coffee Roaster

Hack a heat gun, flour sifter, and pizza pan to build the ultimate DIY coffee roaster

Written and photographed by Larry Cotton

LARRY COTTON is a thankfully retired power-tool designer and college math instructor. He loves music and musical instruments more than ever, computers even less, birds, electronics, coffee-roaster building, and his wife — not necessarily in that order.

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

COST: $100–$150

MATERIALS:

- **Heat gun, Warrior brand, 1500W, dual-temperature** from Harbor Freight
- **Rotary flour sifter, stainless steel, 8-cup capacity** preferably with a flange on the bottom. Chef Giant CGK6056 or similar from TigerChef, Amazon, etc.
- **Aluminum pizza pan, 13", 18 gauge** such as American Metalcraft TP13, from Amazon. All the aluminum parts can be cut from one pan, but there's very little "wiggle room" for a miscut piece. I recommend you order two.
- **Gearmotor, 12VDC, 100RPM, 6mm shaft** Greartisan brand, Amazon B072R57C56
- **Flange coupling connector, 6mm ID** such as Amazon B0CJMDKN8N
- **Speed control, 12VDC output, 2A** I used Aledeco brand, Amazon B09XB18PPN
- **Jack and plug, low voltage** I used RCA audio connectors.
- **Cable, 2-wire, 24ga or heavier, 24" long**
- **12V power adapter, 120VAC to 12VDC, 3A min.** from Amazon, Walmart, Target, etc.
- **Metal tubing, thin wall, ⅞" OD, at least 36" total length** for sifter supports, from Lowes, Home Depot, etc.
- **Plywood, ½" thick, scraps**
- **Wood dowel, 1¼" dia., 6" length** for a new sifter handle
- **Wood dowels, ¼" dia., 1½" lengths (3)** Unauthorized hint: kids' Tinkertoys work!
- **Paint (optional)** fire-engine red for tubes, black or grey for base and motor support
- **Hookup wire, insulated**
- **Craft foam sheet, ⅛" or ¼" thick** for the "feet," from Hobby Lobby, etc.
- **Fasteners** various wood screws, sheet metal screws, machine screws, nuts, washers
- **Green coffee beans** Don't forget these!

TOOLS:

- **Bandsaw or metal cutting shears**
- **Handsaw and hacksaw**
- **Sandpaper**
- **Drill and drill bits**
- **Screwdrivers**
- **Hex nut driver**
- **Vise**
- **Marker**
- **Wire cutters/strippers**
- **Soldering iron and solder**
- **(Optional: Paintbrush, fine-toothed file, drill press)**

Adobe Stock-prime1001

Have you ever craved a cup of coffee brewed from beans you roasted? In a roaster you built? That sports a wobbling disk, an 8-cup flour sifter, most of a 13" pizza pan, and three red tubes?

No?

Well, here's your chance to build one! Roasting times of 12 to 20 minutes are typical for 300g (11oz) of green (raw) beans in ambient temps of 40°F and above, depending on your likes. And unlike most commercial roasters, you can roast back-to-back batches with no cooling pauses!

In the building process you'll sacrifice the flat part of the pizza pan — well seasoned or brand new — to yield most of the roaster's metal parts.

Though it's nowhere near as sophisticated and feature-rich as commercial machines (think $$, technical savvy, and space requirements), I guarantee it will yield many amazing cups of very fresh coffee.

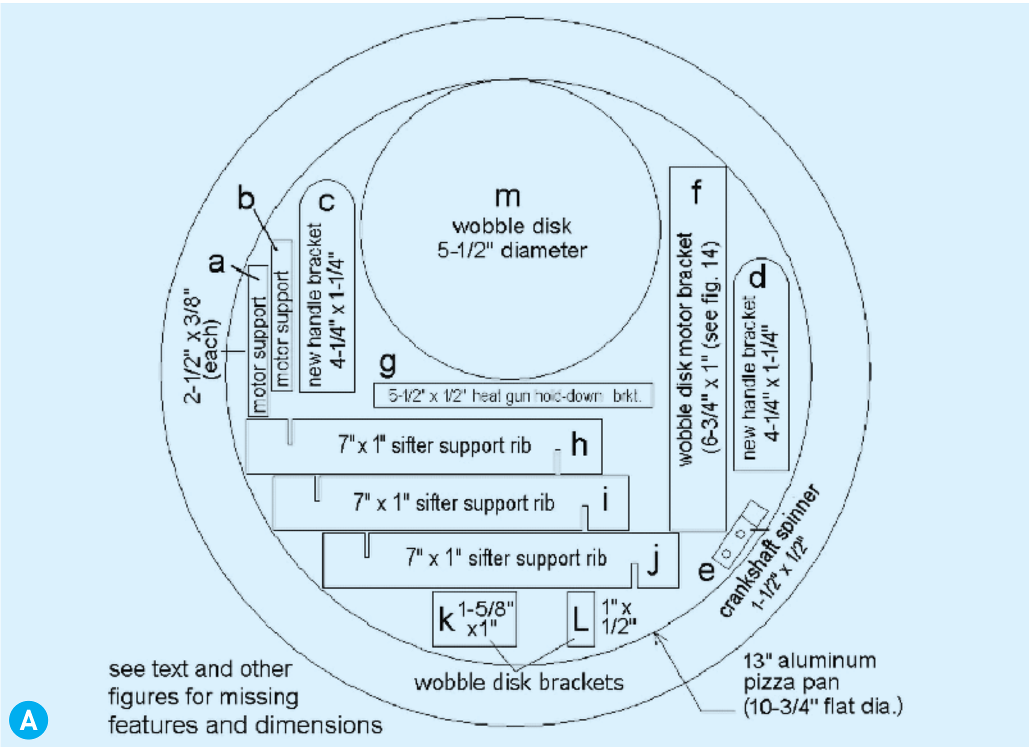
Green beans are widely available online: check out Sweet Maria's (DIY coffee roasters' paradise) and other green bean sources.

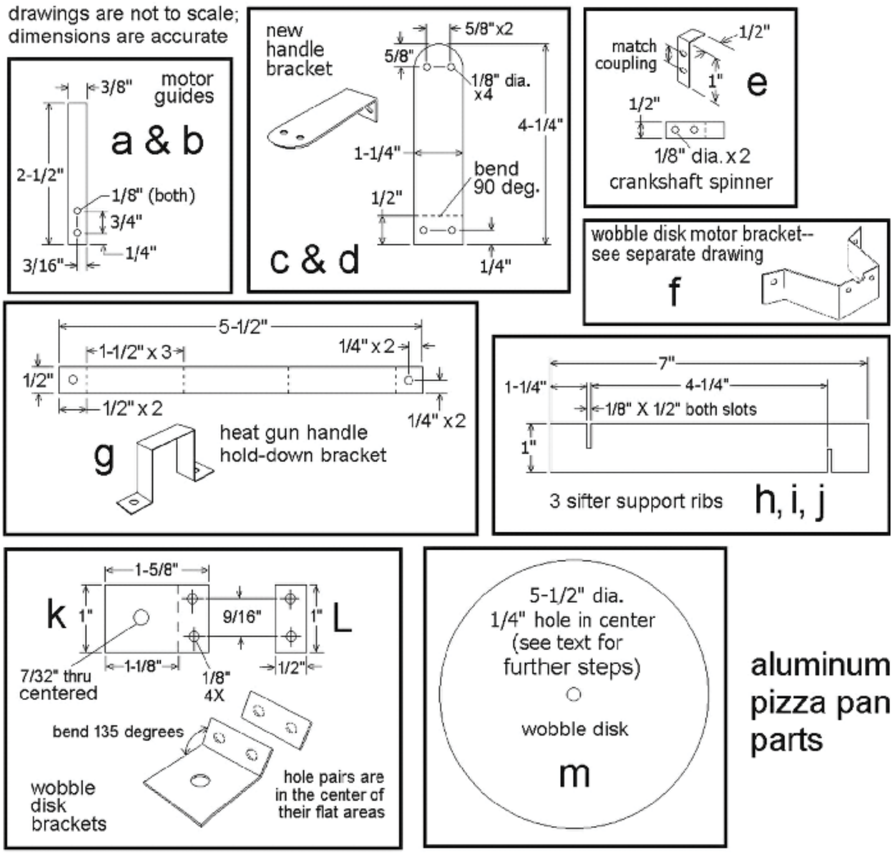
This plan specifies the materials and tools needed to build the roaster. Depending on your workshop and materials on hand, costs should be around $100–$150.

A few cautions before you start: This project requires tools, parts, and procedures that can injure you if safety is ignored. A heat gun (normally used for stripping paint and such), and the sifter surrounding its nozzle, can exceed 450°F. This roaster *must* be used outdoors or in a building or garage with an open door. Coffee beans can emit smoke near the end of a dark roast, and will catch fire if left unattended. And the hard-working wobble disk that stirs the beans could injure you if you touch it while roasting.

Still with me? Great! The main components have been thoroughly tested in more than a few home-built roasters I've built over the years. The cheapest heat gun that Harbor Freight sells can heat the beans to about 450°F; its switch controls two heat/fan settings and off. A small 12VDC motor turning the wobble disk inside the sifter thoroughly agitates the beans — the key to excellent coffee bean development — while exposing every bean to the same amount of heat and time. So let's get started!

Read all about Larry's decades-long quest to build the ultimate DIY coffee roaster! makezine.com/go/roast-quest





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1. PREPARE THE PARTS

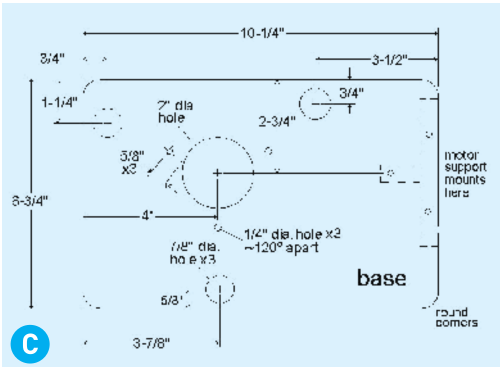
1a. Figures A and B show the 13" pizza pan and all the aluminum parts (lettered **a** though **m**) used in the roaster. They will fit — barely — on the pan's flat area. Copy their outlines *and their letters* onto your pan. You may want to use at least a few paper cutouts to start.

1b. Carefully cut the aluminum parts from the pizza pan with a bandsaw or metal-cutting shears. Don't worry about anything but the outside dimensions and their letters for now.

1c. Cut the roaster's base and the two wobble disk motor support pieces from ½" plywood. Round the base's corners and drill its holes. Sand and paint both parts grey or black. See Figures C, D, and E (on the following page).

1d. Fasten the two motor support pieces together, but don't attach that assembly to the base yet — its height will depend on the exact location of your sifter's sieve, which varies slightly from sifter to sifter.

1e. Find the two small aluminum motor guides,



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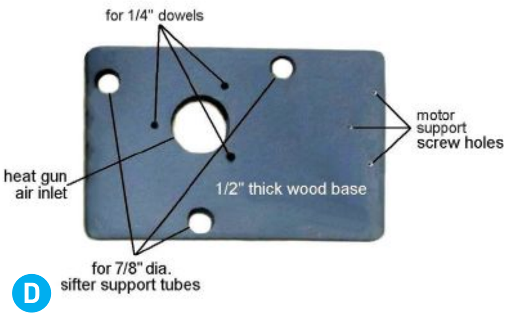

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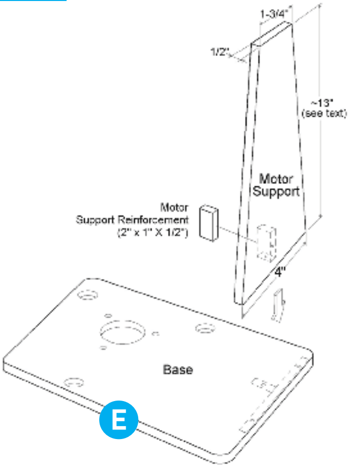
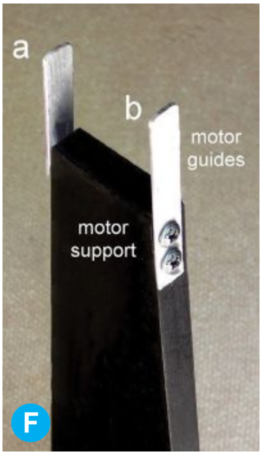
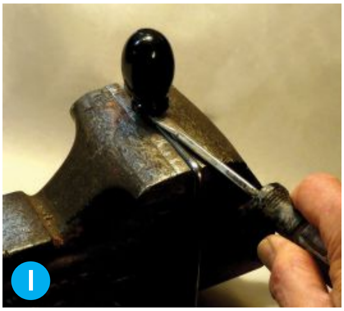






parts **a** and **b**. Drill four screw holes and fasten the guides to the top (small end) of the wooden motor support with two wood screws on each side (Figure F).

2. MAKE A NEW HANDLE

The stock flour sifter's handle gets much too hot to use, so we'll replace it with a better one.

2a. Clamp the sifter's handle in a vise and cut it in half with a hacksaw (Figure G). Carefully pull the two spot-welded pieces off the sifter and recycle them. Gloves are a good idea.

2b. Make a new 6"-long sifter handle from 1¼"-diameter wood dowel and two identical aluminum brackets — parts **c** and **d**.

2c. Drill four holes in each bracket, then bend both to a 90° angle. Fasten the dowel between them using two wood screws at each end. Don't scrimp on the fasteners; *the dowel must not rotate!*

2d. Mount the handle to the sifter in line with the wobble disk shaft (Figure H). Test the strength, rigidity, and ergonomics of the handle; I think you'll like it.

3. ATTACH THE WOBBLE DISK MOTOR

The next few steps are a bit tedious, but not difficult; take your time.

3a. Remove — and keep — the $\frac{5}{16}$" brass cap nut from the end of the sifter crankshaft. Hold the sifter's loops and turn the shaft counterclockwise if necessary to remove it. Recycle the loops.

3b. Hold the shaft in a vise and pry its handle off with a screwdriver (Figure I).

3c. Carefully cut the shaft with a hacksaw as shown in Figure J. The short ¾" section will be driven by the wobble disk motor and its crankshaft spinner.

3d. Temporarily reinstall the sifter's shaft and its cap nut.

3e. Add a flange coupling, often sold in two- or four-packs (Figure K), to the end of the wobble disk motor shaft. Secure it with its included setscrew(s).

3f. Make the crankshaft spinner, part **e**, to match the coupling. Bend it into an L shape and attach it to the coupling with two short (usually 3mm) threaded machine screws as shown in Figure L.

3g. The most important bracket — it holds the wobble disk motor to the sifter — is part **f**. Alignment of the sifter and motor shafts is critical: the motor's crankshaft spinner must easily turn the sifter's shaft with no binding or skipping. As shown in Figure M, drill as many screw holes in the bracket as possible while it's flat. Then bend it, keeping it reasonably symmetrical. If you have access to a bench vise, I recommend using it.

Carefully measure the mounting holes on your motor and transfer that dimension to the bracket. Mount the motor to the bracket with two machine screws. (Typical thread is 3mm, but your mileage may vary.)

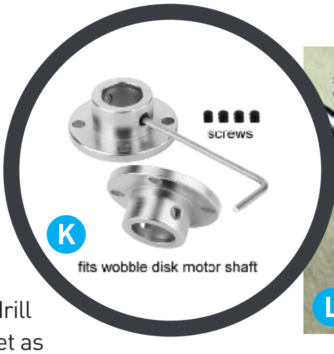
3h. Because sifters — and our own building skills — vary a bit, you'll need to decide exactly where to mount the bracket to the sifter wall. The key is to keep the motor's shaft and crankshaft in alignment. Mark through the bracket's two mounting holes onto the sifter wall. The sifter's midriff-bulge may be in the way (see Figure N). All the holes can be drilled somewhat oversize to allow adjustment of the relationship of the shaft and its driver. Drill those holes (sifter bodies are tough, so use a new drill bit). Then tightly attach the assembly with two machine screws and nuts.

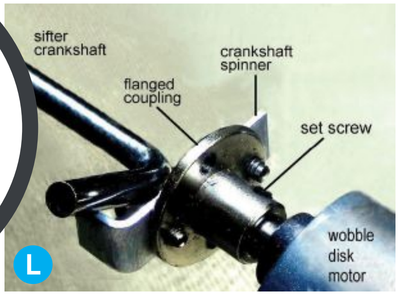
If necessary to compensate for the sifter's bulge, add one or two washers on each side to keep the motor perpendicular to the sifter body.

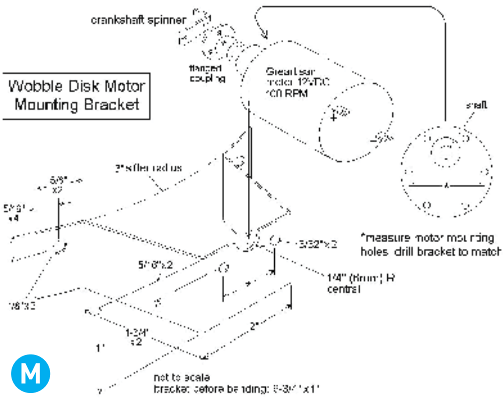
3i. Test the assembly now. Temporarily connect your 12VDC adapter to the motor via the speed control board. Notice the input/output polarities marked on the control board. Run the motor slowly at first. The sifter's crankshaft must smoothly turn clockwise (looking at it from the bracket) with no interference. Please don't take any shortcuts here!

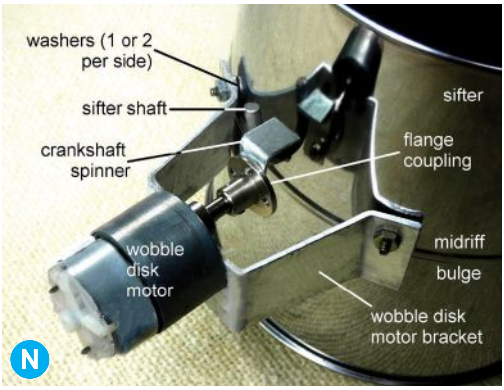
4. MAKE THE WOBBLE DISK

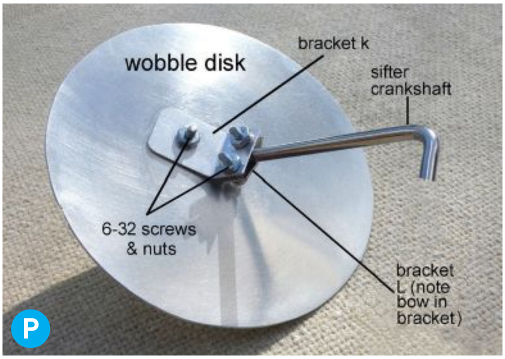
4a. Smooth any rough edges on the wobble disk, part **m**, using a fine-toothed file and/or sandpaper. Drill a ¼" hole in the center of the 5½" disk *at a 45° angle*, using a drill press if you have one (Figure O). If not, clamp the disk vertically in a vise and drill a ¼" hole in the center (hold the drill perpendicularly), then slowly tilt the drill to a 45°

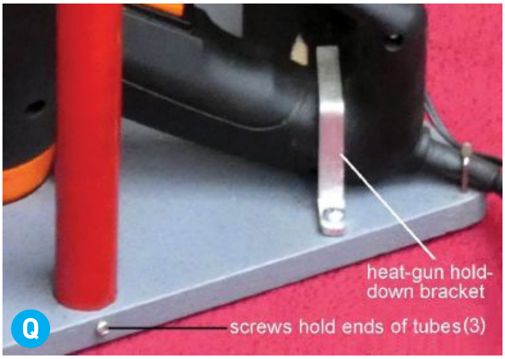












angle as the bit turns. The disk must be at a 45° angle to its shaft to properly agitate the beans.
4b. Make the two brackets **k** and **l** that hold the wobble disk to its shaft. Drill their holes so they line up with each other. Loosely assemble the wobble disk and its brackets with 6-32 machine screws and nuts, keeping all the nuts tool-accessible as shown in Figure P. Push the shaft halfway into the sifter, then between the two bracket pieces, then through the disk.
4c. Tighten the two nuts with a hex nut driver, ensuring the disk and bracket fit snugly together, and mark the disk through the third hole in the larger bracket. Again disassemble and drill through that mark for the all-important attachment screw.
4d. With the wobble disk bracket screws loose, push the sifter shaft halfway into the sifter, then through the brackets and the disk itself. After the end of the shaft passes through its hole on the other side of the sifter, replace and tighten the cap nut, then add a short 6-32 machine screw and nut to hold the bracket to the disk. Tighten that nut very well.
4e. Center the disk in the sifter and tighten its two bracket nuts. The smaller bracket needs to be fastened tightly enough to bend a little, to bow about the shaft. Once more, note that the disk and shaft are at a 45° angle to each other. If any of those screws and nuts are not thoroughly tightened, the wobble disk could slip on its shaft and ruin a roast!
4f. Spin the shaft by hand to ensure the disk doesn't touch the sifter sieve. Press gently on any spots of interference with the sieve. If they still touch, try relocating the disk slightly to ensure there's no drag.
4g. Sifter sieves aren't exactly in the same positions from sifter to sifter. If there's still disk/sieve interference, try trimming the disk locally and minimally. The disk doesn't need to be perfectly round, nor exactly in the middle of the shaft, but its rim needs to be smooth and no more than about 3mm (⅛") from the sieve, while *never touching it*. Any interference will quickly wear a hole in the sieve and your beans will pour down into the heat gun's nozzle and catch fire. Keep that fire extinguisher handy!

5. MOUNT THE UPRIGHTS AND HEAT GUN

5a. Press the three 12" metal tubes into the base and fasten each with one sheet metal screw at the bottom through the outside edges of the base (Figure Q). The end of the tubes should be flush with the bottom of the base.
5b. Find the aluminum heat gun handle hold-down bracket, part **g**. Drill its two screw holes and bend it.
5c. Place the heat gun over its 2"-diameter air inlet hole in the base, among the three small dowels (or Tinkertoys).
5d. Hold the heat gun's handle in place with its bracket and two wood screws. If necessary, bend the middle section of the bracket to apply a bit of pressure to the handle. You may want to also add a cord clamp now (seen in Figure Q at far right).

6. MOUNT THE SIFTER SUPPORT

Now for the most important steps in this build. After much experimentation over the years, an optimum dimension between the tip of the Warrior heat gun nozzle and the 8-cup sifter's sieve has emerged. It consistently delivers an excellent, very even roast in about 12–20 minutes, dependent somewhat on bean variety and ambient temps. That dimension is 1¼"!

6a. Cut a small block of wood 1¼" tall. You'll stand it on the heat gun's nozzle later for spacing purposes. In Figure R, the red area represents that distance between the heat gun nozzle and the lowest point on the sifter sieve.

6b. Make three identical aluminum sifter-support ribs **h**, **i**, and **j**, and assemble them into an extended triangle (Figure S). If needed, temporarily tape them lightly together. Keep that triangle at the ready.

6c. Check the sieve again for dents or protrusions and carefully smooth them.

6d. With the heat gun mounted on the base, place the wood block on its nozzle with the 1¼" dimension vertical.

6e. At this point, you may need to enlist some help; things can get a bit tricky. Lower the triangle about 1" among the three tubes (Figure T). It's OK if it's a little loose. Hold it in place for the next step.

6f. Ask your assistant to lower the sifter — with wobble disk motor attached — until the sifter body just touches the triangle in three places. Then push down both sifter and triangle very slowly and gently until the sieve touches the top of the wood block.

6g. Mark on the tubes where the screws will need to be to attach the triangle. Gently remove the sifter but don't allow any movement of the triangle.

6h. Attach the triangle to the tubes with sheet-metal screws or machine screws and nuts, then remove any tape and the wood block (Figure U).

6i. Once again, check that the wobble disk never touches the sieve by turning the disk manually a few times.

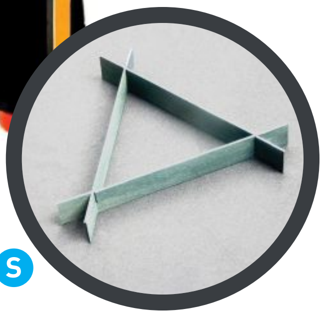
7. MOUNT THE MOTOR SUPPORT

A very important piece — the wobble disk motor support — has been patiently waiting for this paragraph; the roaster will not work without it. Refer back to Figures C–F.

7a. Set the sifter on all three parts of the triangle and close by, or even touching, all three red tubes. It should stay in place — barely balanced.

7b. Carefully measure the distance from the top

R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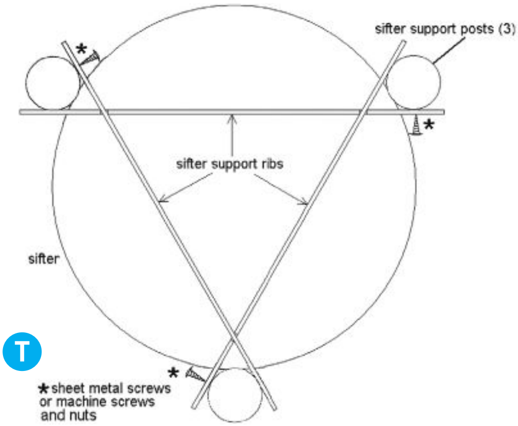

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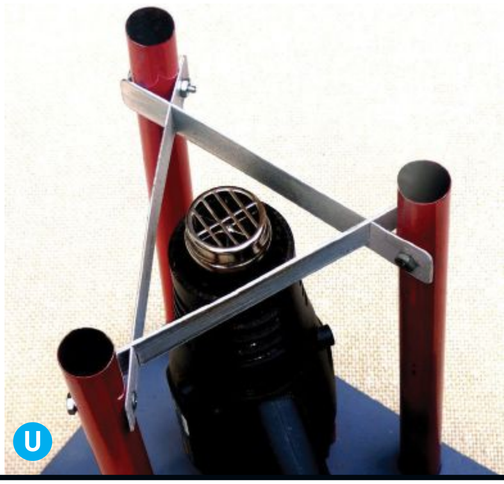

U

of the base to the lowest point of the wobble disk motor body.
7c. Cut the motor support *at the bottom* to the length you measured, and mount it to the base with three 1½" wood screws: two for the support itself and one for the reinforcement piece.
7d. Ensure that the wobble disk motor fits easily between its two aluminum motor guides and rests on the top of the motor support.
7e. Add four 1"-square pieces of the craft foam (as "feet") to the bottom of the roaster's base.

8. WIRING

8a. Mount the wobble disk's on/off/speed control near the top of the motor support (Figure V).
8b. Connect the output of a 120VAC to 12VDC (3A minimum) adapter (transformer) to the input terminals of the speed control (they're marked). The wires can be hidden somewhat if you attach them to the inside wall of the motor support.
8c. Add two short wires from the output of the speed control to a small female jack. I used a surplus RCA jack and telephone wire for this.
8d. Connect a 24", 2-wire cable (24 gauge minimum) between the motor's terminals and a 2-terminal plug to match your jack. Just-roasted coffee beans can be dumped close by without disconnecting, or farther by unplugging.
8e. Now test the speed control. Turn it on and slowly increase the wobble disk motor's speed. Ensure that the wobble disk *turns clockwise* when viewed from the motor side of the sifter, and *doesn't touch the sieve.*

ROAST 'EM IF YOU GOT 'EM

Ready with those green beans? Here's how to use your ultimate DIY coffee roaster:
1. Place the roaster on a hard, sturdy, flat, level surface.
2. The speed of a roast is sensitive to input power. Plug in the heat gun and the 12V adapter. If you use an extension cord, it must be at least 14 gauge and no longer than 15 feet long, to support the heat gun's current draw.
3. Pour about 300g (11oz) of raw green coffee beans into the sifter. Don't start the heat gun yet.
4. Turn on the wobble disk motor and check for moderately fast (60–70 RPM), smooth bean rotation. If all your beans will stay in your sifter at

100 RPM, that works too.
5. Turn on the heat gun using the switch in the handle, to setting II (high).
6. *Stay with the roaster for the entire roast.* The beans will expand and shed small, light pieces of chaff, which makes a mess but is totally benign. Near the end of darker roasts, the beans can emit some smoke caused by heating the oil that is seeping to their surfaces. To me, that's a sign to dump beans.
7. There are many variables, from bean species to ambient temperatures to the roaster itself. If the roast seems too fast, switch the heat gun to its lower temperature and fan speed. If anything seems to be going wrong, unplug the roaster immediately. Check out "Roasting Tips" below.
8. Beans will continue to roast after the heat gun and wobble disk are turned off. So grab your new wood handle, unplug the wobble disk motor if necessary, and *carefully* dump the 400°F beans to cool. I cobbled up a wood-framed metal screen with a cheap Walmart desk fan blowing up into the beans (Figures W and X), but a cool baking sheet can also be a very good heat sink.
9. Unless you plan more roasting, unplug both power cords.

ROASTING TIPS

- If your roast times usually exceed 25–30 minutes, try getting closer to your 120VAC source and/or using a heavier-duty and/or shorter extension cord.

- If a 300g (11oz) roast is done to your liking in less than 10 minutes, toggle the lower heat gun setting to slow the roast a bit. Recall that 12–20 minutes is a typical roasting time for 300g of beans in ambient temps of 40°–90°F.
- Under windy and/or very cool conditions, consider setting the roaster down into an *open-top* corrugated cardboard box. This works well at the beach!
- If your roasts consistently take more than 30 minutes, consider reducing the gap between the heat gun and the sifter sieve. Remove the screws holding the bottoms of the support tubes and the wooden motor support, then cut no more than ¼" off the tube bottom ends and the motor support, and reassemble.

CAUTIONS, WARNINGS, AND TROUBLESHOOTING

- Roast only coffee beans in the roaster.
- Do not roast coffee indoors. Smoke and chaff can be prolific and dangerous; keep in mind the presence and direction of the heat, smoke, and chaff produced.
- Do not use the roaster near combustible or flammable materials/atmospheres.
- The heat gun nozzle and sifter are too hot to touch during use.
- Never insert anything in the heat gun's nozzle.
- Do not look straight down into the roaster while it's on.
- Stay with the roaster from start (loading cool green beans) to finish (dumping 400°F roasted beans).
- Keep young children away!
- Always switch the heat gun and wobble disk off before dumping roasted beans.
- Let the roaster cool before storing it.
- Do not operate the roaster with a damaged power cord or plug, or after the roaster malfunctions, or if the roaster has been damaged. Don't allow its cord to contact a hot surface.
- Never immerse any part of the roaster in water or any other liquid. This includes the power cord(s) and plug(s).

KNOW YOUR HEAT GUN

Read and understand the heat gun manual.

The specified Warrior heat gun has two settings. Start the roast on II (higher heat and fan speed), and switch to setting I if the roast is proceeding too quickly. One sign of that is significant chaff within the first couple of roasting minutes; that's a bit too early. Try to make your roasts last 12–20 minutes or so.

The Warrior heat gun's switch and fan motor are *not spark-free* and can pose a serious ignition hazard. For these and other reasons, the roaster must never be used near flammable materials.

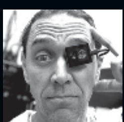
Never obstruct or cover the heat gun's air inlets or nozzle. If air flow is restricted, the heat gun will overheat, blow its fuse, and possibly catch fire.

Build a Better Screen Lock

Respite for the terminally online

Written and photographed by Thomas Garaio

Just 15 seconds left to wait ...



THOMAS GARAIO is a Swiss entrepreneur, designer, and founder of several tech startups, including Oxon in Bern. With his team, he has developed innovation projects for large corporations as well as his own products in the fields of education, IoT, and health care. He is the developer of the NanoPy programming language and the author of various computer science teaching materials.

TIME REQUIRED: 1–2 Hours
DIFFICULTY: Beginner to Intermediate
COST: $90–$100

MATERIALS

» **Oxocard Connect Innovator Kit, and Oxocard Connector Cartridge** from makershed.com/oxocard
» **USB power bank** or other USB power source

TOOLS

» **3D printer and computer**
» **Wire cutters/strippers, soldering iron, and solder**
» **Sandpaper, screwdriver**

Mechanics and electronics are hidden in the removable lid.

The smartphone is our favorite tool, but also a huge time waster. If you need a little help with self-control, grab a 3D printer, some electronics, and these instructions. This tiny time-controlled safe makes your smartphone disappear for a while and frees up time for other things.

First, something important up front: we're printing our safe in plastic, so it's not theft-proof and does not offer a 100% guarantee against misuse. If you lock up your children's cellphones, you have to expect that their intrinsic motivation will be so high that they'll find ways and means to break in, either by programming it or by using brute force. The point of this project is to show you how to build a device like this, what you need to think about, and to give you tips and tricks for further expansion.

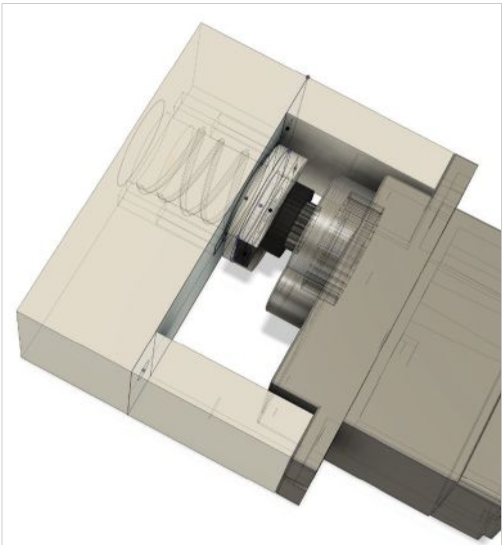
Our cellphone safe — you could also call it a prison — consists of a container and a lid. The lid contains a locking mechanism that is controlled by a servo. The device is plugged into an external microcontroller via a connector cartridge. We use the Oxocard Connect here to make things easy. This runs a small app that allows you to set how long the safe should lock the phone away. As soon as the time has elapsed, the safe opens and you can check your emails again or swipe and scroll through the endless expanses of social media to find the latest "news."

MECHANICAL STRUCTURE

The appliance essentially consists of two parts, the container and the lid with the locking mechanism. The lid is simply inserted by opening it fully (90°) and placing it over the two short axle cylinders. A crossbar fits on the other side so that the lid can be locked in place. When the servo extends the bolt, the housing is closed.

CLOSING MECHANISM

The core of this safe is the locking mechanism. For this we use a commercially available micro servo (SG92R) as found in the Make: Oxocard Connect Innovator Kit.



To move the bolt, the rotation of the servo is converted into a linear stroke using a screw mechanism.

The servo is mounted in the lid and controls a closing mechanism that converts the servo rotation into a linear lifting movement to move a bolt. For this we need a servo with a truncated servo horn. Onto this, we place two plastic parts that screw into each other, to create the screwing movement. The outer part is prevented from rotating by two small rails, so the bolt moves outward and the rotary movement is converted into a lifting movement.

The whole thing is reminiscent of a screw with a nut. If we turn the screw while holding the nut with our fingers, we turn the screw in or out. But because the servo rotation is a maximum of 180°, we need a much higher thread pitch than a screw. In our case, the thread pitch is approximately 4mm–5mm. At 180° rotation, the stroke distance is approximately 2mm–2.5mm.

PREPARATION: PRINTING, CUTTING, AND SOME SANDING

The Oxocard Connect Innovator Kit and a Connector Cartridge are required to replicate this build. All other parts are 3D printed. We also need some plastic glue in a few places to hold the parts in place.

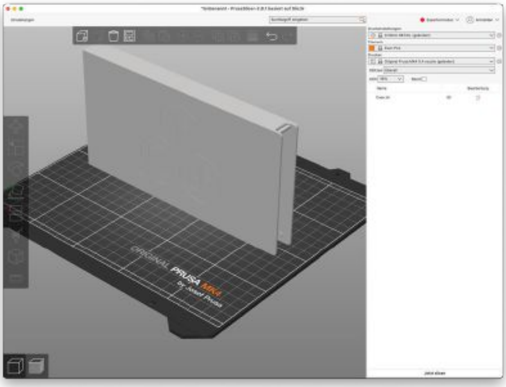
I recommend PLA as the material. I made the parts with matte black filament from the manufacturer ESun. The container is printed with white PLA from Prusa.

For the large container, a layer height of 0.2mm is sufficient and you can print at speed; I have achieved the best print times and quality with a vertical transverse alignment, without support.

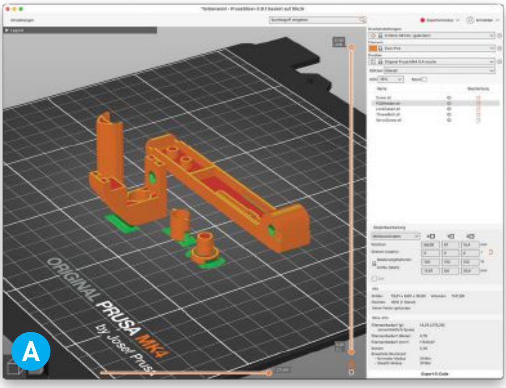
When printing the remaining parts, the alignment on the printing plate is crucial. The thread must be printed in such a way that no support material is required (Figure A). The parts are printed with a layer height of 0.1mm in slow mode.

It's important to assemble and test the parts after printing, before we insert the servo. The *ServoScrew* and *ThreadBolt* must be able to be screwed together without resistance. Sometimes there is still some material that needs to be removed by hand. Screw the parts in and out a few times until everything runs smoothly. Then the *ThreadBolt* goes into the housing (*LockCase2*). Here, too, push the bolt in and out a few times

The Oxocard Innovator Kit comes with the breadboard and servo you need. Just add a Connector Cartridge.



The housing can be printed with 0.1mm or even 0.2mm layers, and does not require any support material.



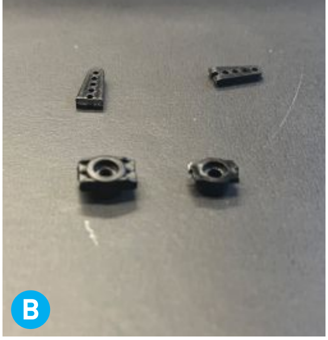
The arrangement of these internal parts is important, so you don't have any support material in critical areas.

until it moves without resistance.

Various servo horns are included with the servo. We'll adapt one of these for power transmission. Trim off the arm(s) so the total length does not exceed 11mm (Figure B). Then sand down the thickness on the top side to 4mm–4.2mm using 400-grit sandpaper (Figures C and D).

SET UP THE SERVO

The servo is our central element. Before we put



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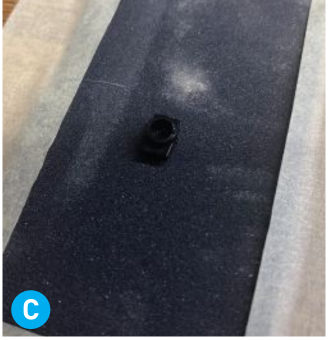

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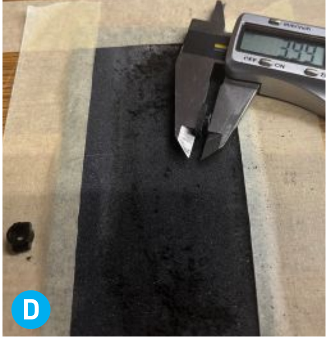


D

Cut and sand the servo horn down to 11mm width × 4mm height.

everything together, we need to make sure that our servo is set to the correct angle. To do this, we build a simple circuit using the Breadboard Cartridge included in the Innovator Kit.

Connect the servo to a pin header on the breadboard as shown in Figure E, and the wires as follows:

Servo brown = GND
Servo red = 5V
Servo yellow = IO 01

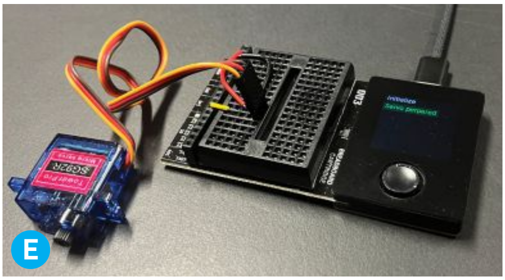
Then connect the Oxocard Connect and start the *InstallServo* program (Figure F). The servomotor should move briefly. If not, check the cables and start the program again.

In order to operate a servo, a PWM (pulse width modulation) signal must be generated. In simple terms, this switches the current on and off in very short periods. Depending on the length (aka width) of each pulse, the servo converts this signal into an angular movement. Our servo has a range of motion of approximately 180° and is connected to pin 1. In line 5 we set the frequency to 50Hz (one pulse every 20ms). Then we can position the servo on lines 6 and 8 with **`writePWM`** (lines 6 and 8).

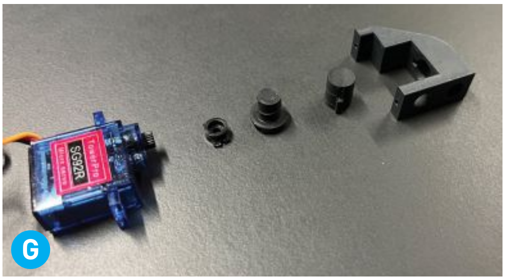
The **function `monitor.push()`** on lines 4 and 9 writes a small confirmation text to the monitor. Further information can be found in the documentation.

ASSEMBLE THE LOCK MECHANISM

For this step we need the servo, the prepared servo horn, and the printed parts *ServoScrew*, *ThreadBolt*, and *LockCase2* (Figure G).



E



G

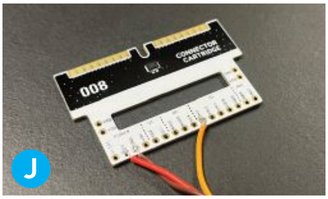
F

```
1   import monitor
2
3   const SERVO_PIN = C_PIN_01       # Servo on IO01
4   monitor.push("Initialize")
5   setPWMFrequency(50) # Servo runs on 50Hz
6   writePWM(SERVO_PIN, 102)      # 102 is about -90 degrees
7   delay(1000)
8   writePWM(SERVO_PIN, 512)      # lock is open: 512 is about +90 degrees
9   monitor.pushc("Servo prepared", MONITOR_GREEN)
```

This script sets the servo to the correct position in preparation for assembly.

Thread *ServoScrew* and *ThreadBolt* pieces together and insert both into the housing. If you turn *ServoScrew*, the bolt should be visible.

Place the servo horn on top as shown here, then screw on the servo.



Shorten and solder the servo cable. Or keep it longer if you want to use the servo later in another project.

Now carefully test-fit the screw and bolt by inserting them into *LockCase*2. You may need to sand the parts to fit. It is important that the bolt can be pushed through the housing *without force*. It is also important that the screw mechanism turns *without force* (Figure H). If everything works correctly, screw the *ServoScrew* and *ThreadBolt* together and insert them into the housing. Then insert the servo horn (Figure I) and screw the servo in place with its mounting screws. Done!

Next, solder the cable to the Connector Cartridge. If you're brave you can shorten the servo cable to 50mm for a very tight fit — or you can leave a little more cable. When soldering, first tin the wires and then the pins. The circuit connections are the same as on the breadboard: red to 5V, brown to GND, and yellow to IO pin 01 (Figure J).

Next, insert the *PCBHolder* part (shown standing up in Figure K) into the slot of the cartridge (Figure L) and then carefully insert the PCB into the lid (Figure M). Make sure that the PCB is inserted in such a way that the EEPROM chip is pushed through the small recess. The *PCBHolder* is a clip that locks it in place (Figure M). To make it hold even better, we recommend using some super glue.

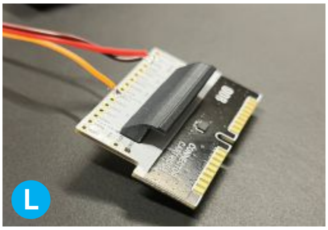
Now we come to the final step: the servo with the housing is also attached to the cover with a few drops of glue. The positioning is simple, as only the two large cylinders are inserted into each other (Figure N).

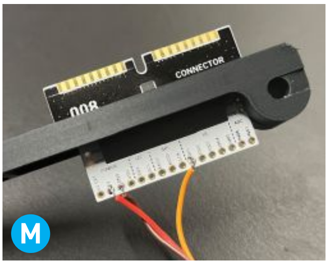
SOFTWARE

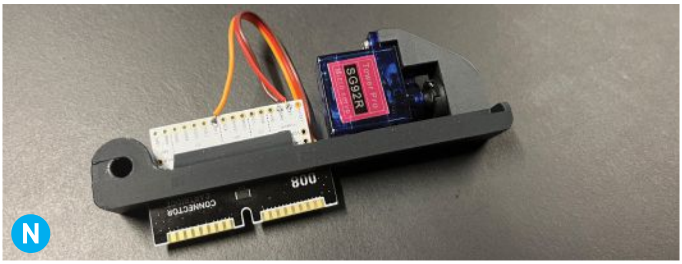
Now that our cover is finished and all the mechanical work is complete, the next step is testing and programming.

First, plug the Oxocard Connect into a computer and transfer the *LockUnlock* script. A message appears on the screen and in the NanoPy editor. Our first script opens and closes the lid at the touch of a button (Figure O).

The global variable **locked** (line 5) saves the current status of the lock.







Insert the *PCBHolder* clip into the slot in the Connector Cartridge board, then secure the whole thing in the lid.

With the **toggleState** function (lines 7–14), we set the servo angle depending on its value. In line 14, we reset the **locked** variable by inverting the current value: **true** becomes **false** or vice versa.

onClick on line 16 is an event procedure. It is called by the operating system when a button is clicked. Here we now call **toggleState**. We set the value on line 19 for the first time and thus update the screen when the script is started.

The script can be started normally via **Run**. One problem is that we always see the automatically started demo program of the Connector Cartridge when we plug that cartridge in. However, you can simply overwrite this by selecting our example *LockUnlock* and clicking on "Load onto cartridge" in the context menu. A display appears on the Oxocard, and after a few seconds, the script is transferred. Unplug and plug it in again. Now we have a first usable version of our cellphone lock, with the Oxocard serving as the key!

TIMER WITH EEPROM MEMORY

With your Oxocard, you can now press a button to close and open the lock. However, we want to make a time-controlled safe that is also — at least minimally — protected against misuse.

Our timer allows the user to set a number of seconds with the joystick and then lock the box at the touch of a button. After the time has elapsed, the cellphone is released again.

To implement this, we need a variable for the number of seconds, and a loop that counts down to zero. Simply done. However, the problem is that it is also very easy to manipulate the device in this way. As soon as you unplug the Oxocard and plug it back in, the variable is empty again, i.e. the time has elapsed immediately and the safe opens. We therefore have to find some way of remembering these remaining seconds between resets. If the script is terminated and restarted, we then need to load the previous value from somewhere. If the value is not yet zero, the system continues counting and only then opens.

Fortunately, each Oxocard cartridge has an EEPROM memory of 64kB. The signature of the cartridge is stored in this memory. When it connects to an Oxocard, this signature is read and a message appears in the editor indicating what has been recognized. We also overwrote the

```
1  import monitor
2
3  const SERVO_PIN = C_PIN_01      # Servo on IO01
4  setPWMFrequency(50) # Servo runs on 50Hz
5  locked = true
6
7  def toggleState():
8      if locked:
9          monitor.pushc("OPEN", MONITOR_GREEN)
10         writePWM(SERVO_PIN, 512)     # 512 is about +90 degrees
11     else:
12         monitor.pushc("LOCKED", MONITOR_RED)
13         writePWM(SERVO_PIN, 102)     # 102 is about -90 degrees
14     locked = not locked
15
16 def onClick():
       toggleState()

   toggleState()
```

LockUnlock: A press of the button closes and opens the lock.

autostart script in the EEPROM earlier with the "Load onto cartridge" function. This memory can also be accessed directly via script and I²C.

We use the functions **writeI2CInt** and **readI2CInt** for this purpose. I²C is a very common communication protocol, which was invented by Philips. The address of the chip is **80**. Now we need a memory address. The memory of the cartridge already contains various data. The header signature is stored in the first 256 bytes. This is followed by up to three files that can be saved. I have decided to start in the middle, i.e. at **32768**, so that nothing is overwritten.

Let's call our variable **lockDurationSecs**, and save the content in the EEPROM like so:

```
writeI2CInt(80, 32768, lockDurationSecs)
```

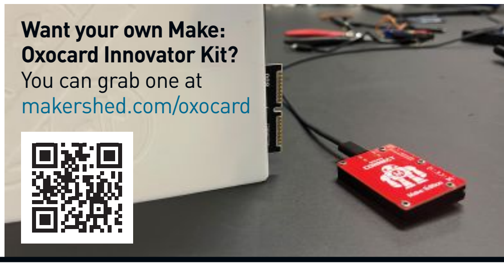
and load again:

```
lockDurationSecs= readI2CInt(80, 32768)
```

The Tresor app (see makezine.com/go/oxocard-phone-safe for the full code listing) provides a GUI for setting the duration and initiating the locking function.

ENJOY SCREEN FREE TIME

There you have it. It only takes a few parts and, thanks to the 3D printer, no extensive tools to build a functioning smartphone safe in a short time. We look forward to your further developments and comments. Let us know your ideas via the #oxocard channel on the Make: Discord Server (makezine.com/go/discord)!



An Electronic Safe

Set your combo with rotary switches — and a timer to thwart brute-force attacks

Written and photographed by Charles Platt

CHARLES PLATT is the author of the bestselling *Make: Electronics*, its sequel *Make: More Electronics*, the *Encyclopedia of Electronic Components Volumes 1–3*, *Make: Tools*, and *Make: Easy Electronics*. makershed.com/platt

Making your own safe may seem an unrealistic project, because the same tools that build it can also pry it open or cut it apart. It can never be really — safe!

Still, there is a purpose to this project. If you see no signs that anyone has tampered with your safe, you can feel confident that the stuff inside has been undisturbed. In this way, it provides some peace of mind, besides being fun to build. It's a perfect weekend project — you can fabricate the safe from sheet aluminum and rivets in about a day, and then wire and install the electronic circuit the next day.

MATERIALS

I decided to use aluminum, because it's so affordable and easy to work with. If you substitute stainless steel, the plans will be the same, but cutting and drilling it will be more difficult, and I think the increase in security will be negligible.

Aluminum sheet is easily found online. I bought four 6"×12" pieces for $20 total. I cut the panels for the safe out of these sheets, as shown in Figure A, where the grid lines are at intervals of 1". Naturally if you want a larger safe, you can use bigger pieces of aluminum (and the price per square inch will drop significantly).

In the United States, sheet-metal thickness is usually measured in fractions of an inch. I chose $\frac{1}{32}$", sometimes described as 0.03" or 0.8mm. You can cut it with shears, such as the vintage pair shown in Figure B, or you can use a hacksaw. If you have a band saw with a bimetal blade, that's the best of all. I don't like using a circular saw for thin aluminum, because the blade can hook into the sheet and throw it in unpredictable directions.

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

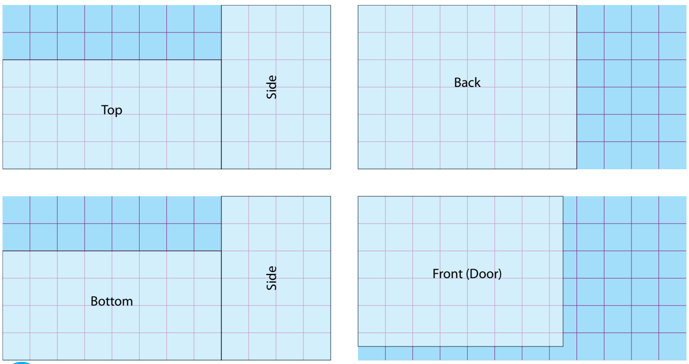
COST: $80–$90

MATERIALS

- **Aluminum sheet, $\frac{1}{32}$" thick, 4 pieces, each 6"×12" or bigger**
- **Aluminum angle, $\frac{1}{2}$"×$\frac{1}{2}$"×$\frac{1}{16}$", 8' total length**
- **Aluminum rivets, $\frac{3}{16}$" diameter, $\frac{1}{4}$" length (70)**
- **Aluminum piano hinge, at least 6"**
- **555 timer IC chips (2)** designated IC1 and IC2 on the schematic diagram
- **Rotary switches, 10-position (3)** S1, S2, S3
- **Pushbutton switch, normally open, SPST** S4
- **Relay, 12VDC 2A, SPST, SPDT, or DPDT** RY1
- **Resistors, 220kΩ (2)** R1, R2
- **Resistors, 10kΩ (4)** R3, R4, R5, R6
- **Capacitors, electrolytic, 10μF (2)** C1, C7
- **Capacitor, electrolytic, 47μF** C2
- **Capacitors, ceramic, 0.1μF (2)** C3, C4
- **Capacitors, ceramic, 1μF (2)** C5, C6
- **Diodes, 1N4001 (3)** D1, D2, D3
- **LED indicators, red (1) and green (1)** rated 12VDC
- **AC adapter** to supply 12VDC at 2A or more
- **Knobs (3)** to match your rotary switches
- **Solenoid-operated latch** rated for 12V
- **On-off power switch** miniature toggle or similar, SPST or SPDT
- **Mini breadboard, 30 rows**

TOOLS

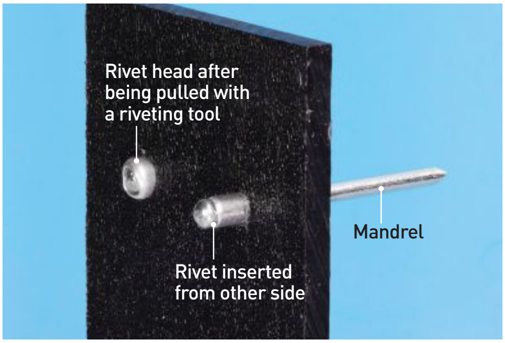
- **Shears, tinsnips, hacksaw, or band saw with bimetal blade**
- **Drill with drill bits** to match your rivet size
- **Flat file and/or deburring tool**
- **Pop rivets** aka blind rivets
- **Pop riveting tool** hand powered or cordless electric
- **Safety gear: work gloves, eye protection, earplugs**
- **Soldering iron and solder**
- **Wire cutters/strippers**



A Cutting panels from four pieces of aluminum, each measuring 6"×12".

B Although blunted by years or use, these vintage shears can still cut $\frac{1}{32}$" aluminum sheet.

C Aluminum piano hinges can be cut to size. You drill your own holes.



D A riveting tool pulls the mandrel until it snaps off.

E A typical hand-powered riveting tool.

F A cordless electric riveting tool.

When working with metal, remember that edges and corners may be sharp. Wear work gloves, and anytime you use a band saw with sheet metal, earplugs are a worthwhile precaution against future hearing loss. After cutting, you can use either a flat file or a deburring tool to clean up sharp edges.

I bought piano hinges for my safe (Figure C), from McMaster-Carr (mcmaster.com). You can trim them to the length that you need, and drill holes where you want them. Amazon has a less expensive but more limited selection.

To connect the panels, I used ½"×½"×1⁄16" aluminum angle, giving the safe an impressively rugged look.

RIVETS

I held everything together with pop rivets, also known as blind rivets. If you've never worked with rivets, they are calibrated in two ways: the thickness of the body, and the length of the body, which should be at least ⅛" longer than the combined thickness of materials that the rivet will penetrate. Figure D shows rivets on the underside of a piece of plastic, before and after being installed.

Rivets are quick and easy. Drill a hole, insert the rivet, pull its mandrel with a riveting tool such as the one in Figure E, and the head of the rivet makes the body swell up, securing it without any need to get access to the underside of the material. The mandrel breaks off, leaving the head of the rivet looking neat and smooth. Cordless electric riveting tools such as the one in Figure F are easier to use, but expensive.

SOLENOID-OPERATED LATCH

For the lock on the safe, I found the latch shown in Figure G. It uses a 12V solenoid — an electromagnet containing a sliding plunger. The power supply can be any AC/DC adapter rated for at least 2A, such as those in Figure H.

Attach the latch to the inside of the door so that the triangular catch flips inward when you close the door and the catch meets the frame.

ELECTRONIC COMPONENTS

I wanted a three-digit passcode to secure my safe, and rotary switches are an ultra-simple way

G A 12V latch contains an electromagnet inside the blue wrapper.

H A selection of 12V AC adapters.

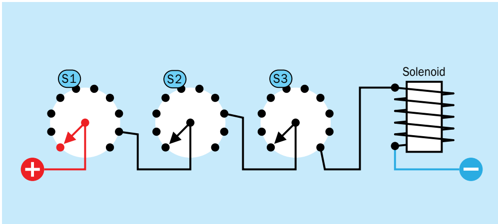
to enable this, using the circuit in Figure **I**. One contact on each switch is wired to the pole of the next switch, so that all three switches must be in their correct positions to activate the solenoid. You now have an ultra-simple combination lock.

A rotary switch is shown in Figure **J**. This one has a knurled shaft, while others may have round or D-shaped shafts that vary in diameter. Make sure you get knobs that match.

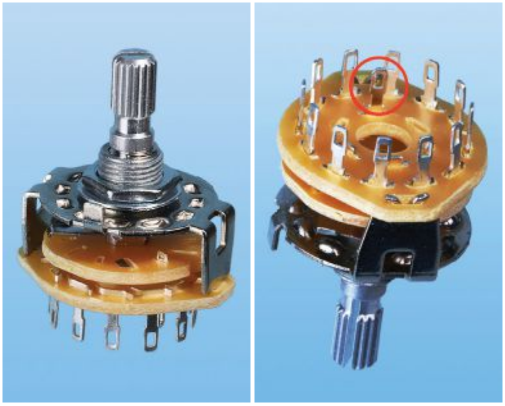
Unfortunately, my system of switches has a disadvantage: It is vulnerable to a "brute-force" attack. A safe cracker simply tries every permutation of switch positions, listening for the lock to open. This may seem laborious, but turning the switches to their 1,000 possible permutations can take less than 10 minutes. Even if you have four switches (10,000 permutations), a brute-force attack is still doable.

How could I prevent such exploits? At first I considered the system used by websites, which may block you after three or four failed attempts to enter a passcode. I liked this idea, but it would require a logic circuit, and I wanted something simpler. I decided to have a button that must be pressed to open the lock, with a 10-second delay before the circuit will allow you to make another attempt.

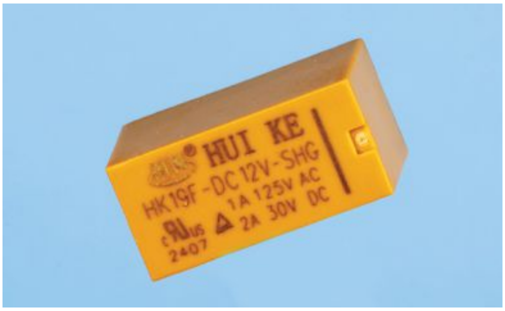
The word *delay* made me think of that most ancient and fundamental friend of makers everywhere, a 555 timer. The original version is ideal for this project, as it can deliver up to 200mA. This is still not sufficient to power the solenoid, but can drive a small signal relay of the type shown in Figure **K**, which takes about 120mA. The output of the relay is rated at 2A, which can activate the solenoid.



I Three rotary switches, wired to allow only one combination that activates the solenoid.



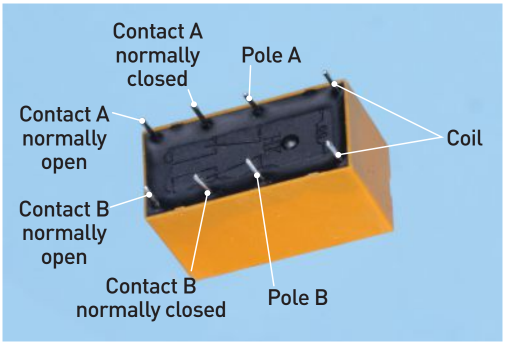
J A 10-position rotary switch. The circled solder terminal is the pole of the switch.



K A typical relay appropriate for a breadboard. It measures about 1"×½".

Best of all, the timer, the relay, and the solenoid can all share the same 12V power supply, whereas a microcontroller would require 3.3V or 5V and would be sensitive to voltage spikes.

When you shop for relays, make sure they have pins spaced in multiples of 1⁄10", to fit a breadboard. The typical pin functions for this type of relay are shown in Figure L, and I found some on Amazon costing only about $1 each.



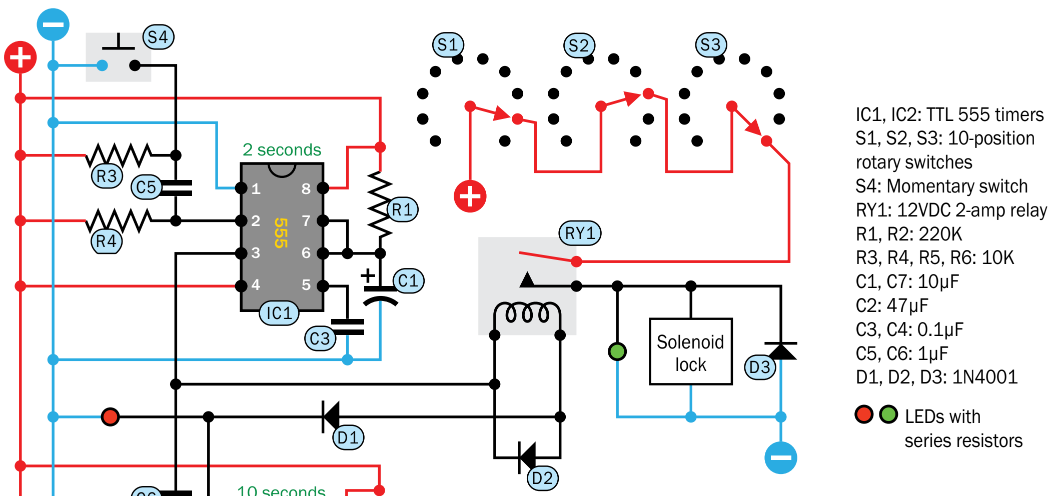
L These relay pin functions are typical, but check the datasheet. For this project, only the coil pins, and Pole A and Contact A (normally open), are needed.

THE CIRCUIT

I assembled these components to create the circuit shown in Figure M. Here's how it works. IC1 is a timer wired in ***monostable*** mode, meaning that it delivers one pulse when triggered. (You'll find full details about 555 timers on many websites, or in introductory books such as my own *Make: Electronics*.) The pulse from pin 3 of IC1 goes to relay RY1, which connects the rotary switches with the solenoid, which opens the lock if the rotary switches are in their correct positions.

The pulse from the relay coil is grounded in pin 3 of IC2. Pin 3 is the output pin of IC2, but this timer hasn't been triggered, yet, so its output voltage is low, which means it can sink current.

The 2-second pulse from IC1 that goes to the relay also goes to C6, a coupling capacitor. At the end of the pulse, the drop in voltage from IC1 draws a tiny jolt of current from pin 2 of IC2, through C6. This triggers IC2, which imposes the 10-second delay. (If 10 seconds seems too long, you can reduce the value of R2 or C2.)



M Schematic for the electronic safe. The three rotary switches are shown in their correct positions to open the lock.

During the delay, IC2 has a high output, so it won't sink current anymore. No matter how persistently you press the pushbutton, nothing happens, because the voltage on each side of the relay coil is now about the same — until IC2 reaches the end of its cycle.

R3, R4, and C5 are necessary, because if I connected pushbutton S4 directly with the trigger pin of IC1, someone could hold the button down, and the output from the timer would continue indefinitely, allowing multiple attempts to find the right switch combination. Remember that the 555 responds to the *level* of input voltage, not to a *change* in voltage. In other words, it is not "edge-triggered."

R4 keeps the input of IC1 normally high. When pushbutton S4 is pressed, it draws a pulse of current from pin 2 through C5, triggering the timer. When the button is released, R3 equalizes the charge on the capacitor, so that it will enable the next button-press.

As for the diodes: D1 prevents current from flowing backward, through the relay coil, to the low output of IC1, when the output from IC2 is high. D2 and D3 are protection diodes, to shunt the spike in voltage which normally occurs when power to a coil is switched off.

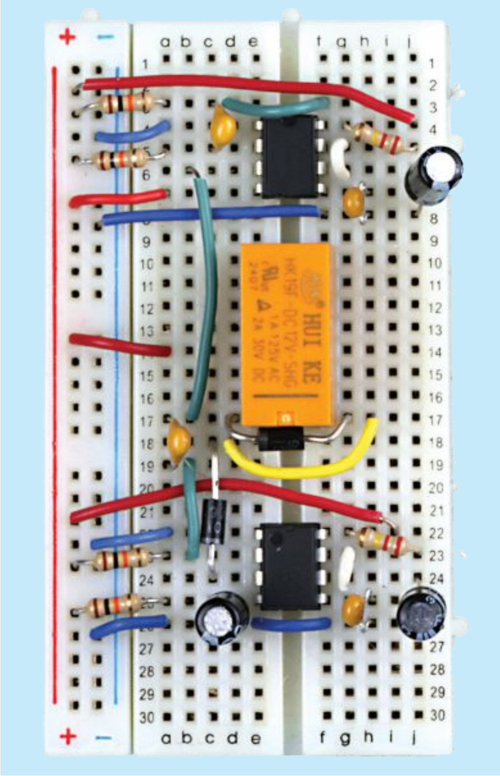
My schematic includes indicator lights to show the status of the circuit. These are shown as little colored circles, representing indicators that contain their own resistors, suitable for 12VDC, as shown in Figure **N**. You can find them on eBay or Amazon. Like many 12V products, they are really intended for people who customize cars.

My complete circuit fits easily on a mini breadboard, shown in Figure **O**, and the finished safe is shown in Figure **P**.

LOCK 'EM UP!

Your safe is now ready to store objects of value, although you have to remember one precaution: After you open and close the door, don't forget to rotate the switches randomly to conceal your secret combination. Otherwise, the safe won't be safe at all.

N An LED indicator nicely packaged, including a series resistor appropriate for 12V.



O The components fit easily on a mini breadboard.

P The finished safe.

Bubble Blaster Brat Bot

Hack a clever toy and a robot arm to make a bubbly companion

Written by Lee Wilkins

LEE WILKINS is an artist, cyborg, technologist, and educator based in Montreal, Quebec, a board member of the Open Source Hardware Association, and the author of this column on technology and the body and how they intertwine. Follow them on Instagram @leeborg_

Time to mix two of my favorite things: bubble blasters and companion bots! In this article, I'm going to show you how to hack a bubble blaster to make your own bubble-blowing buddy.

ABOUT BUBBLE BLASTERS

The idea for this companion bot came from a workshop I ran at my makerspace, Radio Snack (instagram.com/radiosnack.tech). My friend Andy Quitmeyer of Digital Naturalism Labs (dinalab.net) donated a bunch of bubble blasters for us to hack. A couple of years ago, Andy wrote a zine called *BubblePunk* about using bubbles as an environmentally friendly, disruptive activist tool and upcycling technology. You can find a copy of the zine at dinalab.net/2023/04/10/bubblepunk, as well as all of Andy's super useful instructions on how to disassemble bubble blasters, make bubble solution, and more!

When taking apart a bubble blaster, you should be sure it contains the right mechanism. There are two types: the cheaper, old-style ones are composed of a fan and rotating radial circle of bubble wands that dips into a reservoir of bubble solution (Figure A). This works the way we think of blowing bubbles — like blowing many bubbles at a time with a super bubble wand and a fan.

The real innovation in bubble blasters is the newer type that uses a peristaltic pump to draw up the liquid from a container in small plastic tubes (Figure B). The liquid is then pushed through rotating bubble wands and produces a ton of bubbles. The cool thing about these mechanisms is that they are simple to use but very complex inside. They actually are doing three things at once; the same motor is used to turn the radial bubble wand, run a fan, and run the pump. It's a lot of work for just one small motor!

Almost all bubble blasters use very similar mechanisms, bigger or smaller depending on what kind of bubbles they produce. Some have many small bubble openings that produce more of a foam; others have larger openings that make big floating bubbles. Ultimately, it's all the same circular mechanism that varies in diameter.

Normally, I'd now recommend my favorite bubble blasters, but truly there are so many it's hard. Andy donated to us a massive range, and a quick search on Amazon or at your local low-cost

TIME REQUIRED: A Weekend

DIFFICULTY: Moderate

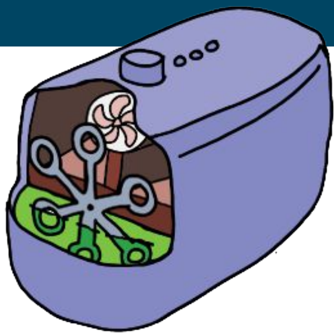
COST: $150–$200

MATERIALS

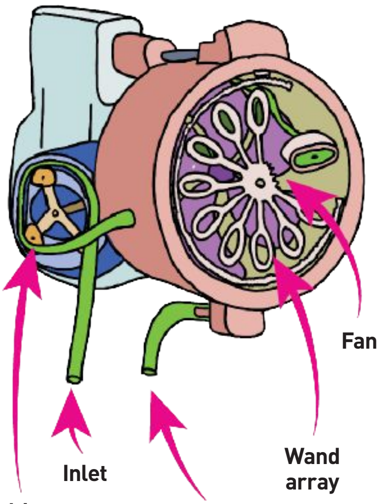
- **Servomotors (3) or 3DOF robot arm kit**
- **Servomotor breakout board, PCA9685** such as Amazon B07H6DDG5H
- **Arduino Uno microcontroller**
- **Faux fur fabric**
- **Bubble blaster mechanism** salvaged from a bubble toy
- **Analog 2-axis joystick breakout board** Adafruit 512
- **Hookup wire**
- **GoPro shoulder mount** Amazon B01LW4EHCW
- **M3 bolts, nuts, and washers**
- **Battery, lithium iron phosphate (LiFePo4), 12V 6Ah**
- **Step-down converter, 5V** aka buck converter

TOOLS

- **3D printer**
- **Soldering iron and solder**
- **Wire cutters/strippers**
- **Needle and thread**



A



B

Lee Wilkins, Andy Quitmeyer / BubblePunk toy shop will reflect this huge variety. You can find Andy's breakdown of bubble blasters at youtu.be/TpurBx8GYRQ. During our workshop at Radio Snack (Figures C, D, and E) we took apart lots of them and found that most have a simple pushbutton connecting the battery. You can either buy a AA battery pack or connect a USB cable and an external battery to power it.

You can put these bubble mechanisms in basically anything, and since they come with a button you can easily turn them on and off. At our workshop, people put bubbles on their Rollerblades, bikes, helmets, and even made a mobile bubbling rat!

C


D


E

My bubble project was Brat Bot, which you may have seen at Maker Fair Bay Area! Brat Bot was able to move around and was mounted to my shoulder. Here's how I made them.

MAKE A BUBBLE BLASTER BOT

1. ASSEMBLE THE ROBOT ARM BASE

Brat Bot was built around a robot arm. There are a ton of different robot arm kits available to purchase, or plans you can find online. I chose a relatively cheap one because I thought it wouldn't need to hold much weight. I originally bought a 6-degree-of-freedom (DOF) arm, which meant it had six servomotors. It was too tall so I ultimately disassembled three of the motors to make it shorter. One thing I learned is that things seem a lot bigger when they're next to your head!

I used the Diymore ROT3U robot kit (Amazon B01LW0LUPT), and I wouldn't recommend it. The way these servo mounts work isn't great for holding any weight at all. As a result, Brat Bot was a bit shaky. I'd recommend spending a little bit more and not using these C-shaped brackets. It's worth a bit of extra weight for a solid mount.

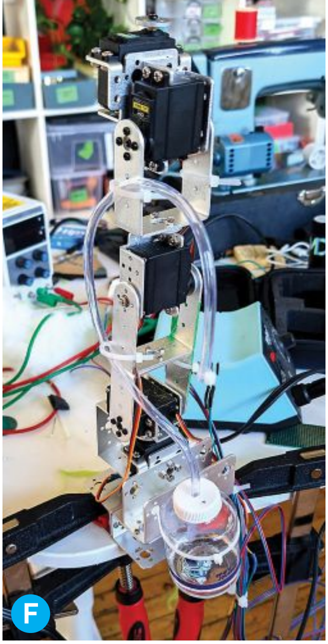
While working on it, I used a clamp to hold the base of the robot to the edge of a table. That way I didn't have to worry about it falling over.

2. BUBBLE BLASTER EXTRACTION & ASSEMBLY

I chose a bubble mechanism that had a built-in LED so that I could get a two-for-one. Lots of bubble blasters have lights in them, just check the packaging. I've even seen a few that have sounds! It's convenient to be able to upcycle the existing circuitry rather than finding a way to mount the LEDs yourself.

I had to extend the tubing to reach the bubble solution on the base of the robot arm, so I used a 4mm silicone tubing (Figure F) which fit snugly over the 2mm tubing that came with the blaster. Make sure this tube is airtight, or you won't be able to pull the bubble solution. I added some electrical tape to be sure.

I chose to mount the mechanism to the fur rather than the armature to make repair access easier. I also had to be mindful that the fur wasn't too close to the spinning fan, otherwise it would get caught. So I created a mount for the


F


G


H


I


J

bubbler that allows it to be sewn into the fur and create a bit of distance between the fur and the mechanism, and then sewed it in (Figure G).

I used this technique of sewing into 3D-printed parts throughout the project to connect soft and hard pieces. The great thing about the faux fur is that I can hide the base easily.

3. 3D PRINTED PARTS

I 3D printed a few accents for Brat Bot using two-color filaments. I like these because they give a unique effect that is almost iridescent. I used both blue/pink and my favorite, pink/green.

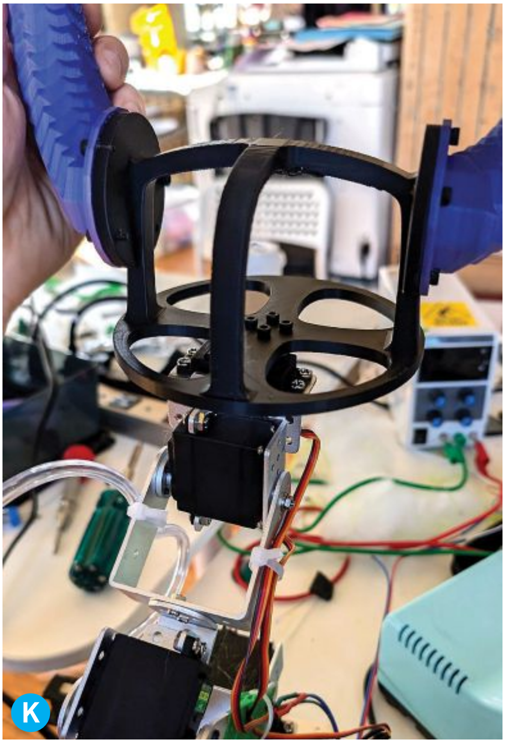
I printed a pair of horns, and some spikes for Brat Bot's back. The spikes would be sewn into the fur, and therefore had a base with small holes for thread to go through (Figure H). The horns (Figure I) had a base with larger holes, so I could use M3 screws to mount them to a skull armature (Figure J).

The skull basically kept the horns at the top of the head and stopped Brat Bot from slumping forward. I tried to do this at first with just Poly-Fil stuffing, but the result was not great. The skull was made to fit on top of a standard servo mount using M3 screws, so it can be articulated both up and down and side to side (Figure K).

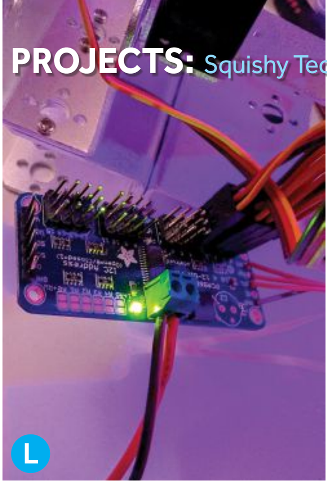
4. WIRING

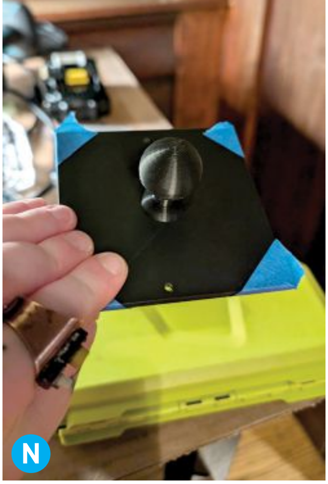
I wanted to get as much weight off my shoulders as possible, so I extended all the wires into a backpack where I housed the microcontroller and batteries. There were a lot of wires, so I zip-tied them all to the motor mounts so they wouldn't get caught as Brat Bot moved around.

I used an Arduino Uno as the brain. I know there are smaller and more compact microcontrollers, but I really find the Uno to be reliable in these scenarios. I connected all the motors to a PCA9685, an I²C-based motor driver that allows


K

Lee Wilkins





me to connect many servomotors at once (Figure L). I covered I^{2}C in my column about haptic motors (*Make:* Volume 84, page 84) if you want to know more!

I connected the bubbler to 5V and ground from my Arduino and wired up the two-axis joystick from the robot kit. I used very long wires so I could hold it while the robot was mounted.

Because I'd be using Brat Bot for long periods of time, I wanted to make sure the battery was sufficient. I only had a 12.8V 6Ah battery handy, so I used a buck converter (also known as a step-down converter) to get the 5V power I needed. Everything fit into either a box (Figure M) or backpack, depending where Brat Bot was going!

5. SHOULDER MOUNT

For the mount, I used a shoulder harness for GoPro cameras. I'd heard from my friend Jorvon (aka Odd Jayy) that companion bots can be hard on the neck/shoulder. Brat Bot was no exception. I recommend you make your robot short and low, and keep its mass as close to you as you can.

I 3D printed a base that fit on the bottom of the robot arm and had a ball joint on the end that fit into the GoPro mount (Figure N). After it broke several times, I ran a large bolt through the base into the ball joint. This gave it the extra strength needed to stop it from snapping.

6. FUR & MORE

When Brat Bot was all wired up securely, I was ready to put on the fur! The reason I chose faux fur is because, honestly, I'm not that good at sewing and I wanted a forgiving material. The shaggy fur hides all my bad sew lines and looks like a fun Muppet.

I made a tube of fabric to go around the robot arm by cutting a rectangle and sewing the long sides together. I also made a cap shape to sew around the skull by cutting a pie slice out of a circle then sewing it back together. I cut two holes for the horns to pop out and sewed the spikes on afterward. I closed the front of the fur with a safety pin in case I needed to get in there, and used some Poly-Fil stuffing to expand it. To make the fur more manageable, I sewed it all inside out using a whip stitch (Figure O) so I could see what I was doing. When it was done, I turned it right side out and it looked great (Figures P and Q). I did have to do a bit of pulling and stitching at the end to get a more round face.

7. CODING

I had some help on the code from my partner, who works professionally with robot arms and has been working on an open source library for controlling them. Honestly, this was a bit of the inspiration for the project. I have always found robot arms to be uninspiring, but we wanted to see if we could make them fun. I feel like this was accomplished!

The code works by setting the servos into four different modes depending on which way the joystick is pushed: Wiggle, Wobble, Intimidate, and Forward. I could also push the stick left and right to manually turn the head of Brat Bot to look at people.

```
if ((quadrant == EAST) && (servo_state.
mode != WIGGLE))
        {
            servo_state = change_
mode(WIGGLE, sequence_wiggle, now,
```

Lee Wilkins

```
target, servo_traj_params.max_
velocity);
        }
```

Each mode was defined as a series of targets, speeds, and durations. When you set the bot into a mode, it will repeat that series of movements until the mode is changed.

```
constexpr SequenceTarget sequence_
wiggle[2] = {
    {.speed_scale = 0.5,
     .duration = 1500,
     .target = {-40, -30, 60}},
    {.speed_scale = 0.5,
     .duration = 2000,
     .target = {0, -20, -20}}};
```

You can explore the whole code file github.com/ChisholmKyle/CompanionShoulderBot.

8. BUBBLER BUTTON

I put a pushbutton on the back of the joystick that was connected directly to the bubbler, so the bubbler isn't actually controlled by the microcontroller, it's just directly wired to the battery. Then I basically had a small controller in-hand that I could subtly use while Brat Bot was out and about!

BUBBLE BLASTIN'

Brat Bot was a huge hit at Maker Faire Bay Area, though not everyone liked getting bubbles blown in their face. If you've made something with a bubbler, let me know, I'd love to see it!

MORE BUBBLE FUN

GIGANTIC BUBBLE MACHINE

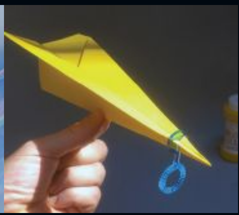
Arduino-controlled Bubblebot blows enormous, undulating soap bubbles. Build it: makezine.com/projects/gigantic-bubble-generator

CNC BUBBLE IRIS

Gordon Kirkwood's bubble obsession grew into an automated machine to blow precise soap bubbles. See it: makezine.com/article/craft/computer-controlled-bubble-blower-will-brighten-your-day

BUBBLE PLANE

Simple plastic tip for your paper airplane leaves a puff of bubbles as it darts away! Make it: makezine.com/go/bubble-paper-plane

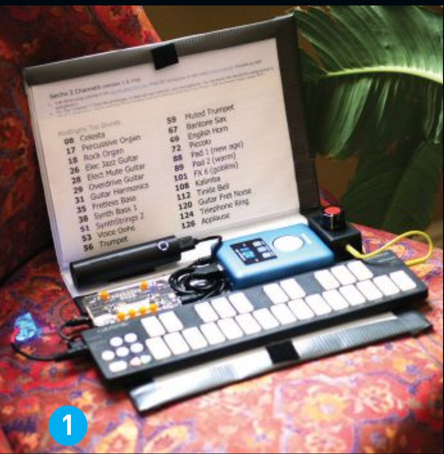


Binders Full of Jammin'

Turn a three-ring binder into a portable music system

Written and photographed by David Battino

DAVID BATTINO (batmosphere.com) is the co-author of *The Art of Digital Music* and writes the popular "Synth Hacks" column for *Waveform.* With his wife, Hazuki, he also self-publishes Japanese storytelling books, which they have performed at four Maker Faires.



1

2

3

4

5

After years of hauling music equipment to jams — and ages hooking it up — synthesizer guru Mark Vail (markvail.com) and I found a solution: We prewired small, battery-powered synths to effects processors and packed it all into briefcases. Now we could simply flip open the lids, plug into the P.A., and play; with headphones we could even jam in cafés without raising a ruckus. But for an airplane trip, I wanted something even smaller.

1 BINDERBLIP

That's when I built BinderBlip. Basically, I drilled out the clips from a three-ring binder and velcroed on a QuNexus MIDI keyboard controller, Midiplus MiniEngine sound module, and Gecho Loopsynth effects processor/recorder. The MiniEngine is unusual in that it's both a USB MIDI host and a battery, which means it can power a keyboard while responding to notes over USB. Its output feeds the Loopsynth (with the orange buttons), which adds echo and records the result to a microSD card. A small USB power bank powers the Loopsynth. For fun, I glued a color-changing LED in a chunk of acrylic ice and lit it with the QuNexus's control voltage (CV) output.

2 ZIPPERBLIP

BinderBlip's 128 General MIDI (GM) sounds were fine for noodling, but I wanted deeper sonic options. So I built my second case around an Audiothingies MicroMonsta 2, a fantastically rich and expressive synth. It's joined by an upscale version of the MiniEngine called the PianoEngine that adds better sounds and a drum machine. Through a hack that converts one of the QuNexus USB ports to a MIDI Out, I can play both instruments at once. A Pokket mixer lets me crossfade between them, DJ style. A zippered orange binder holds it all together, adding a lovely glow to the LED fairy lights.

3 PLASTIBLIP

For my next case, I simplified. There's just one sound source, an ancient iPad Mini 2. But even that model can run a wealth of soft synths and music apps. And unlike newer iPads, it has an analog audio output. I added a Lightning-to-USB adapter so the iPad can power and communicate with my ESI/Artesia Pro Xjam. The Xjam is a wonderful-feeling controller with *polyphonic pressure,* meaning each pad can swell a different note in a chord. It also has a standard MIDI output, which I tapped to light two jumbo blue LEDs that I poked through the binder.

4 SQUISHBLIP

Speaking of pressure-sensitive pads, no one does it like Roli. Playing their rubbery Seaboard Block feels like typing on a wetsuit, but can be incredibly expressive with practice. The keys sense five dimensions of interaction: initial velocity, release velocity, pressure, front-to-back position, and side-to-side position. I found the Seaboard (named after the wave-like contour of the keys) was a perfect fit for a three-ring binder box. The companion Lightpad Block M connects magnetically to the Seaboard and sends MIDI data from both over Bluetooth. Adding my iPhone created a compact, expressive music system with just one cable, the Lightning-to-audio adapter.

5 ZIPPERBLIP DELUXE

A wise musician once said, "The more you bring, the less you play." For a recent plane trip, I got greedy and packed an unholy mess of gear in a briefcase. It again took ages to set up, and was too complex for comfort. Even worse, the TSA took an unwelcome interest, making me rip the system apart at the airport.

For my next gig, at Knobcon 2024, I returned to a three-ring binder system I call ZipperBlip Deluxe. ZBD's faux leather cover holds a Korg Kaossilator Pro (a fantastic jamming instrument), a 1010music Lemondrop (a sumptuous sounding granular synth), and all the batteries I need. To that, I added a Korg NTS-1 MkII effects processor, a Donner DMK-25 Pro keyboard, and a mic. The photo shows a test jam in the park with Mark.

The journey is just beginning. I hope you too have fun making your own "three-ring circuits."

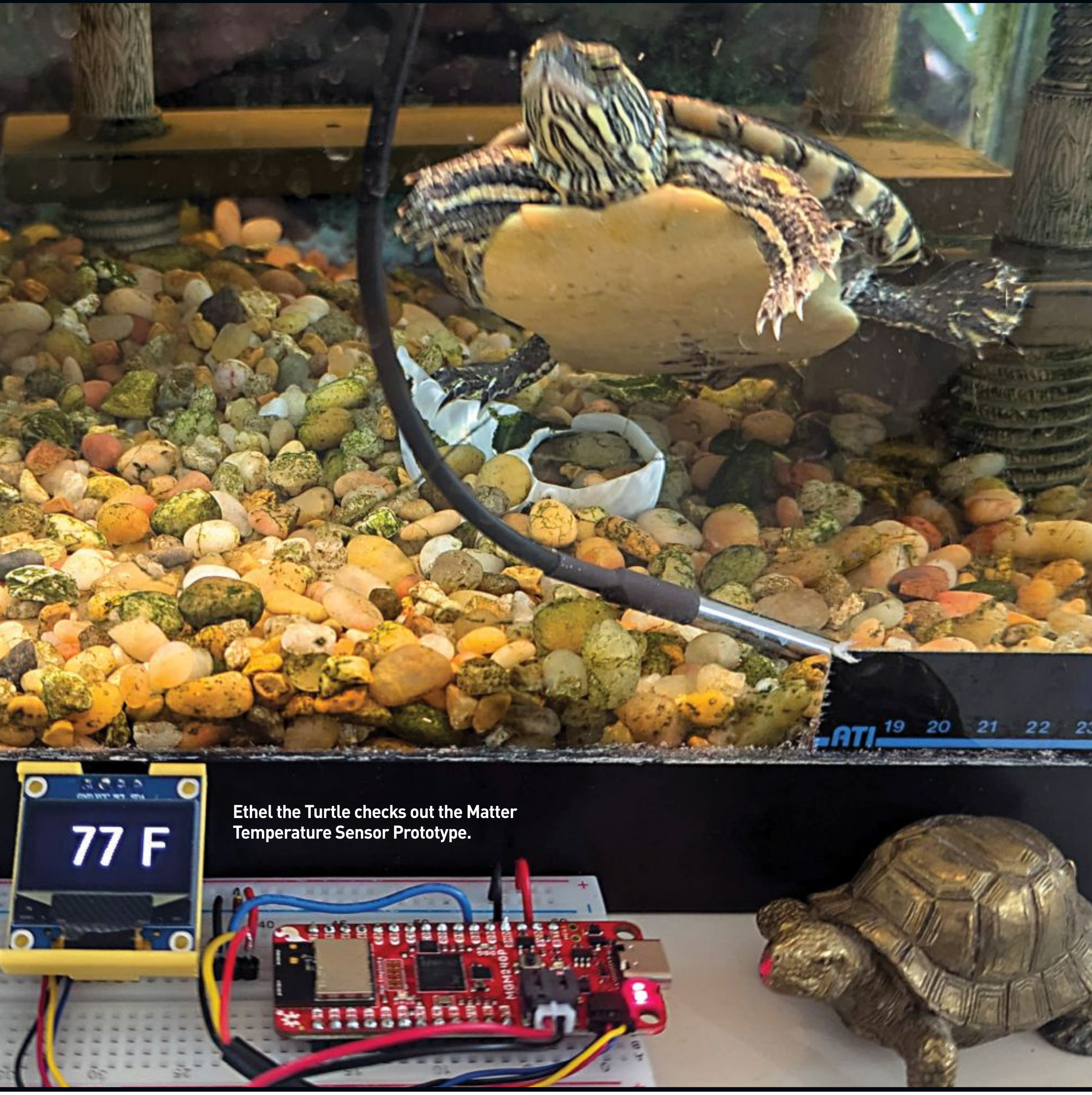
JAMS IN ACTION:

- BinderBlip + SwineWAV: instagram.com/reel/CeU3OSYD_ib
- Knobcon 2023 performance (ZipperBlip Deluxe): youtu.be/pLsCt0uxbKo
- Knobcon 2024 performance (ZipperBlip Deluxe 2): youtu.be/laFfRsSuQ0c

Make It Matter

Explore an emerging home automation standard

Written and photographed by Wayne Seltzer



Ethel the Turtle checks out the Matter Temperature Sensor Prototype.

BOARD #1: ESP32 Temperature Sensor over Wi-Fi using Tasmota

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Beginner to Intermediate

COST: $15

MATERIALS

- **ESP-WROOM-32 Development Board** amazon.com/dp/B08D5ZD528
- **HiLetgo DS18B20 Temperature Sensor Probe Waterproof 1M** amazon.com/dp/B00M1PM55K. This product has a waterproof probe on a 1 meter cable; perfect for the turtle aquarium.
- **47kΩ resistor**
- **Breadboard, hookup wire**

TOOLS

- **Computer**
- **Matter-compatible home automation system** such as Apple Home, Amazon Alexa, Espressif-Matter iOS/Mac app, Google Home, Home Assistant, etc.

BOARD #2: SparkFun Thing Plus Matter over Thread using Arduino

TIME REQUIRED: 1–2 Hours

DIFFICULTY: Beginner to Intermediate

COST: $35

MATERIALS

- **SparkFun Thing Plus Matter board** sparkfun.com/products/20270
- **HiLetgo DS18B20 Temperature Sensor Probe Waterproof 1M** amazon.com/dp/B00M1PM55K
- **47kΩ resistor**
- **Breadboard, hookup wire**

TOOLS

- **Computer**
- **Software:**
  - **Arduino IDE** arduino.cc
  - **Silicon Labs Arduino Core** github.com/SiliconLabs/arduino. Follow the "Installation" and "Getting Started" instructions.
- **Matter-compatible home automation system** such as Apple Home, Amazon Alexa, Espressif-Matter iOS/Mac app, Google Home, Home Assistant, etc.

WAYNE SELTZER is a retired electrical engineer and product manager, currently teaching creative technology and design at the University of Colorado's ATLAS Institute. He founded and manages the Boulder U-Fix-It Clinic, a volunteer organization that helps people fix their broken stuff at ongoing repair events. boulderufixitclinic.org

MAKE YOUR OWN MATTER

If you want to make a home automation device that's compatible with Google Home, or Amazon Alexa, or Samsung SmartThings, Apple HomeKit, Tuya, etc., then you can join their developer programs and get busy. And if you want to build a device that works with *all* these home automation platforms, well, you have a lot of development work to do! No surprise, these developer programs are intended for commercial manufacturers, not so much for makers.

But wait — with many new home automation products implementing the Matter protocol, you might only need to support Matter. The Matter standard (csa-iot.org/all-solutions/matter) offers "One protocol to connect compatible devices and systems with one another. Smart home devices should be secure, reliable, and seamless to use."

Standards are great — is that why there are so many? (The Connectivity Standards Alliance manages Matter, Zigbee, and several other home automation/IoT standards.) But, seriously, will Matter end up as the ubiquitous platform for home automation? It's not clear yet, but with a growing number of affordable development boards and software stacks, it's looking more possible for makers to get into Matter.

The Matter specification includes link layer support for Ethernet, Wi-Fi, and Thread 802.15.4 networks.

ETHEL THE TURTLE — MY MATTER PROJECT

It's always better to have a specific use case in mind when evaluating technologies. Here's mine: My wife Jackie takes excellent care of her pet turtle. Ethel is a painted turtle, 20+ years old, and lives in an aquarium with an automatic feeder, automatic water pump, and a submersed water heater. We have a temperature sensor with an alarm for over and under temperature events, but if no one is home, the alarm goes unanswered. We need a solution when we are traveling. If the temperature is too low, perhaps the heater has failed; we would need to ask a friend to replace it. If the temperature is too high, we should turn on the air conditioner in Ethel's room. We can do this with our existing Home Assistant system.

So, here are two attempts to build a Matter temperature sensor for Ethel; one very simple and limited, using Matter over Wi-Fi, and one much more challenging, using Matter over Thread with the possibility for many add-on features.

BOARD #1: ESP32 Temperature Sensor over Wi-Fi using Tasmota

There are several development boards based on the Espressif ESP32 microcontroller that can be used to build Matter devices, thanks to programming tools and libraries that have been created to make this possible.

Let's start with a simple design to build a Matter temperature sensor using the ESP32 Dev Kit board and the DS18B20 1-wire temperature sensor. These parts are easy to find and inexpensive.

HARDWARE WIRING

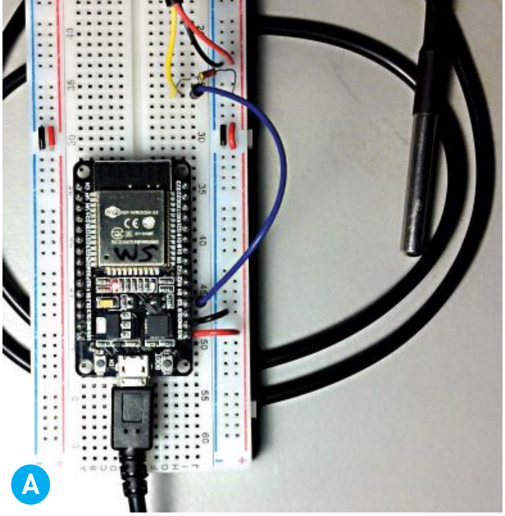
If you search for "ESP32 Dev kit temperature sensor DS18B20 waterproof" you'll find many project examples. Here's my breadboard prototype (Figure A). Connect the components like this:

- DS18B20: black to GND, red to VCC, yellow (signal) to ESP32 pin D2
- Pullup resistor 47K: between DS18B20 signal and VCC.

TASMOTA MATTER

The easiest way to develop the software for this simple Matter temperature sensor is to not write any code at all!

Tasmota (tasmota.com) is open-source firmware for Espressif ESP8266 and ESP32 microcontrollers to create home automation devices. Originally it was developed as a hack to replace cloud-based firmware on commercial products for local control. Now it has support for many products and can be used to make your



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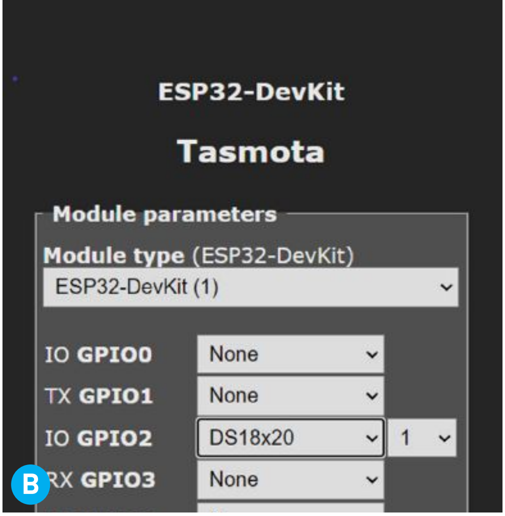
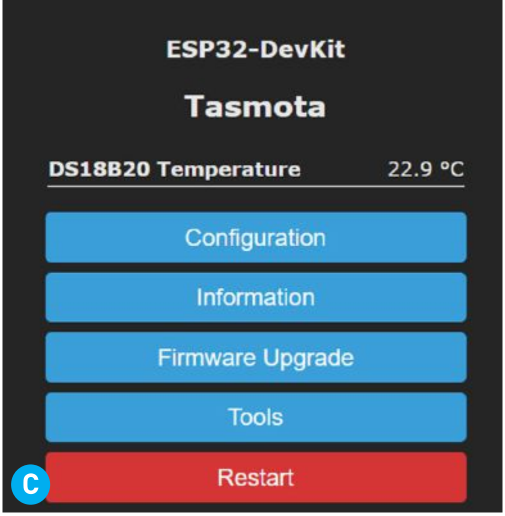
own devices — and it includes support for Matter. Get more details at tasmota.github.io/docs/Matter.

Note that Tasmota's Matter support is Wi-Fi-only at this time; Thread is not supported.

TASMOTA SETUP INSTRUCTIONS

1. Install the Tasmota firmware on the ESP32 from tasmota.github.io/docs/Getting-Started/#needed-software. It's easy to use the Tasmota Web Installer to flash Tasmota using a Chrome-based browser.
2. Configure the Wi-Fi.
3. Click on Visit Device and be sure to remember/bookmark the device's IP address.
4. Click on Configuration → Configure Module. For GPIO2, select DS18x20 – this configures the temperature sensor (Figure B). Then click Save.
5. After the device restarts, you should see the temperature displayed (Figure C). If you're not seeing the temperature, check your wiring.
6. If you'd prefer to display the temperature in °F, use Tools → Console and type:
   `SetOption8 1`
   Go back to the Main menu and you should now see the temperature displayed in °F.
7. You can use Configure Other to change the Device Name and Friendly Name 1, as suitable for your project.
8. Review the supported platform list (tasmota.github.io/docs/Matter/#supported-platforms) for the specific instructions to pair your Tasmota Matter device with your home





automation network. Note that Google Home has some extra instructions, at tasmota.github.io/docs/Matter-with-Google.

9. Follow the instructions at tasmota.github.io/docs/Matter/#getting-started to enable Matter in your Tasmota device, enable Commissioning, then add your Matter device to your existing home automation network. Note that your device can be paired with more than one network or ***fabric***. The Tasmota web interface shows the number of active ***associations*** (Figure D).
10. You can connect other devices to the ESP32's GPIO pins (buttons, sensors, relay on/off controls, etc.) and they will appear in the Matter device, accessible to your home automation network.
11. You can also add various displays (OLED, LCD, etc.) and create Tasmota rules to control the display. See the Tasmota documentation.

ESPHOME AND MATTER?

ESPHome (esphome.io) is another popular platform for developing home automation devices. It works well with Home Assistant (home-assistant.io). Matter is not yet supported, although it is an open feature request at this time.

BOARD #2: SparkFun Thing Plus Matter over Thread using Arduino

Let's take another approach, using some programming to create the Matter device as we'd like, adding some other user interface components.

The SparkFun Thing Plus Matter (sparkfun.com/products/20270) combines SparkFun's Qwiic I²C module ecosystem with Matter, via the MGM240P wireless module from Silicon Labs. The microcontroller is a low-power (as little as 15µA) 32-bit Arm Cortex-M33 running at 39MHz, and the board includes a LiPo battery connector and charge circuit and a microSD card slot. These are all the features you need to make a wireless, rechargeable Matter device that interfaces with just about any imaginable component.

Programming environment possibilities include Silicon Labs Arduino Core, Thing Plus Matter CircuitPython, and Simplicity Studio with Matter, but let's check out the Arduino option, as this is most familiar to the maker community.

SPARKFUN THING PLUS MATTER — ARDUINO

In January 2024, Arduino and Silicon Labs teamed up to provide an Arduino Matter library (github.com/SiliconLabs/arduino/blob/main/libraries/Matter/readme.md). We'll use this for our Sparkfun Thing Plus Matter project.

SOFTWARE SETUP INSTRUCTIONS

1. On your computer, install the Simplicity Studio software from silabs.com/developers/simplicity-studio. You need it to flash the Sparkfun Thing Plus Matter board.
2. Install the latest version of the Arduino IDE from arduino.cc/downloads.
3. Install the Silicon Labs Arduino Core from

github.com/SiliconLabs/arduino) by following the "Installation" and "Getting Started" instructions.

As the instructions say, "If you see the built-in LED blinking, you're ready to go!" Otherwise, review the previous instructions and try again.

The Silicon Labs Arduino Core repository includes several example Arduino sketches. In github.com/SiliconLabs/arduino/tree/main/libraries/Matter/examples/matter_temp_sensor, download the raw file *matter_temp_sensor.ino*, then open it in the Arduino IDE. Compile and upload this sketch to your Thing Plus board. Open the Serial Monitor and you should see:

```
Matter device is not commissioned
Commission it to your Matter hub with
the manual pairing code or QR code
```

We have to get Home Assistant or some other Google, Amazon, etc. home automation device that is a Thread Border Router (TBR) configured for Thread before we can commission this device.

MATTER USING THREAD

Our Tasmota example used Matter over Wi-Fi. The Silicon Labs Arduino Core uses Bluetooth Low Energy (BLE) for commissioning Thread/IPv6 for communications. We'll need a TBR to make this work. My home automation system is Home Assistant (home-assistant.io) and I have a Home Assistant Connect ZBT-1 device (home-assistant.io/connectzbt1) to use as the TBR. Google Home and Amazon Echo devices also support Thread, but alas, all my devices are older models without TBR capabilities.

Follow these instructions to configure Matter Thread on Home Assistant using the ZBT-1 router:

- *Home Assistant Connect ZBT-1 — Enable Thread support:* connectzbt1.home-assistant.io/procedures/enable-thread
- *Case 1: Making Home Assistant your first Thread network:* home-assistant.io/integrations/thread/
- *Home Assistant Matter (BETA)*: home-assistant.io/integrations/matter/#adding-a-matter-device-to-home-assistant

You should now have a Matter device visible in Home Assistant. I also added this device to Google Home and Amazon Alexa. Nice!

This completes a "Hello, World!" project for Matter using the SparkFun Thing Plus Matter using Arduino. Now we can move ahead to build our turtle temperature sensor device.

DS18B20 TEMPERATURE SENSOR

Using the same temperature DS18B20 sensor we used with the ESP32 project, we would expect this to be an easy implementation with the SparkFun Thing Plus Matter as there are several DS18x20 Arduino libraries available. Except, they didn't work. I'm not the first one to notice the problem:

"The OneWire protocol requires strict microsecond timing — which usually cannot be achieved through the Arduino APIs. This is why each chip vendor has their direct GPIO register access functions in the OneWire library," explained Silicon Labs engineer Tamas Jozsi (reply to TomInIowa, githubissues.com/SiliconLabs/arduino/22).

The fix is to install an updated OneWire Arduino library (*Caution: Alpha software!*) for the MGM240P on the Sparkfun Thing Plus Matter board. Download github.com/silabs-bozont/OneWire as a *.zip* file then install it in the Arduino IDE, under Sketch → Include Library → Add .ZIP Library.

Another surprise: The USB serial interface on the MGM240P module on the Thing Plus Matter runs at 115200 bps. Therefore, an Arduino sketch must use **`Serial.begin(115200)`** — any other baud rate will result in unreadable output.

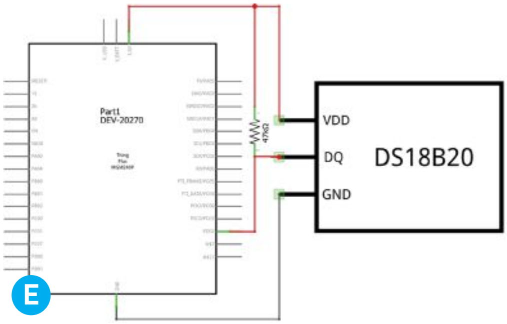
There are several Arduino libraries that support the DS18B20 Temperature Sensor. I used Dallas Temperature. In the Arduino IDE, Tools → Manage Libraries, search for "Dallas Temperature" and install the library.

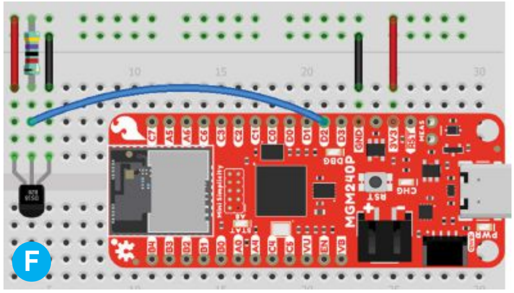
Now try the "simple" example to be sure your hardware and IDE are set up correctly: File → Example → Examples from Custom Libraries → Dallas Temperature → Simple.

Connect the DS18B20 signal line to the Thing Plus D2 pin (Figures E and F). But wait — this is actually the GPIO pin D10 in the Arduino library! So, in the *simple.ino* sketch, change the line:

```
#define ONE_WIRE_BUS 2
```

to read instead:






```
#define ONE_WIRE_BUS 10 // sensor
connected to pin labeled D2, which is
input 10 in Arduino
```

Also change:

```
Serial.begin(9600);
```

to:

```
Serial.begin(115200);
```

Compile and upload the sketch. You should see the temperature displayed in the Serial Monitor.

Now we can combine this DS18B20 sketch (*simple.ino*) with *matter_temp_sensor.ino* to build our project. Here's the combined sketch: github.com/waseltzer/Make-Your-Own-Matter-Device/blob/main/Sparkfun_Thing_Matter_DS18B20.ino.

BONUS: ADD AN OLED TEMPERATURE DISPLAY

It would be useful to have a local display of the turtle aquarium temperature, and it's easy and inexpensive to add an OLED display that uses the I^2C interface via the Qwiic connector on the Sparkfun Thing Plus Matter board. We'll use a 1" display such as Adafruit 326 or Amazon B0B4DHCCKC.

There are lots of examples using these and similar displays in Arduino. The u8g2 Arduino library works with the Thing Plus Matter board (github.com/olikraus/u8g2/wiki).

And here's a working sketch that adds the OLED display: github.com/waseltzer/Make-Your-Own-Matter-Device/blob/main/Sparkfun_Thing_Matter_DS18B20_SSD1306OLED.ino.

OTHER IDEAS TO TAKE IT FURTHER

- Add a check to detect if the Matter network disconnects and try to reconnect. Display something on the OLED to indicate a Matter connection problem.
- Create rules in your home automation system to send notifications on high/low alarms.
- Add a piezo buzzer for a local over/under temperature alarm.
- Add a button to "snooze" the alarm.
- Expose the high/low temperature thresholds as attributes of the Matter device, controllable from your home automation system.
- Add a rechargeable battery to the LiPo jack. Send the battery charge level to Matter. (Note that the Matter specification defines a cluster for the "Power Source." However, it is not yet available in the Silicon Labs Arduino Core library. Check the release notes.)
- What else would you add to this project?

WHAT'S NEXT?

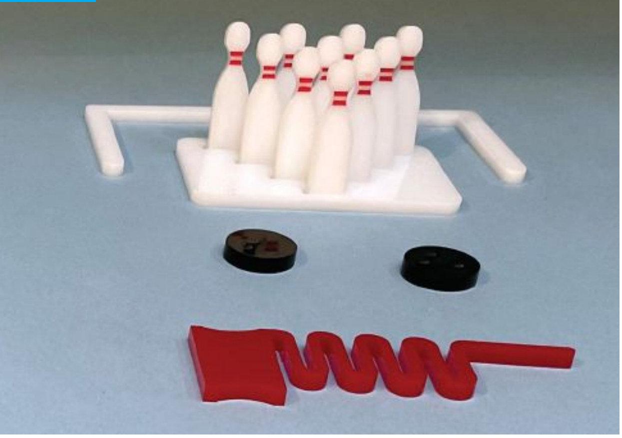
Matter for makers has improved a lot in the last year! But there's lots more to do — support of more development boards for both Wi-Fi and Thread, certifying as an approved Matter implementation, qualification testing with the various home automation products on the market — and we need more example projects to help people get started with their own designs.

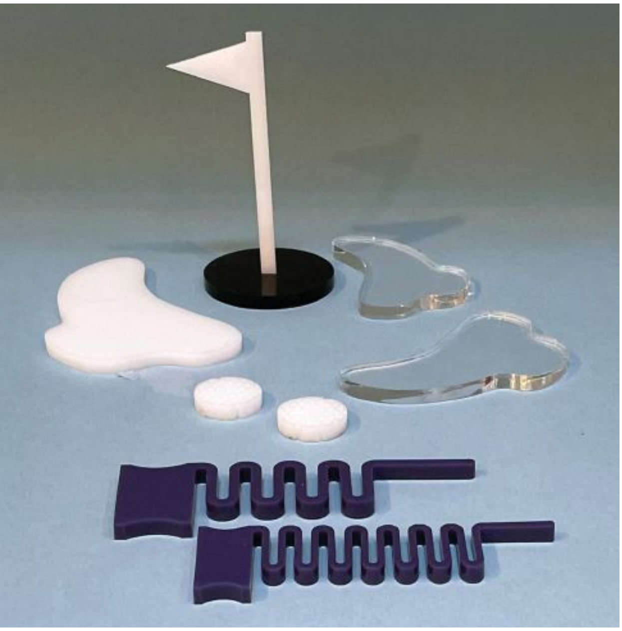
If you want to build your own Matter device, we've shown two possible approaches:

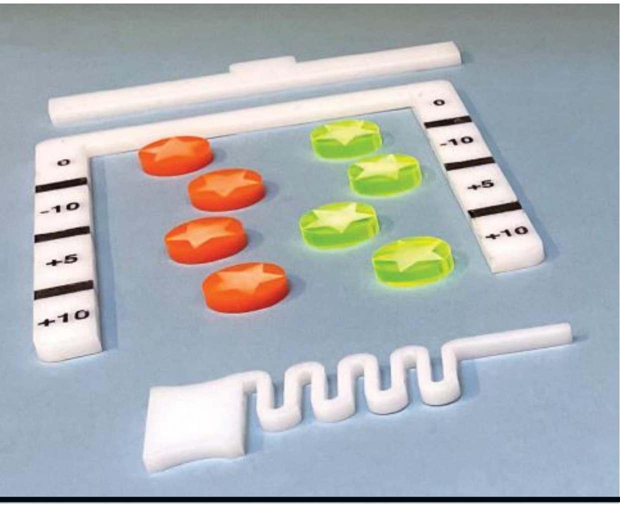
- ESP32 Wi-Fi with Tasmota: inexpensive, easy, limited to the components known to Tasmota.
- Sparkfun Thing Plus Matter: more expensive, Thread only, unlimited possibilities leveraging the Arduino world.

There are more board choices to look at — Arduino Nano Matter, Seeed Xiao ESP32C6 —and more programming languages and development tools to choose from. Want to implement a Matter device in Python? CircuitPython Matter (github.com/adafruit/CircuitMatter) is available and includes some useful examples.

We'll keep exploring. Meanwhile, the *Make:* community looks forward to learning about your Matter project at makezine.com/go/discord.







Flat Flicker Games

Make these mini tabletop games from a single piece of acrylic!

Written and photographed by Bob Knetzger

TIME REQUIRED: 30 Minutes

DIFFICULTY: Easy

COST: $2

MATERIALS
- » **1/4" acrylic sheet**
- » **Acrylic paint (optional)** if desired
- » **Chipboard**

TOOLS
- » **Laser cutter**
- » **Paintbrushes (optional)**

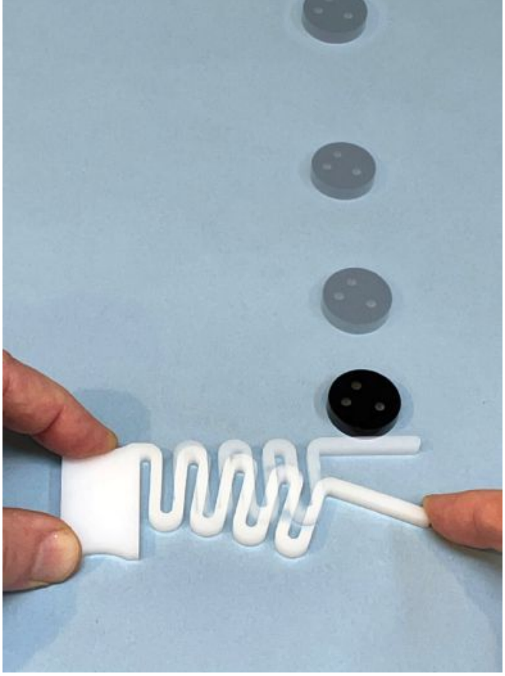
BOB KNETZGER is a designer/inventor/musician whose award-winning toys have been featured on *The Tonight Show*, *Nightline*, and *Good Morning America*. He is the author of *Make: Fun!*, available at makershed.com and fine bookstores.

With a laser cutter you can easily make three different games for lots of fast, flicking fun! When the games are over, the components store neatly in a flat, fold-up folio.

Each Flat Flicker game uses a simple flexible "flicker." The back-and-forth design acts as a folded leaf spring, transforming normally stiff and brittle acrylic into a strong and bendable spring.

Hold the flicker flat on the tabletop and bend the tip of the spring. When you release the spring, it flicks back, shooting a disk across the table. Bend a little for a soft and short shot. Bend a lot for a fast and strong shot. Aim your shot by holding the flicker perpendicular to the desired trajectory.

Try your flicking skills these in one- and two-player games:



FLAT FLICKER BOWLING

Tabletop bowling action for one or more players. One piece of acrylic makes all these game parts: ten pins, two "balls," pinsetter, pit, and flicker (Figure A).

MAKE!

Go online to makezine.com/go/flat-flickers to download the SVG cutting files. I used ¼" acrylic so that the flat bowling pins would stand up on edge and be easy to knock down.

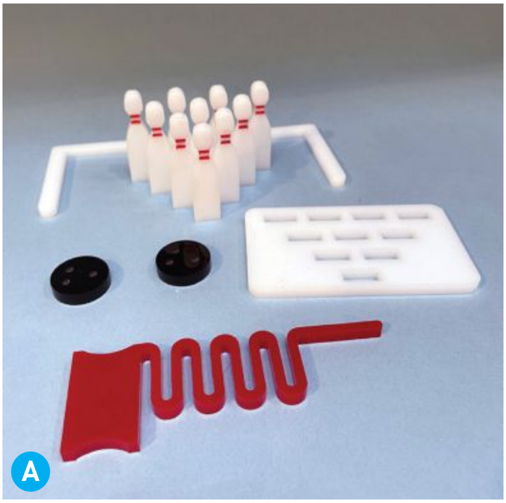
DECORATE!

Leave all parts just one color, or decorate some with paint for a fancy look. I used acrylic paint to add the bowling pins' iconic red stripes. Dab or brush the paint into the recessed, etched features, then wipe off the top surface with a paper towel. Just don't paint the back surfaces of the game parts — you want smooth sliding action.

If you're feeling really fancy, cut different game parts out of different colors of acrylic. I think these black acrylic bowling "balls" and red acrylic flicker look great.

PLAY!

Place the pit (the back of the alley) at one end of the tabletop. Load the pins into the pinsetter and very (very!) carefully, slowly, lift the pinsetter up ... to leave the ten pins standing upright on edge (Figure B).



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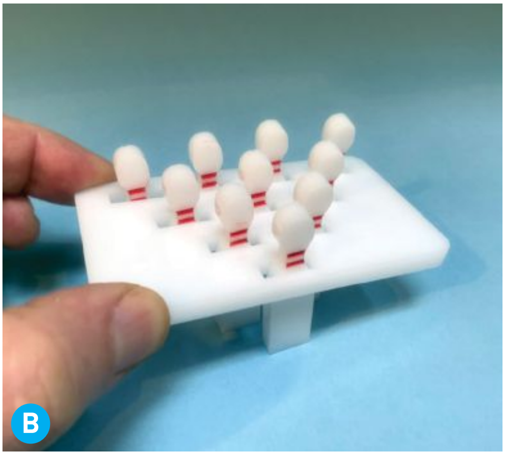

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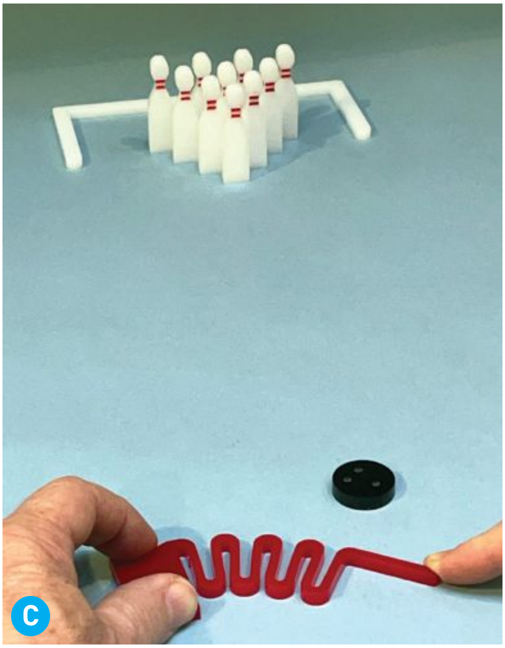
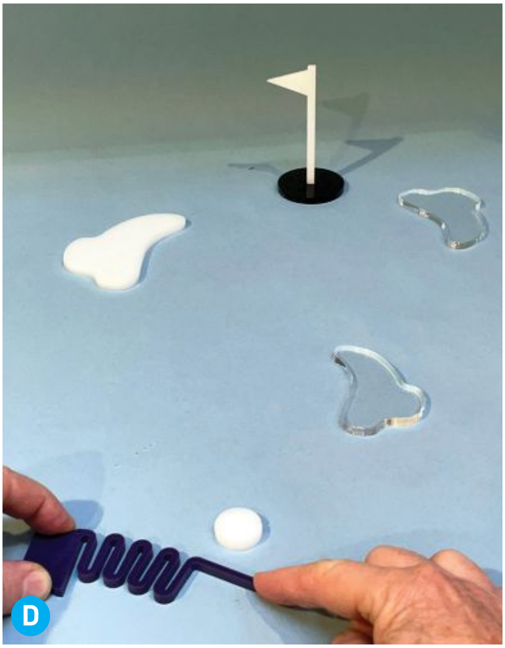
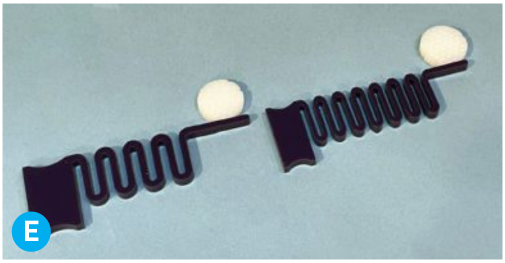




Place the flicker at the far end of the table (Figure C). Bend, aim … and flick! See how many pins you can knock down. Strike! To try for a spare, flick your second "ball" (leave any fallen pins and first ball where they lay.) "Roll" and score 10 frames just like real bowling.

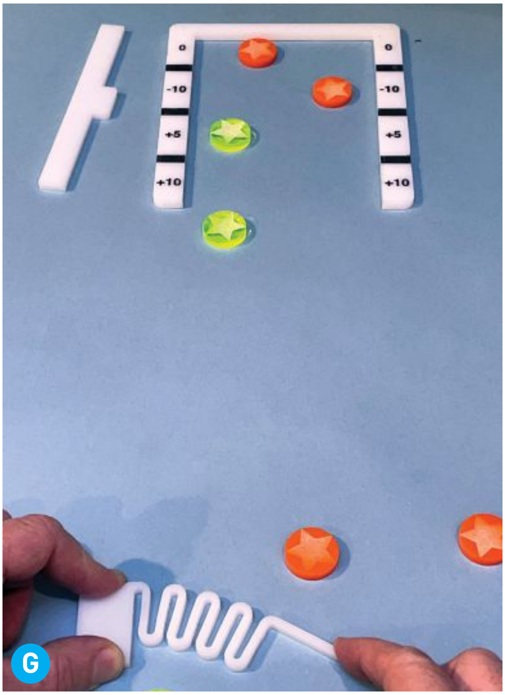


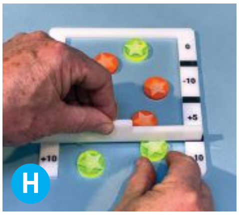
FLAT FLICKER MINI GOLF

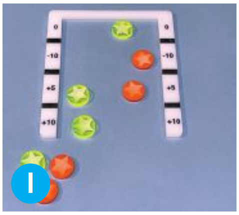
Play this game on a smooth floor. Just like golf, you flick your "ball" to try to hit the "hole" target with the fewest flicks. Place the big disk hole target on the floor across the room and insert the flag. On the other side of the floor, tee up your ball (Figure D) and choose your flicker "club." Use the normal flicker for power and distance. Use the other flicker with longer spring for a softer putt (Figure E).

Hit the "hole" target and the flag will wiggle. Score like golf: Count the total number of shots to hit the target. Then create a new course for the next hole by rearranging the water and sand hazards (Figure F).

TIP: Bank your shots off the water hazards and sand trap, like a mini-golf course.







FLAT FLICKER SHUFFLEBOARD

Tabletop shuffleboard fun for two players! Place the scoring end of the shuffleboard court at one end of the table. Shoot pucks from the other end of the table (Figure G). Take turns flicking your pucks into the scoring areas.

Aim for the most points! Knock your opponent's pucks out of scoring position — or bump your own pucks into the points!

When all pucks are flicked, use the judge bar to check the pucks' position. Hold the bar across the lines between scoring areas, and remove any pucks the bar touches (Figure H). Then add up the points of the remaining pucks (Figure I) and go again (here, green gets 15 points while orange scores –5.) First player to 50 points wins!

STORAGE

When you're done playing, you can store all the game parts in a flat folio (Figure J). Use the leftover laser-cut part as a storage frame. Go online at makezine.com/go/flat-flickers for the pattern of the folio. Cut it out of chipboard, then score and fold.

VARIATIONS

Scale down to make tiny pocket-size versions! I used a Glowforge laser cutter to cut my parts. Its clever, web-based app let me instantly scale down all the parts (Figures K and L). It's also good for rotating or repositioning cutting paths to fit onto odd-sized acrylic sheets. This makes using leftover acrylic scraps really easy.

Think up your own Flat Flicker action games! Flick-Tac-Toe? Flicker Shove-ha'penny? (ask your British friends). Flicker Darts? Whatever Flat Flicker games you come up with will be flickin' great!

50 Dollar Water Turbine

GENERATE 200 WATTS FROM THIS PICO HYDROELECTRIC TURBINE BUILT FROM EVERYDAY MATERIALS

Written and photographed by Daniel Connell

DANIEL CONNELL is an open source low-tech alternative infrastructure designer. He designs and tutorializes things you can make from recycled materials to generate energy, purify water, cook, and communicate. youtube.com/c/OpenSourceLowTech

The $50 water turbine started as a straightforward idea. Flowing water is everywhere, and the energy it carries can be turned into electricity. The challenge was finding a way to do it that's simple, cheap, and useful for people in different parts of the world. A lot of existing pico hydro generators were either too expensive or too complicated to build and maintain, especially for someone without specialized tools or skills. My goal was to make something accessible, something that worked with what people already had or could easily find.

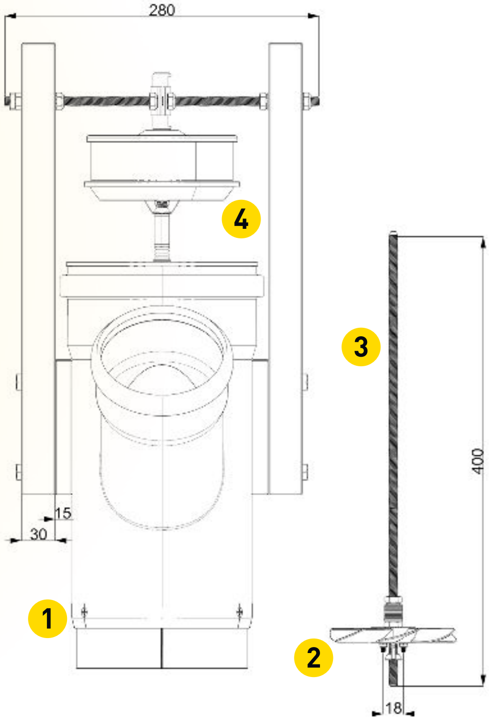
The first version was a metal cone in a barrel hooked up to a motorbike alternator. It worked, kind of, but was clunky and inefficient. The design needed to be smaller, easier to replicate, and cheaper. Over time, through testing in Scotland, Barcelona, and Berlin, it evolved into what it is now: a siphon-action water turbine that produces about 200 watts of electricity (or up to 400 with enough drop and flow, and larger pipe). It's built using off-the-shelf materials like a hoverboard wheel for the alternator, PVC pipe, and a cutting board for the front bearing. Everything can be put together with basic hand tools and a couple of days of effort.

How It Works

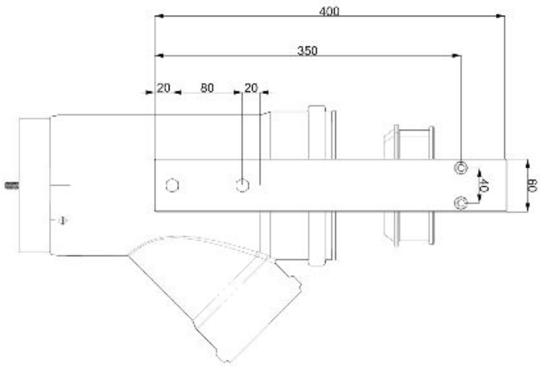
The ***siphon turbine*** works by using gravity and water flow, not high pressure. Water is diverted into a **PVC pipe Y-connector** 1, where it spins an **impeller** 2 mounted on a **shaft** 3 connected to a **hoverboard alternator** 4. The alternator generates electricity as the impeller turns. It's simple, low-tech, and gets the job done. With a 3-meter drop and a flow rate of 20–30 liters per second, the system can produce about 5 kilowatt-hours per day, enough to power about one-third of an average Western suburban home.

This isn't about fancy engineering. It's about creating something that's practical and useful. The materials are cheap and easy to source. A hoverboard wheel can be found secondhand, and the PVC parts are standard fittings. The total cost is $30 to $50, depending on where you're buying parts. It's designed so that anyone can build it, with no prior experience or special skills. For about half the cost of a 120-watt solar panel, this turbine will produce about 10 times the power per day.

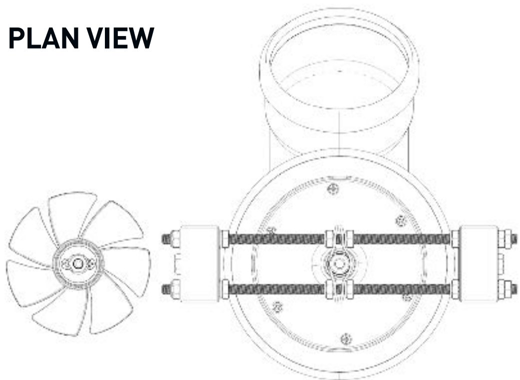
TURBINE FRONT VIEW



SIDE VIEW



PLAN VIEW



Why a Water Turbine?

The potential applications are broad. For people living off-grid, the turbine can power lights, small tools, or a water pump. In rural areas, especially in places like Sub-Saharan Africa or Southeast Asia, it can bring electricity to farms or households that aren't connected to the grid. A lot of these areas have streams or rivers nearby, but running grid power to them isn't practical or affordable. The turbine fills that gap.

One of the biggest advantages is that it works when solar panels might not. During the rainy season, when there's less sunlight, streams and rivers tend to flow more. This makes the turbine a good complement to solar setups, providing consistent power when solar alone can't keep up. Together, they make a hybrid system that's reliable year-round.

The design is also durable. The alternator, originally built for hoverboards, can handle rugged conditions. The PVC and rust-proof components are weather resistant and easy to replace if they wear out. Maintenance is minimal — mostly clearing debris from the impeller and checking for any worn parts. If something does break, the modular design means you can swap out parts without starting from scratch.

For disaster relief, the turbine could be a lifesaver. In areas hit by storms or earthquakes, where grid power is knocked out for weeks, having a small, portable power source could make a huge difference. It could provide electricity for lighting, charging communication devices, or running medical equipment. And because it's so cheap and easy to build, multiple units could be deployed quickly in an emergency.

Even in urban areas, the turbine has its place. Small workshops or off-grid cabins can use it to cut down on electricity costs. It's a practical project for anyone interested in renewable energy, not just people in remote regions. It's also a great educational tool. Schools and community groups can use it to teach about sustainable energy and how simple mechanical systems can solve real-world problems.

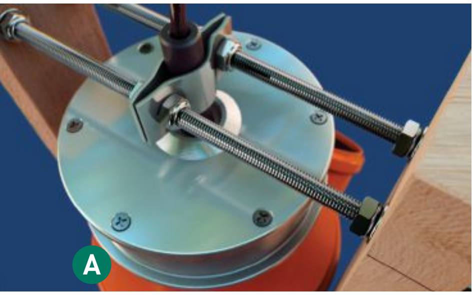
Build Your Own

The open-source tutorial for the turbine is straightforward (opensourcelowtech.org/water_turbine.html). It breaks everything down into steps, with diagrams, photos, and videos to guide the process (Figures A, B, and C). You don't need advanced tools — just a drill, a saw, and some basic hardware. Building it is as much about learning as it is about the finished product. Once it's running, it's reliable and doesn't need much attention. You set it up in the stream, and it works.

The power it produces — 200 watts — is 24/7, so it adds up to enough to run lights and devices, but also tools, basic whiteware such as refrigerators, water pumps, and other low- to medium-power applications. For a small farm, it could run a pump to irrigate crops. For someone living off-grid, it could charge batteries for nighttime use. The electricity is constant, which means it's always there when you need it.

Design Considerations

The inspiration for the turbine came from seeing how limited access to power can be in some parts of the world. Even in regions that have electricity, it often doesn't reach remote farms, homes, and workshops. The idea was to create a tool that people could use to take advantage of the natural energy around them. It didn't need to be perfect; it needed to be practical and affordable.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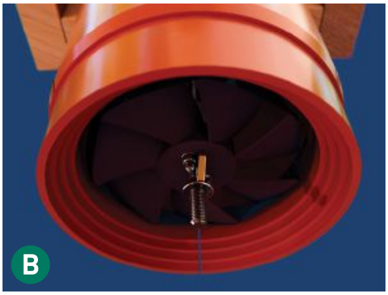
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C

TIME REQUIRED: A Weekend

DIFFICULTY: Easy–Intermediate

COST: $30–$50

MATERIALS

- » **PVC 45° Y connector, 110mm to 160mm size change** Make sure it's *double socket* — with rubber-sealed female connection points on the top and inlet, but not the bottom outlet.
- » **PVC end cap** to fit the top inlet of your Y connector
- » **Computer fan, 120mm, standard seven-blade flat pitch** A stronger fiber-reinforced, high-RPM server fan may be necessary for higher-drop turbine installations, though we will be reinforcing these with heat-shrink.
- » **Battery pack heat-shrink plastic, 180mm flat width** You'll need 50% more than the height of your fan.
- » **Plastic cutting board, 9–10mm thick**
- » **Threaded rod, M8, 1m long** in stainless / galvanized / zinc-coated steel
- » **O-rings, 8mm ID, 2–3mm thick (4)** The fatter the better. You may end up using slightly more or less than four of them.
- » **Wood pieces, about 50mm×15mm×400mm (3)** Best if it's pallet wood or something else that's treated to survive outdoors; if not maybe use weatherproof exterior paint.
- » **Aluminum bar, 2–3mm×24–30mm, 40mm lengths (2)**
- » **Various nuts, bolts, and washers, M8 and M4 sizes** see the complete BOM at the project site opensourcelowtech.org/water_turbine.html

TOOLS

- » **Drill with bits: 4mm, 5mm, 8mm, 10mm, and 12mm**
- » **Tape measure or ruler**
- » **Hole saw, about 34mm**
- » **Hole saw, 16mm** or a spade drill, circle saw, step drill, or anything else that will make a 16mm hole in plastic
- » **Wood saw**
- » **Hacksaw**
- » **Wrenches: 7mm (1) and 13mm (2)**
- » **Metal file**
- » **Computer and printer (optional)** with A4 or US Letter paper. Low quality black and white is fine.
- » **Socket/nut driver, 13mm (optional)**

A big part of the design process was figuring out what materials were easiest to find. PVC pipe is used everywhere, and hoverboard wheels — though they might not seem obvious — are surprisingly cheap and effective as alternators. They're robust, efficient, and designed to handle a lot of wear and tear. The other parts, like the cutting board for the front bearing and the nuts and bolts, are things you can pick up at any hardware store. This approach keeps costs down and makes the turbine accessible to people in different regions.

Testing the turbine in different places helped shape the design. In Barcelona, for example, the focus was on making the turbine more efficient and reliable (Figures D and E). In Berlin, it was about streamlining the build process (Figure F) so that someone with no prior experience could follow the tutorial and get it right. The goal was always the same: simplicity and reliability.

The siphon action is a key part of the design. It uses gravity to pull water through the system, creating enough flow to spin the impeller without needing a lot of pressure. This means you don't have to build a dam or deal with complicated plumbing. A small stream with a modest drop is all it takes.

One of the most satisfying things about this project has been seeing how adaptable it is. The turbine isn't a one-size-fits-all solution; it's more of a starting point. People can modify it to fit their needs, whether that's increasing the flow rate for more power or adjusting the setup to work with different types of alternators. The open-source tutorial encourages this kind of tinkering, and it's been great to see people take the basic idea and run with it. During testing in Kathmandu, we found that a 3D-printed impeller in the shape of a simple Archimedes screw produced even more power (Figure G).

Exploring Clean Energy

This pico turbine is more than just a machine. It's a way of thinking about energy and resources. It's about looking at what you have, figuring out how to make it work, and creating something useful. It's not just for people in remote areas or off-grid communities. It's for anyone who wants to explore what's possible with simple tools and materials.

This kind of innovation is important because it's scalable. A single turbine can power a small home or workshop, but multiple units could support a whole community. For example, a village could use several turbines to charge a battery bank, providing consistent electricity for shared tools, lighting, or refrigeration. It's not about replacing the grid; it's about filling in the gaps where the grid doesn't reach or isn't reliable.

The environmental impact is also worth mentioning. The turbine doesn't burn fuel or produce emissions. It's powered entirely by water flow, making it a clean and renewable energy source. It's not going to save the planet on its own, but it's a small step in the right direction. And because it's made from common materials, it doesn't require a lot of energy to produce.

Building the turbine is a project that anyone can take on, whether you're an engineer, a farmer, or a student. It's a way to learn about mechanics, electricity, and sustainability in a hands-on way. And once it's running, it's a tangible reminder of what you can do with a bit of effort and creativity.

DIY Turbines in the Wild

The turbine has already made a difference in the places where it's been tested and used. In Guatemala, it helped power a fish farm that previously relied on expensive and unreliable fuel-based systems. In Scotland, it's been used to charge batteries for off-grid workshops. These are small steps, but they show what's possible.

The $50 water turbine isn't going to change the world overnight, but it's a tool that can make life better for people who use it. It's proof that you don't need a big budget or fancy equipment to create something that works. And while it's not perfect, it's a step toward making renewable energy accessible to everyone, everywhere.

It's a reminder that sometimes the best solutions are the simplest ones. It's not about reinventing the wheel; it's about taking what's already there and finding a way to make it useful.

$50 Water Turbine playlist on YouTube: makezine.com/go/pico-hydro

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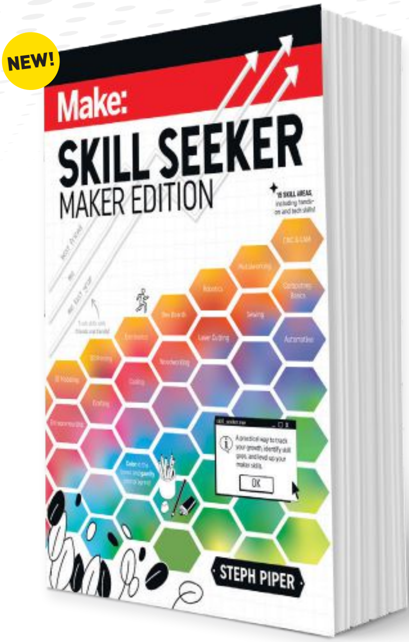

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By Steph Piper

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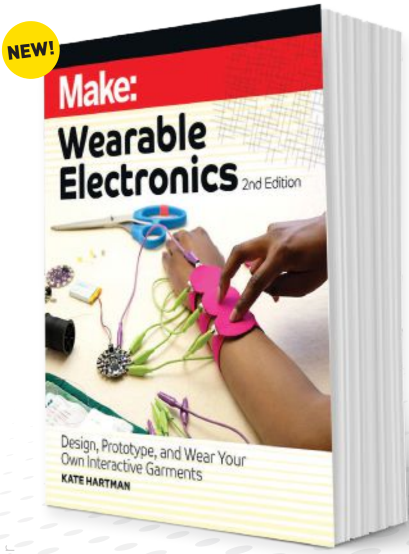

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By Kate Hartman

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ALL ABOUT SMA CONNECTORS

Wi-Fi, radio, high-frequency data — it all goes through these gigahertz coaxial connectors

Written and photographed by Forrest M. Mims III

A An assortment of commonly used SMA connectors for high-frequency signals up to 25GHz.

AN SMA MINI COURSE

If you've used Wi-Fi, broadband, software defined radio (SDR) gear, or other wireless video, radio, or microwave devices with removable antennas, you are probably familiar with the coaxial connectors they employ.

SMA connectors are the most common coax connectors for today's high-frequency gear (Figure **A**). ***BNC connectors*** are used for lower-frequency applications from DC up to 4GHz (Figure **B**). SMA connectors have considerably less signal loss than BNCs, and can be used from DC up to around 25GHz, which makes them essential for internet applications.

Below 4GHz, the only advantage of BNCs over SMAs is accessibility. For example, the front panel on my oscilloscope has a pair of female BNC connectors. The cables of the scope's probes are

FORREST M. MIMS III, an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." His books have sold more than 7 million copies. forrestmims.org

terminated with male BNC connectors that can be quickly plugged into the front panel connectors and secured in place with a quarter-twist.

SMA connectors are smaller, and they're threaded, which greatly reduces the signal leakage that BNC connectors experience. But they require half a dozen twists to connect them. Furthermore, SMA connectors have a typical lifetime of only 500 uses. BNC connectors have a much longer lifetime.

SMA connectors are required for high frequency applications and in applications where their small size is important. They must be twisted tightly together to form a connection, but once connected they can efficiently transfer very high frequencies with very little leakage. While they can be temporarily tightened by hand, they are usually tightened by means of a special SMA wrench.

Both types of connector come in two "genders." Male connectors are terminated with a ***pin***, designed to slip into the hollow ***sleeve*** of the female connector. The two connectors are pushed together to establish a connection, then twisted in place.

The pin of a male SMA connector is centered inside a highly insulating ***dielectric***, a cylinder of PTFE (Teflon), inside an internally threaded, cylindrical housing. Female SMA connectors have a hollow conductor centered in a PTFE cylinder installed in an externally threaded cylinder. The dielectric in a BNC connector is either air or plastic.

TYPES OF SMA CONNECTORS

Because the market for SMA connectors has grown significantly, you can find comprehensive articles about them in product catalogs and online. For example, *EverythingRF* describes the most common kinds at everythingrf.com/community/sma-connectors.

Here are some of my favorites:

Basic SMA connectors: Inline brass and stainless steel male and female SMA connectors are by far the most common. Several are shown in Figure A. The male version has an internally threaded hex nut fairing that provides for tightening onto the external threads of the female.

B BNC connectors are used for lower-frequencies up to 4GHz.

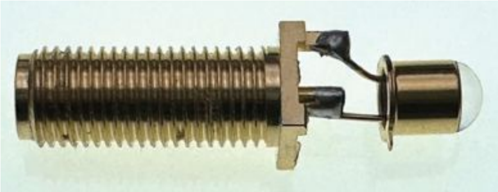
While the male connector is ordinarily positive and the female negative, ***reverse-polarity*** connectors are also available. While these are not often used, watch out for them when troubleshooting a circuit you did not build or design. While a reverse-polarity SMA connector might mate with a standard-polarity connector, the mismatched polarities will keep the connection from working properly.

Most SMA manufacturers recommend carefully tightening SMAs to one another with a torque driver or wrench designed for that purpose. While I sometimes prefer to tighten them by hand, I have learned the hard way that hand-tightened SMAs may eventually loosen enough to break the continuity between the two connectors.

Right-angle SMA connectors: Right-angle versions of basic SMA connectors are readily available. They are especially useful inside crowded circuits.

SMAs with external terminal connections: Both straight and right-angle SMA connectors are available with external, solderable connection pins at one end. These exposed pins can be soldered to an SMA-terminated mini cable or a second SMA connector having the desired polarity. Some SMA connectors have external pins in a 2×2 row designed to be soldered to the edge of a circuit board.

An especially useful feature of SMA connectors with solderable end terminals is that an external component such as an LED, resistor, or even a battery holder can be soldered across the



C LEDs and other components with wire leads can be soldered to SMA connectors with terminal pins.

D Mini-cables with SMA terminations are easily connected with a twist.

Forrest M. Mims III

terminal pins.

Figure C shows an LED soldered to the terminals of an SMA connector. I made this connection by first clipping off three of the SMA's four base terminals and holding the SMA on my workbench with a spring-driven clothespin. I then used a fine-tipped soldering iron to apply solder to the central pin, the remaining SMA base terminal, and the LED leads. While the LED was held in place with the appropriate lead touching the remaining SMA base terminal, I carefully used the soldering iron to simultaneously melt the solder on both the LED lead and the base terminal. I then repeated this step with the second LED lead and the SMA's center terminal.

SMA APPLICATIONS

SMA connectors are widely used to interconnect video and wireless computer systems. They are also used with SMA-terminated cables to connect antennas to high-frequency microwave systems such as Wi-Fi and Bluetooth (Figure D). They have two key advantages over other kinds of connectors:

1. Both the input and output of SMA connectors are threaded. As noted above, this means very high frequency signals cannot leak from the connection after it has been tightened.
2. Threaded SMA connectors provide a firm grasp with one another, which means they can withstand vibration and stress when properly tightened. Even if an SMA connection is very tightly pulled, the wires or cables being connected might break before the SMA connector does.

Though SMA connectors were originally designed for microwave frequencies, they can also be used to interconnect many kinds of low-frequency circuits and even batteries and power supplies. I have built several circuits in which a battery pack and both inputs and outputs were connected by SMA connectors.

Many preassembled circuit boards employ SMA connectors for inputs and outputs. Figure E shows a typical example, a single-board AD5304 logarithmic converter with an SMA output connector.

While the vast majority of SMA connectors are used to terminate wires or circuit board pads, some are designed to couple optical fibers. These connectors are mainly used with plastic fibers. Based on personal experience, SMA-coupled plastic fibers are much easier to implement than using cement and heat-shrink tubing.

SOME PRACTICAL SMA TIPS

1. Always be sure to fully tighten an SMA connector to its partner. Most SMA manufacturers recommend using an appropriate SMA wrench. Be aware that under-tightening by hand may eventually result in a broken connection, and that over-tightening with a wrench may damage the connector.

E Many preassembled miniature circuit boards, such as the AD5304 logarithmic amplifier shown here, are equipped with SMA terminals for input, output, or both.

2. Be sure to use the correct SMA connector. For example, a male SMA must only be connected to a female. While the erroneous connection might appear to work, there will be no electrical connection inside a pair of incorrectly connected connectors.
3. Remember that some SMAs have reversed genders (polarities). This is especially important if you are servicing an existing system with SMA connectors.
4. Avoid using several SMA connectors in a chain. One circuit that I built required that an LED soldered to an SMA connector be connected to an SMA on a circuit board. I tried using a mini cable terminated with SMA connectors, but it wouldn't bend enough to fit. So I tried the ladder-like connection with four SMAs shown in Figure F. While this approach nicely fit inside the circuit's enclosure, it was impossible to fully tighten all four SMAs to one another in the available space. I had to reassemble the circuit to provide space for an SMA cable.

F Too many SMAs: While this arrangement was designed to interconnect two closely spaced boards, I eventually replaced it with an SMA-terminated mini-cable, since tightening all these SMAs was difficult!

BNC AND SMA INVENTORS

Let's close this article by crediting the engineers who played key roles in interconnecting today's high frequency and broadband electronics.

The BNC connector was patented in 1951 by Dr. Octavio Salati of Hazeltine Electronics Corporation. He simplified the threaded ***N connector*** developed earlier by Paul Neill of Bell Laboratories and the quick-release ***C connector*** invented by Amphenol's Carl Concelman. The new connector was designated ***BNC*** after Bayonet-Neill-Concelman.

You can learn more about the history of BNC connectors in a Hackaday article by Dan Maloney (hackaday.com/2018/10/19/the-bnc) and a Botland article by Sandra Marcinkowska (botland.store/blog/bnc-connector) — though this history is not without controversy, writes electrical engineer Davide Andrea (reddit.com/r/rfelectronics/comments/lwa9tc)

SMA connectors were developed under the leadership of Dr. John H. Bryant at Bendix Research Laboratories Division from 1955 to 1962. Existing coax connectors were unsuitable for miniaturization of microwave circuitry used in spacecraft and other applications, so Bryant organized a team that developed mini connectors for microwave circuits. In 1968, their microwave-compatible threaded connectors were formalized as the ***SMA (subminiature version A)*** standard we still use today.

In 1996, Bryant received the highest award given by IEEE's Microwave Theory and Technology Society, "for leadership in the miniaturization of microwave circuits and interconnections, and for pioneer historical research on radar and the work of Heinrich Hertz." Now we makers can rely on Bryant's invention to enhance ours.

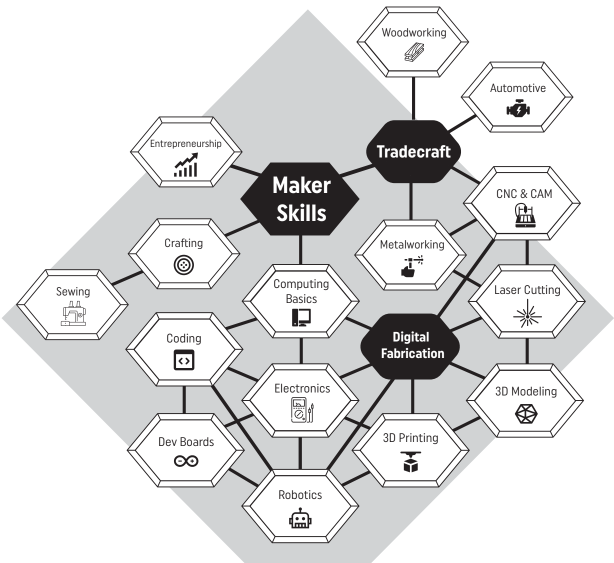
LEVEL UP!

Use a video game-style skill tree to develop your real-world maker and life skills

Written and illustrated by Steph Piper

There is a certain magic in learning a new skill and making something from scratch. Trying new things is a challenging and rewarding habit to build, making us more capable along the way. What if every skill we learned could be visualized on a video game dashboard, with a path to future goals revealed? My book *Skill Seeker* aims to do just that, with a collection of 15 video game–inspired "skill trees" that lay out a set of milestones for a range of skill areas.

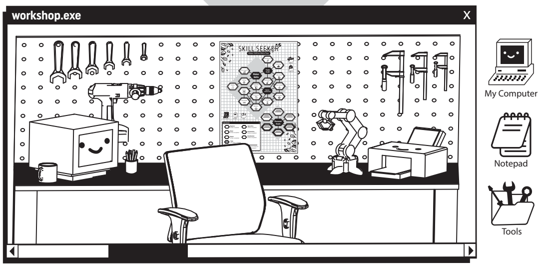
To use a skill tree, you color in the tiles of anything you've already completed. Start at the base of the skill tree and work your way up, moving from basics to advanced skills. With 73 tiles per tree, these are designed to meet you wherever you are on your journey. Get the satisfaction of coloring in the boxes and visualize how far you've come. Identify your skill gaps and get inspired to try new things. You don't have to complete things in a set order, and not every tile needs to be completed. There's no time limit for completion; work at your own pace and customize the base skill trees to suit your personal journey. Calculate your Maker XP score and show off all your skills in a video game dashboard.



This book gives just enough detail as a starting point for you to check the glossary, search, and find out more. Each tile is best used as a springboard for connecting with expert friends, searching how-to videos, attending workshops, and guiding your progress. All skills are aimed at hobbyist level, for adults, young adults, and secondary students as they grow.

I hope you enjoy using *Skill Seeker* as a reflective tool toward becoming your future self while enjoying the journey along the way. You'll try things you might not otherwise, and experience skills that connect us to a past humanity, current practice, and the future skills that will make you more capable and ready for challenges to come.

Happy Skill Seeking!

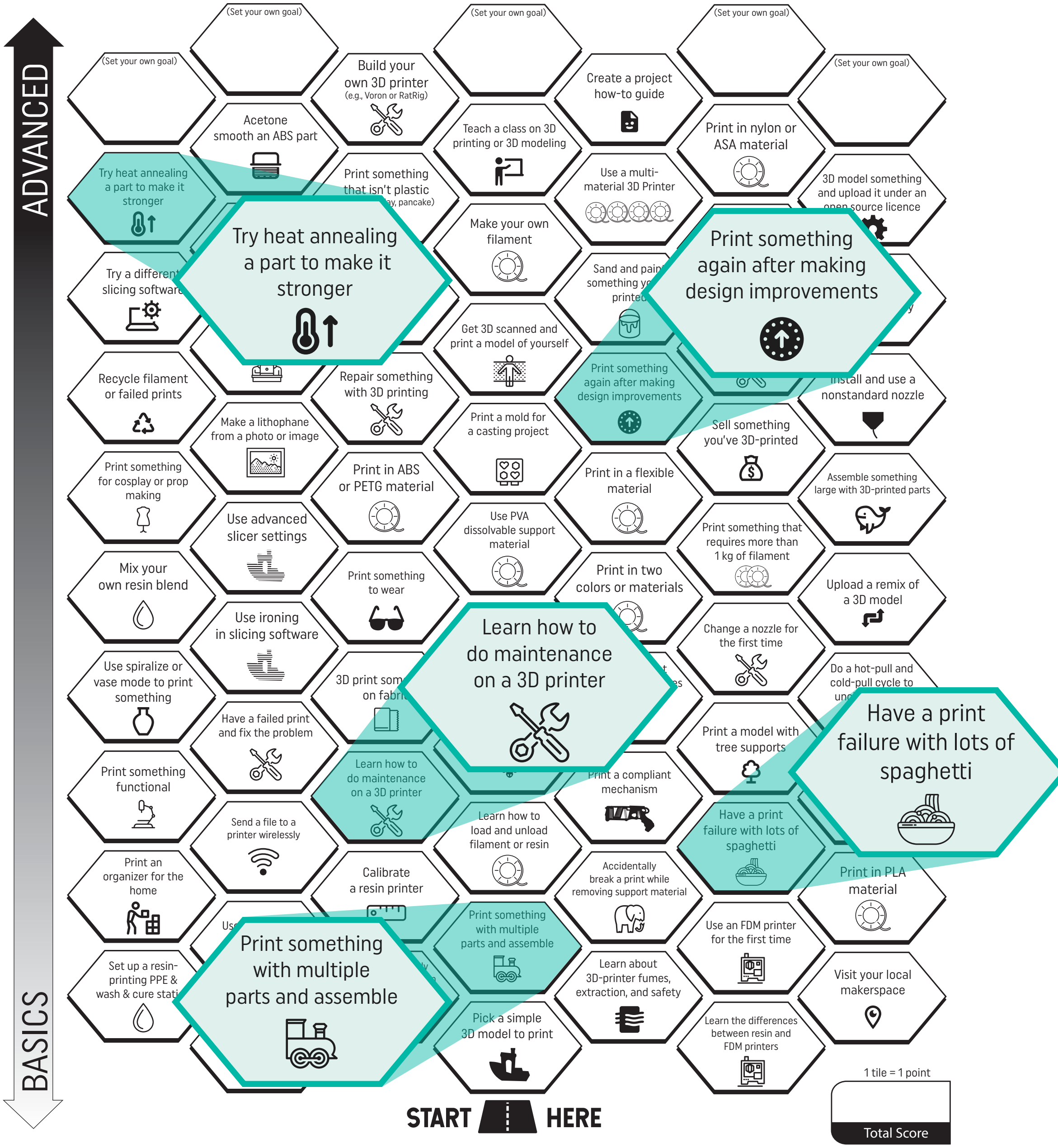


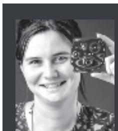
This is an excerpt an from the new Make: book ***Skill Seeker: Maker Edition***, available now at the Maker Shed (makershed.com) and fine booksellers.

3D PRINTING

• Skill Tree: Color in the Boxes •

Color in the boxes of anything you've already completed, visualize your skills, and identify your skill gaps.
Get inspired to try new things, and tailor the skill tree to suit your own journey by swapping in your own goals.





STEPH PIPER is a creative technologist who is passionate about making it easier to learn new skills. She's a makerspace manager at a university library in Queensland, Australia, and has created electronics kits that are now sold globally under the brand name Maker Queen.

DIGITAL FABRICATION EDITION

MORE INFO! For an extended, in-depth version of this review visit makezine.com/go/mk4s-review.

Prusa MK4S

$1,099 assembled, $799 kit, $99 upgrade kit (for MK4) prusa3d.com

Historically, the "S" model upgrades for both the MK2S and MK3S focused on improving reliability, durability, and ease of maintenance. The MK4S is no different with a batch of upgrades that translate into improved print quality, faster print speed, and quality-of life-improvements. On paper, the bed-slinging MK4S is on par with the total print times of popular Core-XY printers touted for such high print speeds. The MK4S features:

- **High-flow nozzle** — The custom-designed Core Heating Technology (CHT) nozzle works with both specialty high-flow filament and regular filament.
- **360° cooling system** — A large fan combined with a 360° shroud can cool particularly challenging overhangs at angles up to 75°!
- **Enhanced connectivity and mobile app** — While the MK4S works both offline and over Wi-Fi or Ethernet, the Prusa Connect app allows users to kick off prints from a browser, schedule print jobs, and remotely monitor the printer via a connected webcam.

As I pushed the MK4S's higher speeds to filament materials other than PLA, it was obvious that high-temperature materials need to be printed in an enclosure. PETG parts were stunning; however, larger prints exhibited some delamination from both the textured and satin bed sheets.

Was it a perfect experience? Almost! The only issue I ran into was with the load cell warning me of stuck filament. After my first few successful PLA prints, I received false-alarm warnings that stuck filament had been detected. I anticipate that this will be addressed in future firmware updates.

The Prusa MK4S high-flow CHT nozzle combined with the 360° cooling system offers improved print speed and quality compared to the already impressive Prusa MK4. Ease-of-use enhancements such as the Prusa app and Wi-Fi setup via NFC tap make the setup process a breeze. The current pricing is higher than some Core-XY competitors; however, the $99 upgrade is a no-brainer for existing MK4 owners.

—Ryan Priore

xTool P2

$4,999 xtool.com

Outgrown your Glowforge but aren't ready for a full-size laser cutter? The P2 is the laser for you.

Unlike most xTool lasers, the P2 isn't a diode, it's a 55W CO_2 laser which can cut through clear acrylics and thicker materials that a diode can't. It boasts a cutting area of 26"×14" plus an optional pass-through for a whopping 26"×118". Built-in cameras make alignment of designs to materials super easy, and laser auto-focus takes care of different material heights.

Optional accessories make the P2 even more powerful: a rotary for engraving curved objects, a riser for swapping between rotary and flat jobs, a conveyor for the pass-through that automatically feeds large workpieces, even an optional air filter so you can run your P2 without exhausting outside.

No need to buy extra software — the P2 works out of the box with xTool Creative Space. You can control it from your Windows or Mac computer, or Android or iOS devices.

Having been used to 40W lasers, I found the 55W P2 powerful and capable of quickly cutting through any reasonable materials I tossed at it. While I really liked the riser for its ability to swap between flat materials and the rotary, I do wish it was a little better built, like the P2 itself. It's a bit flimsy during setup but is fine after.

Overall the P2 is a really well thought-out machine that shows a great evolution of the desktop laser cutter. *—Matt Stultz*

Saturn 4 Ultra

$524 elegoo.com

In the past, resin printers always came with big tradeoffs: big, fast, or cheap — you can have one. With the Saturn 4 Ultra, those days are gone.

The Saturn 4 Ultra is a MSLA printer featuring a build volume of 218.88×122.88×220mm with a 12K mono screen. This means you have a larger build volume than a Prusa Mini or a Bambu A1 Mini but with a print detail that an FDM machine can't begin to touch.

With the addition of a tilt vat system, the Saturn 4 Ultra is fast too. Most MSLA machines on the market use the Z-axis alone to lift the print away from the bottom of the vat. This needs to be done slowly to prevent surface tension from ruining prints. The tilt system peels the print away at an angle, reducing the force required to dislodge it from the vat film. This tilt can be done much faster than moving the entire Z axis, speeding up the entire print.

The Saturn 4 Ultra also includes automatic bed height adjustment and calibration, built-in camera (with a questionable AI component), a resin sensor, and a hinged lid that doesn't require full removal like many other resin printers.

If you are looking to get into resin printing or looking to upgrade your current setup, the Saturn 4 Ultra is *the* machine to go with right now. *—Matt Stultz*

xTool F1

$1,999 xtool.com

The phrase "small but mighty" might have been created to describe the xTool F1. Fully enclosed, it will only take up a small corner of your desk while still giving you dual blue and IR diode lasers. If you're a craft person looking to take a laser to events to personalize items during the event, keep reading, because you've found your laser.

While the cutting area of the F1 isn't large, it's capable of cutting to the majority of its footprint thanks to its mirror-based galvanometer laser instead of traditional XY gantry-based lasers. Galvos use two mirrors that rotate back and forth to bounce the laser beam between them, drawing shapes quickly. This is the same kind of system used for laser light shows but the F1 employs it with its dual diodes to engrave a wide range of materials.

The working area is enclosed by green laser-blocking acrylic, and a fan in the back of the unit provides ventilation to the provided hose.

Want to engrave something too large to fit in the machine? No problem, simply remove the base plate from the F1 and set the whole unit on top of the item you wish to engrave. The F1 adjusts the head of the unit up and down with a motor allowing you to tune in focus to nearly any thickness of material.

Optional accessories include a rotary attachment for engraving on round items such as glasses and tumblers, along with a slide platform for batch production of items.

The F1 uses the intuitive xTool Creative Space for software, but since this machine is G-code based, other software options are available too. You can control the F1 via USB or connect over Wi-Fi, allowing you to run the machine from your phone or tablet, which combined with the built-in top handle makes the F1 perfect for operation on the go. —*Matt Stultz*

TOOLBOX

GADGETS AND GEAR FOR MAKERS Tell us about your faves: editor@makezine.com

EM-Smart One

$2,599 em-smart.com

Like so many things in the digital fabrication world, the cost of fiber lasers is coming down and making the technology accessible to makers everywhere. At the press-time sale price of $1,699, the EM-Smart One brings 20W of metal etching and cutting power to your hands at the price of a desktop 3D printer 10 years ago.

Cutting and etching metals with the EM-Smart One was quick and easy. Fiber galvos kind of feel like magic as you don't see any moving parts or visible beams, images just seem to appear on your items.

It's worth noting that like many fiber galvo lasers, this machine does not come with an enclosure, so safety glasses are a *must* for anyone in the room while this machine is operating.

Setup of the EM-Smart One is the one place where this machine fell down. There were multiple included configuration files to import without clear instructions as to which to import. Even when I found the right one, some of the settings were not correct and required me to go back in and adjust them to get the machine working properly. Luckily, you don't have to change those settings again.

The One is a great starting point for fiber lasers, but EM-Smart has a whole line of machines with many options to choose from. Maybe in the future we can show you what a MOPA can do! —*Matt Stultz*

The Inventor's Workshop: How People and Machines Transformed Each Other

By Ruth Amos, illustrated by Stacey Thomas

$23 Harry N. Abrams

There's a secret world of creativity that's lost to time, the result of finished products obscuring the people and ideas that built the world around us. *The Inventor's Workshop* shines a light on this world, tracing the development of everyday items such as phones, bicycles, and engines to reveal how curiosity and iteration form the path of progress.

This engaging children's book teaches how success is never a straight line: it's a relay race of curiosity, experiments, and new perspectives — with the baton constantly changing hands — that continuously advances a shared goal.

Yes, the intricate illustrations filled with fun little details make you want to savor each page. And mini profiles add context explaining how inventors fit into the complex web of history, particularly highlighting those whose contributions often fall outside the margins of school books.

But much like the creations highlighted in their book, *The Inventor's Workshop*'s real magic comes from how Ruth and Stacey's individual efforts build on each other to create something more than what they could achieve alone. —*Kevin Toyama*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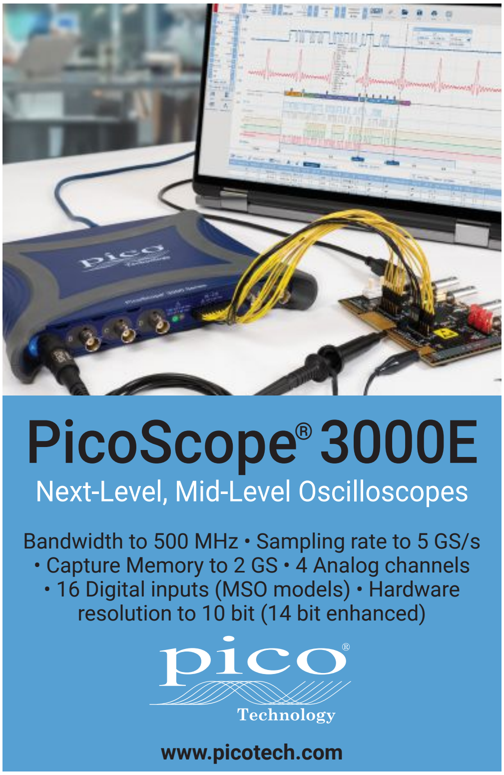
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OVER THE TOP

Carlo Cantavalli

COOKIN' DERBY

Pinewood derbies have been a staple of the Cub Scouts since the 1950s and Nerdy Derbies are a Maker Faire favorite, but I've never seen a variation quite like the Electric Hot Dog Derby at Maker Faire Bay Area this last year.

"Fundamentally, it's just a fancy pinewood derby track," said creator Andrew Leung — but with cars that cook weenies along the way. Each 3D-printed car has about 100 thumbtacks that poke into the hot dogs, and aluminum wheels that draw current from the track through induction to zap them on their way to the finish line.

"I used copper tape to create what effectively is about 90 feet of exposed wire along the length of the track in all three lanes," Leung said. "Electricity passes through the wheels into the spikes and through the hot dog."

A microcontroller from Adafuit controls the full setup, releasing the starting gates at the top and using IR sensors at the bottom to determine a winner. A large 7-segment display tracks the winning time and finally a taser activates at the finish line to give the hot dogs a little extra sear and a satisfying auditory end to the race.

"The reaction was better than I could have imagined," Leung said. "Everyone really liked it, even people just walking by would laugh when reading the sign. The concept alone is pretty funny, and that's before getting a crowd of people together to cheer on their favorite hot dog."
—Craig Couden


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