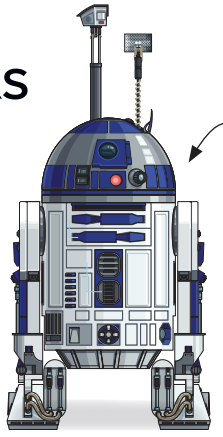
BLASTER MASTERS: 3D Printing Nerf Hacks

Make:



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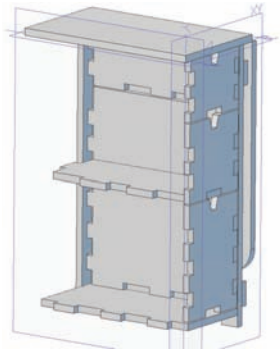
Making a Tiny Table for a Tiny House on the ShopBot Desktop MAX

2' x 4' sheets of spruce fit easily on the Desktop MAX

Sanded and all ready for staining (light walnut color)

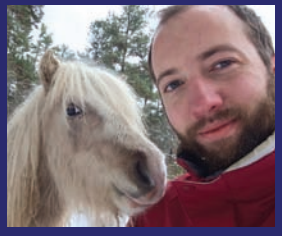
Both Brian and his friend were thrilled with the result



Necessity being the mother of invention, Brian Owen recently helped solve the problem of furnishing a friend's backyard cabin with a table. His friend described the specs dictated by the small home: "No deeper than a computer desk, long enough to seat four friends, but not so long that I can't get by to get to my bed; drawers for hiding things that my infant grandson shouldn't be grabbing; enough space to fit my wheelchair under the table."

Brian said, "I quickly realized such a table didn't exist. So I set out to design and make one!" Brian's day job at ShopBot Tools gave him access to ShopBot's latest CNC innovation, the ShopBot Desktop MAX.

Who: Brian Owen
Where: Durham, NC
Tool: ShopBot Desktop MAX



Brian Owen and Spirit

Read Brian's story about his process at ShopBotBlog.com

"I recalled a table that I'd seen in a children's furniture store, a short table with two drop-leaf ends that could be folded up and tucked into a corner for easy storage. I took the drop-leaf idea and decided to add stability by substituting the normal pull out support with a swing out table leg."

The ShopBot Desktop MAX is ShopBot's answer to customers' requests for a larger version of the popular ShopBot Desktop. Its work area is twice that of the Desktop; this allows for entire parts and products to fit on the bed. The standard aluminum bed is removable, enabling end-machining; a vacuum hold-down bed is an option, too. Brian noted, "This is a powerful and precise CNC tool, and still works on standard household electrical power."

ShopBot Desktop MAX work area: 36" x 24" x 5.5"

What do YOU want to make next? Consider the power, precision, and relatively small size of the ShopBot Desktop MAX. See the full specs and video of the tool in action at our website, then give us a call to discuss your production needs. If you can dream it, you can make it!

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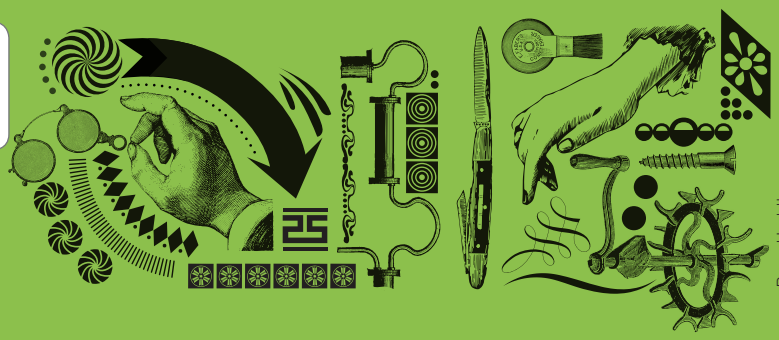

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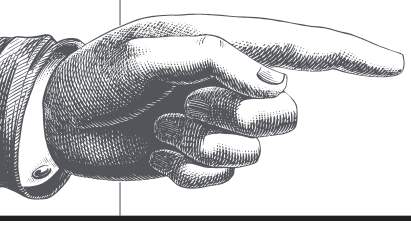

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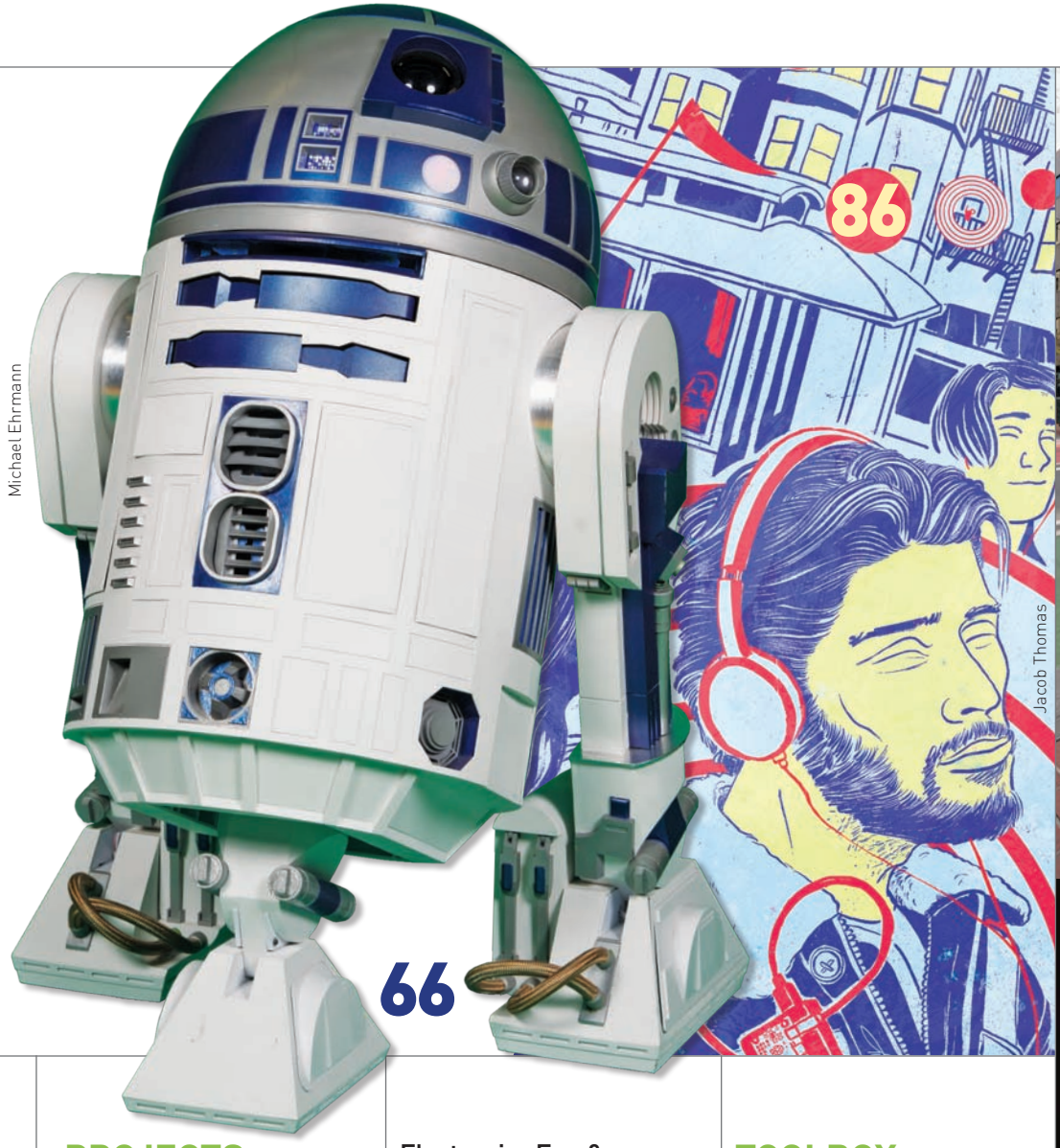

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Make:®

"For the things we have to learn before we can do them, we learn by doing them." — *Aristotle*

"Just YouTube it!" — *Your 14-year-old neighbor*

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What Maker-style skill do you predict will become required learning in schools in the near future?

Kipp Bradford
Pawtucket, Rhode Island [Void Your Warranty]

Core knowledge isn't changing. People still need to learn reading, writing, math, science, politics, history, etc. Instead, Maker skills are teaching tools to make current education more engaging.

Carla Bruni
Chicago, Illinois [What's the Drill?]

Shop class and construction skills. There's a massive shortage of skilled labor and many high schoolers and recent grads need work. Trade work can't be outsourced.

Kathy Ceceri
Saratoga Springs, New York [Flexible Fabricating]

All kids need to know how to troubleshoot. Understanding that there are steps you can take to figure out and solve problems encourages resilience, creativity, and a growth mindset.

Ryan Huddle
Somerville, Massachusetts [Skill School Illustration]

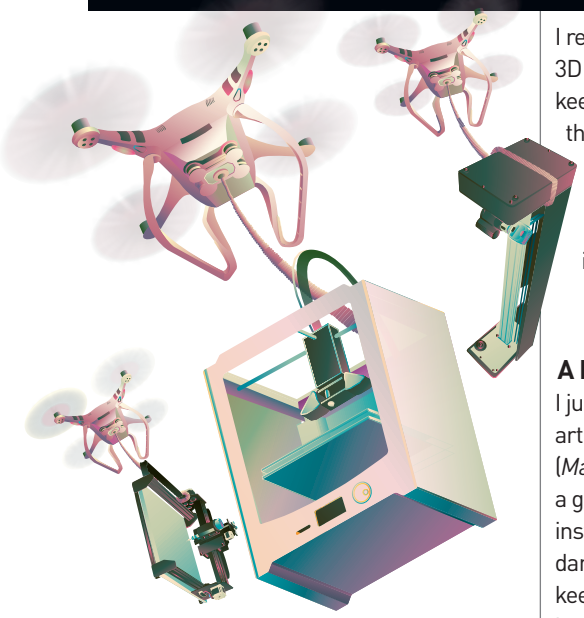
Coding, much like learning how to write, will become an essential skill everyone needs to have. Plus, it will likely come in handy during the future Robot Alien Wars.

Kristin Neidlinger & Edwin Dertien
San Francisco, California [Blow It Up]

Students will dive into "Soft technology skills" to design (wearable) technology close to the skin. It's a hybrid of arts, crafts, and physical computing with many future applications.

Maker Ink, the Perils of Pirate Radio, and Thoughts on Our 3D Fab Coverage

» The *Make:* office went bonkers recently over Maker Ian Cole's new Makey tattoo. Tattoo artist Hoffa at Ascension Tattoo in Orlando, Florida, did the fantastic piece after looking at one of Cole's 3D printed models.



IN RESPONSE TO *MAKE:*'S 3D FABRICATION ISSUE

Hello! I am 12 years old, in sixth grade at Ecker Hill Middle School, and after seeing your most recent 3D printer issue, I wrote a grant submitted by our resident Gifted Education Specialist and our school will soon be receiving a Printrbot Simple. Thank you for teaching and inspiring makers of all ages. *— Ian, Park City, Utah*

I have noticed a very disappointing trend in the last year of *Make:*. Too much of the magazine has been devoted to 3D printing. Don't get me wrong, 3D printers are an exciting technology, but they don't need a whole edition of *Make:* dedicated to their review. In the December/January Issue you not only have the giant section with the 3D printers but all of the projects require a CNC or a 3D printer. I love *Make:* but please don't turn it into a glorified catalog for expensive technology.

— Matthew Cline, via the web

I really appreciated the comparison of 3D printers in *Volume 48*. Good effort to keep the ratings fair and objective even in the presence of some subjectivity. However, didn't anyone time these prints? Even something that is very slow can be shown to be better than something that is very, very slow.

— Roger Koch, via the web

A PIRATE'S LIFE, BUT NOT FOR ME

I just ran across the Raspberry Pirate Radio article by Sam Freeman and Wynter Woods (*Make: Volume 38*, page 80). All in all, it's a great hack. But the config file editing instructions (Step 3, page 81) are potentially dangerous: despite an earlier advisory to keep the frequency within the FM broadcast band, the text shows the frequency being set to 108.20MHz. Transmitting on this or other frequencies between 108.1 and 117.9MHz could interfere with the use of nearby navigational aids or potentially lead an airplane on an incorrect course and lead to a crash. I strongly recommend making appropriate revisions to the online articles.

— Les Niles, via the web

MAKE: TECHNICAL EDITOR JORDAN BUNKER RESPONDS

While the original project was meant as a clever hack, the concerns raised about the project are definitely worth noting. Transmitting radio signals with square waves results in inadvertent transmission on frequencies that are harmonics of the fundamental frequency (the one you're intending to transmit on). If those harmonics fall outside of the FM band, they could overlap with first responder radio bands, or even the frequency used for air navigation locator devices. Thankfully, most of this issue can be resolved by building a simple bandpass filter between the antenna and the Pi, which you can see at makezine.com/go/pirate-bandpass. While it won't completely eliminate the harmonics, it will dramatically reduce their decibel levels, which will reduce interference on those bands. As always, when you're working with radio equipment, double- and triple-check your local laws to make sure you're in compliance. Many cities also have local amateur radio clubs filled with knowledgeable people who are more than happy to answer questions.

READER TIP: the Unibit

I'm probably late to the table with this, but the short answer to drilling holes in sheet metal and plastic is to use a unibit made by Irwin tools. Even as a kid 40+ years ago, I thought it was just a gimmick and dismissed it without a second thought. A couple years ago, a co-worker convinced me to try one. I experienced a curious mix of both joy and regret: joy at the perfect hole created, regret that I had gone so long, made countless ragged holes in sheet metal before trying the unibit. *— David Schaer, Marietta, Georgia*

Make: Asks

This issue is all about building up your Maker skills, but we can't cover everything here. What skills do you want to learn next? Send a note to editor@makezine.com with "Maker skills" in the subject line and let us know!

James Burke, Jessica King

I, Maker

BY DALE DOUGHERTY, founder and Executive Chairman of Maker Media

WITH THIS ISSUE, WE HAVE PRODUCED 50 HAND-WROUGHT, MACHINE-PRINTED EDITIONS OF *MAKE*. I wouldn't have predicted with issue No.1 that it would inspire the Maker Movement. I just didn't think that far ahead. There was too much work to be done to get out the first issue and prepare for the next. To be truthful, it was easier to imagine it failing.

It's hard to predict the future and the big leaps that come often unexpectedly. Most of us don't work in the future, unless you're Isaac Asimov and you write science fiction like *I, Robot*.

In 1964, Asimov visited the World's Fair in Queens, New York, held at the same location that World Maker Faire is nowadays. I recently came across an essay written by Asimov 50 years ago about that visit, which spoke to me of Maker Faire as well as the World's Fair.

"What is to come, through the fair's eyes at least, is wonderful," he wrote. "The direction in which man is traveling is viewed with buoyant hope, nowhere more so than at the General Electric pavilion. There the audience whirls through four scenes, each populated by cheerful, lifelike dummies that move and talk with a facility that, inside of a minute and a half, convinces you they are alive."

Asimov asked himself, "What will life be like ... 50 years from now?" His thoughts, paraphrased here, are surprisingly prescient.

- Electroluminescent panels will be in common use
- Gadgetry will continue to relieve mankind of tedious jobs
- Robots will neither be common nor very good, but they will be in existence. The I.B.M. exhibit at the present fair has no robots but it is dedicated to computers, which are shown in all their amazing complexity. If machines are that smart today, what may not be in the works 50 years hence? It will be such computers, much miniaturized, that will serve as the "brains" of robots.
- General Electric will be showing 3D movies of its "Robot of the Future," neat and streamlined, its cleaning appliances built in and performing all tasks briskly
- The world of 50 years hence will have shrunk further
- Much effort will be put into the designing of vehicles with "robot-brains," vehicles that can be set for particular destinations and that will then proceed there without interference by the slow reflexes of a human driver. I suspect one of the major attractions will be rides on small roboticized cars which will maneuver in crowds at the two-foot level, neatly and automatically avoiding each other.
- Only unmanned ships will have landed on Mars, though a manned expedition will be in the works and the Futurama exhibit will show a model of an elaborate Martian colony
- The fair will feature an Algae Bar at which "mock-turkey" and "pseudosteak" will be served
- The world will have few routine jobs that cannot be done better by some machine than by any human being. Mankind will therefore have become largely a race of machine tenders.
- All the high-school students will be taught the fundamentals of computer technology, will become proficient in binary arithmetic, and will be trained to perfection in the use of the computer languages

He sees the future even beyond 50 years, such as autonomous cars and an unmanned landing on Mars as well as the limited abilities of robots. However, one can also be frustrated that the world has not kept pace with his predictions. We are still working too hard in the present — why does anyone have to do their chores? Sadly too few high school students are learning programming languages.

Asimov concludes with a paragraph that is quite stunning, perhaps imagining Makers as the "lucky few" who represent the truth of young Maker Joey Hudy's catchphrase: "Don't be bored. Make something."

"Mankind will suffer badly from the disease of boredom, a disease spreading more widely each year and growing in intensity. This will have serious mental, emotional and sociological consequences ... The lucky few who can be involved in creative work of any sort will be the true elite of mankind, for they alone will do more than serve a machine."

We need more than just an elite group who are Makers. A better, more optimistic vision of the future is one in which everyone is a Maker. Inspiring that future remains *Make:*'s mission. Just imagine doing more and making together for 50 new issues or even 50 years from now.

Hep Svadja

MADE ON EARTH

The world of backyard technology

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

JAMESDORANWEBB.COM

FAUNA FROM FLOTSAM

One of the marks of a great sculptor is the ability to imbue the inanimate with life. **James Doran-Webb** has mastered this with his breathtaking animal sculptures.

Made from reclaimed driftwood and steel, Doran-Webb uses a variety of tools to shape the wood, including chainsaws, band saws, axes, chisels, angle grinders, and standard carpentry tools. He's been collecting driftwood for almost 30 years and has amassed around 40 tons to draw from. His favorite medium is molave, a hardwood local to his adopted home in the Philippines.

"Finding that elusive piece can take hours," says Doran-Webb. "Think of a 10,000-piece jigsaw with several parts missing and you can visualize the frustration sometimes felt."

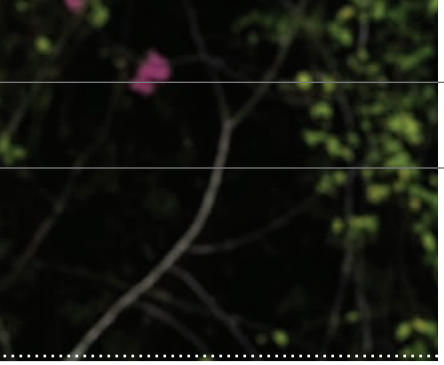
Structural support comes from a stainless steel armature, and though some of the poses may look precarious, the armatures are engineered to carry double the load of the driftwood and to withstand gale-force winds.

Driftwood is attached to the frame with steel bolts and screws in subsequent layers that can be up to 8" in depth. Even with his team of six artists, sculptures can take anywhere from 1,500 to 15,000 hours to complete.

"When I work with wood I slow down and enter a comfortable world of creativity where it's just me, my tools, and the piece I am working with," Doran-Webb says. "I guess it is similar to meditation in that it revitalizes me."

— Craig Couden

See video of the build process at makezine.com/go/fauna-from-flotsam.



Horse Photo Courtesy James Doran-Webb

Courtesy Izzy Swan

WALKING WITH DINOSAURS

Izzy Swan was inspired to make a rideable, mechanical Tyrannosaurus rex after showing his kids *Jurassic Park*. His son thought it would be fun to ride a dinosaur and Swan figured he could make it happen. "I think as a whole, I tend to look at things a little differently, and I love to design — that coupled with an insatiable curiosity to try new things leads to some pretty wild ideas and projects," he says.

Though there are a lot of pieces that make this machine come to life, the most complex part of the project is the legs, which were inspired by those Theo Jansen uses on his wind-powered Strandbeests. Swan had been working on mechanical legs for quite some time, and this T. rex gave him the opportunity to test it on a particularly fun project. It took him a few iterations, but he finally came up with a leg design that brings to mind the strutting stride of an imposing T. rex. And it's all powered by an 18V cordless drill.

Swan is a retired furniture manufacturer and fifth-generation craftsman. "Because rustic furniture is not always straightforward, it required me to design and make some of my own equipment," he says. "More then anything, I hope my projects will help people to realize that making/building is fun, and with a little thinking it is possible to do some pretty amazing stuff."

— Nicole Smith

PLOT TWIST

BOOKART.CO.UK

The pop-up books of **Paul Johnson** wouldn't look out of place in a museum or art gallery, but to really understand Johnson's work you have to imagine seeing these pieces in a classroom. "One half is working in books. One half is teaching literacy to children," Johnson says. For him, the pop-up books were a way to get children excited to read and write by first getting them interested in the book itself. And these books are exciting, not just as works of art, but as works of inspired engineering.

Instead of folds, these books are held together entirely by paper piano hinges and dovetail joints. Avoiding folds has many practical benefits: there's less paper fatigue, individual pieces can be easily replaced, and the books can be packed completely flat — perfect for the many and far-flung workshops that Johnson teaches.

Once he has an idea for a story, he begins work on the structure of the book. First comes a rough model, constructing its architecture while playing with the structure. Then the individual pieces — there can be around 200 of them in each book — of this template get traced onto large sheets of dyed watercolor paper and assembled.

One piece, when held downward, looks like a loose stack of papers. Turn it right-side up and the book expands before your eyes with little more than gravity acting upon it. "There's an element of surprise, there's an element of performance," Johnson says. The same two elements, he says, are critical when it comes to teaching. — *Lisa Martin*

Hep Svadja

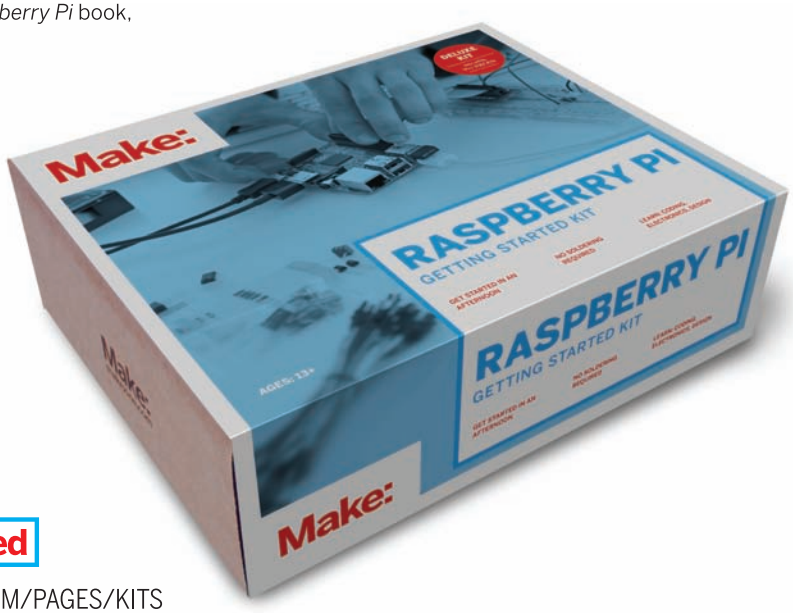
Make:

GETTING STARTED KIT

Raspberry Pi, Deluxe Kit

NOW IS THE TIME TO GET STARTED WITH RASPBERRY PI

Raspberry Pi is a low-cost, Linux-based computer that's the size of a credit card. Our deluxe kit contains the Raspberry Pi 2 board and case, our own Make: *Getting Started with Raspberry Pi* book, 8GB Micro SDHC card, Wi-Fi adapter, and 60+ circuit components so you can begin your coding and electronics projects right out of the box.



Maker Shed

MAKERSHED.COM/PAGES/KITS

A CREATIVE SPARC

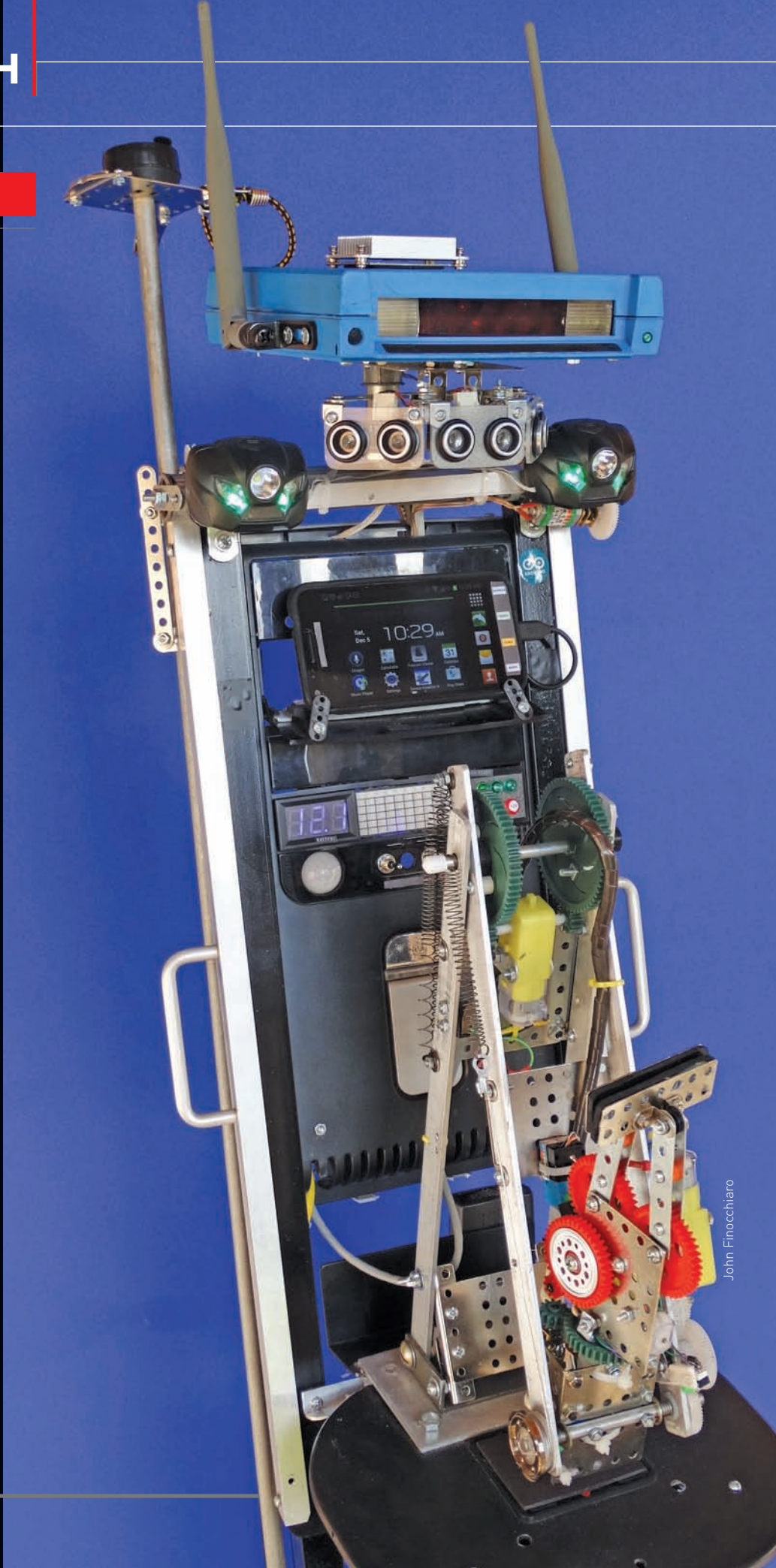
SITES.GOOGLE.COM/SITE/TECHNTIRES

Upon receiving a robotic arm that he was less than happy with, **John Finocchiaro** decided to do what any good Maker would: make something better. In Finocchiaro's case, instead of simply adding better servos or beefing up a linkage or two, he decided to make an entirely new arm and attach it to a 57"-tall mobile robot. It features a base made out of an uninterruptible power supply (UPS), dual Arduino processors, and scanning "Cylon" eyes housed inside old telephone equipment with bunny ears.

The Sentry/Project Assistant/Robot Companion, or SPARC as Finocchiaro calls his robot, is able to move about and take voice commands via an Arduino using an EasyVR (voice recognition) shield. Commands include movement, arm control, and even querying of the internet through an integrated cellphone. The second Arduino processor is tasked with operating the motors and a sonar unit that enables object avoidance and limited following capability.

Finocchiaro also gave SPARC an extendable mast made from a ½" wooden dowel. It can lift a light bulb 2½", allowing Finocchiaro to change a bulb while on a ladder and forever answering the question: How many robot companions does a Maker need to build to help him change a light bulb?

— Jeremy S. Cook



John Finocchiaro

Make:

GETTING STARTED KIT

Arduino, Special Edition

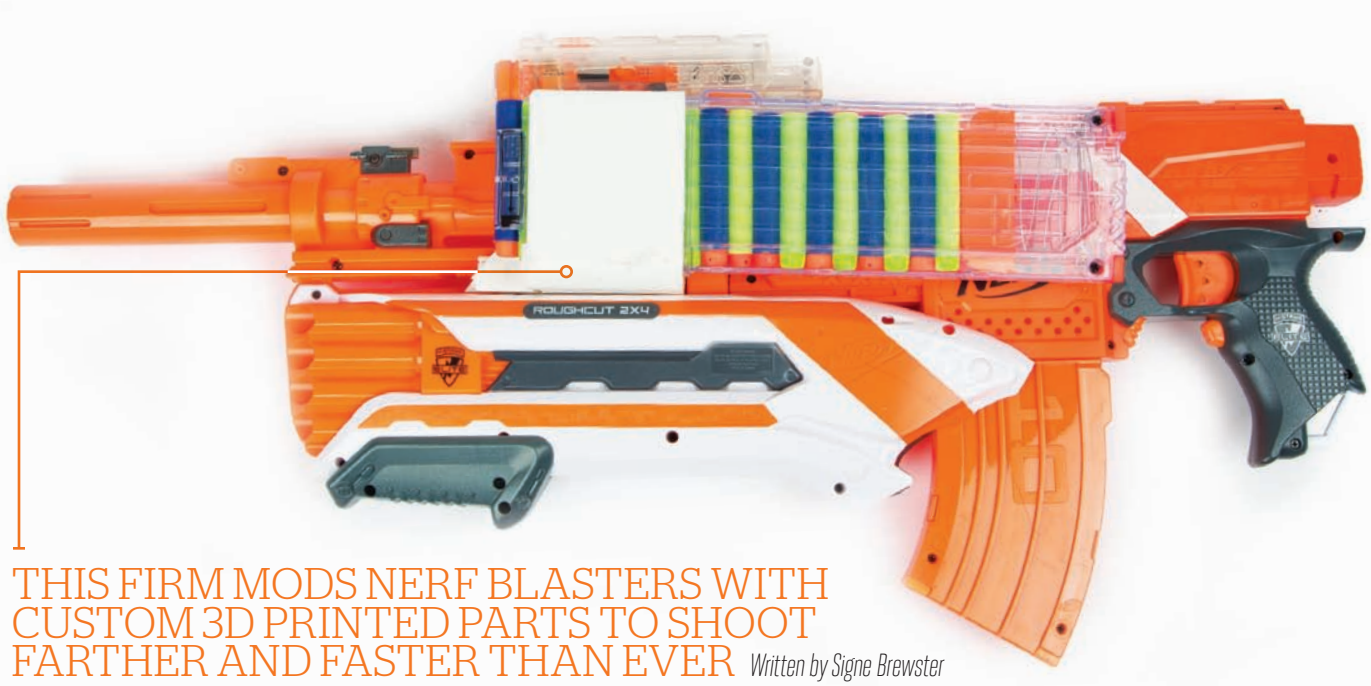
THIS KIT MAKES IT EASY TO GET STARTED WITH ARDUINO

Let Arduino Co-Founder Massimo Banzi walk you through the basics with the *Make: Getting Started with Arduino* book, then put your new-found skills into practice with the included Arduino Uno R3.

Whether you have a specific project in mind or just want to experiment, the solderless breadboard and assortment of LEDs, resistors, buttons, and jumper cables in the box will have you up and running in no time.

Maker Shed

MAKERSHED.COM/PAGES/KITS



THIS FIRM MODS NERF BLASTERS WITH CUSTOM 3D PRINTED PARTS TO SHOOT FARTHER AND FASTER THAN EVER *Written by Signe Brewster*

BLASTER MASTERS

SIGNE BREWSTER is a San Francisco-based science and technology journalist who covers robotics, drones, 3D printing, and the Maker Movement.

JUSTIN KELLY OPENED THE DOOR FOR HIS POSTMAN ON WHAT HE PRESUMED TO BE A ROUTINE PACKAGE PICKUP. But this time the postman brought the local postmaster, who handed Kelly a letter demanding he stop shipping weaponized toys to Singapore or risk extradition.

Despite the seriousness of the allegations, Kelly and the postmen had a good laugh. Several weeks before, Kelly had mailed a Nerf blaster modification kit to Thailand, and customs in Singapore caught it when it routed through there. The kit was designed to increase the battery power flowing through the receiving blaster, boosting its firing strength. Aiding one man's quest to launch foam darts a few more feet had landed Kelly under Postal Service monitoring for three years.

Kelly learned his lesson. As the founder of blaster-modding firm LaserGnomes, he now puts limits on how far and fast his mods will fire darts. Every year he ships about 600 Nerf blasters and parts all over the world from his office in Emeryville, California. His best-known part, the SlugFire, allows the three-dart Nerf Sledgefire shooter to channel all three barrels of firing power into one huge dart, or any other type of dart. Another modification combines the bodies and parts of three Nerfs into one with a custom mechanism that allows you to both cock and fire it by pumping the handle. Kelly has also been known to customize Nerf blasters to look like props from video games, or whatever else a customer requests.

Enthusiasts began experimenting with modifications soon after Nerf released its first blaster model in 1989. Simply replacing the spring that sits behind a Nerf dart can extend its range. But Kelly is part of a growing group offering a new modification option that would have been impossible even 10 years ago: He 3D prints parts. The result is the potential for greater customization, more experimentation, and the ability to adapt to whatever the Nerf community demands.

AN INFECTIOUS HOBBY

When chemical engineering student Eric Beitle was a freshman at the University of Arkansas, his dorm was a battleground. Epic Nerf fights broke out on the regular as students sought release from school-induced stress.

"Somebody would buy the new next greatest thing and somebody else would buy the new next greatest thing," Beitle says. "It almost turned into a bit of an arms race because we were all rather competitive."

Beitle's response was to begin modifying his battle weapons. He greased insides to help the darts move more smoothly. He attached different barrels to convert one blaster into a close-range shotgun. He bought a SlugFire from Kelly and began shooting large darts.

Beitle, now a sophomore, has since joined his campus' Humans vs. Zombies scene, where hordes of foam sword-carrying "zombies" strive to tag other students, turning them into the undead too. The students can shoot zombies with a Nerf blaster to freeze them for 15 minutes.

Blasters that shoot farther and faster, and those with more ammo compatibility, are obviously an advantage. As a result, modded blasters have become a staple in the games.

Many Humans vs. Zombies games begin with a rule that players can only use single-shot blasters. That includes Nerf's Sledgefire, a design that's relatively boring and low-power — until you add a LaserGnomes SlugFire mod.

"We took a poorly received blaster and turned it into the must-have of any HvZ competition," Kelly says. Some Humans vs. Zombies chapter leaders, finding the modifications unfair, have even complained to LaserGnomes.

Modded Nerf blasters are hugely popular overseas on continents like Asia and Australia, where people like Kelly's Thai customer have to work around strict laws that ban airsoft, paintball, and even high-powered projectile toys. People lusting after guns seek out whatever substitute they can, which often leads them to the Nerf modding community. Kelly estimates that at least half of his orders come from abroad.

Greg Heffner, who runs another Nerf 3D printing service called 3D Printed Solid, began selling a mount for Nerf accessories last year. Since then, his website has expanded to carry more than 70 products. He sells 3D printed camera mounts and dart holders, plus custom blasters.

"There is a good amount of experimentation and development done by young enthusiasts and they take pride in their work," Heffner says. "The parts are small and simple in design. Contrary to injection molding, you can create, modify, and adjust your designs in a short period of time."

REVENGE OF THE NERF

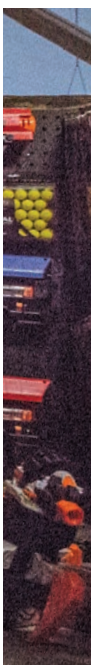
"LaserGnomes started for vengeance, which is I guess a bad way to start things," Kelly says. One day in 2012 his roommates attacked him in their apartment with Nerf blasters, and he decided he needed to retaliate.

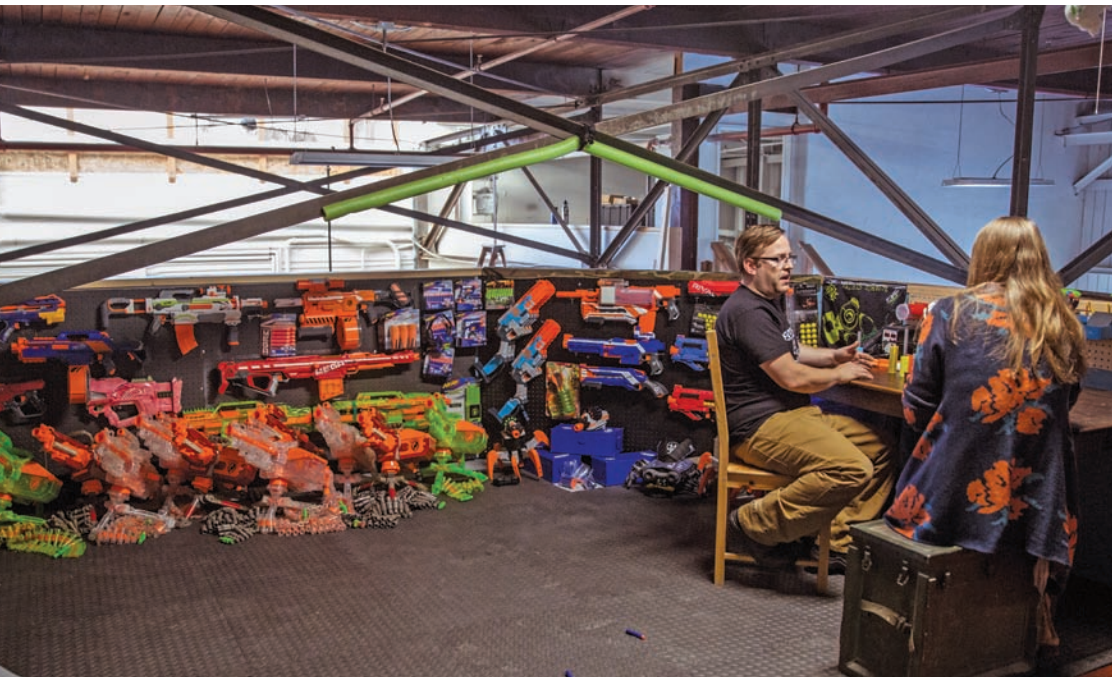
Kelly bought an Alpha Trooper, a classic-looking Nerf blaster capable of shooting from a clip of 12 or more darts. He painted it with camouflage colors and attached a GoPro and a laser pointer. The entire contraption was held together with duct tape and glue.

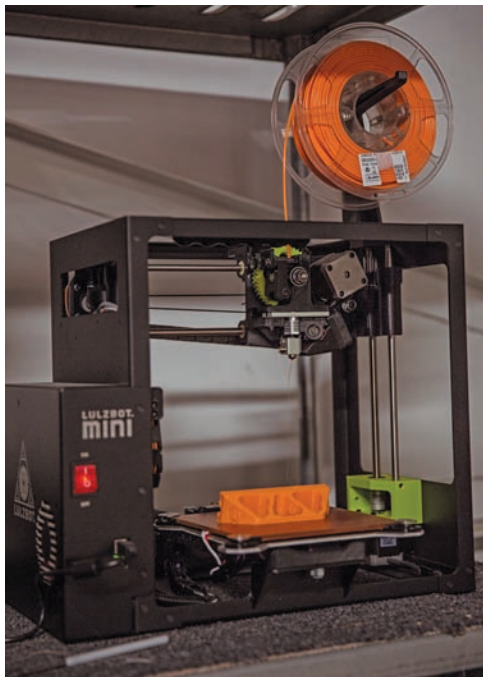
He got his revenge, but in the process discovered an intense online community of Nerf blaster modders and began to fall deeper into the field. Six months later he acquired a 3D printer from Type A Machines.

At the time, Kelly was a 3D animation and visual effects student at Academy of Art University in San Francisco.

Hep Svadja







When a class challenged him to put together a mock company, he decided to build a real one instead: LaserGnomes. (The name "comes from the combination of innovative technologies — lasers — for the betterment of the environment through mindful designs and applications — gnomes.") The initial idea was to collect Nerf blasters and repair them or harvest them for parts, but it soon grew to encompass custom accessories and modifications.

"Being able to mount a GoPro in a very specific way was one of the first things we did. Then, taking two different blasters and merging them into one. We started getting requests like 'Can you make it look like '*Halo*,' or '*Fallout*,' etc.," Kelly says.

Kelly refined his 3D printing chops as one half of Mind 2 Matter, a now-defunct 3D printing and metal casting service that ran out of the Bay Area Advanced Manufacturing hub in San Leandro, California. Kelly split with his co-worker and the center and founded Proto.House, a 3D printing on-demand service.

Today, Kelly runs Proto.House and LaserGnomes out of his 600-square-foot lofted workspace, which sits above the dusty office of SoulMind, a CNC milling and laser etching service. Flowtoys, which makes colorful batons and juggling clubs, also shares the workspace, with plans for Proto.House to begin 3D printing some of its parts. It's a cozy and collaborative-feeling space where experimentation feels key to everyone's business plan.

USING FRACTALS AS FEEDBACK

When Kelly set out to build the SlugFire dart adapter, he could have made precise measurements of a Nerf blaster's existing parts and replicated them. But Kelly likes to practice what he calls fractal design: draw up plans for many variations on the same part, and then make them all. He likes to print many versions of a part at once so he can test the effects of minute changes in his designs, looking for a balance of power and accuracy. Then he takes the best-performing option and tries more designs based on it.

Kelly's Nerf creations all start out on paper. He measures with calipers anything the part is meant to replace or attach to, and then eyeballs the rest. Occasionally he will 3D scan a part, but the output tends to be more of a reference than a final product. Instead, he builds 3D designs by hand in Tinkercad.

For SlugFire, Kelly began with seven different 3D prints of possible designs.

"We were trying to capture the most air, but I wasn't sure what size the barrel needed to be," Kelly says. "Instead of measuring or using complicated math, I just printed seven different versions and tested them empirically, and then with that answered moved forward."

Kelly had his team of interns refine the SlugFire further by measuring the firing speed of each design iteration with a chronograph. At one point, a dart clocked just over 100mph, fast enough to break glass — not to mention skin.

"We knew we had something that was both amazing and not suitable for the public," Kelly says. The final version of the SlugFire had toned-down firing power, which allowed it to be safer and more accurate.

Since that first version of the SlugFire, it has changed continuously. When a customer breaks something from LaserGnomes, Kelly asks for it back. He examines the damage and integrates improvements into the design so future pieces that go out are more durable.

This process of iterating on small design changes over and over again would take months, and likely be cost prohibitive, if not for Kelly's army of 3D printers. On a weekday in early November, Kelly had 12 LulzBot Minis printing parts simultaneously. They are all manned via

a central Raspberry Pi controller Kelly programmed himself, since out of the box LulzBots can normally only be controlled one at a time.

THE QUEST FOR COMPATIBILITY

If you were a child in the 1990s or 2000s, there's a good chance you spent some time running around with a Nerf blaster in hand. But if you bought one today and brought it home to use with your vintage Nerf dart collection, you'd make a harrowing discovery: Most of the darts won't fit. Hasbro switches darts' lengths and widths frequently, forcing you to buy new darts for new blasters. Remedying that is one of LaserGnomes' other focuses.

"My product allows you to reload any dart you want. You could even be using off-brand darts. You could be using darts from the 1990s," Kelly says. "You load it in there and now you can fire it."

Let's say that you want to use one of your old Nerf blasters. If even a tiny part breaks, you might think your only choice is to toss out the whole thing. Hasbro doesn't sell replacement parts or make its designs particularly easy to crack open for repairs. The oldest Nerf blasters are slowly disappearing as they break one-by-one, and Hasbro nudges people toward buying a replacement instead.

Kelly's armory contains a 1995 Nerf Crossbow, an iconic wine and teal colored dart-shooting bow. Today it is one of the rarest of all Nerf shooters, meaning the remaining units are too expensive to buy just for harvesting parts. Kelly's came with a snapped part, but he was able to repair it thanks to 3D printing.

Kelly doesn't share his printable performance-enhancing modifications. But he does share legacy replacement part designs. "Ultimately, I envision inspiring enough people that someday there's a collection of online design files that are just open, that Hasbro just charges a dollar a download or just gives it out," Kelly says.

STAYING AHEAD OF HASBRO

Hasbro, which has only responded to Kelly's work with favorable comments on social media, seems to be catching on to the desires of the community, offering new products like the Modulus, a 2015 blaster that can be modified with interchangeable handles, clips, and more. The company is also selling gaming-friendly blasters that shoot balls capable of traveling farther and faster than darts. Between Hasbro's recent debuts and the efforts of modders, Nerf blasters have a new appeal for children, teenagers, and grown-ups alike. Adults can modify their old favorites to suit modern needs or trick out models still available on store shelves.

The addition of balls, plus other trends such as increasing power usage in blasters, is keeping Kelly alert for changing customer requests. But as long as clients find Hasbro's Nerf offerings lacking, LaserGnomes will be in business.

Your Turn!

Written by Lisa Martin

MOTION ACTIVATED NERF TURRET

Use an infrared motion sensor and an Arduino to turn your blaster into a defensive turret.
makezine.com/go/motion-activated-nerf-turret

SCRATCH-BUILT NERF BLASTER

Not satisfied with your store-bought rig? Build your own using PVC and aluminum piping for better accuracy and longer range shots.
makezine.com/go/scratch-built-nerf-blaster

MAKE YOUR OWN NERF DARTS

You can never have too many Nerf darts. Use this tutorial to make your own ammo and never be caught with an empty chamber again.
makezine.com/go/diy-nerf-darts

Jason Poel Smith, Simon Jansen, Ben Ryan

Going Glocal

Maker ProFile
Written by DC Denison

AtFAB's founders talk distributed manufacturing

WIFE/HUSBAND PARTNERS ANNE FILSON AND GARY ROHRBACHER ARE FORWARD-LOOKING. They run an architecture firm, are both professors at the University of Kentucky, and co-founded AtFAB, a studio that designs simple, modern goods to be made in a whole new way — with networked, independent, digital fabrication workshops.

"SHIP INFORMATION, NOT STUFF"

Gary Rohrbacher: We really believe that there is such a thing as digital craft. A CNC router actually brings you as close to the material as any conventional working tool. You can admire the precision of a piece, the puzzle aspect of it.

Anne Filson: So many things in our households have been around the world several times. The raw materials are from one continent, they are processed in another place, the screws and hinges are sourced from somewhere else, and the labor is from China. That's a massive carbon footprint. But there are milling machines and plywood everywhere, why don't we make more products close by?

GR: We've heard that called "glocal." That's a tagline for distributed manufacturing, which we think is the wave of the future.

A SHRINKING WORLD

AF: The distance between the designer and finished project has collapsed. With digital fabrication, you can model a product on your computer, and others can make a finished project from your design with machines that are almost everywhere.

GR: High-quality CNC machines are now available for a relatively low price. Software has focused on direct fabrication.

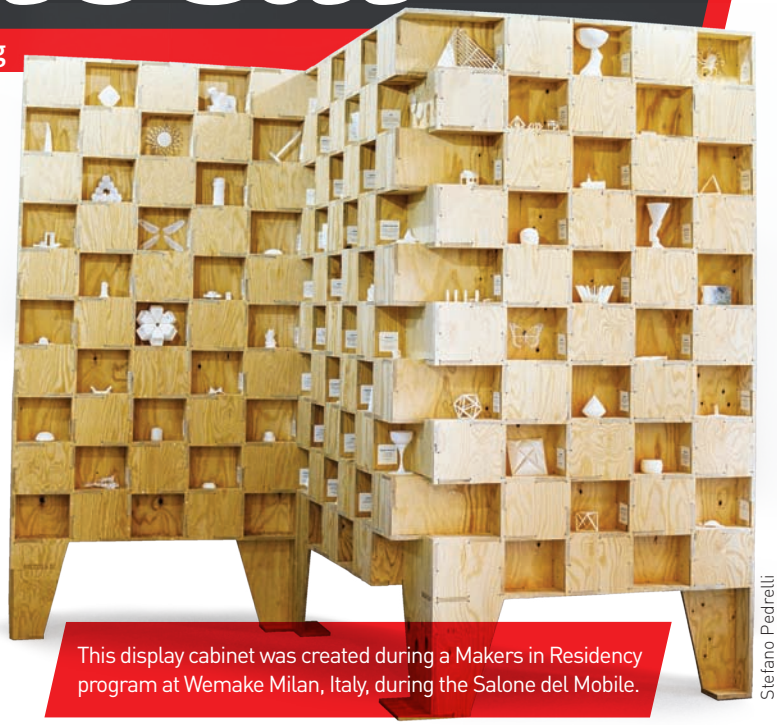
THE HONESTY OF PLYWOOD

AF: Centuries-old joinery techniques, and the turning functions of a lathe have produced furniture that looks a certain way. We're interested in making something that looks like it was cut from a CNC router and has had as little processing as possible.

GR: We're not beholden to plywood exclusively but it's available everywhere in the world, it's renewable, and it has a great strength-to-weight ratio.

GR: It's not trying to hide the fact that the furniture is all from a flat sheet of stock material. It's puzzle pieces. The assembly is clear, explicit, right out in front of you. Nothing is hidden. There's no artifice, no ornaments, no secrets. The ornament is the tool paths.

AF: Embedded in that artifact is a different story, but it's still a rich and compelling story, and you participated in it.



Stefano Pedrelli

This display cabinet was created during a Makers in Residency program at Wemake Milan, Italy, during the Salone del Mobile.

CREATE YOUR OWN

GR: Products like SketchUp are giving people the power that once only big design firms had.

GR: Try Opendesk in London. They've built an API that connects the consumer, designer, and local manufacturer. Go to the Opendesk website, choose a design, and their interface will find the closest local manufacturer near you.

AF: The barrier to entry is pretty low, and you can start with smaller, cheaper machines and keep upgrading as your business upgrades. If you're working with an inexpensive CNC machine like a ShopBot, the cost of machine is around $15,000, plus a few thousand more to set up.

AF: As more people in society recognize their agency as Makers, Makerspaces are going to have more functions than just an introductory one. They can become manufacturing hubs.

For more Maker Pro news and interviews, visit makezine.com/go/maker-pro.

Read Filson and Rohrbacher's new book, *Design for CNC: Practical Joinery Techniques, Projects, and Tips for CNC-Routed Furniture*, available this April from Maker Media at makezine.com/go/design-for-cnc.

DC DENISON is the editor of the *Maker Pro Newsletter*, which covers the intersection of Makers and business. He is the former technology editor of *The Boston Globe*.

I Fab A Dream

When making is inclusive, good things happen

Written by Dale Dougherty

ONE OF THE BIGGEST CHALLENGES AND OPPORTUNITIES FOR THE MAKER MOVEMENT IS DRAMATICALLY INCREASING PARTICIPATION IN THE AFRICAN-AMERICAN AND LATINO COMMUNITIES. Colin "Topper" Carew, who was an architect, and a writer and producer in Hollywood before landing at the MIT Media Lab, has been working with Historically Black Colleges and Universities (HBCUs) to help provide opportunities for students to make and invent. Recently I interviewed Carew to ask him about the importance of African-Americans and Latinos realizing the potential of the Maker Movement.

"The Maker Movement is one of the few things out there that has the possibility of leveling the playing field in technology," says Carew. "One of the great detriments to the inclusion of more African-Americans and Latino Americans in technology has been a lack of access. Makerspaces provide that possibility. In Boston, there are a significant number of Makerspaces and the African-American population does find its way to those spaces.

"Making should be an opportunity we provide to all people," he continues. "Starting at very young ages, we have to grow and nurture our young people. Schools will eventually come on board and we need them. But most of the modeling happening in this country right now is going on outside of the schools. This is where young people get turned on."

"By creating an environment where young people can play, experiment, and make mistakes, where they can learn to solve problems, where they can flourish artistically, where they can use code just like a paint brush or a musical scale — all of these things are what make for a more complete and well-rounded individual," Carew says. "Ultimately, they become more confident, curious and capable."

One of Carew's talking points with HBCUs is what happens when the African-American community gains access to tools. "Go back to the early days of miniaturized recording machines. Now a young person could have access to a recording device, which at one point in time might have cost $400 an hour. Now they had this machine. I watched as these young people got the means of production, and, with the code being the 12 notes of music, they began to invent things. One of these things became rap, one of these things became hip hop. Now those things are Americana. That culture has impacted everything."

At World Maker Faire last fall, I met DJ and hip-hop producer, Jazzy Jay, one of the founders of Def Jam Recordings. In an oral history interview by National Association of Music Merchants, Jazzy Jay said that he started a home production studio with "the crappiest stuff you could dig out of the garbage, out of people's stereos that they threw out." He added, "it was all primitive but it taught me how to manipulate electronics. We couldn't afford going to the store to pay for this stuff." At Maker Faire, Jazzy Jay was appearing with DJs from ThudRumble. "I get this event," he said to me. "I'm a geek myself. I love seeing all of this."

Carew says that Makerspaces can give young people the same kind of tools for production. "Once they have access and the code is understood by those communities, there's going to be an explosion — I don't know what it is. But I know that something wonderful is going to happen and it will be characterized one day as Americana. So the value of propagating a movement that brings those populations in is going to have a wonderful, long-term, highly productive impact on American culture, productivity and competitiveness."

This is beginning to happen in youth Makerspaces across the country. Maker Education (makered.org), of which I am the chairman, looked at 51 in the United States and found that participants average 42% White, 20% African-American, 18% Latino, and 14% Asian.

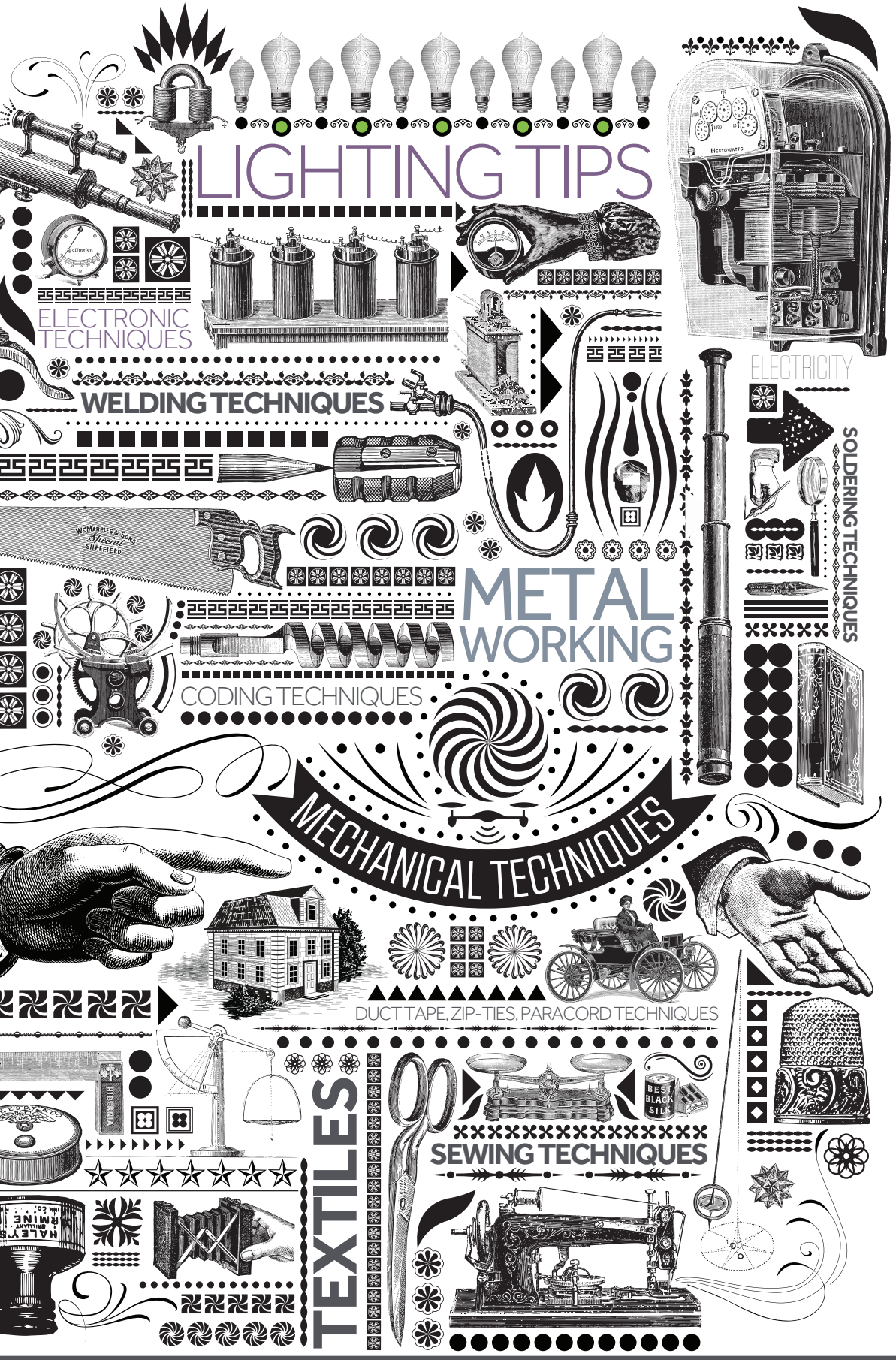
"When I talk to the HBCUs, I help them see the vision and see what is happening," Carew says. "At Spelman College, young women designed a camera that mounts on a laboratory microscope. They designed and fabricated it and the new camera replaced an $850 camera. The expensive cameras now sit in a pile on the floor. Now every student who wants her own personal camera can get one for $20. That's why the Maker Movement is an important platform for long-term productivity and accessibility."

Here are a few noteworthy programs that are engaging young African-Americans and Latinos in making:

- ***The Parachute Factory*** is a Makerspace in Las Vegas, New Mexico serving Hispanic and Native American youth.
- ***Verizon's Minority Male Maker*** program, which is a summer training program for middle school minority boys.
- ***DIY Girls***, founded by Luz Rivas in Los Angeles, provides hands-on tech experiences for young girls and women.
- ***The South End Technology Center*** in Boston, which is the first community Fab Lab to spin out of the Center for Bits and Atoms at the MIT Media Lab.

Simon Zachary Chetrit


KINETIC
ART
KNIFE TOOL TIPS
DUST EXTRACTION
WOODWORKING
DRILL AND ROTARY TOOL TIPS
SAW TOOL TIPS
TIPS
SKILL SCHOOL
STOP GAUGE
EAGLE AUTOMATIC NO86C
WORKING WITH SILICONE AND PVC
MEASURING TOOL TIPS
SAFETY AND FIRST AID
WINSOR&NEWTON
WATER COLOUR
CHINESE WHITE.
WORKING WITH PAPER/CARDBOARD
LIQUID GLUE
GLUE AND AFFIXING TECHNIQUES



MAKING IS OFTEN AS CHALLENGING AS IT IS REWARDING. With each new project there are different tools, materials, or techniques to master. In time, the happy accidents that come with experience guide you to the tips and tricks of a particular activity; those then help break down the fear of failure that we all experience when trying something completely new. These little details don't just save time, they are often what separate the true craftsperson from the amateur.

To a great extent, learning new skills is what being a Maker is all about — and is often as fun as completing the project you're working on. Stretching your skill set and pushing the boundaries of what's possible is the heart of the Maker ethos. To help you with that, we've assembled a multitude of Master Maker knowledge across a wide variety of disciplines. Whether you're a seasoned Maker, or just getting started, you're bound to learn something new within these pages that can be applied to your next big idea. Ready, set, skills!

Written by Jordan Bunker • Illustrated by Ryan Huddle

Written by Sean Cusack

Metal ZONE

SEAN CUSACK is a materials scientist, chemical engineer, and co-owner of design and fabrication firm Sheet Metal Alchemist, Inc.

EVEN BEGINNER PROJECTS CAN ROCK **STEEL**, **ALUMINUM**, AND **COPPER**

BUILDING WITH METAL IS GREAT — IT'S STRONG, VERSATILE, AND LOOKS COOL. When you're getting started on a metal project, the first step is determining what type of material will work best. For most projects, steel, stainless steel, aluminum, and copper have a good range of properties and are easily available at a reasonable price. Although many other alloys and metals exist (titanium, bronzes, pewter, etc.), they are usually used in specialized applications. It is easier to stick with one of the discussed alloy groups if you are a beginner.

METAL GEOMETRIES AND STRUCTURAL SHAPES

The type of metal used for a project is a key decision; the shape of the metal for structural purposes is also integral to your project. These are the most common geometries available, and each has its own advantages and disadvantages:

FLAT BAR: Strong along flat axis only, easy to bend into curves along other axis. Simple to bolt to.

C-CHANNEL: Retains ease of bolting that flat bar presents, with greater structural strength along other axis.

ANGLE IRON: Generally used to create flanges off of flat plate.

BOX TUBE/ROUND TUBE: Structurally the best shape offered — 4 walls make these shapes strongest in any direction.

I-BEAM: Steel-saving design for applications requiring high vertical loading with limited torsional loads for the structure's weight (buildings, bridges, static structures).

Hep Svadja, chillim — Adobe Stock

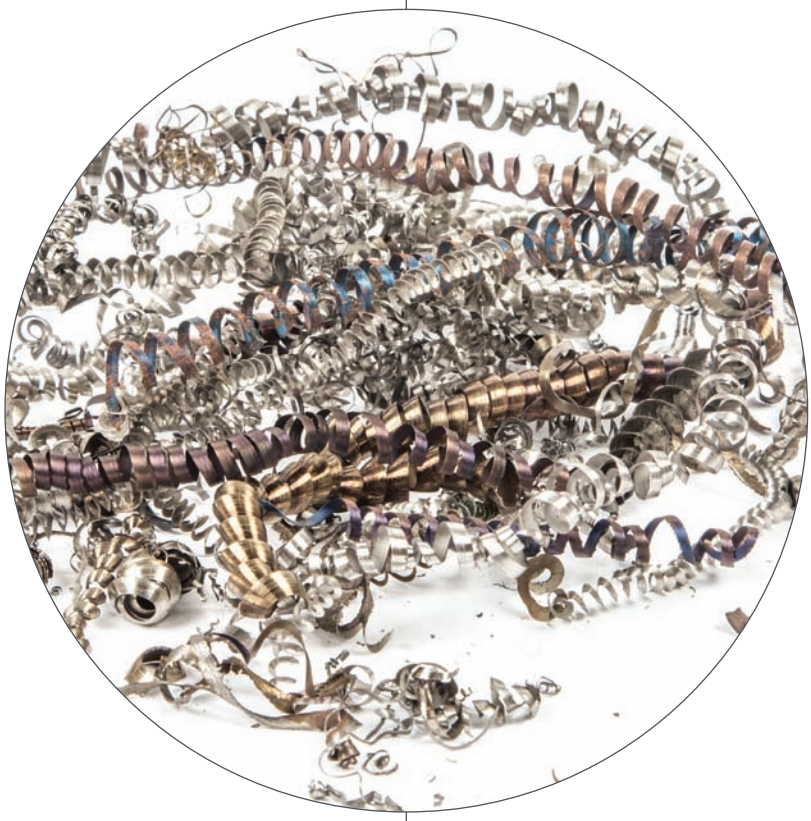
FOUR PROPERTIES OF METALS:

Ductility/Formability: The ability to draw metal into a wire, or form it into different shapes. Tools that bend metal exploit formability, and these operations will be harder/not possible with less formable metals.

Weldability: The ease of welding a material. Easier to weld materials require less prep, and less expertise with a welder. Harder to weld materials require high welder dexterity, more advanced welding techniques, and perhaps special considerations like additional gas purging, preheating, or exotic weld gases.

Machinability: The ability to cut a metal with a blade. Highly machinable metals can be cut at high speeds and with less expensive band saw blades, milling tools, or drill bits. Cutting tools that are based on friction (anytime sparks fly — abrasive cut off wheels, angle grinders) do not exploit machinability and can be used to cut less machinable metals.

Tensile strength: The amount of force you need to exert to snap a metal. When newcomers are looking for a "stronger" metal, they usually mean they want a metal with a higher tensile strength.



4 PROPERTIES OF METALS

	STEEL	STAINLESS STEEL	ALUMINUM	COPPER
Ductility / Formability	Medium	High	Low	Very High (if annealed)
Weldability	Easy	Medium	Hard	Very Hard
Machinability	Medium	Hard	Easy	Very Hard
Tensile Strength	Medium	High	Low	Very Low
Weight	Medium	Heavy	Light	Medium
Cost	~$0.50/lb	~$2.00/lb	~$2.50/lb	~$9.50/lb

MATERIAL CONSIDERATIONS:

STEEL

+ Cheapest of metals
+ Right down the middle of almost all properties
+ Readily available in structural shapes
− Susceptible to rust, needs to be protected
− Harder to cut than aluminum — cannot use the same tools you would use for wood

STAINLESS STEEL

+ Most protected metal of the class — will not rust unless exposed to acid due to chromium or nickel content — forms a transparent oxide layer
− Heavy
− Difficult to fabricate and maintain stainless status — other metals affect corrosion resistance
− Warps easily on welding, and can blow off molybdenum causing rust

ALUMINUM

+ Most practical lightweight material
+ Oxide layer protects from rust as long as it is protected from other metals
+ Very easy to machine
+ Readily available in structural shapes
− Hard to weld for beginners
− More expensive to buy, fewer number of CNC technologies for plate cutting

COPPER

+ Potential for beautiful patinas and aging
+ Inert to many other metals
+/− Easily formable, but work hardens quickly — need to use a torch to temper metal while hammering

Written by Robert North

Strength IN Numbers

2×4s AND PLYWOOD ARE A MAKER'S BEST FRIENDS

ROBERT NORTH is a former United States Marine, a home improvement TV host, and Master Craftsman with over 16 years in the building trades. Find him on Facebook as Craftsman Rob North.

PLYWOOD AND 2×4S ARE THE SKIN AND BONES OF MOST MODERN STRUCTURES. Both are inexpensive, easy-to-find, and endlessly adaptable. But just because they're commonplace doesn't mean they're simple. Here's a quick overview of what makes these materials such an essential for Makers, along with a few tips and tricks for your next project.

2×4s

A type of "dimensional lumber," 2×4s, as they're commonly known, actually measure 1½"×3½". 2×4s are invaluable in residential and commercial construction, but their strength and low cost make them a great option for many projects.

SELECTION

When shopping for 2×4s you'll want to take your time selecting each piece to find the straightest boards possible. Sight down the length and look for any twisting or bowing. Because they are made in such vast quantities, you'll find 2×4s for sale that are anything but straight.

STRENGTH

Oriented on-edge a 2×4 has a considerably greater ability to resist bowing then on its face. However, the real strength of the 2×4 is achieved when it's used as part of a system. Used in wall framing the 2×4 "studs" are placed vertically every 16" inches and connected to horizontal 2×4s that are called plates. Done properly, a 2×4 studded wall can hold a whopping 1,100lbs of load per linear foot!

CLEAN UP

Most 2×4 stock in the United States is yellow pine. While it's considered a soft wood, yellow pine is very strong and easy to cut and shape. Unfortunately, this wood can contain pitch or sap, which will gum up your saw blades and can even make them unsafe to use. Clean your blades with a pitch and resin remover or a biodegradable product like Simple Green. Once they're clean give them a good rinse with water and dry them thoroughly.

PLYWOOD

This layered, engineered wood has applications from woodworking to aircraft construction, and everything in between. Also known as sheet stock, plywood is made by peeling a log on a large lathe, creating a long continuous sheet that is then cut and stacked into layers known as plies. A sheet of plywood must contain an odd number of layers, with a minimum of three core layers along with the outer or "face" layers.

GRADES

In lower-grade products, the grain of each layer is rotated 90° to the previous layer and will contain voids within the core plies. Higher plywood grades will be rotated 45° per layer and have little or no voids at all.

Marine-grade plywood resists delamination and fungal attacks. Aircraft-grade plywood is stronger, lighter, and more flexible. Pressure-treated stock is meant to be used in outdoor applications like sheeting or decking.

STABILITY

A critical benefit to having the grains of each ply run in different directions is that they counteract wood's natural tendency to expand and contract across the grain. This provides structural stability, ensuring that the sheet stays the size that it was intended.

FACE PLIES

Plywood is available in a wide variety of "face" plies. Softwood faced plies, such as pine, are the most common, but you can also find plywood faced with hardwoods or even oily exotic woods intended for furniture.

ROLL YOUR OWN BENDY BOARD

One of the more unusual types of plywood is "wiggle" or "bendy" board. These products are designed to be flexible and allow for heightened creativity, but they can be expensive. Here's a trick for making your own flexible plywood using a process called kerfing.

1. Select a product that's at least ⅜" thick and preferably with thin plies.

2. Cut out the piece that's meant to be bent, making sure the "face" grain is running with the length of the piece.

3. Make shallow crosscuts on the backside of the piece in the area that's going to have the radius. These cuts should be about ⅛" apart with the blade stopping short of cutting into the last layer of core ply. With so many different types of plywood out there, the depth and spacing of each cut will vary. You'll need to experiment.

4. Give the remaining uncut plies a thorough soaking. This will soften the fibers of the wood and allow them to bend to your will.

ADAPTING 2×4 FOR FURNITURE

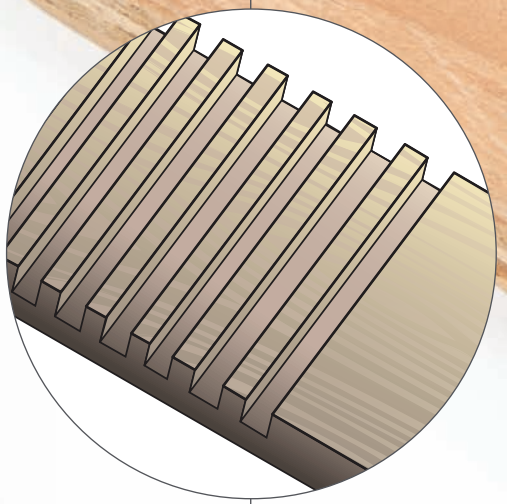
One of the best-kept secrets of the 2×4 is its ability to be used in furniture making. Lurking inside that unassuming lumber is perfect woodworking stock just waiting to be released.

1. Flatten one face on a jointer or with a hand plane.

2. With the flat face down, run it through a thickness planner until it reaches your desired thickness. This will ensure that both faces are parallel to each other.

3. Give it a trip through your table saw to square off one edge.

4. With one edge perfectly straight, flip it over and cut the stock to the desired width. The result will be material that's straight, square, easy to mill, and very inexpensive. Use it to make templates, as set up stock for cuts, or as the finish material itself.



Create a flexible joint in plywood by creating a series of parallel channels in the section you'd like to bend.

Hep Svadja, James Burke

Flexible Fabricating

Written by Kathy Ceceri

MAKE IT WITH **PAPER**, THE FUN AND FORGIVING BUILDING MATERIAL

Hep Svadja

KATHY CECERI is the author of Paper Inventions and Making Simple Robots. You can find more of her work at craftsforlearning.com

CARDBOARD TECK INSTANTUTE has been making with cardboard for the last 10 years in Vermont. Their PinBox 3000 tabletop pinball machine kit can be found at pinbox3000.com or at makershed.com. CTI is Professors Ben T. Matchstick and Pete Talbot.

PAPER, ONE OF THE MOST FAMILIAR, INEXPENSIVE, AND ABUNDANT MATERIALS AROUND, IS GREAT FOR ARTS AND CRAFTS. With the right techniques, however, you can also use it for anything from prototyping small models to constructing furniture or even boats and buildings. Here's how to push the limits of its potential.

TYPES

A combination of thickness, stiffness, "tooth" or surface texture, and finish (matte, glossy, or none) can change the way paper holds its shape and how it takes pencil, ink, or glue. Some popular types of paper and their uses include:

COPY PAPER: Medium weight and fairly smooth, it's good for writing by hand as well as for printing. It's also stiff enough to stand up if used for small paper models.

ART PAPER: Pricey, thick, and usually somewhat rough, it's designed for pencil, ink, and paint. Tear it against the grain for nice frayed edges.

CARDSTOCK: Stiff, smooth, and thin, it straddles the line between paper and cardboard. Good for greeting cards, paper models, and other stand-up building projects.

CONSTRUCTION PAPER: Soft, rough, and often brightly colored, it's not as stiff as cardstock but still good for kids' pop-up cards and other 3D crafts. The best paper for little hands to practice scissor skills.

TISSUE PAPER: Thin and brightly colored, use it to create a faux stained glass effect or dampen it and let the colors run for a watercolor effect.

ORIGAMI PAPER: Lightweight but stiff, it will hold a sharp crease and even spring back if you compress it when folded. Generally colored or printed on one side only.

More choices include ultra absorbent coffee filters (for pseudo tie-dye projects), wax paper (iron two sheets together to "laminate" leaves and other flat objects) and freezer paper (good for stencils, will stick lightly to fabric when ironed).

FOLDING AND ROLLING

For nice sharp creases — V-shaped valley folds or hump-backed mountain folds — score your sheet first along the fold line by indenting it with any kind of dull point. For coils and rounded bends, roll it around a toothpick or pencil.

CUTTING PAPER

Scissors should have sharp, small, pointy blades. For long straight cuts, use a craft knife or box cutter. Run it lightly along a metal straight edge, making multiple swipes if needed. A desktop programmable vinyl cutter is easy to use for delicate, precise projects, and much less pricey than a laser cutter.

CONNECTING

Ordinary white glue is long lasting and secure enough for most needs. Spread it thinly with a flat toothpick, craft stick, or index card, or use a paintbrush or roller. Glue sticks and spray adhesives work instantly but are less permanent. Use binder clips to clamp pieces while you build.

STRENGTHENING

To make models sturdier, glue multiple layers together, alternating grain if possible. You can build with thin paper and card by bending or rolling it tightly into rods. To make models last longer, reinforce them with clear packing tape or by brushing on clear sealant, epoxy resin, thinned glue, or shellac.

WORKING WITH CARDBOARD

Cardboard can be found all around you. You can rip it, bend it, cut it, or even shape it with a laser cutter. Using a projector, you can transfer papercraft designs onto cardboard to scale-up fun slot-and-tab projects.

BOARD TYPES

When we talk about cardboard, most of the time we're actually referring to common corrugated C-flute fiberboard. This is the 4mm thick, slightly squishy stuff most cardboard boxes are made from. It consists of two layers of rough, fibrous paper, with one inner fluted layer. There are varying sizes of fluting with thicknesses ranging from around 12mm triple ply to 1.8mm E Flute. The corrugation provides rigidity and bears weight when oriented vertically.

CUTTING CARDBOARD

Lasers, water jets, die cuts, jig saws, utility knives, and tough scissors all cut cardboard. Score with a penknife and crease with a bone folder. A tri-edge architectural ruler also makes a handy tool for creasing. A rotary tool can carve fancy curves quickly, if you don't mind noise, dust, and fuzzy edges.

SHAPING

Creasing along the grain can produce curvature, while working against the grain requires a hard crease or a score, so that the corrugate does not break the line. Fold into the cut, so that there are no exposed layers of corrugation. Wet cardboard can be molded into subtle shapes using a damp cloth and dried in sunlight.

HARDWARE

Handheld staplers from Bostitch and Rapid 31 with "sword-points" can be used for hard-to-reach joinery. Mr. McGroovy's Box Rivets (available at makershed.com) are snappy joinery for articulated points or easy tear down. Enlarged slot and tab systems used by paper crafting and nomadic furniture designers are desirable for intuitive assembly/disassembly.

MAKING IT LAST

For durability, avoid tape if you can — especially duct tape. Masking tape can be employed for sealing gaps without compromising strength. A cooked starch-based papier-mâché (see recipe, top right) can add strength and use up your extra scraps. If you want to waterproof, seal with shellac.

PERFECT PAPIER-MÂCHÉ RECIPE

This recipe was originally introduced to me by Vermont's Bread & Puppet Theater. It has served me well.

Dissolve 1 cup of cornstarch in 2 cups of cold water, then slowly mix it into a half-gallon of boiling water. Turn off the heat and stir periodically while it cools, about 45 minutes. Keep stirring until you can see the glue adhere between the tines of a fork and the appearance is consistently cloudy and milky.

Rip scraps of cardboard and drop in water until the layers separate. Wring out scraps until the paper feels leathery and wrinkled.

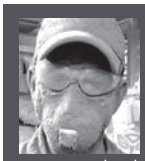
Apply the paste liberally with your hands to the scrap and wipe surfaces free of all glue, pushing firmly on the edges to adhere the fibers.

— Ben T. Matchstick

Worth Repeating

Written by Shawn Thorsson

SILICONE BLOCK MOLDS ARE A QUICK AND EASY WAY TO MAKE A WHOLE BUNCH OF THE SAME THING



SHAWN THORSSON learned at a very young age that the surest way to get the coolest toys was to make them yourself. Now he makes costumes and props for films, promotional uses, and the occasional private commission.

ONE OF THE BEST MATERIALS FOR MAKING DETAILED MOLDS IS SILICONE RTV MOLD-MAKING RUBBER. The RTV stands for "Room Temperature Vulcanizing," which means that once you mix up the materials, you don't need to put it in an oven to cure it.

There are a lot of ways that you can use silicone to make molds. The simplest by far is the "block mold." In essence, you pour silicone into a box that contains your prototype. Once it cures into a solid rubber block you remove it from the box, remove the prototype from the mold, pour casting material into the mold, wait for it to cure, and then remove your part from the mold. Properly mixed and poured, detail reproduction with silicone rubber is usually flawless.

Since silicone rubber usually doesn't stick to anything (the major exception being more silicone) it means you can cast parts without having to add any kind of mold-release agent that might fill in or otherwise obscure small details.

BUILD A BLOCK

The box needs to be big enough to get about ½" of material around the piece. Scrap cardboard and hot glue are perfect for mold boxes. It's vital to make sure to glue all of the seams well, both inside and out, to keep the liquid silicone from leaking. Make sure your prototype is free of any flaws, including fingerprints, as these will show up in every piece.

Put a dab of glue on the bottom of the prototype and center it in the box. This keeps the prototype from shifting or floating away as the silicone is poured. Mount it on a piece of clay to give the part some extra material that can be cut off later.

BANISH THE BUBBLES

Mix up a batch of silicone in accordance with the manufacturer's instructions. Note: Most silicone mixtures are determined by weight, not volume.

When you mix and pour silicone rubber, the biggest enemies are air bubbles. Air bubbles trapped in the rubber will become weak points that will possibly tear open and cause the mold to fail. Bubbles trapped against the surface of the prototype will become lumps of extra casting material in the final parts.

Start by pouring the liquid rubber into a corner of the mold so that it fills up and flows across the surface of the prototype. This minimizes the number of bubbles that get captured against the surface. Lift your container as you pour to draw the silicone into a thin strand, which aids in the rupturing of bubbles created during mixing.

If you have access to a vacuum chamber, you can evacuate bubbles from the liquid rubber after you mix it. If you don't, just use a type of silicone with a longer cure time in order to give the bubbles more time to float to the surface.

CAST AWAY

Once the rubber has cured solid, tear away the cardboard mold box around the part and gently peel the rubber off of the prototype. Now you can use the mold to cast parts in a variety of materials.

Whenever you cast urethane resin parts in a silicone mold, there will be a tiny bit of oily residue from the silicone that is left on the parts. In order to make the parts ready for painting, the residue has to be washed off with warm, soapy water.

KNOW YOUR TERMS

» **PROTOTYPE** The original piece you're trying to duplicate. Also called the "master" or "model."

» **MOLD** The hole shaped from the prototype.

» **CASTING MATERIAL** The stuff you'll fill the mold with in order to make the part.

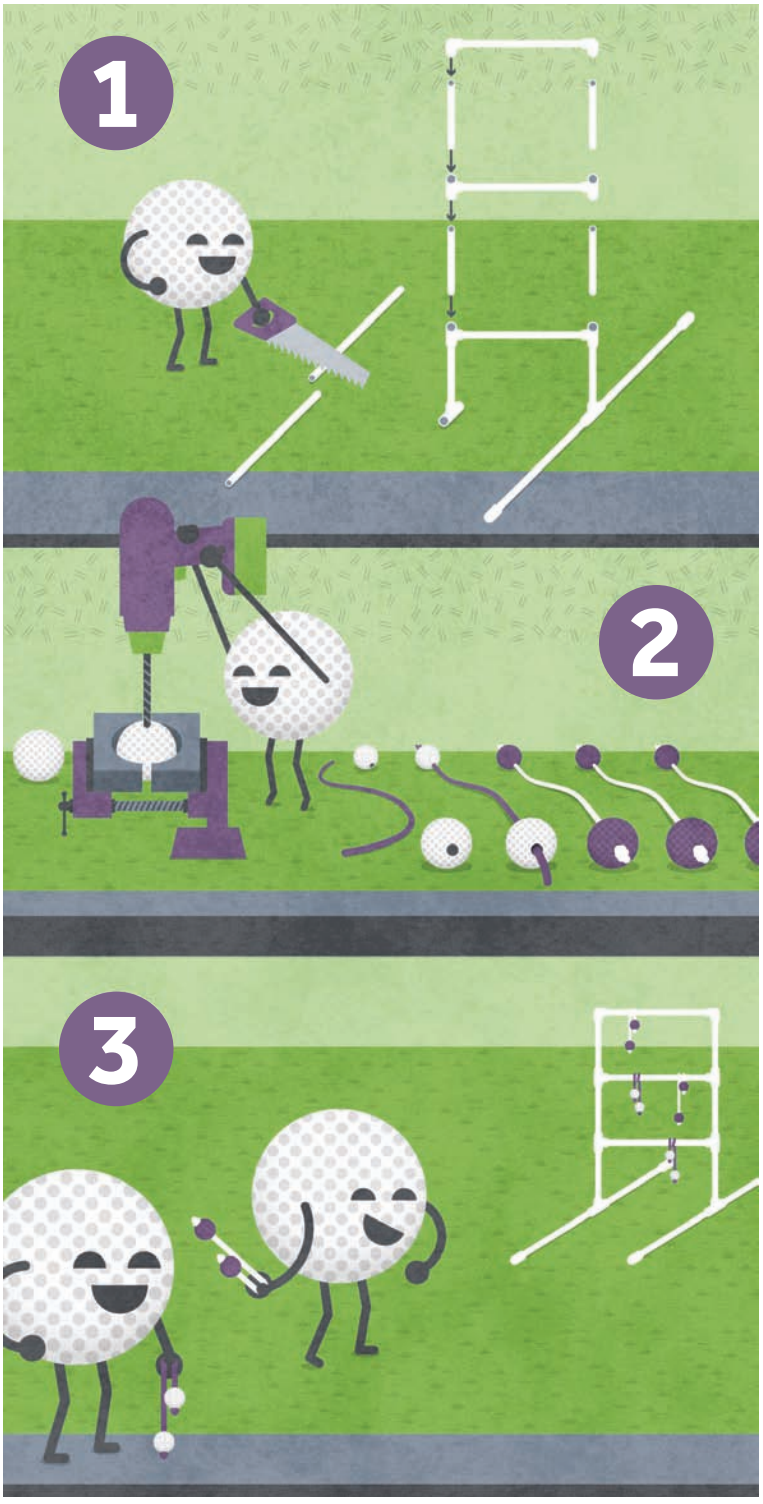
» **PART** The copy that comes out of the mold.

Recycle your expensive silicone by using chunks cut from old, worn-out molds to fill up space in your new mold.

Hep Svadja

1-2-3 PVC Ladder Toss

Written by Jeremy S. Cook ■ Illustrated by Andrew J. Nilsen



PICNICS, TAILGATE PARTIES, AND OTHER OUTDOOR GATHERINGS ARE GREAT, but a little friendly competition makes things more interesting. You could buy a ladder toss set, but what fun is that? Here's how you can make your own!

1. ASSEMBLE THE LADDER

Press pipes into fittings as shown, using the 24" lengths for the ladder rungs (and feet) and the 12" pieces to form the vertical ladder rails.

You can press-fit it all, or you can use PVC cement on joints where you value rigidity over portability.

2. DRILL THE BOLAS

Drill a 3/16" hole through the center of each golf ball. A drill press with a vise is very helpful for securing the ball while drilling.

3. TIE THE BOLAS

Cut 6 lengths of cord to 21" and melt the ends to prevent fraying. Thread each cord through 2 golf balls and knot each end securely. To tell the difference between each set of 3 bolas, use 2 different color balls or cords.

TO PLAY:

Set up your ladder in an open area. Establish a toss line 15 feet (or 5 paces) from the ladder. The first player will toss 3 bolas, then the second will toss 3, with the objective to wrap them around rungs on the ladder. The top rung is worth 3 points, the middle 2, and the bottom 1. Games are generally played to 21 points, but "house" scoring variations are common. It's oddly satisfying to see your golf balls wrap around a pipe — even more so if you're competing with friends!

Time Required:
2–3 Hours

Cost:
$20–$30

YOU WILL NEED:

- **Golf balls, solid core (12)** ideally 2 colors, 6 of each
- **Strong cord, 1/8" or 3/16" diameter, 12' total length**
- **PVC pipe, 1/2" diameter, 10' lengths (3)** cut to lengths of 12" (6) and 24"(7)
- **PVC fittings, 1/2": tees (6), elbows (2), and caps (4)**
- **PVC cement (optional)**
- **Paint (optional)**
- **Drill** Use a drill press if possible.
- **Vise**
- **Hole saw, 1 3/4" (optional)**
- **Saw**
- **Knife**
- **Lighter**

PRO TIP:
To make a drilling jig that won't mar the ball, drill a 1¾" hole through a scrap of 2×4, then saw it in half.

JEREMY S. COOK (@JeremySCook) is an engineer in the Southeast United States, and has a BSME from Clemson University. Outside of work he's an avid Maker and experimenter, building anything that comes into his mind.

See build photos at makezine.com/go/pvc-ladder-toss.

Material Possessions

Written by Ellen Howes

MAKE **FABRIC** THE FOCUS OF YOUR NEXT PROJECT

AS A COSTUME DESIGNER, I WORK EXTENSIVELY WITH FABRIC — and most of what I know about fabric is from making a lot of mistakes. Here are some tips to help you learn from mine.

CHOOSING

It's important to first consider what you need the fabric to do. Do you need it to stretch around something or drape over something? Do you need it to be flowing or stiff? Is the fabric you're choosing washable? Does it fray easily (i.e. does it need to be hemmed)?

CUTTING

Rather than using scissors all the way across to cut a straight line on a large portion of fabric, it's much faster and more accurate to use the "snip and rip" technique. Simply snip parallel or perpendicular along the grain of the fabric, grab both ends tight, and rip! You'll get a straight tear. Be sure to leave extra fabric to account for seams.

HEMMING

Structural pieces like hats don't necessarily need to be hemmed, so you can save it for clothing or other soft goods that will eventually need to be washed. Other ways to avoid hemming are to use nonwoven fabrics or you can use tools such as hem tape or Fray Block. For projects that do need a hem, do it twice to hide loose ends and add durability: tuck loose threads in by folding fabric back, sewing, and then folding back again. Beware of stretchy fabrics. They're very difficult to work with, as they must lay flat without being stretched while sewn. Otherwise they will look really funky really fast!

REVERSE ENGINEERING

It takes practice to understand the way fabric works, but one of the best ways to grasp sewing construction is to take something apart and see all the pieces that went into it. Patterns are a great way to learn too. Even trained designers still use patterns to make garments.

OTHER USES

Fabric isn't just for clothing and upholstery. I use felt for everything: glue small circles to the bottom of furniture legs to prevent them from scratching hardwood floors, apply to the sharp edge of furniture that you always bump your shin on, or use as cushioning when storing breakables.

MEASURING TIP:
Fabric is measured in yards. Use the tiles on the floor of the fabric store (usually 12"×12") to estimate how much fabric you have/need. 3 tiles = 1 yard

CUTTING NOTE:
Ripping only works for woven fabrics, and works best with those of medium thickness. Do not attempt this with pressed or formed fabrics such as felt, leather/faux leather, plastics, etc.

HEMMING TIP:
For hemming rounded areas or circles, make small snips around the edge of the fabric before hemming and always pin in place first!

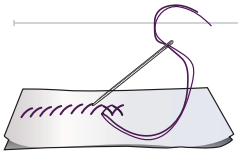
ELLEN HOWES
is a costume designer in Oakland, California. While she has a Master's in Theater Arts with an emphasis in design, her sewing skills are entirely self taught.

JASON BABLER
is a sculptor, designer, and DIYer. He likes to make monsters in his studio and is on the advisory board of his local makerspace.

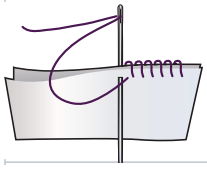
Hep Svadja

SEWING

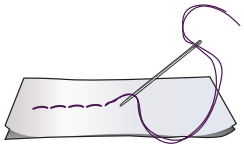
If your project requires attaching two textiles together or affixing an object like a button, you'll need to know some basic sewing skills. You'll need a needle, thread, and scissors. Needle threaders and thimbles are also helpful. Start with one of these five basic stitches:



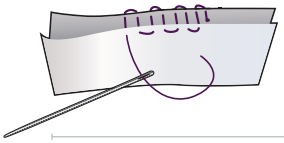
Cross-stitch — Commonly used for decorative purposes, the cross-stitch is X-shaped and arrayed like tiles.



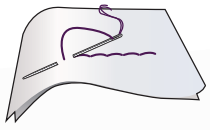
Whipstitch — The thread spirals around the edge of one or both pieces of fabric. Commonly used to affix patches.



Running stitch — The thread runs straight along the fabric, going up and down with visible spacing between stitches on each side of the fabric.



Ladder stitch — Like the name implies, this stitch goes to the right, up, to the left, up, and repeats. Also called a blind or hidden stitch, this is useful for creating an invisible seam.



Backstitch — Similar to the running stitch, except that the thread doubles back so that there is no visible spacing between stitches.

KNITTING

Knitting is the craft of using needles to make yarn into a patterned textile. In addition to needles and yarn, a knitter can also use a tool called a stitch marker to keep track of how many stitches they have per row. Check the packaging of the yarn you buy — it'll tell you what size your needle should be to work with it. Every new project starts with a "chain stitch," and from there, different patterns are executed to render different shapes such as hats and scarves.

Ready to try your hand? Knit a cozy pair of boots at makezine.com/go/knitted-boots.

LEATHER

Working with leather is an incredibly satisfying hobby. It's extremely versatile and so durable that your projects are bound to last for years. As with any new hobby, the terminology and sheer variety can cause some confusion. Here's a crash course so you can jump right in.

THE MOST COMMON TYPES OF LEATHER ARE:

Vegetable Tanned — You can tool, cut, stamp, and dye this durable leather for most of your projects. Tanned by plant-based tannins, this is the foundation of high-end wallets, belts, and pet collars. Buy this first to start playing with how leather works. Look for scraps at Tandy Leather stores near you.

Latigo — More pliable than veggie tanned, this leather cannot be tooled, stamped easily, or formed. It's a combination of veg-tanned and then chrome tanned (tanned using chromium sulfate), which looks great and more finished than its veg-tanned cousin.

Bridle — I love this leather — it's expensive but incredibly beautiful. Bridle is treated with oils and usually dyed with gorgeous, rich colors. In addition to its aesthetic value, this type of leather withstands weather very well.

Cordovan — Cordovan leather is made from horses, specifically from the rump. It's very durable, and very expensive. Graduate to this when you have the skills and money to play with high-end leather.

Suede — This is the soft, furry layer of material between the outside skin of the animal and the flesh. Suede is often used as liners for projects, but it can't get wet and therefore is difficult to clean.

Upholstery — This leather is soft but cannot be tooled at all. Used in sofas, cars, and clothing.

MEASURING

Most leather is sold by the square foot, and the thickness (weight) is measured oddly, specifically in "ounces," although it's not the same measurement that you are used to. Roughly, one ounce equals approximately 1/64". Big straps and belts are usually around 8–9oz and wallets are usually made with 3–5 oz.

Ounce	Inch
1	1/64
2	1/32
3	3/64
4	1/16
5	5/64
6	3/32
7	7/64
8	1/8
9	9/64
10	5/32

THE BASICS

National chain Tandy Leather is where most folks start out. As you get more focused on the craft, check out their tools. Most have an accompanying video, tandyleather.com and tandyleather.com/en/leather-buying-guide.html.

VIDEO TUTORIALS

I've learned a lot from watching others work. These two guys have the best video tutorials and patterns around: ianatkinson.net and armitageleather.com.

BOOKS

The granddaddy of leather literature, Al Stohlman's books are hand illustrated and most of the techniques inside are still relevant today tandyleather.com/en/category/stohlman-leather-craft-books.

— Jason Babler

Turning Heads

GET TO KNOW THE VARIOUS TYPES OF **SCREWS** AND THEIR USES

Written by Jeremy Cook

JEREMY S. COOK is an engineer with 10 years of experience at his full-time profession, and has a BSME from Clemson University. Outside of work he's an avid Maker and experimenter, building anything that comes into his mind!

SCREWS ARE, AT THEIR BASIC LEVEL, AN INCLINED PLANE WRAPPED AROUND A SMALL CYLINDER. Due to modern manufacturing methods, these amazing building blocks for machinery can be produced incredibly cheaply, and allow for a quick and strong way to attach things together. They come in many different shapes and sizes, designed for specific applications.

MACHINE SCREWS

Machine screws can be used in precision machinery, and are defined by major diameter as well as threads per inch. Metric screws are specified with the letter "M," the diameter, then the thread pitch. So "M6 × 1" would be a 6mm diameter screw with a thread pitch (spacing between threads) of 1mm. Unified National threads, also known as "English" or "Imperial," are defined by the screw number — 10 for example, signifying a .190" diameter — and threads per inch. So a 10-32 screw is a #10 (.190") diameter, and has 32 threads per inch. Larger English screws are known by their fractional size. For example, a ¼-20 screw would be ¼" in diameter and has 20 threads per inch.

SELF-THREADING SCREWS

If you're working with wood or sheet metal, self-threading screws form the material as needed, allowing you not to worry about the thread pitch quite as much. Simply drill a pilot hole into the material, and screw your fastener in. One disadvantage of this type of fastener is that it can damage your material, especially if it needs to be removed and reinstalled on a regular basis.

SCREW HEAD TYPES

Screws come with different types of heads, including the flat head (-) and Phillips head (+), as well as hex head (shaped like a hexagon), and Torx head (shaped like a six-pointed star). Though those head types are quite common, there are many other variations, including some that are meant to resist attempts at removal. A good screwdriver set with a variety of interchangeable tips is extremely useful for creatively voiding your warranty!

FEMALE THREADS

Screws, though interesting in themselves, aren't much use without something to attach to. In the case of self-threading screws, the screw, when inserted into your chosen material, forms it into the correct shape. For machine screws, you can use a nut of the correct size, or you can form female threads into your material using a tap set. To use a tap, drill the appropriate pilot hole, then twist the tap into the hole. This can be extremely useful to minimize parts, and when you'd rather not put a screw entirely through both pieces of material.

Hep Svadja

WOOD SCREWS

FLAT HEAD

PHILLIPS HEAD

HEX HEAD

TORX HEAD

Sticky Situations

SELECT THE RIGHT **GLUE** FOR YOUR MATERIALS

Written by Rebecca Husemann

REBECCA HUSEMANN
is a design student writing her bachelor's thesis while working at the German version of *Make:* magazine.

FOR YEARS I WONDERED WHY ALL MY BEAUTIFUL SMALL-SCALE MODELS KEPT FALLING APART. I underestimated the most important factor: adhesive. You can glue almost everything with super glue — but some materials just won't stay together. Is it possible to glue rubber to glass? Will plastic stick to wood? Once you mix several different materials, it can get really confusing. For those moments it's convenient to have a handy table that gives a quick overview.

ADHESIVES CHART

MATERIALS → ↓	Paper	Fabric	Felt	Leather	Rubber	Foam	Styrofoam	Plastic	Metal	Ceramic	Glass	Balsa	Cork	Wood
Wood	W	C/W	Sp/C	W/C/Ca	C/Ca	C	2K/H	L/C	2K/C/L	C/Ca	C/Ca	W	W	L/W
Cork	H/W	H/L	W	Ca/C	Ca/C	2K	W	L/Ca	C/Ca	L/Ca	Si	W	W	
Balsa	W	H/W	W	Ca/C	C/Ca	C	2K/H	L/Ca	2K/Ca	L/Ca	C/Ca	W		
Glass	A/W	A	A	A/Ca	Ca	Sp	2K/Sp	C/L	2K/C	2K/C/L	2K/L			
Ceramic	A/H	Ca/A	Ca/A	Ca/A/C	C/Ca	A	Ce/C	L/Ca/C	2K/C/L	Ce/Ca				
Metal	A/H	A	C	C/Ca	C/Ca	C	2K/H	2K/C	2K/C					
Plastic	H/Sp	Sp/C	Sp/C	Sp/Ca	C/Ca	Ca	Ca/C	L/Ca/2K						
Styrofoam	Sp/C	A/H	Sp	A	L	L/A	A/Sp							
Foam	Sp	Sp	Sp	C	C	Sp								
Rubber	Ca/C	A/C	C	Ca	Ca									
Leather	F/Sp	F	2K	C/F										
Felt	A/H	F/H	H/F											
Fabric	A/H	F/H												
Paper	A/W													

A= All-purpose-glue
F= Fabric glue
Sp= Spray adhesive
H= Hot glue
C= Contact adhesives
L= Construction adhesive (Liquid Nails, Loctite)
Ce= Ceramic glue
Si= Silicone
W= Wood glue
Ca= Cyanoacrylate (super glue)
2K= Two-component adhesive

Hep Svadja

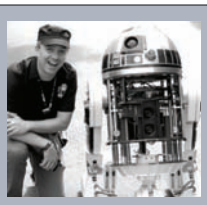
Jacob LaRocca's all-duct-tape model of the Serenity spaceship from *Firefly*.

CREATE ALMOST ANYTHING WITH **DUCT TAPE**

Utility Player

Written by Jacob "Rocket" LaRocca

JACOB LAROCCA is an electrical engineer who loves to build duct tape models in his spare time, as well as make props from movies and video games for his company Rocket Props.



DONALD BELL Donald is a projects editor for *Make:* who enjoys playing guitar, skateboarding, and hanging out with his son. Email donald@makermedia.com to pitch him your project ideas.

WHEN YOU SEE A ROLL OF DUCT TAPE, YOU PROBABLY DON'T IMMEDIATELY THINK, "I WANT TO BUILD SOMETHING OUT OF JUST THAT." But duct tape is an insanely versatile material, and once you grasp its tendencies and habits, you can build nearly anything with it.

THE TAPE

Duct tape varies by brand and by grade in four main attributes that I refer to as stickiness, strength, flexibility, and rip-ability. Generally, the mid-range priced duct tape is a good bet, but some of the higher quality stuff is even better. What you are looking for is a tape that rips easily both horizontally and vertically, and doesn't collapse on itself too easily.

PRO TIP: Gorilla Tape is not the same thing as conventional duct tape. It will rip the skin off your fingers. Not fun.

TOOLS

I use very few tools: a pair of diagonal cutters, a set of dental picks, and some hobby knives are all that are needed. Don't use scissors because the adhesive will destroy them. Calluses on the hands help, but they are not required, as you will develop them over time.

SOME LESSER KNOWN USES FOR DUCT TAPE

» Open a tightly sealed jar.

» Cut a sufficient length and then twist it into a cord.

» If you've injured yourself, you can make a splint, butterfly bandages, or hold a cotton pad over a blister with duct tape.

» Hide a small item, like taping an extra house key to the underside of your car.

» String some up from the ceiling to passively catch flies and mosquitos.

» Tape around the hem of your pant leg so water doesn't seep up the fabric when it's raining.

» Prevent glass from shattering during moving or a strong storm by reinforcing mirrors or windows with tape.

» If the glass is already cracked, tape over the crack and any sharp edges with duct tape before moving or disposing of it.

— Sophia Smith

J Shia, Hep Svadja

CREATING STRUCTURE

Every single one of my models has a duct-tape armature. It may look like wire, but it is actually duct tape rolled inside out. Find a smooth surface that has very small variations in it. Plastic folding tabletops are a good example. Enamel, Formica, or even stone will work, however the smoother the surface the more the tape will stick, and it will be harder to roll the tape.

Stick a piece down onto the table top and carefully feather the top edge. Then use the heel of your hand and pull back and down so that the tape rolls inside out in a tight roll. It won't be pretty the first time, but with practice you'll be able to bang them out like nothing. Once you get the hang of it, try varying the diameters by overlapping a few pieces of tape or ripping the piece lengthwise.

CREATING STRENGTH

Duct tape is extremely strong, however, it is only strong in certain directions. If you need a strong sheet of tape, alternate the directions you are laying it down. If you need a structure to support weight, use geometry and angles to engineer self-supporting armatures. Double, triple, or quadruple roll the armatures and they will be incredibly strong, while still remaining flexible.

You can create rigidness by having a thick core, and then placing thinner armatures all the way around it. Because the adhesive is on the outside of the armature, when multiple pieces are placed together in parallel or perpendicular, they become very strong.

LAYER IT ON

The key to a good, smooth, curved surface is layering. If you layer multiple pieces on top of each other in one length (say, four 1' pieces on top of each other) then it is less likely to inherit surface abnormalities underneath it. The more layers, the smoother it will look, but the less flexible it will be.

IT'S A CINCH

The zip tie or cable tie is a well-known tool for bundling together wires and other elements of your project. Here are two little-known tricks for using zip ties to keep things separated.

ZIP TIE STANDOFF

Here's a way to tidy up data cables, fuel lines, pneumatic tubes, and bicycle brake lines.

1. Cut off a ¼" section of clear vinyl tubing.
2. Run your zip tie through the small section of tube, leaving it sitting midway down the zip tie.
3. Wrap the smooth side around whatever you're trying to wrangle.
4. Feed the pointy end back through the ring of vinyl tubing with the smooth sides facing each other.
5. Cinch up the loop by adjusting the vinyl tubing ring toward the cable, creating enough length for the ends of your zip tie to be secured around whatever you're fastening it to.
6. Zip it up, trim off the extra, and repeat as needed.

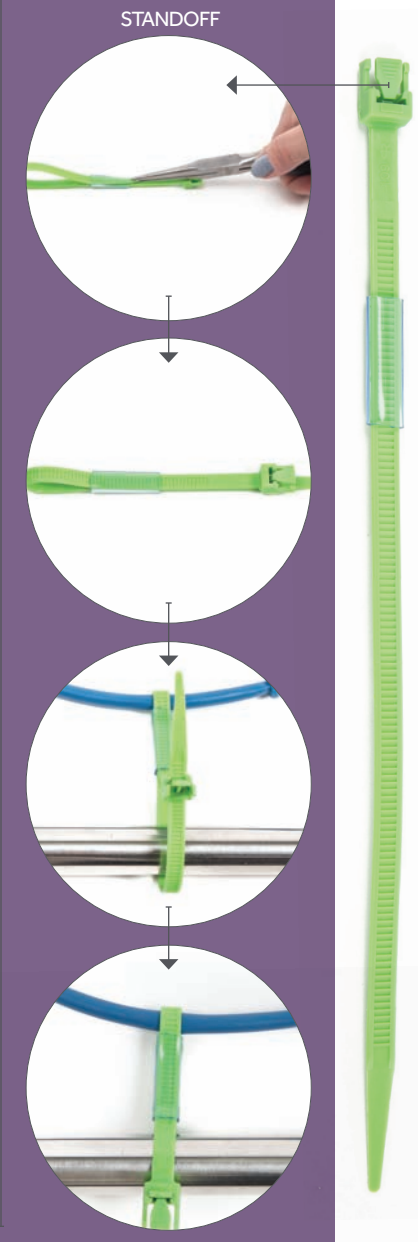
ZIP TIE CABLE WEAVE

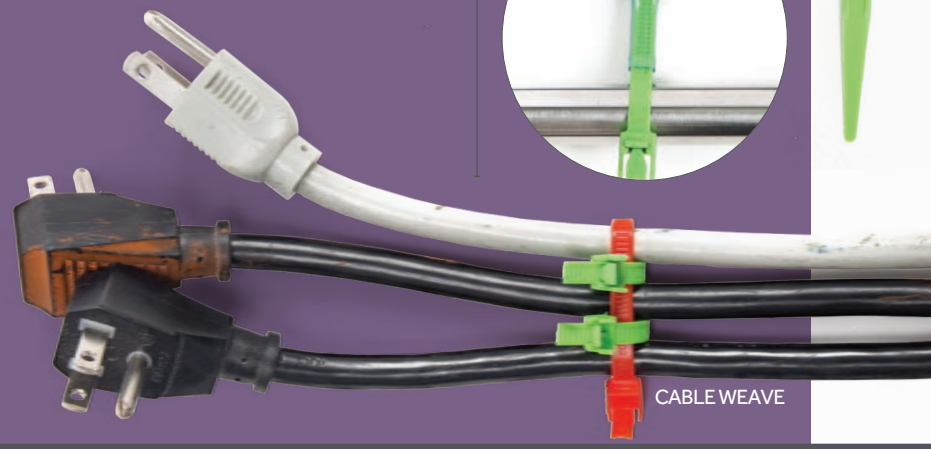
This is a simple way to gather up any group of thick cables while simultaneously keeping them separate from one another.

1. Lay your cables down parallel to one another and count them. The number of zip ties you'll need is equal to the number of cables.
2. Loosely attach one zip tie across the entire bunch of cables like a collar. Leave plenty of slack.
3. Loosely attach the remaining zip ties around the first, between and in line with each cable.
4. Tighten the first zip tie, then move on to the small rings. Trim excess. — *Donald Bell*

PRO TIP: STEEL ZIP TIES

In case you ever need to wrangle something that would melt through a traditional plastic zip tie, grab yourself a pack made from stainless steel. These are commonly used as straps for motorcycle exhaust pipes, but their shiny chrome look could make for a cool, practical accent for your next project.





Molten Metal

Written by Rusty Oliver and Caleb Kraft

WELDING AND **SOLDERING** GIVE YOU THE POWER TO FABRICATE STEEL, CONTROL ELECTRONS, AND MORE

RUSTY OLIVER is an artist, instructor, and founder of Hazardfactory, an industrial arts studio that generates high quality risk for public consumption in Seattle, WA.

CALEB KRAFT is a senior editor for *Make:*. After several years of constructing crazy ideas, Caleb has used solder in a variety of ways — sometimes with great success.

WELDING PRO TIPS

- Quality matters! Spend a little more than you would like to and buy a Miller, Lincoln, or Hobart. These machines are durable, well supported, and can be resold for 80% of their purchase value where cheap machines cannot.
- 120V machines are extremely portable especially when running FCAW. Being able to weld ¼" steel wherever you can extend a heavy extension cord is no joke!
- 220V machines will always make the job easier, but they are much, much less portable and may require installing heavy-duty electrical circuits in your shop.
- Good MIG machines are DC output. Only truly horrible MIG machines are AC output. AC output tends to produce very shallow penetration in steel.

Having trouble creating a quality weld? Be sure to check out our online "Checklist for Creating a Good Weld" companion piece [makezine.com/go/welding-tips].

MIG WELDING

Most welding systems use either gas or electricity to generate the temperatures needed to permanently fuse metals together, along with a filler material to help strengthen the connection. Metal Inert Gas (MIG) welding incorporates an automatic wire feeder into the process, general making it the easiest welding method.

MIG machines are assessed by their amperage output. A 90A output is very low and only found in machines of dubious quality. A 120–140A output range will work pretty well for mild steel up to 3⁄16" thick. Machines from 140–250A output are much easier to use but they will require a 220V, 50A circuit. Larger machines are even easier to use, but if you don't work in ½" thick steel routinely, you don't need one.

Most MIG welding machines can do both Gas Metal Arc Welding (GMAW) and Flux-Cored Arc Welding (FCAW).

GAS-SHIELDED WELDING

Using a stream of inert gas to keep the metal fusion process clean from atmospheric contaminants, the GMAW process is easier for most beginners, but it requires a high-pressure cylinder of inert gas — a 3-to-1 ratio of Argon and CO_2 is the most common. These are available from your local welding supplier. You will also need a regulator and a hose and fittings to connect this to your machine.

In GMAW the polarity of the operation is DC electrode-positive, and this polarity coupled with the shield gas result in lower heat input. Machines running on 120V input perform better on thinner materials, but struggle with steels over ⅛" thick.

FLUX-CORE

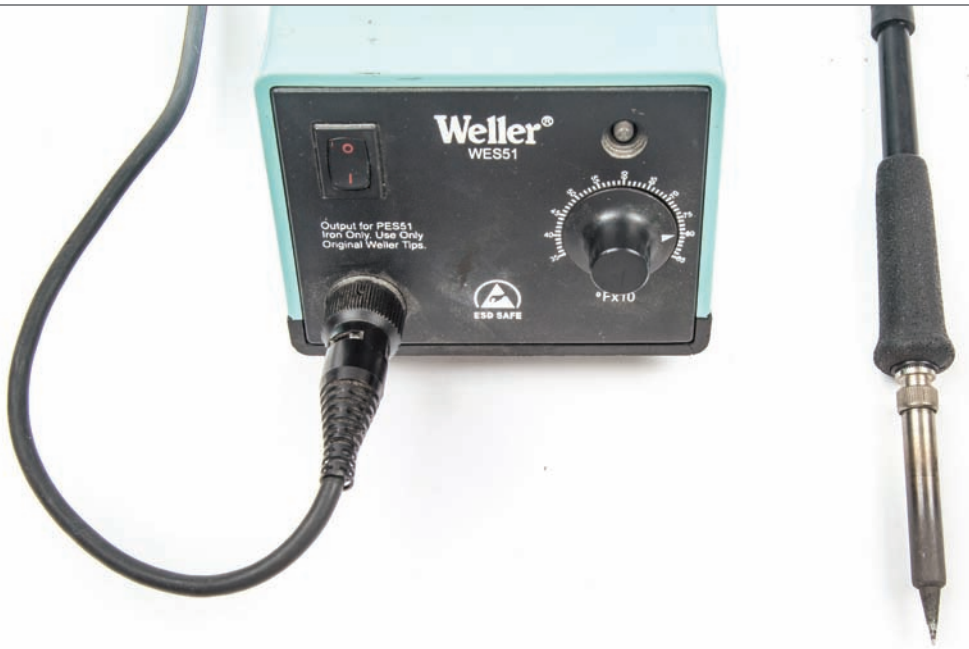
FCAW is a little harder to get used to than GMAW. It uses an electrode that creates CO_2 as it melts under the welding arc, typically not requiring an additional shield gas.

The controls for FCAW wire speed and arc voltage must be set very differently than they are for GMAW. FCAW is run DC electrode-negative — the polarity and the CO_2 generated by the electrode tend to produce excellent penetration, but also spatter, resulting in a messier appearance. FCAW is capable of welding up to 3⁄16" or ¼" with a 120V input, 135A output machine, but the same machine running GMAW will not produce good welds in thicker material.

WELDING STEEL VS. ALUMINUM

Steel is much easier to weld correctly than aluminum, and beginners with inexpensive equipment can weld steel readily. Most MIG welding machines will state that they can be used to weld aluminum with an additional "spool gun." This is essentially false. A MIG machine with 120V input lacks the amperage output for effective work in aluminum. In short, trying to MIG aluminum with a 120V machine is a painful and expensive exercise that should be avoided. — *Rusty Oliver*

Hep Svadja



SOLDERING

Typically, you'll find hand-soldering components, pipe joining, and stained glass making as the three main uses of soldering. Here are the basic steps to each method.

PCB ELECTRONICS SOLDERING

Handheld soldering irons, generally 15–30W, are used for joining electronic components. These can be soldered together directly, but commonly incorporate through-hole soldering onto printed circuit boards (PCBs), with the components' leads placed through the board and soldered to it.

TECHNIQUE: Place the component's leads through the appropriate holes on your PCB. Position the soldering iron to make as much physical contact as possible with the lead and the corresponding pad on the PCB — this is important for ample heat transfer. Add solder directly to the pieces to form a union. Remember to remove the iron's tip quickly to avoid heat damage to the PCB.

PIPE JOINING

Not all solder is intended to conduct electricity. In the case of plumbing applications, solder is used to join copper pipes together and form seals. This isn't done with a soldering iron, but with an open flame.

TECHNIQUE: Begin by cleaning your pipe thoroughly with high-grit sandpaper or steel wool. Apply flux to the part that will fit inside the joint and assemble your two pieces. Heat the point of the union, making sure to get all sides heated evenly by moving your torch from side to side.

Touch the solder where the two pipes meet, and it will melt and get pulled inside the joint, spreading around the entire circumference of the pipe to create a good seal.

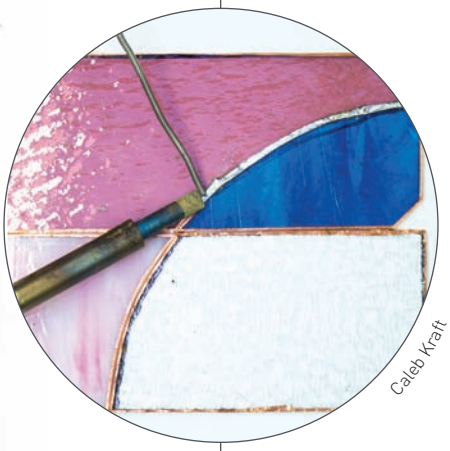
STAINED GLASS JOINING

Stained glass often has an organic nature to it, meaning that the connections aren't always a perfect angle or perfectly aligned. Using solder as a joining structure allows for a more flexible approach by filling the gaps between pieces of glass. A stained glass soldering iron is typically 100W, with a broad, flat-headed tip.

TECHNIQUE: Cut your glass to the shape you want then add a border of copper around the perimeter of each piece. Line up the pieces in the desired position, then apply flux to the copper foil tape.

Drag the hot tip along two adjacent pieces of glass, applying solder during the motion to form a joint. Your iron should be hot enough that as you drag it and apply solder, the gap between the two pieces is easily filled with the molten material. Once the entire art piece is connected, flip it over and do the same on the other side.

— Caleb Kraft



Caleb Kraft

PCB PRO TIP:
The solder should have a smooth transition onto the pad and the component. If it is balled up like rain on a windshield or has a dark outline around the pad or component, your solder has most likely failed and should be redone.

PIPE JOINING PRO TIP:
Don't worry if you spot a leak. Simply reheat and reapply solder.

STAINED GLASS PRO TIP:
Never "push" the iron along the joint, as it may damage the foil tape or shove the glass out of the way.

LEARN HOW TO USE A **MULTIMETER** PROPERLY, AND TO CHOOSE THE BEST **MOTOR** FOR YOUR BUILD

Go WITH THE Flow

Written by Charles Platt

CHARLES PLATT
writes *Make:*'s Electronics Fun and Fundamentals column. See page 80 for his latest project.

Hep Svadja

MULTIMETERS

Your eyes can't show you what's happening inside a circuit, but a meter can.

Every meter has a "common" socket, color-coded black and labeled "com." Plug the black probe into this socket.

You'll also find a red-coded socket, labeled with the letter V and an ohm symbol to tell you that it measures voltage and resistance. If it is also labeled mA, it will measure current in milliamps (mA) — but a separate socket may have that purpose. Yet another socket is set aside for high currents, up to 10 or 20 amps.

Connect your red probe to the appropriate socket and turn the selector dial to the units that you want to measure *before* you touch the probes anywhere.

Touch the black probe to the negative side of the power supply, touch the red probe to any other location in a circuit, and you'll monitor the voltage (electrical pressure) between them (Figure A). If you have an auto-ranging meter, it takes a moment to respond. A manual meter is faster, but you have to turn the dial to specify the upper limit of the voltage range.

Checking voltage is the most basic way to troubleshoot a circuit — you can look for bad connections, burned-out components, or a dead battery.

Current consists of a flow of electrons. Pass it through the meter cautiously, as too much current will blow the internal fuse. When trying to measure current, never attach the meter directly to a power source (Figure B).

To measure the resistance of a component, disconnect it from a circuit (Figure C). The value in ohms tells you how strongly a component will resist current.

Most simple electronic circuits use DC power, but meters can measure AC too. Many have an AC-DC button, but some have AC options on the selection dial.

You can buy a meter for as little as $5 on eBay. Costlier meters will be more accurate, will do auto-ranging, will contain a replaceable internal fuse, and their switch contacts may last longer. They will also have extra features, such as measuring the value of a capacitor or the frequency of a stream of pulses from a microcontroller. They'll also do continuity testing, emitting a beep when wires are properly connected or a switch is closed.

You'll find that I discuss more aspects of meters in my book, *Make: Electronics*.

MOTORS AND SOLID STATE RELAYS

In a world of DC motors, AC motors, stepper motors, and servo motors — which should you use?

The speed of a basic **DC MOTOR** fluctuates with voltage and with the amount of work that it has to do. This makes it unsuitable for precise applications, although it can be controlled by rapidly pulsing its power supply. When fitted with reduction gearing, it becomes a "gearhead motor," as shown in Figure 1. DC motors are affordable, reliable, quiet, and simple to use, making them a great option for many projects.

An **AC MOTOR** is controlled by the frequency of its AC power supply. It was a popular choice in old-style phonograph turntables or electric clocks where the speed was governed by 60Hz house current. Capable of generating high torque, 110V and 220V AC motors are found in fans, washing machines, and industrial equipment. See Figure 2.

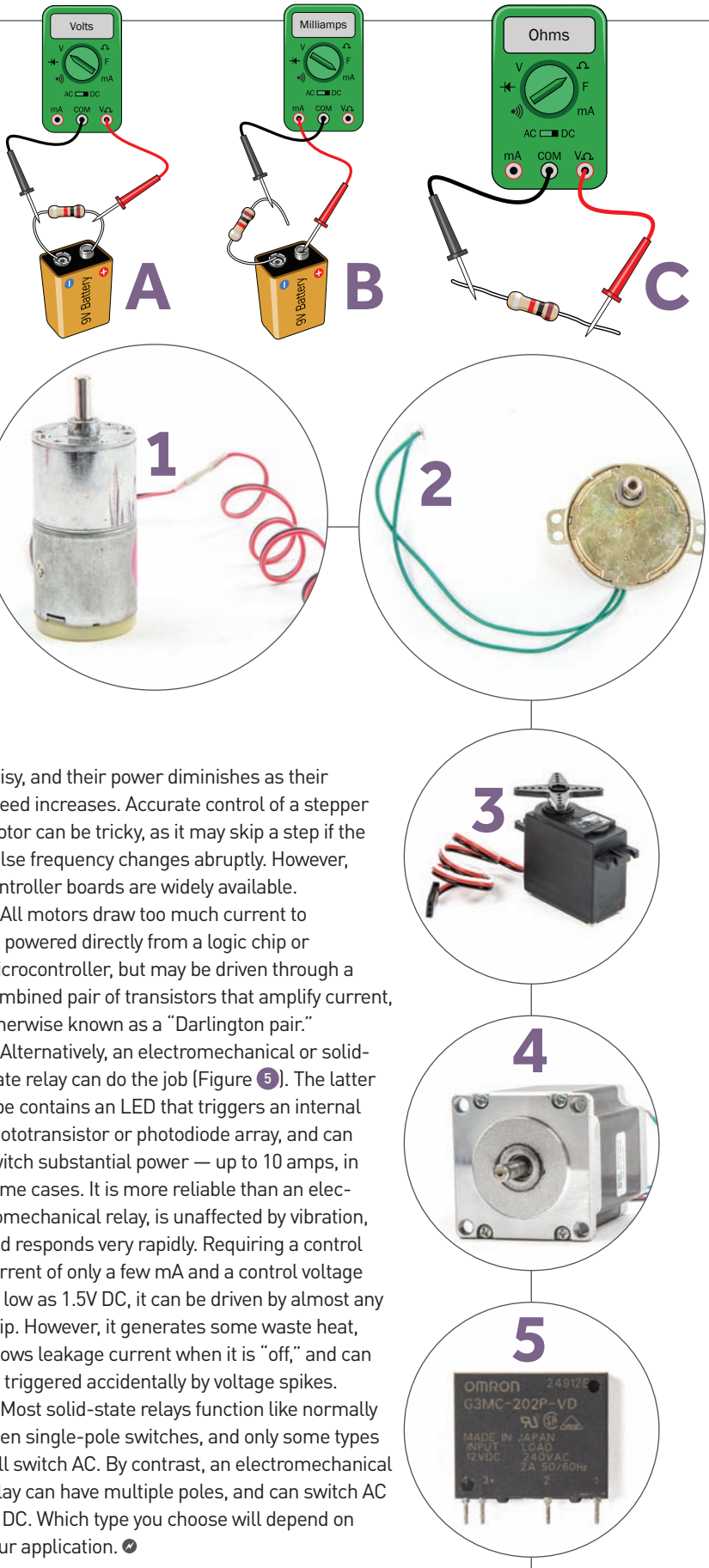
SERVO MOTORS rotate quickly to a precise angle, then hold that position while resisting any attempt to change it. Powered by about 5V DC, they require a separate AC stream in which the width of each pulse determines the motor's turn angle. Most microcontrollers have servo control built in. Servos are light, powerful, and ideal for setting the rudder angle in a model aircraft or boat. The Futaba S3003 (Figure 3) is a low-cost example. Most servos can only rotate through around 270°, but a few can rotate continuously. (See "Your Obedient Servo" in *Make:* Volume 44.)

STEPPER MOTORS turn in fixed steps when a control voltage is switched between multiple input wires. The steps can be counted by a microcontroller, as shown in Figure 4. Widely used in robotics, they tend to be somewhat noisy, and their power diminishes as their speed increases. Accurate control of a stepper motor can be tricky, as it may skip a step if the pulse frequency changes abruptly. However, controller boards are widely available.

All motors draw too much current to be powered directly from a logic chip or microcontroller, but may be driven through a combined pair of transistors that amplify current, otherwise known as a "Darlington pair."

Alternatively, an electromechanical or solid-state relay can do the job (Figure 5). The latter type contains an LED that triggers an internal phototransistor or photodiode array, and can switch substantial power — up to 10 amps, in some cases. It is more reliable than an electromechanical relay, is unaffected by vibration, and responds very rapidly. Requiring a control current of only a few mA and a control voltage as low as 1.5V DC, it can be driven by almost any chip. However, it generates some waste heat, allows leakage current when it is "off," and can be triggered accidentally by voltage spikes.

Most solid-state relays function like normally open single-pole switches, and only some types will switch AC. By contrast, an electromechanical relay can have multiple poles, and can switch AC or DC. Which type you choose will depend on your application.



Charles Platt

Programming Is Expression

Written by Tom Igoe

RATHER THAN **LEARNING TO CODE**, YOU SHOULD START THINKING COMPUTATIONALLY

SCHOOL ADMINISTRATORS AND EDUCATORS ARE CURRENTLY ZEALOUS ON THE IDEA THAT EVERY STUDENT SHOULD LEARN COMPUTER SCIENCE. "Think about the world we live in now," says New York Mayor Bill de Blasio, "Hundreds of thousands of good jobs will be accessible to those with coding and other essential skills." I agree that everyone should learn to program, but I disagree with Mayor de Blasio's motivations. You shouldn't learn to program in order to get a good job. Learning to think computationally can give you a new way to understand and describe your world. Learning to program can make you a more expressive person.

We express ourselves in many different forms, and each form has its core elements. Musicians rely on pitch, rhythm, and timbre. Visual artists and designers use color, form, and scale. Performers use movement, gesture, and timing. Computational thinking is another form of expression, and it rests on a set of core elements as well: **Inputs and outputs** connect a computer to the rest of the world. **Named memory addresses** called **variables** keep track of important properties, like temperature, bank balances, or button pushes. **Conditional statements** define what to do when one of the properties changes significantly (for example "if my bank balance drops below $10, email me"). Various forms of **iterative loops** are used to continually check for changes in a system's inputs and to update its outputs. **Functions** combine several statements into repeatable actions. These concepts underlie every form of programming.

If you like to make things, you probably either design them with computers, or you put computers inside them. You may think you're just a novice, but as you use these tools, you're learning to program. If you think computer programming is all about math, you're wrong. It's about describing a situation precisely, and giving good directions for what to do when conditions change.

CONSIDER THESE EVERYDAY MOMENTS:

- If the temperature goes below 65°, turn on the heat
- When the drum solo starts, mute the guitar track and spotlight the drum kit
- It's just a jump to the left, and then a step to the right. With your hands on your hips, you bring your knees in tight.

All of these statements embody computational thinking. They could all be programs.

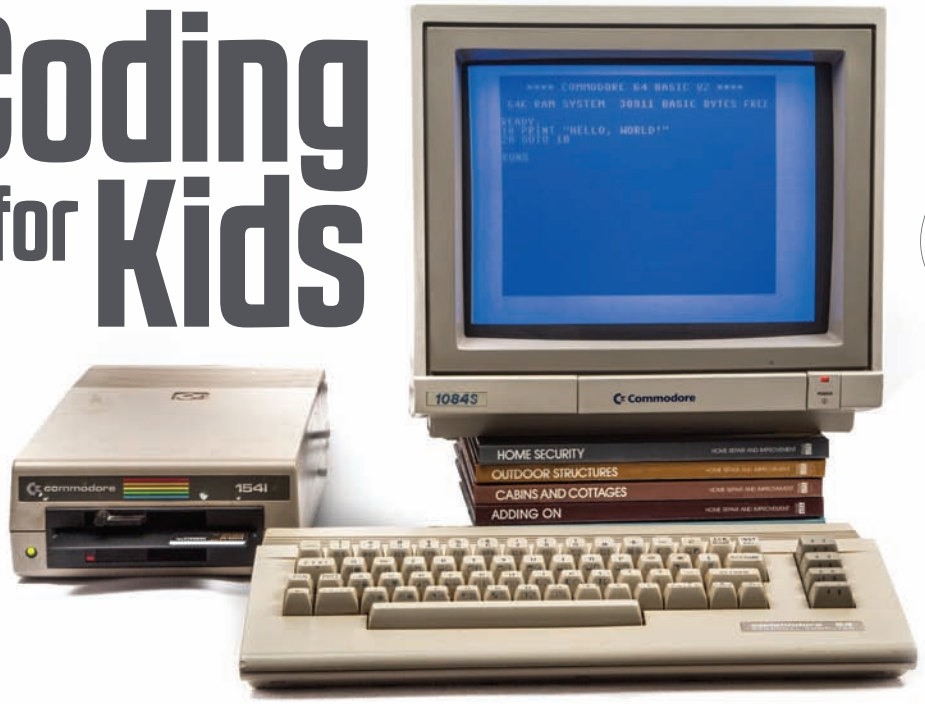
Computational thinkers aren't just programmers. They're the people who can create lovely intricate patterns in Illustrator, or make a really cool gizmo in Minecraft, or make a MIDI synthesizer play crazy microtonal jazz solos. They understand not only how to make a computer speak, but they also have an imagination for what it could possibly say. People often ask, "What language should I learn?" There is no right answer because you're going to learn several if you start programming. Pick something that computers are used for that excites you, and find out what languages are used to make it happen. With each new application, you're likely to learn a new language, and you'll become a better programmer and a better computational thinker as you do.

Speaking and writing isn't just something that linguists do, nor should programming be something that just computer scientists do. So learn to program. Like any form of expression, it will widen your view of your world as you learn to master it.

TOM IGOE is an associate arts professor at NYU's Interactive Telecommunications Program, and a co-counder of arduino.cc.

Lucas Saugan

Coding for Kids



HEP SVADJA is *Make:*'s photographer and photo editor. In her spare time she is a space enthusiast, reptile wrangler, metal fabricator, and teaches code to teens and tweens.

PUT YOUNGSTERS ON THE PATH FOR **TECH SUCCESS**

TEACHING KIDS TO CODE OFFERS A LOT OF CHALLENGES THAT YOU DON'T RUN INTO WHEN INSTRUCTING ADULTS. Kids don't have a ton of real world experience, so a lot of analogies fly over their heads. Abstract thinking can take a lot more effort, so you need to keep things more concrete. Many kids have extremely short attention spans, especially in groups. And if there isn't a cool payoff almost immediately, they are going to get bored and zone out. All the lecturing in the world won't get the lesson into their heads at that point.

When teaching children programming, the goal is to empower them to understand the everyday systems they already use, and to know they have the skill to pick this kind of stuff up, both now and later in life. Not everyone wants to do software development for a living, no matter how smart of a career choice it is, but programming is creeping more and more into other fields every day.

FIND YOUR RESOURCES

When I was looking for a text to teach coding, I wanted something that spoke to children at their level without coming off as boring or condescending, and that also had projects available almost immediately even at the rudimentary learning level. I chose *Python for Kids* (in its first iteration, an e-book titled *Snake Wrangling for Kids*) by Jason Briggs. Later when some of my new-to-programing friends talked about their frustrations with the online learn-to-code resources aimed at adults, I started giving copies of this book to them too. To this day I still recommend it.

The following websites are valuable to new learners as well:

1. **code.org/learn**
2. **khanacademy.org/computing/computer-program ming**
3. **codecademy.com**
4. **oreilly.com/learning**

PICK A PROJECT

Programming involves a lot of choices that can become overwhelming to those who don't yet have experience to make informed decisions. Making sure kids have a project in mind will help narrow options, which in turn will help prevent them from quitting in frustration.

Selecting a platform, such as using a Raspberry Pi, will help with questions like what operating system distribution to use or programming languages to learn, as there are recommendations available, and a large community for advice. Some boards have their own operating system designed specifically for use with that board, which usually means better documentation regarding the way they work together, and better support when a programmer runs into problems. And if kids know or are more comfortable with so-called front-end languages, there are boards that use those as well.

CODE ON

Once a programming language is learned, others become much easier to pick up — kids could add iOS or Android programming to their initial language and actually make their own apps. Whatever you do, make sure they keep programming past their first project, so that they gain even more experience, and build on the skills they already learned. It may not end up giving them a new career, but it will change the way they look at the world and the things they use every day.

NodeBots [nodebots.io] is an ongoing meetup specifically to build JavaScript robots, and incidentally, a perfect place to find a project if you don't already have one in mind.

Hep Svadja

Written by Tim Hunkin

Move It

LEARN THE TRICKS OF USING **GEARS** TO ADD MOTION TO YOUR PROJECTS

WHETHER TO SLOW DOWN A MOVEMENT, SPEED IT UP, OR CHANGE ITS DIRECTION, IT'S EASY TO find technical information about gears. But using them, especially custom cut pieces, can still be tricky because they have to work so precisely together. I've learned some lessons along the way — here are a few.

FABRICATION

- Really large gear teeth can be hand cut. I once made all the teeth for a clock with an angle grinder. Large teeth are easier to make because the distance between the shafts is less critical.
- When getting metal parts laser cut, allow a tiny gap between the teeth of a pair of gears (I use a 0.4mm gap for MOD 2 gears). The output gear will be a bit wobbly (backlash), but this is preferable to the gears being too tight (lots of friction).

GEAR ALTERNATIVES

- I often drop the speed of a DC motor by 4 to 1 simply by putting diodes in series with it — the motor loses surprisingly little power.
- Don't use gears to reduce the speed of an ungeared motor. A motor with a built-in gearbox will be less noisy and more powerful.
- For changes in speed less than 5 to 1, a belt or chain is often easier.

GEARING RESOURCES

- Pre-made gears of all types are available through various outlets such as McMaster Carr.
- Designing gears and gear trains is easy and fun with the websites geargenerator.com and woodgears.ca/gear_cutting/template.html.
- An exhaustive treatment of gears and gear design, including how to choose the right gears and determining gearing calculations, can be found in the book *Handbook of Practical Gear Design* from CRC Press.
- The website 507movements.com offers an incredible assortment of gear combinations, along with various other forms of mechanical motion, from pulleys to levers to linkages.

FOUR-BAR LINKAGES

This handy mechanism is commonly found as the arm sections on the classic folding-arm desk lamp, keeping it pointed in the same direction while raised and lowered. It can also convert a motor's rotation into an oscillating waving motion, and is often used to keep windshield wipers blades in parallel so as to not bump into each other. Visit singsurf.org/things/fourbar.php to construct and animate any combination of bar lengths. — *Ben Krasnow*

TIM HUNKIN trained as an engineer but became a cartoonist for a U.K. Sunday newspaper. He next made *The Secret Life of Machines* TV series and now runs arcades of homemade coin-operated machines in Southwold and London. timhunkin.com

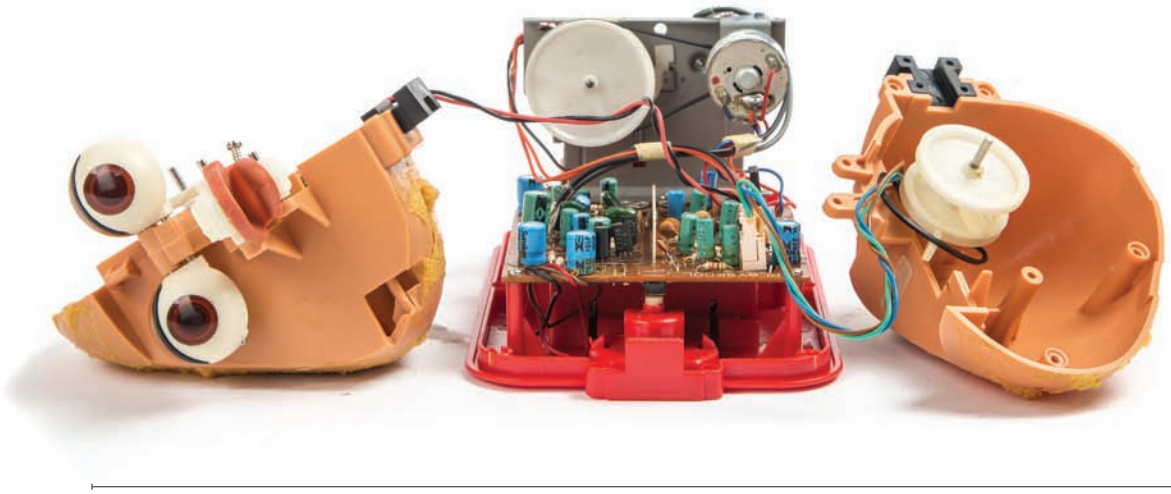
BEN KRASNOW works at Verily Life Sciences, and previously developed V.R. hardware at Valve. He writes about shop lighting on page 53.

WHAT'S A MOD?

The module number of a gear is the ratio of teeth to diameter, when diameter is measured as distance to the mesh point (where the teeth of one gear meet the teeth of another). A MOD 2 gear with a diameter of 30mm will have 15 teeth. Knowing this number simplifies calculating the proper distance between gear shafts.

Exposed gearing can add a fascinating mechanical element to your projects — as in the clock Tim Hunkin built for the Exploratorium. Benjamin Cowden's geared aluminum candleholder, from *Make:* Volume 21, includes both a four-bar linkage and a primer for making your own gears. makezine.com/go/geared-candleholder

Hep Svadja, Tim Hunkin



KIPP BRADFORD is a biomedical engineer and Research Scientist at the MIT Media Lab. He has founded startups in the fields of transportation, consumer products, HVAC, and medical devices, and holds numerous patents.

Void YOUR Warranty

Written by Kipp Bradford

UNLOCK A WEALTH OF PARTS — AS WELL AS LESSONS — **INSIDE YOUR GADGETS**

TAKING THINGS APART CAN BE A GREAT WAY TO LEARN HOW THEY WORK AND ARE CONSTRUCTED. As anyone who has visited a junkyard knows, some discarded objects also hide fully functioning components (motors, switches, etc.) with lots of useful life left in them. Getting at the guts of the gizmos and gadgets all around us can be a bit of an art, especially as the things we buy have become more integrated. Whether you are taking apart your dishwasher to examine its innards, or you are harvesting stepper motors from your old printer to make a robot arm, here are some tips for hacking everyday objects.

BE SAFE

Voiding a warranty is OK. Getting burned or electrocuted is not. You can generally ignore the "no user serviceable parts inside" label. However anything indicating flammable, explosive, high-voltage, or a shock hazard requires extra precautions and expertise to prevent serious injury. Always unplug power (including batteries) before working on something and always safely discharge high-voltage capacitors.

USE THE RIGHT TOOLS

Tamper-proof fasteners like Torx once made it hard to take things apart. Nowadays, screwdrivers matching just about any fastener are easy to find online or in local hardware stores. It's much easier to disassemble things without damaging them if you have the same tools that were used to assemble them in the first place.

CLAMP IT DOWN

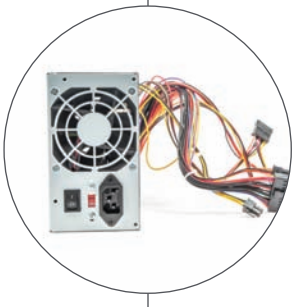
Secure parts when sawing, drilling, or hammering at them. Your fingers and hands are irreplaceable, so don't put them in harm's way when you find stubborn parts that need a little extra coercion to crack open or pull apart.

SEARCH BEFORE YOU START

Find existing teardown instructions or videos online (see YouTube University, page 56). It's a sure bet that someone has not only taken apart your device, but they've made a YouTube video of their efforts (and probably added bad '80s rock music as a soundtrack). iFixit.com also has an impressive collection of repair guides and disassembly instructions.

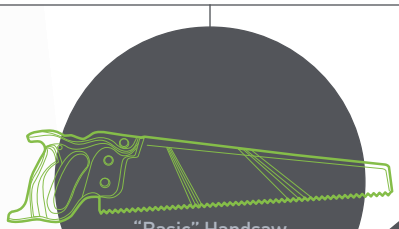
DOCUMENT

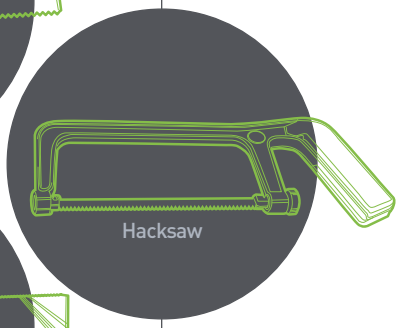
Keep track of your disassembly process. Photographing and sharing your teardown is a great thing to do. Even if you don't want to share, there is a lot to learn from studying how things are put together and what components were used to make a device. Manufacturers come up with all sorts of clever designs that might be helpful for your next project.

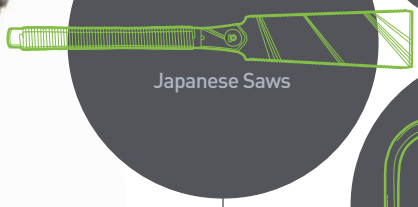


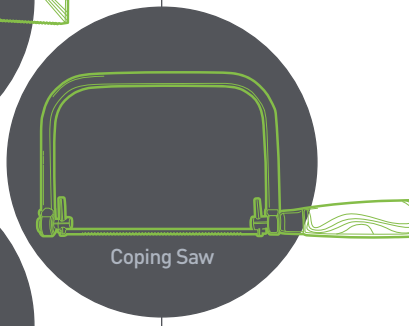
Hep Svadja

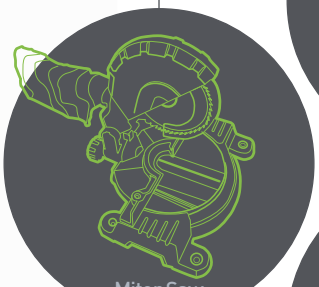
PAT AND MIKE MURRAY are twin brothers who lead a team of professional artists, software developers, and fabricators working and playing under the name Maker Twins & Co.

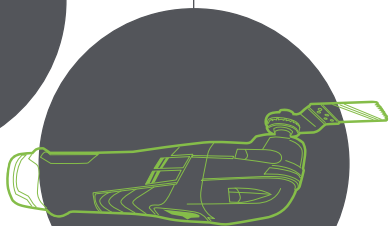












Cutting Class

Written by Pat and Mike Murray

FIGURE OUT WHICH **SAW** IS RIGHT FOR THE JOB — THEN LEARN TO USE IT

ARCHIMEDES SAID "GIVE ME A LEVER LONG ENOUGH AND A FULCRUM ON WHICH TO PLACE IT, AND I SHALL MOVE THE WORLD." His timeless insight into the power of simple machines can also shed some light on the importance of appropriate tool selection — especially the most appropriate saw for the material you want to cut.

"BASIC" HANDSAW

Arguably the most iconic and reliable of all wood saws, it's no doubt that this tool has changed the world. They're also useful for reminding you that you're out of shape when cutting a simple 2×4.

HACKSAW

This type of handsaw features a fine-toothed blade tensioned in a C-frame. Commonly used for cutting metals and plastics. Take special care to clean it when cutting aluminum, as it will often gum up on softer metals.

JAPANESE SAWS

A family of pull saws known for a thinner blade with crosscut teeth on one side and rip teeth on the other. These saws make cutting dense wood easy by first starting a guide path with the crosscut edge, then switching over to finish the cut with the rip-teeth edge. The Ryoba style is the most useful type.

COPING SAW

Popular with artists, this simple but useful cutting tool consists of a thin blade tensioned in a C-shaped frame that uses interchangeable blades for both metal and wood. It can cut tight radiuses but perhaps its most useful feature is the ability to remove the blade and thread it through a drilled hole to cut inside profiles.

JIGSAW/RECIPROCATING SAW

If you've ever needed to cut a custom shape out of a sheet of plywood or even polycarbonate, you know how useful this tool can be. If a perfectly straight line is what you need, then leave this tool on the shelf. Even in the hands of a skilled operator the blade will drift easily. (See Perfect Cuts)

CIRCULAR SAW

There are two types of electric circular saws, the worm drive and the sidewinder. The worm drive saw has enough torque to cut through wet lumber and concrete. The behind-the-blade handle placement reduces kickback, and the blade's left-side position makes it easy to see your cut line if you're right-handed. The sidewinder's motor, attached directly to the blade, weighs less but also has less torque. (See Perfect Cuts)

TABLE SAW

Ripping, crosscutting, mitering, and beveling can all be accomplished using the table saw. Usually not very portable, but its versatility makes this one of the most useful tools in a shop.

BAND SAW

Perhaps the most useful saw for cutting both metal and wood, this tool has loads of cutting power and runs very quiet — it won't wake the neighbors in the middle of the night. Like jigsaws, band saws can drift if you're not paying close attention to the line.

MITER SAW

Perhaps your dad always told you not to cut corners, but that is exactly what this saw is used for. Handheld versions are paired with a miter box fitted with guides for 45° and 90° cutting. Electric versions like the compound miter are great for cutting custom angles, making these ideal for molding and trim work.

OSCILLATING SAW

This seemingly novel tool began filling Christmas stockings just a few years ago. Orthopedic surgeons, however, have been using sterilized versions for decades. Its vibrating blade is useful for precise cuts within limited space.

Remember, few saws are specifically designed for cutting flesh and bone but most will do it if given the opportunity. Keep it safe!

Hep Svadja and James Burke

PERFECT CUTS

Written by Chris Weisbart

It's likely you have a jigsaw and a circular saw, and it's not uncommon to not be that great at using them. All pros know that accurate cuts come from the most basic of tips: know your tool. The simple act of making test cuts in scrap wood with your saw before you begin serious work will save you time and frustration as you learn the quirks of a new, or "new-to-you" tool.

Does the saw pull to either side as it moves through the work? How well does the kerf (the cut made by the blade) line up with the indication marks on the guard of the saw? How slow do you have to go in order to control the blade and avoid it wandering off the mark? Once you know the answer to these questions by putting your saw through some tests, the following tips can help you get the most accurate results using even the most elementary equipment.

MEASURE AND LAY OUT

- Securely clamp workpieces down, use accurate straightedges, and make dark marks with a sharpened pencil or marker to ensure an accurate result.
- If measurement is critical, use a utility blade to scribe measurement or cut marks. The thin, flat edge will ensure your mark is as close as possible to the exact point you need to cut from. If you need a dark line, use the blade for initial marks and then re-trace them with a straightedge and Sharpie or pencil afterward.

CIRCULAR SAW CUTS

- The key to great circular saw cuts is to use a guide. Numerous commercial options are available, usually made out of aluminum, but we prefer homemade versions that use pre-cut lumber's factory edges to provide a straight edge.
- If you *must* use a circular saw without a guide, mark a clear line per above, go slow, and have an assistant vacuum along the cut to remove debris and keep you going in the right direction.
- Don't forget to account for the blade width and know which side of your line you are cutting on for an accurate result.

JIGSAW CUTS

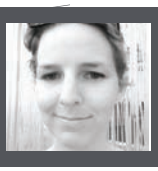
- Jigsaws are notorious for drifting off axis to create non-perpendicular cuts. The best way to avoid this is to make roughing cuts before the final cut, so that your final cut has less pressure and density pushing against the blade. Aim for ¼"-⅛" around your desired cut.
- Use the best blade for the job. Most blade manufacturers sell kits with numerous types and shapes of blades. Learn which blade is right for your material and type of cut and use accordingly.
- Higher-end jigsaws are engineered to clear debris from in front of the blade so that you can see where you are going. If your saw doesn't have this option, have a helper lead your cut with the nozzle of a shop vac to ensure a clear view of your cut line.

***CHRIS WEISBART** is a designer and woodworking aficionado who has built numerous museum exhibits for the last 10 years.*

Written by Lisa Martin

Never a Dull Moment

GET EXACT WOODWORKING RESULTS WITH A MARKING KNIFE



LISA MARTIN is an editorial intern at *Make:*. She loves seeing what Makers are working on.

BOB KRAMER has been hand forging custom knives for 25 years. After working in professional kitchens, Bob became fascinated with sharpening knives which then led him to the world of making knives from scratch.

FOR PRECISION HAND-WOODWORKING, A MARKING KNIFE IS ESSENTIAL. This flat-on-one-side, beveled-on-the-other blade has a variety of uses that will make your wood cuts easier and more accurate.

MARKING

How thick is your pencil lead? Whatever your answer, I guarantee that the blade of your marking knife is thinner. This can really make a difference for cuts where even 1/16 of an inch will matter. You won't need to decide which side of the line to cut on. Plus, your knife will cut through the fibers of the wood, instead of wobbling across them like a pencil might.

V-REST

The first few strokes of the saw are the most important. Line up your cut with an engineer's square, then drag the marking knife a few times to cut through the fibers to make a V-notch for your saw to rest in. This keeps the saw from jumping or shifting for those first few strokes.

DOVETAILS

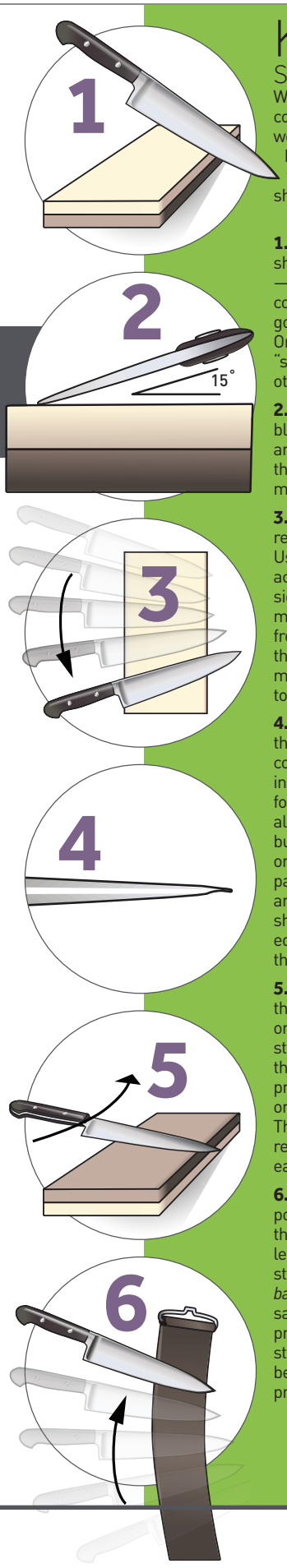
The rule to measure twice and cut once should really be reversed for dovetail joints. You should only be making measurements (or using a template) on the board you plan to cut your tails out of. To create the pins on your other board, use your marking knife to trace the outline before you saw and chip out the waste wood.

VISIBILITY

Having trouble seeing the line you cut with your knife? Take a pencil and go over the cut, then use an eraser on the flat of the wood. The lead inside your razor-sharp line will remain, making it easier to see.

KNIFE SHARPENING

Whether it's used for cooking or precision woodworking, a knife is one tool you'll want to keep sharp. Some tips:



1. Begin with a sharpening stone — a 1,000/6,000-grit combination is a good starter stone. One side works to "set" the edge, the other to refine it.

2. Sharpen the blade at a 10°–15° angle — essentially the slope of a matchbook.

3. The pressure required is 4–6lbs. Using a slicing action across the coarser side of the stone, make 5 passes away from you, then flip the knife over and make 5 passes toward you.

4. As the two planes that form the edge come together and intersect they will form a wire edge, also known as a burr. If you don't feel one, make 5 more passes on each side and check again. You should feel this wire edge from the heel of the knife to the tip.

5. Once you create the wire edge, move on to a finishing stone to refine it. Use the same angle and pressure as you did on the first stone. This stone will only require 10 strokes on each side.

6. For a high-polished edge, place the knife edge on a leather strop and stroke the knife *backward*, using the same angle and pressure as with the stones. You should be able to slice printer paper easily.

— Bob Kramer

Hep Svadja, James Burke

Finish Strong

Written by David Picciuto

EXPERT TECHNIQUES TO BEAUTIFY AND PROTECT YOUR **WOOD PROJECTS**

DAVID PICCIUTO is extremely passionate about woodworking, making, and design. You can find out more about him and view more wood-working tutorials at MakeSomething.tv.

David Picciuto

THERE ARE A COUPLE OF REASONS WHY YOU SHOULD APPLY A FINISH TO YOUR WOOD PROJECTS. The most important reason is that it adds a layer of protection from wear and tear and keeps the moisture out of the wood. This will ensure your project will last a long time. The other reason to finish your project is purely for beauty. With all the time you spent creating your masterpiece you may as well take that final step and give it some "wow" factor. For me, the most exciting time of any project build is adding that first coat of finish and seeing that grain pattern pop for the first time.

Of course, anytime there are a hundred ways to do a task there will be confusion on how to complete it. I like to simplify my finishing technique into two methods: one is quick and easy, the other takes more time but brings out the natural beauty of the wood.

For the first, I use nothing more than a satin lacquer spray. I always get consistent results with Deft brand spray lacquer, but I'm sure there are other brands that work just as well. The reason I opt for a satin finish is because a glossy treatment will highlight imperfections and tends to cheapen the look.

This rattle-can technique dries fast and you can apply new coats about every 20 minutes. Three to four light coats is usually plenty, followed by a rubbing of #0000 steel wool before the final one.

For a more lustrous finish, I mix equal amounts of boiled linseed oil, Minwax Wipe-On Poly, and mineral spirits. The boiled linseed oil goes deep into the wood and brings out the grain. The polyurethane adds some protection, while the mineral spirits thin down the mixture, allowing you to apply very light coats. Only make enough for the project at hand, as storing it is not recommended.

Apply the mixture liberally (I like to use an old T-shirt), wait 20 minutes, then wipe down the entire project with a clean cloth to remove any standing liquid. I repeat this process four more times, applying only one coat per day. It takes a long time but the payoff is well worth it: the result is flawless, with no brush marks or streaks. This finish also soaks into the wood instead of sitting on top like lacquer, and leaves a nice "touchable" feel.

HAND-HELD ROUTER

TABLE ROUTER

CNC ROUTER

Spinning Bits

MASTER THE **ROUTER** FOR ADVANCED MAKING

Written by Emily Coker

EMILY COKER is Queen of the Makey Robot Army. She's a Jill of all trades, a Maker, tinkerer, artist, and crafter who loves drawing comics, reading comics, and can cook like a mad scientist.

ROUTERS ARE VERSATILE, POWERFUL TOOLS USED TO CUT, CONTOUR, AND SCULPT MATERIALS. Essentially a giant motor spinning a sharp bit at an ultra-high speed, they're commonly hand-held, but also used in table-mounted and CNC configurations. Routers are useful for projects big and small — although big tend to be the norm. Understanding the ins and outs of each type will help you get the best results possible.

HAND-HELD ROUTERS

The most basic router you'll find is a fixed-base machine. A motor ranging from 6 to 12 amps sits on top of a platform that glides over the material you're cutting, its bit extending below. Don't underestimate the power — routers have a tendency to jerk and run away, catching many new users by surprise. Plunge-base variations allow for more gentle bit insertion into the material. Using a router bit with a bearing allows your work piece to act as a guide, keeping your cut even throughout. For starters, this is handy for putting a rounded edge on a flat piece of material.

TABLE ROUTERS

A table router is a stand-alone machine that offers a vertical routing spindle which protrudes upward through the tabletop. Material is fed into the machine while the spinning bit forms and cuts to the desired depth at speeds between 3,000-24,000rpm. Table routers provide more stability and control than hand routing.

This style router features a guide fence that helps control cuts, but it can be used without it, such as when attaching a template to the material and using a ball bearing guide and bit to route the negative material. Using a pin router is another way to cut your material — this includes using a template and pin opposite the bit to guide cuts. Pin routing is more advanced, typically left to experts.

CNC ROUTERS:

A CNC router is a computer-controlled machine that performs routing through CAD/CAM software and programming. There are two different types of CNC machines: the gantry style in which the router spindle moves over secured material, or the fixed-bridge style in which the router is mounted and the bed moves. CNC routers move along three axes (X-Y-Z) utilizing a three-motor drive system; advanced machines use four motors.

CNC routing is perfect for production cutting and to reduce the risk of human error. It's a good idea to perform air cuts before running the actual cut. With any routing, researching the bits is imperative for the correct cuts and best results.

PRO TIPS

» **Go through the routing motions** before you turn your router on, making sure the height of your chair works with the job, that no cords get in the way, that your clamps are positioned properly, and that your hair and clothes are tucked away.

» Routers are very noisy and messy — make sure you have **eye and ear protection** so the dust and noise don't impair you.

» **Use the "climbing cut"** — moving the router in the direction of the bit rotation — for sections that are susceptible to tear out. But be aware of the likelihood of the router pulling away fast.

» **Know the wood you are cutting into**. Listen to your tool, pay attention to how it looks, smells, sounds, and is behaving. When routing properly, the router should be stable and steady, with no howling, jumping, or burning smells.

Hep Svadja, table router photo courtesy harborfreight.com

ROTARY TOOLS

These handheld devices, most commonly from Dremel, can drill, grind, carve, sand, polish, and engrave, using a limitless variety of bits and attachments. Some pointers:

WOOD

» Sand in the direction of drum rotation for finer results.
» When carving, use a grinding stone for a fast, smooth finish. Aluminum-oxide stones work quickest, while silicon-carbide stones get smoothest results.

METAL

» Cut metal against the direction of wheel rotation, and make sure your material is mounted in a vise to avoid the tool climbing.
» Sanding drums and grinding stones will quickly remove burrs and sharp edges.

DRILLING

» With a diamond hole-cutting bit and a little lubricant you can drill holes in glass, gemstones, rocks, porcelain, bones, and other tricky materials.

Written by Carla Bruni

What's the Drill?

DRIVE SCREWS AND BITS WITH THE RIGHT TOOL FOR THE JOB

MANY OF US ALREADY HAVE THE EVER-HANDY DRILL IN OUR GARAGE OR TOOLBOX, but more recently, a new tool has emerged that looks a bit like the love child of a drill and a pug: the impact driver. This isn't merely a new look for our trusty standby, but a whole new tool that excels in powering screws into tough materials with rapid, twisting blows. Here's a cheat sheet to help you determine if you need one or the other — or both — in your arsenal.

DRILL

Pros:

- Works great on jobs requiring care or precision
- Applies a constant torque
- Accepts a wide variety of drill and screw-driving bits
- Accepts accessories such as wire-wheel brushes and rotary sanders
- Has a slip clutch that allows you to adjust torque
- Relatively inexpensive to purchase

Cons:

- Can stall when driving long, large fasteners
- Has the potential to strip screws
- Bits can come loose in the chuck
- Can put strain on the user

IMPACT DRIVER

Pros:

- Powers screws through some seriously dense material with more torque and concussive blows
- Prevents wrist strain because it's doing more work
- Drives long screws with little effort
- Less likely to strip screws
- Easier to fit into tight spaces due to its smaller body

Cons:

- Costs more than a drill
- Makes a lot of noise
- Only accepts hex-shanked driver and drill bits
- Too much of a beast for more precise, delicate jobs

Both of these handy companions are slowly moving towards a frankentool that combines the drill's precise versatility with the impact driver's power. In the meantime, as a general rule, if you're working with drywall, softer woods, veneers, plastics, or brass screws, stick to the drill because it won't dent or break the material. If you've got a project that requires a ton of screws, using long or thick fasteners, or driving through dense materials (such as building a deck), save your wrists and some time and go with an impact driver.

Hep Svadja

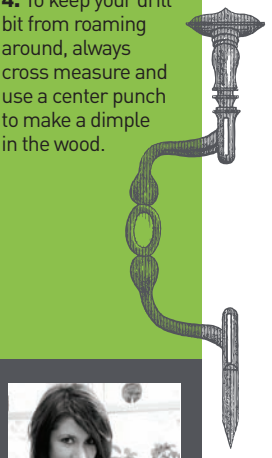
CHEAP TRICKS FOR DRILLING STRAIGHT HOLES

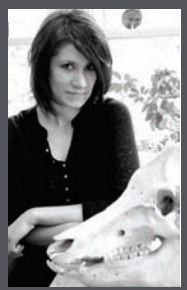
1. Lay down an old Clay Aiken CD, reflective-side up. Position the drill bit in the center hole and line it up with its reflection in the CD for a 90° angle.

2. Make a jig by nailing together a couple of 1×2 or 1×4 scrap pieces to form a right angle. Place it on its side, with the bit pressed flush and tight against the inside corner. Drill down.

3. Spring for a drill guide, which cost as little as $15 and can turn your drill into a drill press. They can also drill at fixed angles.

4. To keep your drill bit from roaming around, always cross measure and use a center punch to make a dimple in the wood.





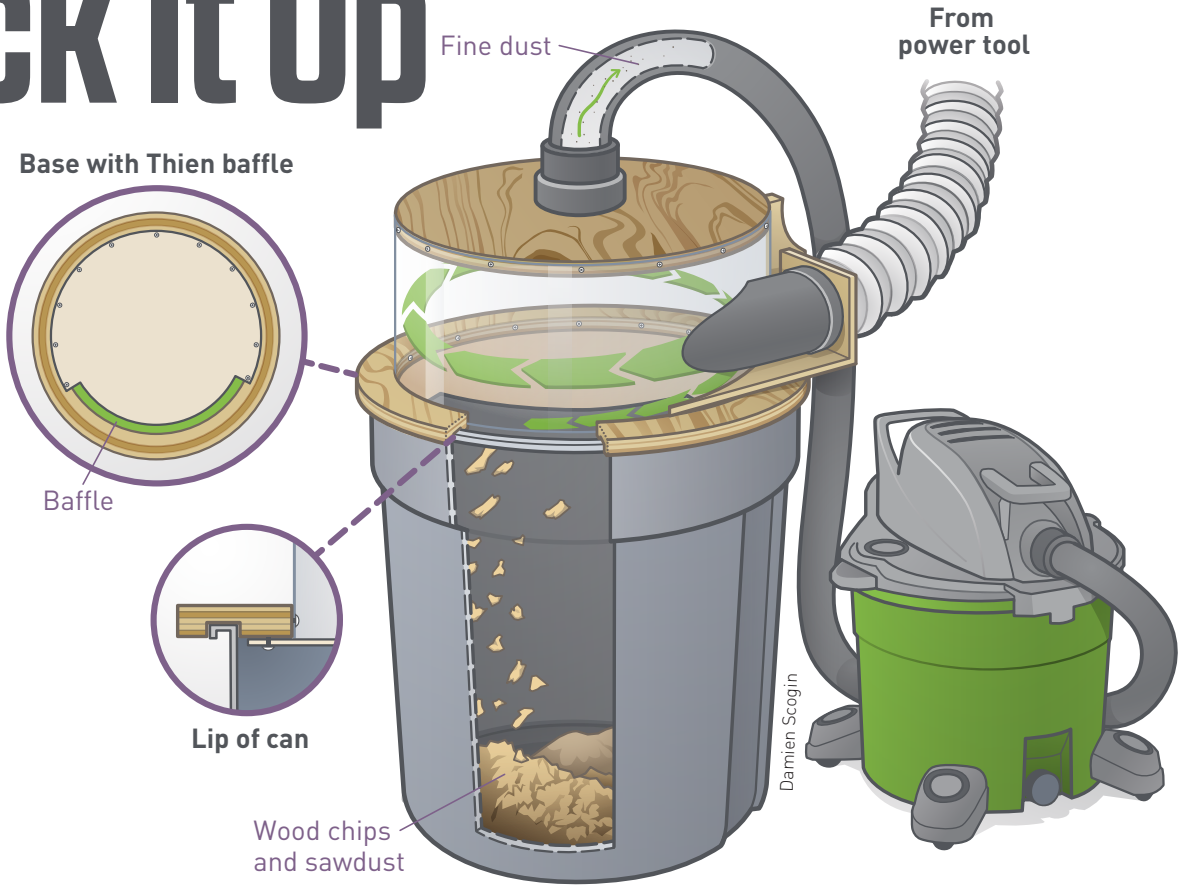
CARLA BRUNI is an architectural historian who spends her time saving old buildings. She's teaches DIY workshops, landmarks buildings, restores homes, runs repair clinics, works in salvage, and aspires to be a Viking blacksmith.

Suck It Up

KEITH HAMMOND is a projects editor for *Make:* who enjoys building surfboards and Lego spaceships. He wrote "How to Detect Killer Asteroids" in Volume 47.

Materials

- **Plywood: ¾", and ¼" or ⅛"**
- **Polycarbonate sheet, 1/16"**
- **PVC pipe and couplers, 3"**
- **PVC adapter, 3" to 2½**
- **Wood screws**
- **Hot glue**



CAPTURE THE MESS BEFORE IT'S MADE, WITH A **DIY DUST COLLECTION SYSTEM**

DUST COLLECTION

Whether it's sawdust, carbide grit, aluminum shavings, or powdered circuit boards, you don't want that stuff clogging your workpiece, your eyes, or your lungs. A dust collection system not only protects your health, it also keeps your tools cleaner and safer, reduces fire risk, and keeps mess off the floor.

Systems for big workshops typically have a powerful central vacuum and dedicated 6" or 4" hoses for each tool, with "blast gates" to shut off the suction to tools not in use. It's a doable DIY project if you've got lots of space. But most small workshops can benefit greatly from a movable system based on an ordinary wet/dry shop vacuum and its standard 2½" hose.

TIPS

» Newer bench/table tools may have a standard 2½" dust port, where you can plug in a shop-vac hose. Hand tools like sanders are easier to operate with a 1¼" hose.

» To mate different ports and hoses, you can buy standard adapters at your local home store or cut down a universal adapter to fit — but you should still plan on needing duct tape, because many toolmakers haven't yet standardized their dust fittings.

» Ditch the dustpan — instead, push debris into a dedicated "floor sweep" box attached to your vacuum.

» Swap your shop vac's filter for a HEPA filter to capture the finest dust. But wear a mask or respirator anyway — a shop vac has good static pressure but doesn't move enough air volume to filter all the air in your workspace.

PROJECT:
DIY CYCLONE DUST SEPARATOR

Here's a rewarding weekend project that turns an ordinary shop vacuum into a capable mini dust collector. A "cyclone" dust separator creates a swirling vortex of airflow to spin out all the big chips and sawdust particles, so they drop through a gap in the bottom baffle, into a waiting trash can. Only the finest of fines will reach your vacuum — saving you dozens of filter changes and prolonging the life of your vac. Plus it's see-through, so your friends will love watching the cyclonic action, and you'll get to brag, "Yeah, I made that!"

Make: engineering interns Anthony Lam and Jenny Ching built this dust separator based on a design by Ray Mowder, who was inspired by the original cyclone baffles by J. Phil Thien. It's a "top-hat" style that sits on a 20gal trash can without modifications to the can, so it's easy to move or stow when not in use. Get the complete how-to at makezine.com/go/cyclone-dust-separator.

Hep Svadja

A Bright Idea

INCREASE PRODUCTIVITY AND EASE EYESTRAIN WITH IMPROVED **WORKSHOP LIGHTING**

Written by Ben Krasnow

BEN KRASNOW works at Verily Life Sciences, and previously developed V.R. hardware at Valve. Follow his personal projects on his YouTube channel: youtube.com/bkraz333.

1

2

3

UPGRADING THE LIGHTING IN YOUR WORKSHOP MAY BE ONE OF THE LEAST EXPENSIVE and most impactful changes that you can make. "But I can see the parts on my workbench just fine," you might say. Yes, however lighting is not simply a question of being able to see your project, but a question of eyestrain, productivity, and enjoyment. If you take photos of your work, they will look significantly better under upgraded lighting, and you will save electricity too.

Straight 4' fluorescent tubes are the mainstay of shop lighting for good reason. They are inexpensive, energy-efficient, and deliver diffuse light, but there are some important differences among the various types. The older large-diameter tubes are called T12 (The number after the T indicates the tube diameter in eighths of an inch). These tubes are often powered by heavy iron magnetic ballasts, which convert the mains voltage into something that the tube can use. Magnetic ballasts cause the light to flicker, sometimes noticeably, and also produce a buzzing noise. They are also relatively energy-inefficient. If you have T12 lighting in your shop, you are a good candidate for a simple and really effective upgrade (Figure 1).

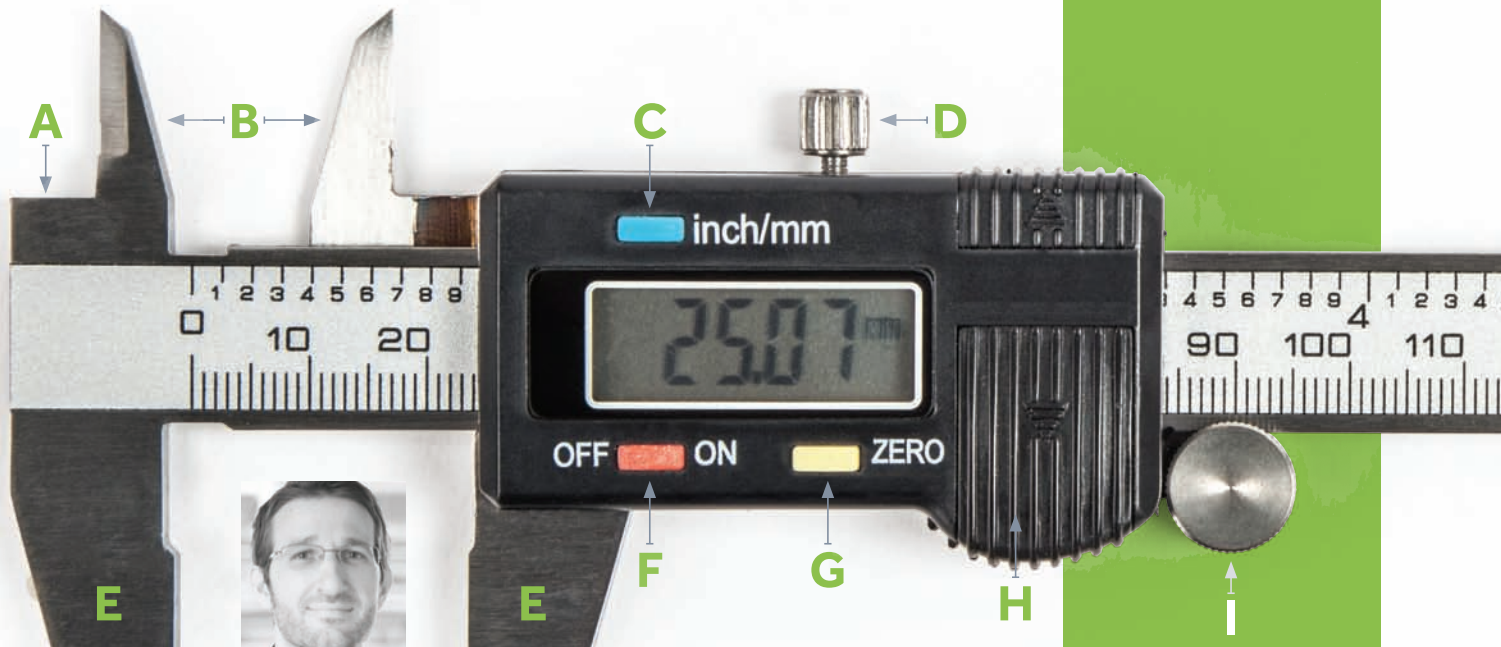
Newer T8 fluorescent tubes have the same pin arrangement on the ends of the tube, so they fit perfectly into an older T12 fixture, but they require an electronic ballast, which is where the energy savings are made. The electronic ballast does not produce an audible buzz, and the light flickers at over 20KHz, well above perception. You can find electronic T8 ballasts for 2-bulb and 4-bulb fixtures at your local hardware store, or online for $10 to $25 (Figure 2). Replacing an old magnetic ballast is very straightforward, and often does not require the fixture to be removed from the ceiling.

PRO TIP:
T5 fluorescent is much more expensive than T8, requires you to change your whole fixture, and offers only marginal efficiency improvements compared to T8.

Once you have your fixture upgraded, you'll want to choose decent T8 tubes that produce a full spectrum of colors. The fullness of the color spectrum is represented by a numerical value called the Color Rendering Index (CRI) of a lamp, with higher values allowing you to see colors as they truly are. However there is some subjectivity here, so it's possible that a lower CRI lamp will appear more pleasing than a higher CRI lamp. Finally, the color temperature of the light describes how red or blue the light is. For workshops, I'd highly recommend 5000K to 6500K. A really great tube is the Philips F32T8 TL850 (Figure 3).

LEDs are ideal for task lighting. The Ikea Jansjö lamp is one outstandingly helpful option (Figure 4). However, LEDs are still more expensive than T8, comparable or less energy-efficient in lumens per watt, and require a whole new fixture.

4



OWEN SMITHYMAN is a content developer at Other Machine Co. His three loves are collaboration, learning new things, and his amazing wife.

CORRECT USE OF **DIGITAL CALIPERS** IS VITAL TO GETTING PRECISE MEASUREMENTS

Accuracy is Everything

Written by Owen Smithyman

ANATOMY

A. STEP GAUGE (NOT VISIBLE): Measures the distance from an edge to another point on an object

B. INSIDE JAWS: Measures the inside dimensions of an object. These are delicate, so be careful.

C. INCH/MILLIMETER BUTTON: Switches between units of measurement

D. LOCKING SCREW: Prevents the caliper jaws from moving

E. OUTSIDE JAWS: Measures the outside dimensions of an object

F. ON/OFF BUTTON: Turns on the calipers and sets the current position to zero

G. ABS BUTTON: Temporarily sets the current position to zero ("absolute" mode)

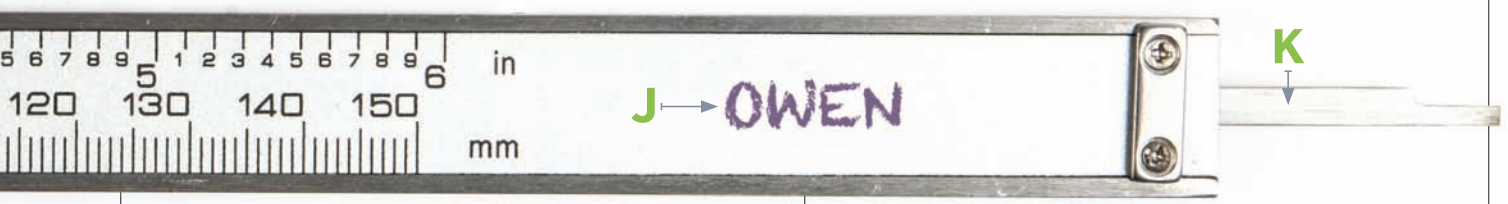
H. BATTERY COMPARTMENT: Holds the battery

I. THUMBWHEEL: Opens and closes the jaws

J. YOUR NAME: Tells people that these are your calipers. It's important in shared workspaces!

K. DEPTH GAUGE: Measures the thickness of an object or the depth of a hole

Hep Svadja



IN ORDER TO TAKE ACCURATE MEASUREMENTS, IT'S IMPORTANT TO KNOW HOW TO USE CALIPERS PROPERLY. Digital calipers are your best friend when it comes to taking measurements of small objects. For digital fabrication work (CNC mills, 3D printers, CNC routers, and laser cutters) they're downright indispensable for ensuring that your material dimensions in software are consistent with the material's actual dimensions.

Most decent calipers are accurate to within +/-0.001" (0.02 mm), which is enough to make sure you don't cut too deep when milling and to know that your design will fit within the piece of material you're using.

WHY USE CALIPERS INSTEAD OF A RULER?

In a word, accuracy. A ruler and your eyeball might be fine for many scenarios, but not when it comes to making sure your machine mills at a depth of 0.003" and not 0.006" or 0.001".

DIGITAL VS. ANALOG

It's much easier to read digital calipers, and they're often not any more expensive or less precise than dial calipers.

ZERO OUT BEFORE TAKING MEASUREMENTS

With each use and with the jaws closed, press the Zero/ABS button to reset the calipers. If you skip this step, your subsequent measurements may not be accurate.

MEASURING OUTSIDE DIMENSIONS

Use the outside jaws to measure the outside dimensions of an object. Make sure that the object is parallel to the jaws, or else the measurement won't be accurate.

You can also use the outside jaws to measure the thickness of an object. For CNC mill users, this is the most important measurement. Your material thickness needs to be accurate or your tool will cut too deep or not deep enough (Figure **1**).

MEASURING INSIDE DIMENSIONS

Use the inside jaws to measure the inside dimensions of an object. Make sure the object is perpendicular to the jaws (Figure **2**).

MEASURING DEPTH

Use the depth gauge to measure the depth from one surface to the next. Make sure the calipers are perpendicular to the surface being measured (Figure **3**).

Welcome to YouTube University

Written by Caleb Kraft

WITH THE PLETHORA OF RESOURCES ONLINE, LEARNING NEW SKILLS IS A SNAP

CALEB KRAFT is a senior editor for *Make:*. He teaches viewers to make all manners of crazy builds in his new online video series, *Controlled Chaos* (youtube.com/makemagazine)

BEING A NATURAL BORN KNOW-IT-ALL, THE WORDS "I DON'T KNOW" WOULD HAVE BEEN BLASPHEMOUS TO MY YOUNGER SELF. There was a time when I literally thought that I should have an answer to any question, or that I couldn't participate in any project unless I was already familiar with the toolset.

For many years I fantasized about things I'd like to do, only to leave the concept on the floor because I didn't know how to do it. "I want to make a giant metal sculpture! ... but I don't know how to weld" or "I want to build a robot to feed my dog! ... but I don't know how to code." These obstacles were perceived as insurmountable, and they killed my idea unless I participated in some training toward those goals.

Then, the internet happened and I suddenly had access to a massive learning resource. Let's be clear, I'm not talking about reference material. Libraries have existed since the dawn of written communication. I'm talking about the connections that evolved into communities on message boards, YouTube, and sites like the *Make:* blog.

Over the years these communities have grown stronger through shared knowledge. The experience, tips, and tricks have allowed entry into skills I had previously thought utterly inaccessible. I found that not only was the information available, but I could usually find a person whose style resonated with my own, which allowed me to understand their message much better.

Let's take the example of welding a sculpture. Before internet forums and YouTube, I would have gone to a school or workplace that allowed me to learn the machinery. Then, after establishing some experience with the materials and tools, I'd begin exploring my own interests and developing skills to match my initial goal of making a big sculpture.

Now, I can find tutorials specifically for welding big sculptures. Not only that, I can pick and choose who I want to learn from! If one person isn't giving me the information I want, there's a good chance there is someone else who can.

Perhaps the best part is that after figuring out how to apply all this information to my goals, I'm now compelled to share my experiences. Though there may be many tutorials on the same subject out there, *my* voice might resonate with someone more than others.

I used to hate saying "I don't know." Now, I love it. It means the beginning of a new adventure. The futile connotation of the words has completely disappeared from my life.

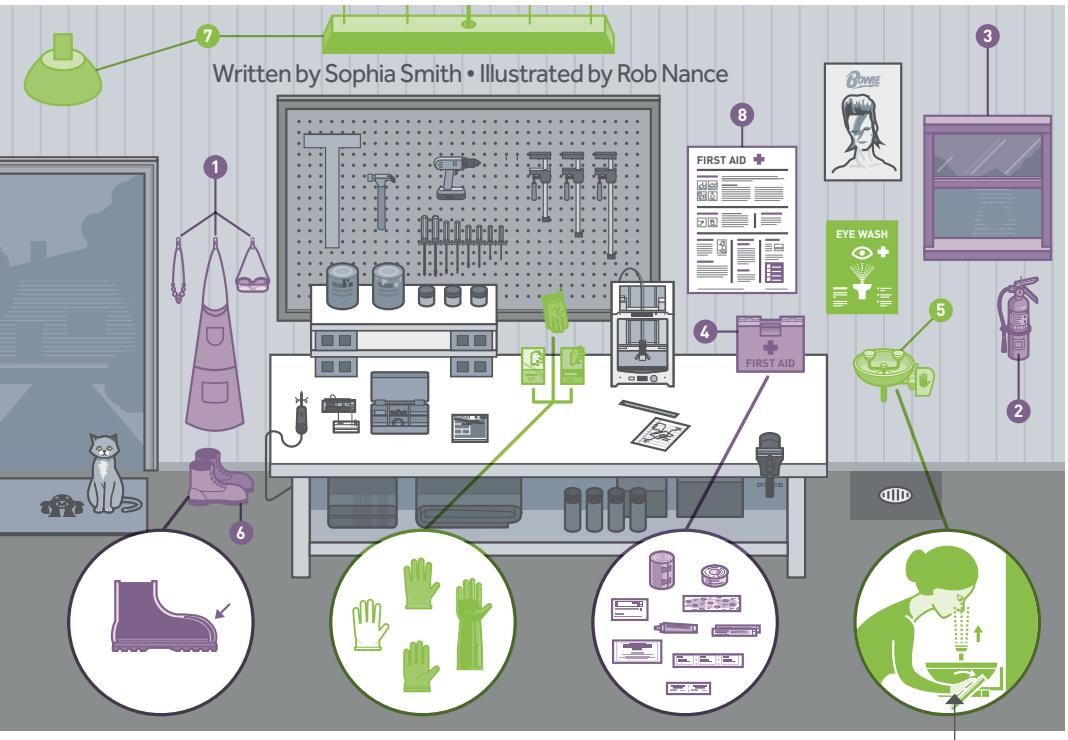
How am I going to build my next project? I don't know!

Hep Svadja

Better Safe Than Sorry

OUTFIT YOUR WORKSPACE TO PROVIDE **HEAD-TO-TOE PROTECTION**

Written by Sophia Smith • Illustrated by Rob Nance



WHETHER YOU'RE STARTING YOUR OWN MAKERSPACE OR SPRUCING UP YOUR GARAGE, it's important to incorporate safety features. Better to be prepared and not need it than unprepared when you do!

WORKSHOP NECESSITIES:

1. A coat hook and/or catchall should be placed near the door for loose clothing and jewelry. You can also use this area to store your personal protective equipment (PPE) so that you can put it on right when you enter the shop.

2. A fire extinguisher should be in an accessible area where it is plainly visible, between 3–5 feet off the ground.

3. Make sure your workshop has windows and a good ventilation system, especially for projects involving chemicals or dangerous fumes.

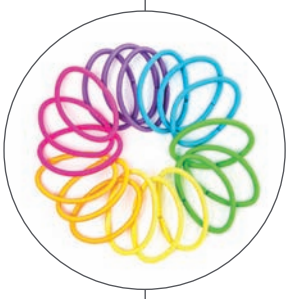
4. Keep a first aid kit with bandages and antibacterial ointment at the ready.

5. An eyewash station should be set up next to your first aid kit, especially if your project involves sparks, shavings, chemicals, or other materials that could release irritating particles into the air.

6. Any closed-toe shoe is better than none at all, but steel-toe boots provide ankle support and grip to protect against falling in addition to protecting your toes from heavy objects that might get dropped.

7. Bright overhead lights will increase visibility, which in turn makes for a safer workshop.

8. Display information on safety and first aid treatment in a highly visible area, ensuring it is readily available when and where you need it most.

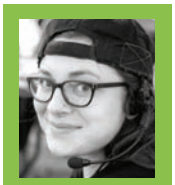


How do I safely tie up hair?
Opt for a bun over a ponytail because it gathers the hair closer to the scalp. Flyaways and shorter layers can be held back with clips or headbands. Hats can further protect against sparks, splashes, and particles.

How do I rinse my eyes?
3D print this threaded component, screw it onto a water bottle, and you've got a quick and effective eyewash station. Visit makezine.com/go/eyewash for the file.

GIVE US A HAND

PROJECT INVOLVES ...	USE THESE GLOVES:
High heat	Welding or professional-grade cooking gloves
Oil or grease	Avoid natural rubber (*i.e.* latex) gloves, opt for PVC (*i.e.* vinyl) gloves, or nitrile gloves
Hazardous chemicals	Latex, neoprene, or nitrile, depending on the chemical
Sharp edges	Kevlar, leather, or cotton, depending on sharpness and level of exposure
Wet/organic materials, e.g. gardening	Nitrile
Heavy machinery	DO NOT use gloves, they can become caught in machinery and pull your hand in



SOPHIA SMITH is a San Francisco based writer. Outside of writing for *Make:*, she can be found nerding out on books, baking, politics, and fitness. She tweets @sophiuhcamille.

Hep Svadja, Caleb Kraft

Accidents Happen

ADMINISTER **FIRST AID** UNTIL HELP ARRIVES

Written by Kelly Davis and Cameron Blissard • Illustrated by Dan Page

SEVERED FINGER

If someone's finger is completely cut off you must act quickly to try save the detached digit.

Start by placing some clean fabric over the open wound and applying direct pressure. Elevate the hand as well. As the fabric soaks with blood it may be tempting to discard it and replace it with a fresh one, but do not: removing it also removes the clot.

Locate the severed finger and wrap it in fabric, then put it into a bag of ice. Do not place the finger directly on ice, as this can cause damage to the cells.

Writing the time of the accident in Sharpie on the hand or arm near the wound can also be helpful in the bustle of the emergency room.

SKEWERED

Keep the injured person calm and immobile. Resist the urge to remove whatever object is protruding: moving or extracting it could further damage tissues or cause internal bleeding.

Wrap a towel or piece of cloth around the exposed object. This helps stabilize it, and also absorbs blood, helping form a clot. Be sure that the wrap pressure is even and on the wound.

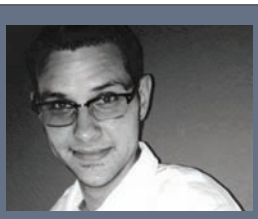
If the cloth becomes soaked, do not remove it, as that will also remove the clot — just wrap additional layers over it.

NO MATTER HOW SAFE WE INTEND TO BE, AND HOW MANY PRECAUTIONS WE TAKE IN OUR WORKSHOPS, ACCIDENTS WILL STILL OCCUR. It's inevitable. It's why we keep our first aid kits stocked, and keep a phone handy.

When an accident happens, call 911, evaluate the injury, and administer first aid until paramedics arrive. Keep this list of emergency scenarios and responses for quick reference.

Your actions could mean the difference between losing a limb and walking away with a scar.

KELLY DAVIS
is a Los Angeles-based registered travel nurse and respiratory therapist.



CAMERON BLISSARD
is an EMT with experience working in burn and medical surgery units.

SEVERE BURN

Keep the burned area clean and do not apply any ointments. You can lightly cover a burn with a clean cloth, but do not wrap it tightly. Burns swell, and wrapping will apply too much pressure. Putting cool, wet cloth on the burn can help reduce swelling and soothe the pain a bit.

If a hand is burned badly, be sure to keep the fingers apart. This can save the tissue on the sides of the fingers from further damage, and avoid painful separation later.

KNOCKED OUT BY BLUNT TRAUMA

You've witnessed someone hit on the head and fall to the ground unconscious. Do not move the person. If there is damage to their skull or spine, attempting to wake them or have them sit up could make things worse, including possibly causing paralysis.

Check for a heartbeat and begin CPR if necessary. Apply pressure with a cloth if there is a bleeding cut.

If the person regains consciousness, try to keep them from moving around until paramedics arrive.

Written by Gareth Branwyn

A Decade in the Making

GARETH BRANWYN is a freelance writer and the former editorial director of Maker Media. He is the author or editor of over a dozen books on technology, DIY, and geek culture. He is currently a contributor for Boing Boing and WINK Books. And he has a new best-of writing collection and "lazy man's memoir," called *Borg Like Me*.

DEBUTING IN FEBRUARY OF 2005, *MAKE:* POSITED THE IDEA THAT THE WORLD WAS CHANGING, that advanced high-technologies and the collaborative powers of the internet were creating the perfect environment for all of us to claim an identity as "Makers." In the years that followed, *Make:* became as much a community, a way of living in the world, as a publication. It is only as strong as the innovative individuals and collaborative groups who engage with it.

For our 50th issue, we've collected a small sampling of these Makers who've had great influence in the Maker Movement. We asked each to tell us what they've been working on, and to share an indispensable tip or two, from the practical to the more high-minded. Here is some of what they had to say.

One of Star's circuit boards, based on the designs of Forrest M. Mims.

STAR SIMPSON

(starsimpson.com) is an engineer, Maker, and entrepreneur. She studied electrical engineering at MIT, created the TacoCopter, and co-created the Octopart PCB Reference Card. Star has written for *Make:* and presented at Maker Faire.

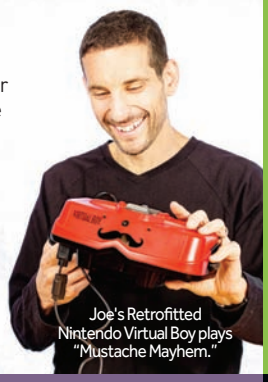
STAR'S TOP TIP: Not only build things, but think about the process of building them. Learn how to plan your work. The more you know about what you're going to do before you do it, the better you become as an engineer.

PROJECTS: I'm in the middle of creating and releasing a series of circuit boards that bring Forrest M. Mims' (author of *Getting Started in Electronics* and *Engineers' Notebook* series and a *Make:* columnist) iconic designs to life as hardware circuit boards. I just shipped the first set of prototypes (see inset photo).

JOE GRAND

(grandideastudio.com) designs high-tech consumer electronic devices. He wrote the first Skill Builder, on soldering/desoldering, in *Make:* Volume 01.

JOE'S TOP TIP: Print a 1:1 scale version of your PCB design and check for mechanical fit and component footprint match.

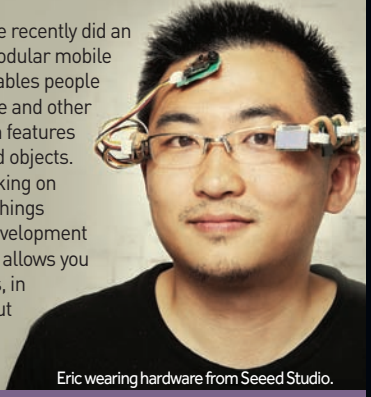


Joe's Retrofitted Nintendo Virtual Boy plays "Mustache Mayhem."

ERIC PAN

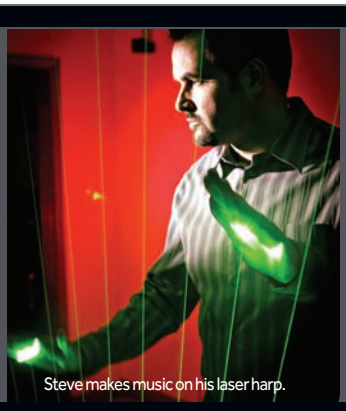
(seeed.cc) is the founder of Seeed Studio, an open hardware facilitator in Shenzhen, China. His work has appeared numerous times in *Make:* and he has presented at many Maker Faires.

PROJECTS: We recently did an open source modular mobile phone kit. It enables people to embed phone and other communication features into devices and objects. We're also working on an Internet of Things Wi-Fi-based development platform which allows you to develop apps, in minutes, without requiring any programming.



Eric wearing hardware from Seeed Studio.

Hep Svadja and Juliann Brown, Hep Svadja, Autumn Andel, courtesy Eric Pan


Steve makes music on his laser harp.

STEVE HOBLEY

(stephenhobley.com), created the laser harp project featured in *Make:* Volume 15, and has created many of our online Weekend Projects.

STEVE'S TOP TIP: Being a Maker has given me a stronger belief in myself, which has spilled over into almost every area of my life. I know that, deep down, there's little I can't do if I set my mind to it."

SEAN MICHAEL RAGAN

(smragan.com) is co-founder and editorial director of Foundry, a regular contributor to *Popular Science*, and was an online and technical editor at *Make:* for years.

SEAN'S TOP TIP: Organization is the difference between having a parts library, which is an invaluable tool, and having a pile of junk, which is a curse. If you're going to be a pack rat, at least be a tidy one.


See how to make Sean's hideaway table on page 72.


Marc teaches at Lehigh University.

MARC DE VINCK

(nerdstink.com) is professor of practice in creativity at Lehigh University in Bethlehem, Pennsylvania. He is the former director of product development at Maker Media and has been a *Make:* fixture for most of the past decade.

MARC'S TOP TIP: I always tell my students to be sure to solve *real* problems, find solutions to things that people really care about.

LIAM CASEY

(pchintl.com) is the founder and CEO of PCH, designers of custom product solutions for everyone from startups to Fortune 500s. Liam has presented at the *Make:* Hardware Innovation Workshop and at MakerCon.

LIAM'S TOP TIP: Hardware entrepreneurs should think far beyond just the making of the product. The steps required to bring that product to market is where they encounter stumbling blocks.


Liam's clients include drone companies.


Matt's hat, tricked out with his LEDs.

MATT METTS

(blinkinlabs.com) is an artist and engineer and the person behind small, interactive lighting technology studio Blikinlabs. Matt was a contributing editor to *Make:* for years and also a software engineer at MakerBot.

MATT'S TOP TIP: Make a removable mount for a PCB-based project: Attach standoffs to the PCB using screws, then glue the other ends into your case. To swap out the board, just unscrew it!

JIM NEWTON

(techshop.com) is the founder of TechShop. Over the years, he has regularly participated in Maker Faire and appeared in the pages of *Make:*.

JIM'S TOP TIP: Did you know that you can dissolve ShapeLock in chloroform solvent? This allows you to do things like dip objects into it, cast it in a mold, or paint it onto surfaces and form thin sheets.


Jim in the workshop.

MEG ALLAN COLE

(megallancole.com) is a star in the crafting heavens of YouTube and the DIY blogosphere. She has been creating videos about crafting and DIY since the launch of Threadbanger in 2006. She currently makes videos for HGTV's Handmade channel on YouTube.

MEG'S TOP TIP: The advice I find myself sharing most often is to just do it. Sporting goods ad references aside, diving in is sometimes the biggest challenge. We Makers and creators can get stuck in our heads, with perfectionism and approval holding us back.
Dive in. Try it out. Try something different. You'll eventually find your way and your rhythm. But only if you begin.

PROJECTS: I've been making DIY videos with HGTV for the past 2 years. More recently, I partnered with Kin Community on my MACC (Meg Allan Cole Crafts) YouTube channel. I wanted the channel to be a place where we can create a conversation within the community about (dare I say it) the deeper issues of life. I'm also hosting a show, *Design Goals*, on HGTV.com, where we discuss issues around design.

Meg and her dog Gracie take a walk in their matching EL wire costumes.

Kipp's micro liquid chiller.

KIPP BRADFORD

(kippbradford.com) is an entrepreneur, technology consultant, and educator. He has written for *Make:* magazine and its website, and organized several Mini Maker Faires.

PROJECTS: "Virus Simulation" is an artwork collaboration with my friend Lauren Kalman, consisting of circuit boards designed as wearable jewelry. The electronics simulate the behavior of the human papilloma virus, sharing information whenever two devices are in front of each other. If that information is an infection, the virus spreads after an incubation period. We wanted to make visible an invisible virus that affects a lot of people.

Chauncey is a 3D printed flower care robot that John designed.

JOHN EDGAR PARK

(jpixl.net) was one of the on-air personalties behind the Emmy-nominated *Make: Television*, and has been a contributor to nearly every Maker Media project, from the magazine and the website to Maker Faire and Maker Camp. In his voluminous extra time, he is also a computer animation technical director at DisneyToon Studios.

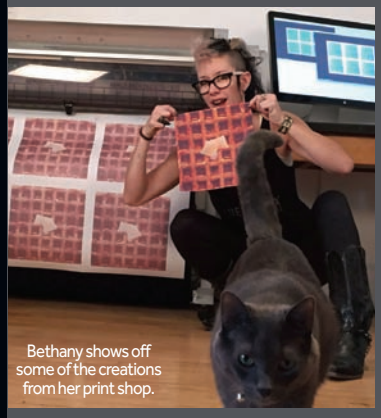
JOHN'S TOP TIP: Look at estate and yard sales and at flea markets for hand tools. The quality is often better and the cost lower than what you'll find in a big-box hardware store — and they have so much more character.

Mark's device keeps oils and solids from separating in natural peanut butter.

MARK FRAUENFELDER

(boingboing.net) was the founding editor of *Make:* and has been one of its guiding lights since its inception. A prolific Maker, his latest project rotates a jar of peanut butter every 24 hours to keep it mixed.

MARK'S TOP TIP: Buy a pair of digital calipers and learn how to use them. You can get a decent pair for $15. If you are doing any kind of 3D printing, they are a great investment.



Bethany shows off some of the creations from her print shop.

BETHANY SHORB

(cyberoptix.com) is an artist, product designer, and owner of The Cyberoptix Tie Lab. Her work has frequently been covered in *Make:* and she has exhibited at numerous Faires.

BETHANY'S TOP TIP: If you're a Maker pro, don't DIY your accounting! Leave that to the pros. Pick your DIY battles carefully. Usually, the aspects that you really love are the ones you should do yourself.

Bill's wiffle ball pitching machine.

BILL GURSTELLE

(williamgurstelle.com) is an author, educator, speaker, and engineer. He is the author of eight books and has been a frequent contributor to *Make:* since its inception. He currently writes the magazine's regular "Remaking History" column.

PROJECTS: My current project is turning my columns into a series of books. I think the column, with its triple focus on science, history, and DIY is a recipe for making technology fun and meaningful.

The urban guerilla movie theater houses a projector and sound system.

MISTER JALOPY

(misterjalopy.com) is a Maker, artist, writer, teacher, and shop keeper. He currently runs Coco's Variety, a one-of-a-kind bike shop in Los Angeles. He was a columnist in *Make:* and one of the Movements' more thoughtful early articulators.

PROJECTS: I've gotten interested in vintage hi-fi. Hi-fi was a small world of music-loving idealists that were taking wildly different approaches to finding the perfect sound.

Courtesy Kipp Bradford, Carla Sinclair, Mark Frauenfelder, courtesy Becky Stern, John Edgar Park, Karen Hansen Gurstelle, Bill Gurstelle, Robyn Twomey

Creating a badge on Orchard, Bunnie's open source hardware platform.

BUNNIE HUANG

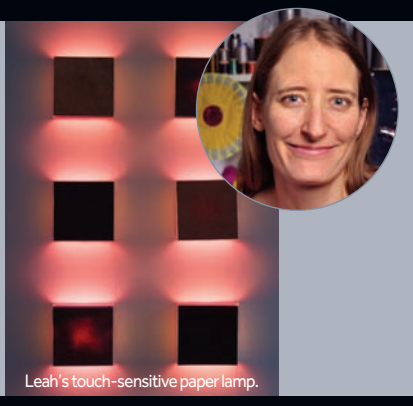
(bunniestudios.com) is a widely known high-tech Maker and small-scale hardware developer. He has been featured in *Make:*, written for *Make:*, and presented at both Maker Faire and MakerCon.

BUNNIE'S TOP TIP: Remember, supply chains are made of people. Never forget the human side of things when trying to scale up your ideas.

LEAH BUECHLEY

(leahbuechley.com) is an artist, engineer, and educator who works with, and often combines, "high" and "low" technologies. She is the creator of the LilyPad Arduino widely used in wearable and soft circuit applications.

LEAH'S TOP TIP: Laser cutters are the most powerful tools in a shop. They're much more versatile, incredibly fast, and most importantly, flexible.



Leah's touch-sensitive paper lamp.

The "Evardo" is a DIY electric vehicle.

TIM ANDERSON

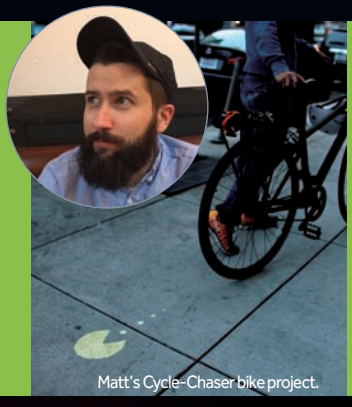
(mit.edu/people/robot) was a fixture in the magazine for years, a contributor to the *Make: Best of Instructables* book, and a regular at Maker Faire Bay Area.

PROJECTS: Made from wine barrel hoops, advertising banners, and surplus solar panels, you could drive solar-electric residential vehicle (RV) "Evardo" a few miles, stop and help people work on their projects, then sleep in the back.

MATT RICHARDSON

(mattrichardson.com) is a Product Evangelist for Raspberry Pi, handling outreach within the U.S. He is also a former Contributing Editor to *Make:*

MATT'S TOP TIPS: Break down your project into manageable chunks. You might have fabrication, electronics, code, and documentation. But even within those major categories, you should break it down even further.



Matt's Cycle-Chaser bike project.

Anouk demonstrates her Faraday cage dress.

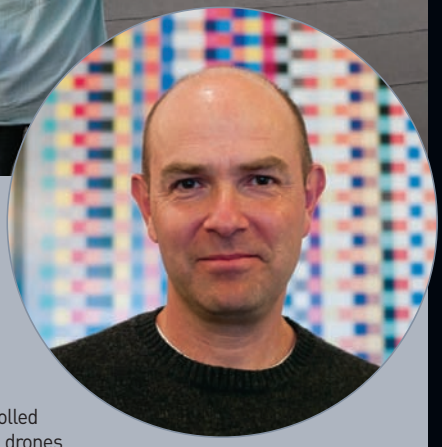
Scott Torborg, Bunnie Huang, courtesy Leah Buechley, Tim Anderson, Andrew Rossi, Matt Richardson, Kyle Cothern, Martijn Cruyff

ANOUK WIPPRECHT

(anoukwipprecht.nl) is a Dutch fashion designer and fashion technologist. Her work has been featured in *Make:*, the *Make:* website, and Maker Faire. In 2014, she first wowed the crowds at Maker Faire Bay Area with a catwalk fashion show featuring high-tech wearables.

ANOUK'S TOP TIP: Learn the language of each discipline that you use. A programmer thinks in code, a designer in how things flow, an architect in how they are constructed, etc. These are all languages you can learn how to speak, like French or Italian.

Chris with 3D Robotics' Iris+ drone.



CHRIS ANDERSON

(3drobotics.com) was the editor-in-chief of *Wired* for 11 years. He is the co-founder and CEO of the pioneering company, 3D Robotics, developers of autonomous and radio-controlled aerial vehicles. His work with drones, his thoughts on the import of the Maker Movement and on being a professional Maker, have appeared in *Make:* and been presented at Maker Faire and MakerCon. The drone technology he co-developed was featured on the cover of *Make:* Volume 19.

CHRIS' TOP TIPS: Get a proper soldering iron (I like Weller). Use a heat gun on heat-shrink tubing! (I can't imagine how I used to shrink the tubing before). Buy some Helping Hands! The base-mounted any-angle spring clamps aren't cheap, but they're a zillion times better than the ones at the hardware store.

PROJECTS: I've been working on autonomous electric go-karts with Carl Bass [of AutoDesk], using a drone controller from 3D Robotics. We plan to race them on full-size racetracks.

Kate's Monarch shoulder pads sense the wearer's fight-or-flight response and expand to look more fierce.

3D Robotics, Joi Ito, Max Lander, courtesy Kate Hartman, Renee DiCherri, Instructables, Kelly Williams kellywilliamsphotographer.com, courtesy Tom Igoe

KATE HARTMAN

(katehartman.com) is an artist, technologist, and educator exploring the fields of physical computing, wearable electronics, and conceptual art. Her work has appeared in *Make:*, at Maker Faire, and she is the author of *Make: Wearable Electronics.*

KATE'S TOP TIP: There is no right way to make something. While tutorials and DIY kits are great, making is ultimately about experimentation, innovation, and bringing together tools and methods from different disciplines to accomplish new and exciting things!

PROJECTS: One of my most recent is Monarch (pictured), a muscle-activated kinetic wearable. By physically extending natural body language, Monarch explores how wearable technologies can become a form of personal expression.

Eric and his son's Mad Max costumes.

ERIC WILHELM

(instructables.com) is the founder of Instructables. He has a Ph.D. from MIT in mechanical engineering. Eric believes in making technology accessible through understanding, and strives to inspire others to learn as much as they can and share that knowledge with those around them.

ERIC'S TOP TIP: Take one step forward every day. Over time, those steps will add up to something great.

TOM IGOE

(tigoe.net) is an artist and teacher of physical computing. He is also the co-creator of the Arduino. Tom frequently has appeared in *Make:* and presented at Maker Faires, and he's the author of the seminal *Making Things Talk*.

TOM'S TOP TIP: Always think about the person you're making something for. I see so many cool tech projects that end up in a drawer because they weren't built with an actual user in mind.

A networked candle that flickers and flares when you touch it.

Luzena Adams, Jimmy DiResta, both photos Erico Platt, Jie Qi, Asli Demir, Cliff Stoll, Stephen Brown — Mobile Digital Arts

Jimmy's restored fireman axe.

JIMMY DIRESTA (jimmydiresta.com)

is a Maker's Maker. There seems to be little that he can't fabricate, out of nearly any given material. His always impressive and clever talents have led to such DIY television shows as *Dirty Money*, *Hammered*, and *Trash to Cash*. Currently, Jimmy is a YouTube Maker star, as a regular on *Make:'s* Workshop video series, on the Core77 channel, and on his own popular Jimmy DiResta channel.

JIMMY'S TOP TIP: Want to lean how to use a machine? Make something on it! Among other things, you quickly learn how to hide your mistakes.

PROJECTS: I love my new fireman axe restoration and handle fabrication with leather sheath. I used an axe head and an ash wood blank that a friend had given me. And I recently took on a project of turning a chess set on a lathe. After turning a set of pieces, I made molds out of them and cast the full set in ivory and black. I am probably most proud of the body of videos I've built up on YouTube. I get so many wonderful letters from fans telling me how inspired they are and how much they've learned from my videos. That's a really great feeling.

A cat carrier made from a Singer sewing machine case.

CHARLES PLATT

(makershed.com/platt) is a fiction author, science and tech journalist, and an independent technologist. He is one of *Make:'s* contributing editors and is the author of the best-selling *Make: Electronics* books and the *Make: Encyclopedia of Electronic Components*.

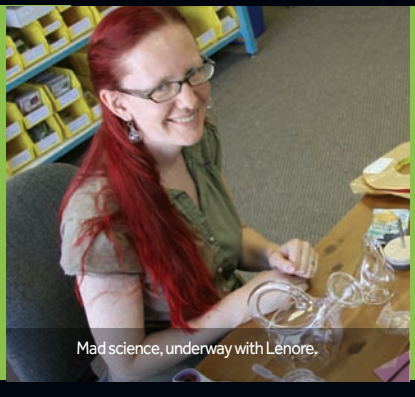
CHARLES' TOP TIPS: Quality shop tools enable quality work. Save time by using modeling software or even just simple math before building a prototype.

JIE QI (technolojie.com)

is a doctoral candidate in the Responsive Environments group at MIT's Media Lab. Her work and how-tos with paper circuits and "circuit stickers" has appeared in *Make:* and on the website.

JIE'S TOP TIP: A prototype moving into manufacturing gains positive qualities, but features get cut, too. I find it worth clarifying, for yourself and your project, if the trade-off is worth it.

Dandelion art lights up with Jie's circuit stickers.



Mad science, underway with Lenore.

LENORE EDMAN

(evilmadscientist.com) is one of the two top lab coats behind Evil Mad Scientist Laboratories. Lenore and her husband Windell Oskay have been featured frequently in *Make:* and have been regulars at Maker Faire since the first in 2006.

LENORE'S TOP TIP: We use our driving time to work through current project problems, flesh out items on our long to-do list, and brainstorm new ideas.

JAY SILVER (makeymakey.com)

is founder/CEO of Makey Makey and JoyLabz. Before that, Jay was a Ph.D. student at MIT Media Lab where he won a Lemelson-MIT Award for Invention and Innovation. He was also Intel's first-ever Maker research scientist.

JAY'S TOP TIPS: When you believe in people a little, they believe in themselves a lot. Every learner's path is different and every path is beautiful.

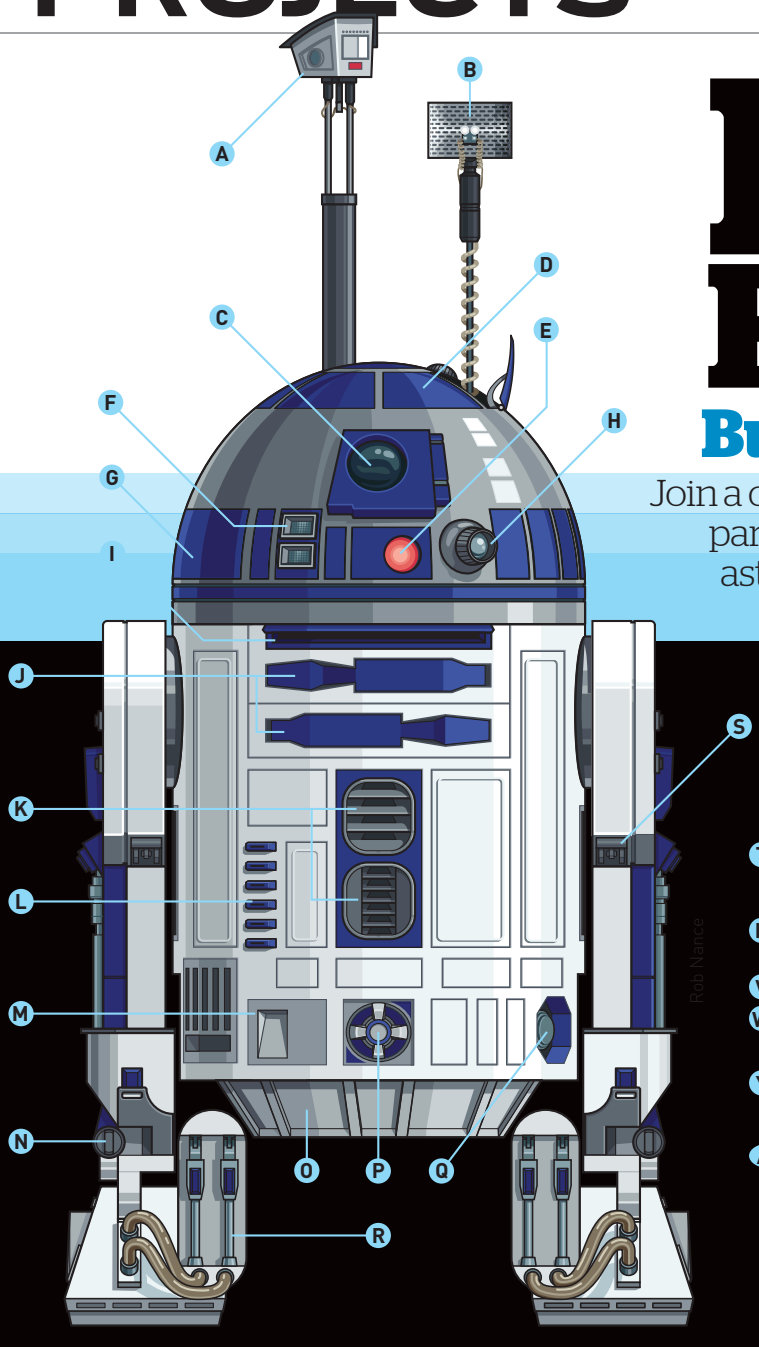
Jay demos his Makey Makey Go.

Droid Factory:

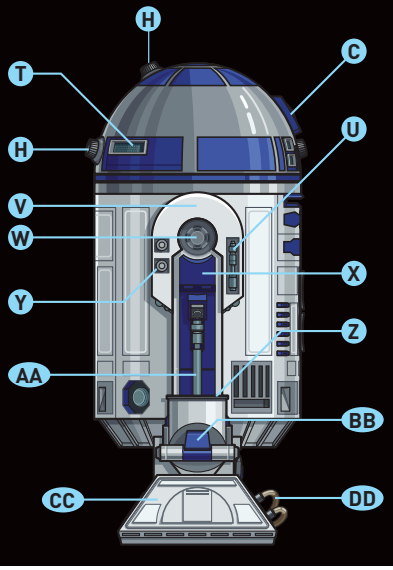
Build Your First Artoo

Join a club of Makers sharing CNC and 3D printed parts, to construct your very own, full-size astromech droid. You know you want to!

Written by Paul Gentile ■ Illustrated by Rob Nance



Time Required:
6 Months-3 Years
Cost:
$500-$10,000



- A Periscope
- B Life Form Scanner
- C Radar Eye
- D Pie Panels
- E Processor State Indicators (PSI)
- F Front Logic Displays
- G Dome Panels
- H Holoprojectors
- I Large Data Port
- J Utility Arms
- K Front Vents
- L Coin Slots
- M Coin Return
- N Ankle Cylinder
- O Skirt
- P Power Coupler
- Q Octagon Port
- R Battery Box
- S Under Shoulder Detail
- T Rear Logic Display
- U Shoulder Hydraulics
- V Shoulder Horseshoes
- W Shoulder Hub
- X Booster Cover
- Y Shoulder Buttons
- Z Ankle Bracelet
- AA Leg Strut
- BB Ankle Cylinder Wedge
- CC Drive Units (Feet)
- DD Foot Hoses

ASTROMECH ANATOMY ACADEMY

A fully operational R2 unit can have hundreds of parts, but these are the key external details (or "greebles") you need to know to craft your own movie-accurate droid buddy. Some of these part names are official, from Lucasfilm/Disney's *Star Wars* universe; others are R2 builders' own pet coinage.

PAUL GENTILE is a Maker and self-described professional geek. He and his wife and two sons have a passion for making, scouting, video games, and technology. Paul co-founded Soldering Sunday (solderingsunday.com) to help young Makers learn electronics, and he's an officer of FUBAR Labs, New Jersey's first Makerspace.

IF YOU'VE BEEN TO A MAKER FAIRE YOU'VE PROBABLY COME ACROSS ONE OR MORE LIFE-SIZE R2-D2s ROAMING ABOUT OR PARTYING WITH THE DJ. These robots and other *Star Wars* "astromech" droids are built by people like myself who are part of the R2 Builders Club. Some of us are crazy for robotics, some just want a screen-accurate replica of their favorite *Star Wars* droid. For many of us, it's both — we love that we can build a real robot that's an iconic character.

When people encounter R2-D2 they go through stages of surprise, happiness, and then curiosity. "Did you buy it? Did you build it? Is it a kit? How long did it take? What can it do? Can I build one?"

Yes, you can. R2-D2 is not for sale, and there's no complete kit available. However, anyone can build an R2-D2.

THE R2 BUILDER'S PATH

The R2 Builders Club (astromech.net) maintains an official set of blueprints, CAD files, and 3D files for printing, and our members make and share parts. Don't worry if you don't have a particular skill — you can learn it. That's the Maker spirit. Club members are always willing to share knowledge and techniques. If we can do it, so can you.

In this article I'll walk you through a typical R2-D2 build — a simple and relatively affordable 3-leg, radio control setup, with dome lights and Bluetooth audio. You can add functionality later.

The R2 Builders Club was started in 1999 by Dave Everett as a Yahoo Group for "those interested in building a replica R2." Today we have thousands of members, with a Builders Council to moderate our forums, oversee our official R2 specifications, and approve part suppliers. Anyone is welcome to join, it's free, and it should be the first step on your journey to building your very own droid.

WHY BUILD AN R2?

Let's discuss a few things to help you avoid the Dark Side. Why build a full-size R2-D2?

» **You can't buy one.** R2-D2 and its imagery are the property of Lucasfilm and Disney, and they haven't granted anyone a license to sell full-scale operating replicas. There are sellers on the internet offering a "full size R2" or parts. Stay away. The forums are full of members who found these weren't quality products.

» **You have Lucasfilm's blessing.** The club has a mutual understanding with Lucasfilm and Disney that we don't exploit our droid building. We don't sell droids or droid kits to the general public. Over the years, we've had the opportunity to measure original R2 units from the Lucasfilm archives for our official blueprints.

» **Because it's fun!** Figuring out how things work and solving challenges is an adventure. When you build your droid, it truly is yours and is infused with your personality.

BEFORE YOU BUILD

Building an astromech droid is a big project, but if you break it down into its parts it's easily achievable. First, ask yourself these questions:

» **Which droid will you build?** R2-D2 is popular but there's a universe of astromechs to choose from. Do you want a droid that's screen accurate to a particular movie?

» **What functionality will you include?** Will your droid be static, radio controlled, or have some autonomy? Will its panels open? Perhaps to reveal accessories like a Periscope, Life Form Scanner, or even a lightsaber launcher? Will it be a 2-leg, 3-leg, or, most challenging, a "2-3-2" with a retractable center leg?

» **What materials will you use?** Underlying all these decisions are money and time. The biggest driver of both will be the materials you build with.

CONSTRUCTION MATERIALS

» **Aluminum** When *Make:* profiled the club a decade ago (*see Volume 02, "R2-DIY"*), an all-aluminum droid might cost $20,000 and weigh over 300lbs. Since then, builders have contributed new "diet" aluminum parts that are cheaper, lighter, and stronger. Today an aluminum droid can weigh less than 200lbs and be built for half that cost. Still, it's the premium option.

» **Styrene plastic** is affordable and lightweight: A styrene droid can weigh well under 100lbs. **Dave Everett's styrene plans** allow a patient builder to hand-cut flat styrene stock and build a

Michael Ehrmann

Materials

R2 builds vary widely — here's what goes into our beginner's build. For more sources and part numbers, visit makezine.com/go/building-your-first-r2.

CUSTOM PARTS, THROUGH R2 BUILDERS CLUB:

» **Styrene R2 dome, laser cut: inner, outer, and dome ring** from Daren Murrer of Cincinnati, Ohio, makezine.com/go/r2-d2-dome. Or try a fiberglass dome from Austin Roghelia and Scott Murphy of Cocoa Beach, Florida, marsprops.com.

» **Styrene R2 body CNC kit** from Frank Pirz of Jackson, New Jersey, r2d2.media-conversions.net. Includes body frame and skirt, utility arm box, shoulders (2), legs (2), foot covers (2), battery boxes (2), center leg, center foot, and center foot shell.

» **Styrene body skins (2-part)** Buy from Frank Pirz (see above) or cut your own, following the blueprints by Dave Everett at astromech.net/forums/downloads.php.

» **Plastic external details** aka "greebles" — R2's vents, radar eye, etc. I used 3D-printed parts from Andrew Radovich of Pekin, Illinois, monkey3dparts.com, and cast resin parts from Brenda Thomas of Jacksonville, Florida, creativesolutions.vpweb.com. Or 3D print your own from the STL files at astromech.net/droidwiki.

» **Teeces Lighting System v3.2** for R2's dome. Get a kit with preprogrammed Arduino from Nate Lesan, Gardner, Kansas, makezine.com/go/teeces. Or order PCBs from oshpark.com and solder them yourself (see youtube.com/murphydigital).

» **Slip-ring and adapter kit (optional)** powers the dome from the body; from Glyn Harper, U.K., makezine.com/go/harper.

OFF-THE-SHELF PARTS:

» **Lazy Susan bearing, 17-3/8" diameter** Rockler part #12451

» **Delrin bearings, 5/16" (200)** aka acetal bearings

» **Styrene sheet, white, 3mm, 2'×4'** for making minor parts

» **Weld-On cements for plastic: #3 (1 pint) and #16 (2 pints)**

» **Polymer braided water supply hoses, 30" (2)**

» **Floral craft rings, 18" (2)**

» **Neodymium magnets, 3/8" disc, 1/16" thick (20)**

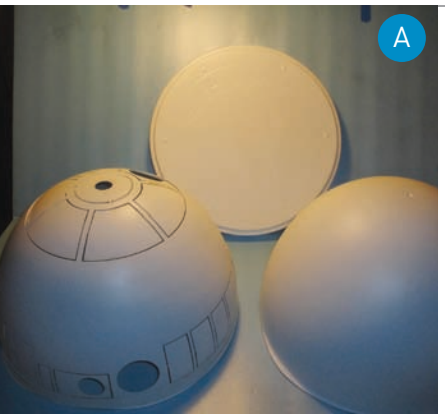
» **Epoxy putty** such as Bondo

» **Miscellaneous hardware**

Electronics

» **R/C transmitter and receiver**

» **LiPo battery packs (3)** 5,000mAH, 4S 30C, 14.8V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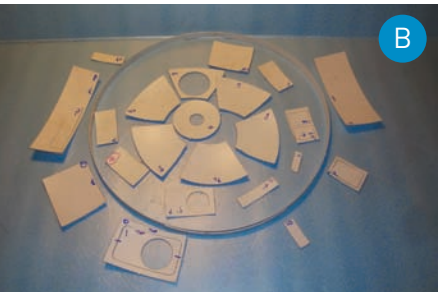
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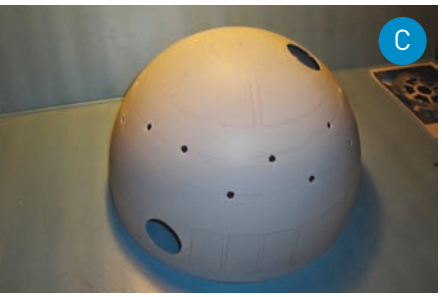

C


D


E

complete droid with very simple tools, for as little as $500. CNC-cut styrene makes the job quicker.

» **Wood** is strong, light, and affordable — it's generally used for the frame and legs and then covered with styrene. Many builders have used the **Senna Wood Frame** plans to build their R2.

CHOOSING A DOME

R4 and R5 series astromechs have a **conical head** that's easily made from flat styrene. R2-D2, however, requires a **true dome** that's not easy to duplicate. In the past we'd wait for a club supplier to produce a "run" of domes; in the meantime members used BBQ grills, squirrel baffles, and lampshades. Today R2 domes are available in aluminum, cast composites, or vacuum-formed ABS styrene, which we'll use in this build.

PRE-MANUFACTURED PARTS

Builders have stepped up to provide pre-manufactured components in aluminum, cast resin, 3D printed plastics, and CNC-cut styrene. Frank Pirz recently engineered a new generation of CNC styrene parts that are stronger and lighter by design. Club members can buy these (r2d2.media-conversions.net) or cut their own — just contact Frank through the club forums (username: mediaconvert) to get the AutoCAD drawings.

For this build, we're using Frank's CNC parts for the droid body, with a combination of 3D printed and cast-resin "greebles." Let's get started!

BUILDING YOUR FIRST R2-D2

Here's a quick flyover of a lengthy build; for more details, visit the project page at makezine.com/go/building-your-first-r2.

BODY CONSTRUCTION

1. CUT THE DOME PANELS FREE

The outer dome is laser-cut — just trim the excess, and cut the panels free from their retaining tabs (Figures A and B).

TIP: Before you cut anything, label everything — many parts look similar once they're all over the workbench.

2. TRIM THE DOME SUPPORT RINGS

The dome base needs internal support, and a pair of floral craft rings work perfectly. Trim to fit on top of the dome ring. You'll glue them later.

3. CUT HOLES FOR DOME COMPONENTS

Align the outer and inner domes, then mark and cut holes for the 3 holoprojectors (the front one is what we see R2 use for the "Help me, Obi-Wan" hologram), the front PSI, rear PSI, front logic displays, rear logic display, and the "magic panel." (This particular dome panel defies engineering — it looks like it's made of metal, but it lights up in some scenes and it opens in others.) Test-fit your logic frames.

4. GLUE THE DOMES TOGETHER

Drill glue holes around the inner dome as shown in Figure C. Align the inner and outer domes, then flow Weld-On #3 cement between the layers, through the glue holes. Tape in place to dry.

5. PREP THE DOME BEARINGS

R2 builders discovered that Rockler's Lazy Susan bearing happens to be a perfect fit between R2's dome and body, enabling his head to spin 360°. Unfortunately it's loaded with grease, hard to turn, and noisy. Clean it and replace the steel ball bearings with acetal (Delrin) ones, and it works beautifully.

Drill matching holes in the Rockler, the body frame, and the dome ring. Now generously epoxy the dome ring and floral rings into the dome.

6. CUT OUT INNER DOME PANELS

Eventually you'll want to make the dome panels operable. Cut the inner dome now to allow for that (Figure D). For the "pie panels" on top, the inner lip should measure 20mm on 3 sides and 10mm at the bottom, where the hinge will go. After cutting, gently sand the edges.

7. TEST-MOUNT THE RADAR EYE

R2's "radar eye" is the focal feature of his "face." If you compare movie to movie, that radar eye moves around quite a bit! Almost all builders will end up placing it by eye — pun intended. If it looks good to you, that's where it goes.

If desired, make a hole now in the dome underneath the radar lens, so later you can place sensors or a camera.

8. BUILD THE BODY FRAME AND SKIRT

Following Frank Pirz's instructions, the styrene "egg-crate" frame and skirt go together fast — slot A into slot B. Mark the parts before assembly (Figure E) — your little Makers can help. Flow Weld-On #3 between joints to tack them in place, then follow up with Weld-On #16 for strength (Figure F). The frame might seem flimsy but the skins will lock it together.

Attach the skirt to the bottom of the frame. The skirt will be visible later, so fill any gaps with model putty or Bondo, and sand smooth (Figure G).

Paul Gentile

9. TEST-FIT THE DOME

Test-mount the Rockler bearing's outer ring to the frame. On its inner ring, add upward guide bolts to match the holes in your dome ring. Use nuts to adjust the gap between frame and dome, so it spins evenly. R2 is coming to life!

10. ATTACH THE SKINS

The styrene skins are also a 2-layer process. Wrap R2's frame with the first layer, check the fit, and adjust. Tack the skin in place with Weld-On #3 and follow with Weld-On #16. Secure with straps, painter's tape, or strong magnets, and let everything fully cure. If you want the body doors to open, cut them out now.

Repeat with the second layer.

TIPS: Don't cut doors out before gluing the skin — it'll make the skin flimsy and difficult to position. Some builders prefer glues to solvents here — the skins are thin, and too much solvent can cause ripples that need to be fixed later.

11. TEST-FIT ALL BODY COMPONENTS

Trial-fit your "greebles" and adjust if needed. For example, R2's two utility arms tend to rub the skin as they open; to fix this, just sand the backside of the arms at an angle.

Don't glue any components in place yet.

12. BUILD SHOULDERS, LEGS, AND FEET

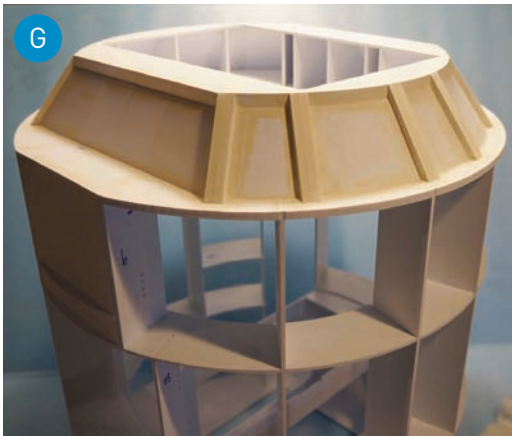
Like the body, the legs go together fast. Tack in place, then bond, then fill any gaps with a plastic filler (Figure H, following page). The shoulders are round at the top (we call those the horseshoes) and have mounting bolts for the body on one end, and for the legs on the other. Frank's styrene legs incorporate the ankles and are extremely strong.

We're building a 3-legged R2, where his center foot is extended for easy cruising. The left and right legs are set at an angle of 36° by the shoulder mounting plates in the frame (Figure I).

13. BUILD THE DRIVE SYSTEM

R2 will be driven by two Razor 100W 24V scooter motors, one in each foot. The drive system is probably the most challenging part of the build, but with a little patience you can do it in a simple workshop. I used the tools at my local Makerspace, FUBAR Labs in New Jersey.

The design calls for 2 wheels in each foot, driven by a chain. You'll need to fabricate short axles, attach the sprockets



NOW SHOWING: R2-3D PARTS

In recent years the biggest change in building an R2 is the advent of 3D-printed parts. The R2 Builders Club now has a catalog of approved and verified parts that you can download at astromech.net/droidwiki. You'll still find cast resin parts supplied by club members, but now you can buy 3DP parts or print them yourself.

If you think of R2 as a large puzzle with hundreds of pieces, you'll see why the club works hard to protect the integrity of the parts. You can find 3D printed "R2 parts" on eBay or Thingiverse, but if they're not to club spec you've wasted your money and your time. Do yourself a favor and stick with approved parts.

Andrew Radovich, aka Monkeyman, is one of the leading 3DP parts designers and suppliers in the club. He's printing everything from the holoprojectors in the dome to the half rounds on R2's feet. Andrew prints in ABS plastic; he started with a Solidoodle 3 but now has built several printers from scratch just to keep up with demand. Contact him via the club at makezine.com/go/monkeyman3dp.

3D printed astromech parts by Monkeyman, waiting to ship to other R2 builders.

- **Battery charger**
- **Battery cable, 2-wire, 25'**
- **Servo cable, 3-wire, 25'**
- **Servo connectors, male/female pairs (24)**
- **Battery connectors, XT60 type, male/female pairs (10)**
- **Gearmotor, 30:1 ratio**
- **Motor controller, 5.5V–30V, 15A** Pololu #1381 or 1376
- **Wheel, 80mm×10mm**
- **Mounting hub for 6mm shaft**
- **Bluetooth speaker**

Drive System

- **Razor scooter motors, chain drive, 100W 24V (2)**
- **Motor controllers, 5.5V–30V, 25A (2)** Pololu #1381 or 1383
- **Drive chain, #25 (¼"), 60"**
- **Chain connection links, spring clip type (8)**
- **Sprockets: 9-tooth with hub (2), 22-tooth with hub (2), and 22-tooth plate (4)**
- **Steel shafts: ½" dia., 3¼" long (2) and ¼" dia., 4" long (1)**
- **Ball bearings, flanged, ¼" ID, ½" OD (4)**
- **Shaft collars, ¼" ID (4)**
- **Rubber wheels, 5"×1¼" with ½" Delrin bore (4)**
- **Swivel caster with rubber wheel**
- **Delrin rod, ⅜" dia., 6" length**
- **Compression springs, ¼" OD, 9⁄16" long (4)**

Paint and Finishing

- **Spray primer, white (20 cans)**
- **Spray paint: white satin enamel (10 cans), metallic cobalt blue (5 cans), purple gloss (5 cans), silver metallic enamel (5 cans)**
- **Rub & Buff Wax Metallic Finish, silver**
- **Craft paint, bronze metallic**
- **Foil tape**

Tools

- **Eye protection**
- **Gloves, nitrile or latex**
- **Weld-On applicator bottles**
- **Utility brushes** for glue
- **Utility knife, hobby knife**
- **Straightedge, steel**
- **Files, rough and smooth**
- **Sandpaper, various grits**
- **Screwdrivers**
- **Allen wrenches**
- **Hand drill or drill press**
- **Step drill bit, ¼"–¾"**
- **Tap and drill set**
- **High-speed rotary tool**
- **Bandsaw, coping saw, hacksaw**
- **3D printer (optional)**
- **Routing table or CNC cutter (optional)**


H

to the wheels, cut the chain to length, and then assemble it all (Figures J and K). It's a good rainy weekend project. For every part of the drive system, I made at least one spare, just in case.

For more detail on the drive systems see makezine.com/go/r2drive .

14. FOOT COVERS AND BATTERY BOXES

Frank's design uses styrene for the flat sections and 3D-printed parts for the curved pieces (Figure L). Often we think of 3D printing as a singular design choice, but in this case it's combined with other materials in a very practical design. Removable panels, held in place with magnets, allow access to batteries and the mechanicals in the foot.

15. BUILD THE CENTER FOOT

The center ankle attaches to the skirt, and the center foot has a swivel caster that lets R2 move any direction and turn in a very tight radius.

ELECTRONICS

For our R2 we're keeping it simple: radio control for movement, Bluetooth audio, a Teeces lighting system, and Pololu motor to turn the dome.

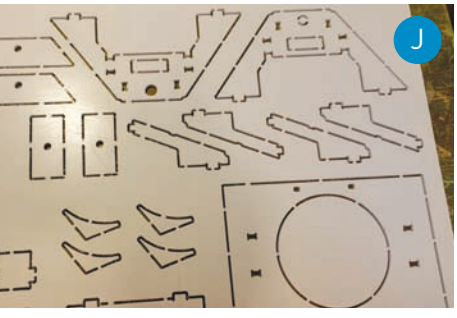
1. CONNECT THE DRIVE MOTORS

Connect your scooter motors to two Pololu 25A motor controllers, one in each battery box. You're using two 5,000mAH 14.8V LiPo batteries, again one in each battery box. This should give you several hours of run time. With this setup, 12 volts is plenty of power (Figure M).


I

2. MOUNT THE DOME MOTOR

For the dome motivator, we're using a 30:1 metal gearmotor from Pololu, with their 15A motor controller and 80mm wheel with high-traction sticky tire. This wheel will ride on the inside of the Rockler bearing to spin the dome, using a spring mount to maintain tension.


J

3. CONNECT THE R/C SYSTEM

All 3 motor controllers can be connected to a typical R/C receiver. Drive and steering are on my right stick, dome control on my left.

Since R2 can weigh in at 100+ pounds and a loose droid is never a good thing around people, I suggest using a 2.4GHz system with a failsafe that returns all controllers to neutral if signal is lost.

» **Next Level:** An alternative to R/C is the ServoShock system (servoshock.com) which pairs a Sony PS3 game controller via Bluetooth (or USB) to a receiver module that can connect to 10 servos, has 17 digital outputs, and automatically returns to neutral if signal is lost. And it's got an optional Arduino shield you can leverage for additional functionality.

4. BUILD THE DOME ELECTRONICS

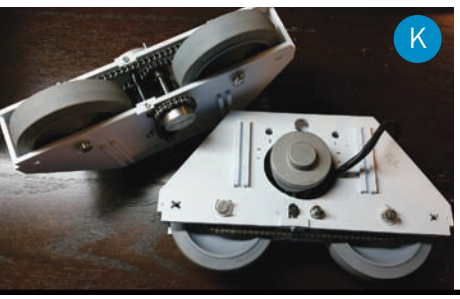
R2's dome electronics as seen in the movies include 2 big round PSI lights, front and rear logic displays, and 3 holoprojectors. The easiest way to illuminate these is with the Teeces V3 Dome Lighting System (joymonkey.com/run), available through the club. It's an older system, but an easy DIY kit that includes an Arduino Pro Mini to run the lights (Figures N and O). (Soldering the Teeces kit together is what led me to FUBAR Labs and the whole Maker Movement — so I am a little partial to this kit!)

Once the kit is built, mount the logic lights to your logic frames. The PSI mounts are a homebrew solution from the club using 1½" PVC pipe fittings from the local home superstore.

Inside R2's body, you need to power the dome motivator and your R/C receiver. Add another 5,000mAH 14.8V LiPo battery, connect it to the motor controller (ESC) and use the ESC's 5V out to power your receiver (Figure P).

TIP: Use R2's doors to access the electronics so you don't have to remove his dome all the time!

For the lights, you could put a smaller battery inside the dome, but I prefer to route power from inside R2's body, using a 24-wire slip ring with an adapter from fellow R2 builder Michael Erwin. This adapter has a DB25 connector on each end so you can remove the dome easily. And it can handle 2 amps per channel; again, you don't need it now, but it will be there when you're ready for it.


K


L


M

» **Next Level:** Add servos to open panels and move the holoprojectors (you can see my holo servos in Figure Q), or accessories like the life form scanner or periscope that rise out of R2's dome. You've prepped your dome for these, but you can tackle them later. (There are 6 more movies due out — you have some time!)

5. ADD SIMPLE BLUETOOTH SOUND

R2's chirps and beeps strike a chord in people — they'll ask you if R2 can make specific sounds they remember. Of course the club has a whole library of R2 sounds. Just pair a Bluetooth speaker with your smartphone, and download a soundboard app that you like. Add your R2 sounds, and place your speaker inside R2. My little speaker cost $35 and is very loud, even in a crowd.

» **Next Level:** Now I use a Bluetooth receiver and local audio amp with twin 100W speakers!

FINISHING AND ASSEMBLY

1. TEST-ASSEMBLE

Assemble the major components of your droid. Test all your electronics and the settings of your motor controllers. When it's all to your liking, take it all apart again. It's time to paint.

2. PAINT EVERYTHING

Which parts should be which color? Check the reference photos in the Club's wiki and you'll see that R2-D2 has changed his looks over the years. Paint R2 to the scheme you're happy with. I've never had a kid run up to R2, throw his arms around him, and say, "R2, your holoprojector is the wrong color."

For the "aluminum"-colored parts I used Eastwood "Almost Chrome" spray paint. I went with a satin white, and for R2's signature "blurple" color, aka "Hypo Blue," I alternated between metallic blue and, while that was still wet, a quick dusting coat of gloss purple (Figure R). (For more painting tips, check the project page online.) For R2's shoulder joints, I used aluminum foil tape for a sharp, bright look. Foot hoses are made from braided faucet hose, with a bronze metallic paint.

The last detailing choice is weathering. I love the weathered R2s, but I want the pristine, ready-for-the-big-ceremony R2. (I might need to build a second droid!)

How do builders get a painted dome to look even more like milled aluminum? Rub and Buff, a wax paste with metal in it. Find it at a craft shop. It takes a lot of elbow grease, but it's worth it.

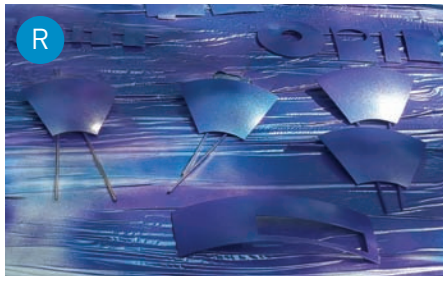
3. ASSEMBLE YOUR DROID

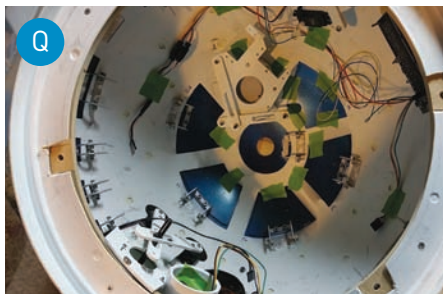
Welcome to the fleet! You've joined an elite few who have a showable, fully operational droid. We have thousands of members, but there are less than 500 operational droids, and less than 200 screen-showable droids worldwide.

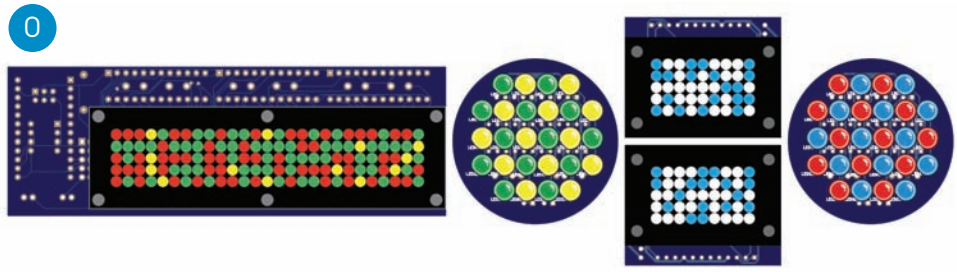
That wasn't bad at all, was it?! What do most builders do when they complete their droid? Start a second one. In the meantime there's plenty of opportunity to show off your R2 at Maker Faire, attend charity events with the 501st Legion, take him to libraries, and brighten up people's day. You'll inspire other Makers, and maybe make some brand-new Makers too.

Get lots more photos, build tips, part numbers and sources, and share your R2 build at makezine.com/go/building-your-first-r2.

PARTY ANIMAL: Everyone loves R2-D2 and can't resist taking a picture with him. Here's my wife, Maricel, and her friends — the usual scene at my house when friends come to visit!







Foldaway Frame Table

There when you need it. Gone when you don't

Written by Sean Michael Ragan

Time Required:
5 Hours
Cost:
$200–$250

I FIRST SAW THIS IDEA IN THE 1973 DIY CLASSIC *NOMADIC FURNITURE* — A PICTURE FRAME THAT FOLDS DOWN TO BECOME A TABLE. Recently, I found a German site selling a similar design for almost $1,000. I'd always wanted to build one, so I took on the challenge of matching the Germans' quality at a better price. My design is sturdy and easy to deploy, revealing a handy hidden whiteboard. When stowed, it protrudes less than 2" from the wall, shows no fasteners, and locks securely in place. Part of the trick is using one standard piano hinge and one reversed hinge to make it all fold up tight.

1. CUT THE PANELS AND HINGES

Saw the markerboard and melamine to 35⅛" long, then rip the markerboard to 23¼" wide, and the melamine to 23". Apply edging to the long sides of the melamine.

Hacksaw a 20" length of continuous hinge, and clean up with a file. Punch the pin out of the leftover hinge, reverse one leaf (see Figure A), tap the pin back in, then saw the leftover to 20" too.

2. BUILD THE BACKBOARD

Cut 2 pieces of aluminum angle to fit the markerboard's long edges. On each piece, mark a parallel line down an outside face, $^{9}/_{16}$" from the corner. On your line, drill five $^{5}/_{32}$" holes: one $^{7}/_{16}$" from each end, one in the middle, and 2 halfway between these. Countersink all holes, from the outside, to three-quarters depth.

Fit the angles to the markerboard edges, drill matching holes, and secure with rivets from the front. Center the reverse hinge along the backside of the board's bottom edge and likewise drill and rivet in place. Once all rivets are set, punch the broken-off mandrels out from the flange side.

Finally, drill four $^{5}/_{32}$" mounting holes, midway between the 2 rivets in each corner, through both aluminum and markerboard.

3. ADD THE WORKTOP

Cut a 23" length of aluminum bar to fit one end of the melamine, then use the standard hinge to locate and drill 10 holes in it as shown (Figure B). Attach bar and hinge together to the melamine edge, with wood screws. Now lay the melamine on the markerboard, between the angles, with the protruding lip of the bar flush against the

Hep Svadja

markerboard's top edge. When everything's aligned, secure the reverse hinge to the bottom edge of the melamine with wood screws.

4. BUILD THE QUICK FRAME

Mount one ball catch in each of the longer Quick Frame tubes with the ball centered 6¾" from the end. Use the catch plate as a template to drill three 5/32" holes, then step-drill the middle hole to 9/16" to accept the catch body. File away the "countersinks" on the back of the catch plates, thread the catches into the plates as far as they'll go, and rivet the plates to the tubes (Figure C).

Assemble the Quick Frame by pounding the corner connectors into the tube ends with a rubber mallet, making sure to orient the long tubes with the catches directly opposed.

Turn the table assembly facedown and place the Quick Frame around it, with the catches nearest the top hinge leaf (Figure D). Align the edges as squarely as possible, locate and drill mounting holes in the Quick Frame to match the hinge, and fasten with rivets. Finally, mount 4 rubber feet on the back corners by driving sheet metal screws into the plastic Quick Frame connectors.

5. HANG AND ADJUST

With a helper, mount the backboard to the wall using drywall anchors or other suitable hardware (Figure E). Make sure, before you commit, that there is room for the table to deploy, and that it's flat and level when folded out.

Once it's hung, test the folding action, but be gentle, as the catches are probably sticking out too far right now. Screw the catches in until they just clear the aluminum angle; you should feel firm resistance as the balls compress their springs. Now locate the detent holes by rubbing the aluminum with pencil lead and closing the frame a few times to leave tracks in the pencil markings (Figure F). Mark centers where the tracks end, drill to 3/8", and deburr the holes with a file. Verify that both catches click cleanly in place when you stow the frame. If not, adjust the detent holes with a round file. I didn't use the detent plates that came with the catches — the simple hole works great.

Finally, add short strips of velcro loop tape on the frame's bottom corners to prevent scuffing.

6. ART IT UP

Align the poster frame to the Quick Frame edges, open the top flap, drill through the mounting holes, and fasten with rivets. Repeat for the side and bottom flaps, then mount your art in the frame. Test the folding action a couple times (Figures G and H), clean up any pencil marks or blemishes, and your foldaway table is ready to use.

Get the complete assembly diagram and more step-by-step photos at makezine.com/go/foldaway-frame-table.

Sean Michael Ragan

SEAN MICHAEL RAGAN (smragan.com) is a writer, chemist, and longtime contributor to *Make:*. His work has also appeared in *Popular Science*, *Chemical & Engineering News*, and *The Wall Street Journal*.

Materials

- **Markerboard, 3/16", 4'×2'** such as Home Depot #926009
- **Melamine shelf board, ¾", 4'×2'** Home Depot #252297
- **Melamine edging, ¾"×6', iron-on type** such as Edgemate #901-013-R25-PG
- **Continuous hinge, 1½", 4'** Everbilt #15372
- **Aluminum angle, 1¼"×1/8", 8'** such as Crown Bolt #56830
- **Pop rivets, 5/32"×¼" (46)** such as Stanley #PAA54-5B
- **Aluminum flat bar, 1"×1/8", 3'** such as Crown Bolt #44690
- **Wood screws, flat head, #5×1½" (20)** such as Everbilt #806981
- **Quick Frame square tubes, 1": 35¾"(2) and 23¾"(2)** Order 80/20 Inc. part #9000-Black-FB factory-cut, 8020.net, cut to 35.75" and 23.75", respectively
- **Quick Frame 2-way corner connectors, 1" (4)** 80/20 Inc. #9220
- **Surface-mount ball catch, ½" (2)** such as Prime-Line #N7288
- **Front-loading poster frame, 36"×24"** Snapezo #SNAP-24-36-B-32MM
- **Recessed rubber feet (4)** such as Amico #A11120700UX0247
- **Sheet metal screws, #6×½" (4)** such as Crown Bolt #34441
- **Drywall anchors (4)** or other suitable mounting hardware
- **Adhesive velcro tape, ¾" wide, 22" length**

Tools

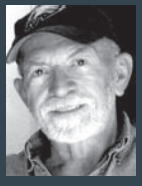
- **Table saw**
- **Clothes iron**
- **Hacksaw** or metal chop saw
- **Round file**
- **Round punch, 1/16"** or small nail
- **Hammer**
- **Pencil**
- **Yardstick**
- **Drill and twist bits: 5/32", 1/8", 3/16", ¼", 5/16", 3/8", 7/16", ½", and 9/16"**
- **Countersink bit**
- **Screwdriver bits**
- **Pop rivet tool**
- **Rubber mallet**
- **Scissors**
- **Hobby knife**

NOTE: If you want to soften the unfolding action a bit, deploy the table halfway (onto a stool or other prop) and cover the hinge leaf on the Quick Frame with velcro loop tape. Then remove the prop, unfold the table fully, and trim away any excess tape with a hobby knife.

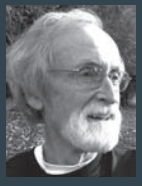
Inspired Chaos

Written by Phil Bowie and Larry Cotton

Build a portable Double Pendulum to create abstract time exposures



PHIL BOWIE is a lifelong freelancer magazine writer. The new, fourth novel in his suspense series is out on Amazon. Visit him at philbowie.com.



LARRY COTTON is a semi-retired power tool designer and math teacher. He loves music, computers, birds, photography, electronics, furniture design and his wife – not necessarily in that order.

WHEN DR. ROBERT REED, A PH.D. AT NORTH CAROLINA STATE UNIVERSITY, spotted the fascinating "Double Pendulum" article by William Gurstelle in a 5-year-old copy of *Make:* (Volume 22, April 2010), he asked us if we'd build two such pendulum rigs to help teach chaos theory to his students. He wanted the rigs to be portable for quick setup anywhere, with red and white LEDs (NC State colors) for creating arty, abstract time exposures.

We began by building a sturdy wooden stand (Figure A) capable of handling the sometimes-violent slinging forces generated by the crazily gyrating pendulum arms. We fastened the parts with wood glue and 2½" screws. The 2×4s at the bottom cross with a half-lap joint. We added four rubber feet for stability and painted the stand flat gray to minimize reflections during photography.

Otherwise we pretty much followed Bill Gurstelle's specs for the components (makezine.com/projects/double-pendulum). We used precision U.S.-sized bearings (¾" OD × ¼" ID × 9/32" thick) so a U.S.-standard ¾" spade bit and assembly hardware would work. We super-glued them into acrylic arms, which we painted white for good visibility in motion. We added red stripes on the short arms to indicate placement of the LED pods. We also used standard ½" diameter plastic spacers, and chose ¼" thick foam for the Rott spacer.

MAKING THE LED PODS

The LED pods (Figure B) are our own invention, held in place by strong neodymium magnets. They automatically turn on when snapped onto the arm ends. The pods are self-contained in spring-steel

Phil Bowie

strawberry hullers that look like clumsy tweezers but fit well on the pendulum arms, allowing fast, no-tool installation and removal. Strawberry huller designs vary in thickness, thus stiffness — so you may have to grind the sides of the bend somewhat to make it flexible enough to work.

Slide a scrap of ¼" plywood between the arms of the huller for backup while you center-punch and drill a 13/64" hole in one arm, 3/8" from the bent end, to accept the LED, and a clearance hole in the opposite arm for the machine screw. Clip off the top (–) lead of the disc battery. Insulate the long lead of the LED with heat-shrink tubing, then solder it to the bottom (+) tab of the battery. Super-glue a disc of thin insulating foam rubber inside the huller on the side opposite the LED hole. Maneuver the battery and LED into place and glue the battery (soldered-tab side) to the rubber insulator. Wrap the short LED lead around the machine screw and tighten the nut.

Finally, super-glue a neodymium magnet into the finger depression on the battery arm of the huller. *Important:* Magnets for both LED pods must have the same pole facing outward.

Using a flat-bottomed bit, drill a slight depression in each short pendulum arm, about 1¼" above the bearing's center, to hold a disc magnet for positioning the LED pods. Your huller spacing may vary, so test-fit your pod before drilling.

Finally, super-glue one magnet into each pendulum arm. These magnets' poles must be *opposite* of the magnets glued onto the LED pods. (They will attract each other through the battery.)

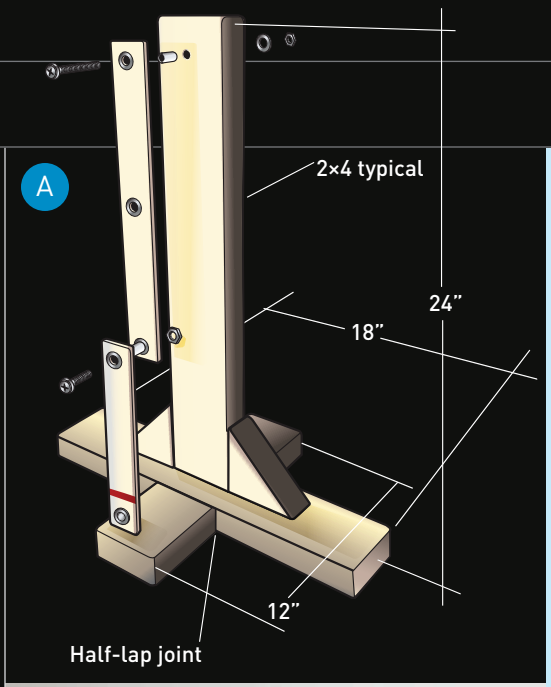
USE IT

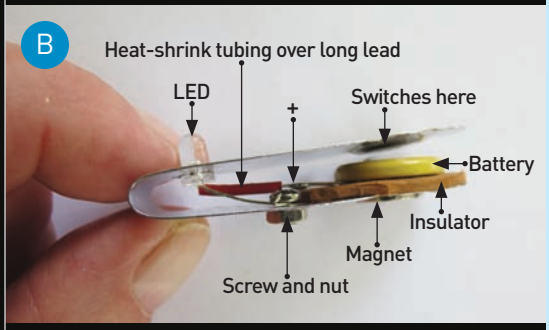
When the pod is snapped in place on a pendulum arm, the magnets will hold it firmly and also complete the circuit to light the LED. For storage, slip a short length of surgical tubing over the huller's battery-side jaw to keep the LED from draining the battery, which will last for up to 200 accumulated hours in many 10- to 20-minute time-exposure sessions.

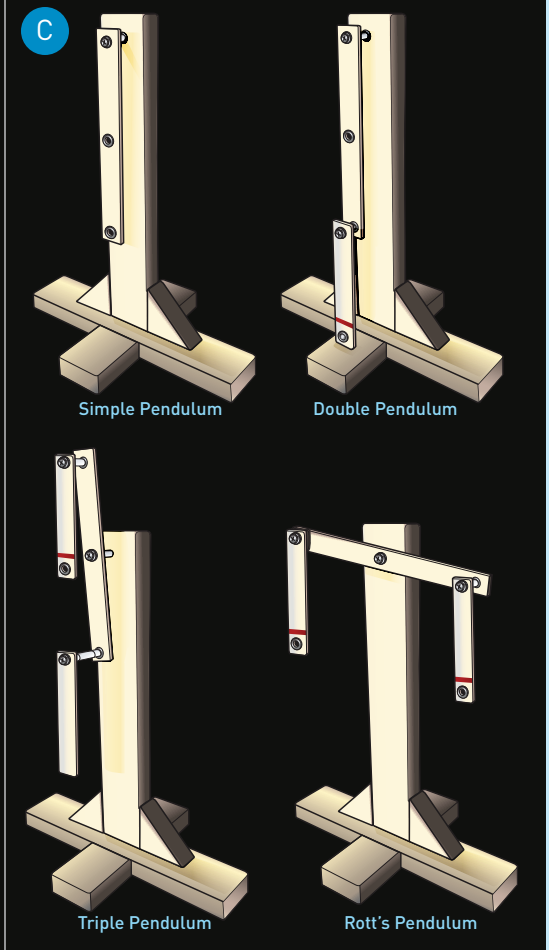
After assembling at least 2 pendulum arms per Figure C, give the pendulum a shove and capture the action with a 5- to 10-second time exposure. Hard as you might try, no exposures will ever be the same.

And that's the intriguing, often startling natural state of chaos.

See step-by-step photos and share your own chaos photography on the project page at makezine.com/go/double-pendulum-2.







Time Required: A Weekend
Cost: $40–$60

Materials

- **Lumber, 2×4, 5' length**
- **Acrylic or polycarbonate sheet, ¼"×12"×12"** We used acrylic from a glazing shop.
- **Ball bearings, R4AZZ size, ¼"×¾"×9/32" (7)** Amazon #B002BBD8VY
- **Bolts, ¼-20: 1" (1), 1½" (1), and 3¼" (2)**
- **Nuts, ¼-20 (3)**
- **Washer, ¼" ID**
- **Nylon spacers, ½" diameter: 1" (2), ¾" (2), and ¼ (1)"**
- **Paint (optional)**
- **Craft foam, ¼"×1½"×1½"** for the Rott spacer
- **Wood glue**
- **Wood screws, 2½"**
- **Rubber feet (4)**

FOR LED PODS

- **Strawberry hullers, spring steel (2)** such as Amazon #B006CFQ33K. We got ours from Mitchell Hardware, info@mitchellhardwareonline.com.
- **LEDs, super bright (2)** superbrightleds.com/cat/through-hole
- **Coin cell batteries, CR2032, with solder tabs (2)** such as Panasonic #CR2032-1F2
- **Neodymium magnets, 12.5mm×2.5mm disc (4)** such as Indigo Instruments #44204-2.5, indigo.com
- **Machine screws, #6-32 × ⅛" (2)** with nuts
- **Heat-shrink tubing, ⅛"**
- **Craft foam sheet, 1mm–2mm thick**
- **Flexible tubing, ¾" ID, 2" length** such as surgical tubing
- **Cyanoacrylate (CA) glue** aka super glue

Tools

- **Saws** for wood and plastic
- **Drill and twist bits: ¼" and 13/64"**
- **Spade bit, ¾"**
- **Flat bottomed bit, ½"** such as a Forstner bit
- **Center punch**
- **Adjustable wrench or small socket set**
- **Soldering iron and solder**
- **Wire cutters**
- **Grinder or rotary tool (optional)**

+ Bill Gurstelle's original *Make:* article also inspired a snap-together pendulum kit: the Chaos Machine at fatbraintoys.com.

James Burke, Phil Bowie and Larry Cotton

Written by Edwin Dertien and Kristin Neidlinger

Blow It Up

Use a quadcopter motor and coffee cup to make your own inflatable gear

BLOWN OFF: With a puff of air, Kristin Neidlinger's *Inflatable Manifestation Dress* goes from form-fitting to off-putting, depending on the wearer's mood.

IT'S LATE AT NIGHT AND YOU FIND YOURSELF IN A PART OF TOWN WHERE YOU PROBABLY SHOULDN'T BE. *By the pricking of the hairs on your neck you realize you're being watched, followed ... somebody is sneaking up. Your heart starts pounding, palms become sweaty. Before you can even think, your arm muscles suddenly grow enormous, spikes come out of the back of your coat, and a protective collar shields the back of your neck. You stop. The universe holds it breath as you turn around to face ... a stray cat, quickly skipping out of sight.*

From the soft robots in *Big Hero 6* to the living quarters of the Mars One project, inflatable technologies are blowing up in popularity. No wonder — they allow for lightweight, safe, and soft barriers between squishy humans and hard tech or threats in the environment.

During her master's work at California College of the Arts, Kristin explored the use of inflatable technology for wearables, and found endless possibilities for animating the body and amplifying human behavior or emotions. There are functional designs for isolation or protection, like an inflatable vest to calm the wearer or a helmet that protects from a bike fall. Then there are empowering forms, like a soft inflatable exoskeleton that protects personal space, or inflatable "muscles" that blow up when the wearer feels threatened.

To further develop these possibilities, we created a set of simple technology "building blocks" for workshops at the Creative

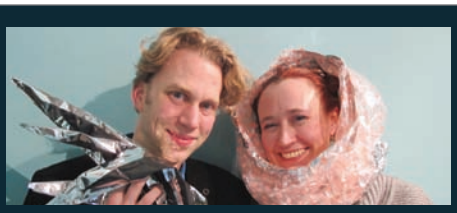
HIGH OR LOW?
KNOW BEFORE YOU BLOW

When working with air, there are two variables of interest: **air volume** and **air pressure**. Inflatable technology comes in two basic forms: high pressure, low volume (pneumatics) and high volume, low pressure (balloons). Pneumatic cylinders typically use high pressure, with an airflow as small as possible. On the other side of the spectrum are the high volume, low pressure blowers you use to inflate an airbed or a bouncy castle.

For both approaches, we've built low-cost DIY solutions: the InflataCup inflator for balloon type applications, and a pneumatic air muscle using an R/C servo, aquarium valves, and a PET soda bottle as a pressure reservoir. Build both projects at makezine.com/go/inflatable-wearables.

Eli Beitzuri

MEMORY SPIKES: Kristin Neidlinger's *Goosebump Poof* is an inflatable wearable that responds to thoughts. When memories are evoked, the spikes stand on end, alert with emotion; they rest when the wearer is relaxed or introspective.



EDWIN DERTIEN (edwindertien.nl) is a creative roboticist at the University of Twente, where he teaches physical computing, sensors, tinkering, and explorative design. He also runs FabLab workshops at the ASSortiMENS foundation, for kids and for people with autism-related issues.

KRISTIN NEIDLINGER is a biomedia designer and founder of Sensoree (sensoree.com), where she crafts phenomenal technology to expand and enhance physical embodiment. She holds an MFA in interactive design from California College of the Arts, and has performed and exhibited works from Berlin to Brazil.

Technology department at University of Twente (Netherlands) and at Stanford University's Institute of Design (d.school) during the TEI 2015 conference.

ELECTRONICS FOR INFLATABLES

To make wearable interactive inflatables, you need a system with a few basic components: on one side, sensors, electronic control, and electrical power; on the other side, air supply, airflow control, and the actual shapes (muscles, bellows, spikes) or "actuators" to inflate.

For the electronics side, picking up biometric or proximity sensors from Adafruit or SparkFun is an easy way to get started, and an Arduino microcontroller can act perfectly as electronic "glue." Since wiring is the #1 reason for system failure (and the most error-prone, time-consuming task) we tried to minimize it by choosing SparkFun's ProtoSnap kits, which combine a credit-card-sized Arduino Nano with FTDI USB-serial converter, RGB LED, light sensor, pushbutton, and a prototyping section, all on one PCB. Eventually you can snap off the parts you don't need. A similar approach is used with the Bitalino, a snap-off biomedical sensor board we've been using to make our devices respond to body signals.

Another happy choice: we chose standard 2,600mAh USB power banks as our power source. They're small, portable, easy to charge in our ever-present ecosystem of USB ports and phone chargers, and they connect directly to the Proto-Snap board using a standard USB-mini cable.

DIY: MAKE AN INFLATACUP

After trying to blow things up using small CPU fans, we decided we needed more power. With the arrival of cheap, mass-produced quadcopters there's no shortage of small high-powered motors and fans capable of large air displacement. You could sacrifice a small copter (or upcycle the one that crashed in your kitchen sink), but we chose a spare quadcopter motor and propeller set by RC Logger (Conrad/Reely in Europe). With a diameter of 60mm, these fit nicely in a paper cup. We started mounting the fans in a coffee cup for several reasons: you need something to protect

Time Required:
1-2 Hours
Cost:
$50-$100

Materials

To make a DIY inflator:

- **Paper coffee cup with snap-on lid**
- **Mini quadcopter motor with 60mm prop, without gearing** We use RC Logger #89051RC, set of 4 for $20. Amazon #B00RLHF2U8 looks similar.
- **Speed controller, servo pulse input, 1.5A output** Sol-Expert #ER105 or #ER100 is a nifty design with an ATtiny45 and two push-pull logic level FETs, and they ship worldwide affordably (sol-expert-group.de).
- **Arduino microcontroller, breadboard-compatible** such as Arduino Mini, item #MKSP17 from the Maker Shed (makershed.com), or the Nano, Micro, or Trinket
- **Sensor of your choice** We used a Sharp infrared distance sensor; you could try an ultrasonic distance sensor, LDR light sensor — or even aluminum foil as a capacitive sensor.
- **Mini breadboard** Maker Shed #MKKN1, makershed.com
- **Jumper wires** Maker Shed #MKSEEED3
- **Capacitor, 1,000µF 6.3V (optional)** to smooth the power supply. We use a Panasonic. Try SparkFun, Adafruit, Mouser, or Digi-Key.
- **Hookup wire**
- **USB "power bank" battery pack, 2,000–2,600mAh** from an electronics or discount store or Amazon
- **USB to USB-micro cable** depending on your Arduino board
- **Cardboard**
- **Molex Picoblade crimp connectors (optional)**

Tools

- **Hobby knife**
- **Hot glue gun**
- **Soldering iron**
- **Pliers (optional)** for crimping Molex connectors; they're expensive

Optional, for DIY plastic fabric:

- **Clothes iron** for fusing plastic
- **Parchment paper**
- **Plastic bags** preferably recycled

Elena Kulikova, Edwin Dertien

A

B

C

the blades from fabric (and vice versa), and something tubular to guide the airflow, and finally, the snap-on plastic lid allows for easy detachment of your "cup inflator" from the garment or inflatable device you've made.

1. EXTEND THE COPTER MOTOR'S WIRES

Remove the original connector and solder longer wires directly to the motor terminals. (For our kits, we use the matching Molex Picoblade connectors, but be aware the special crimp pliers will set you back $300 or more!)

2. CUT AIRFLOW HOLES

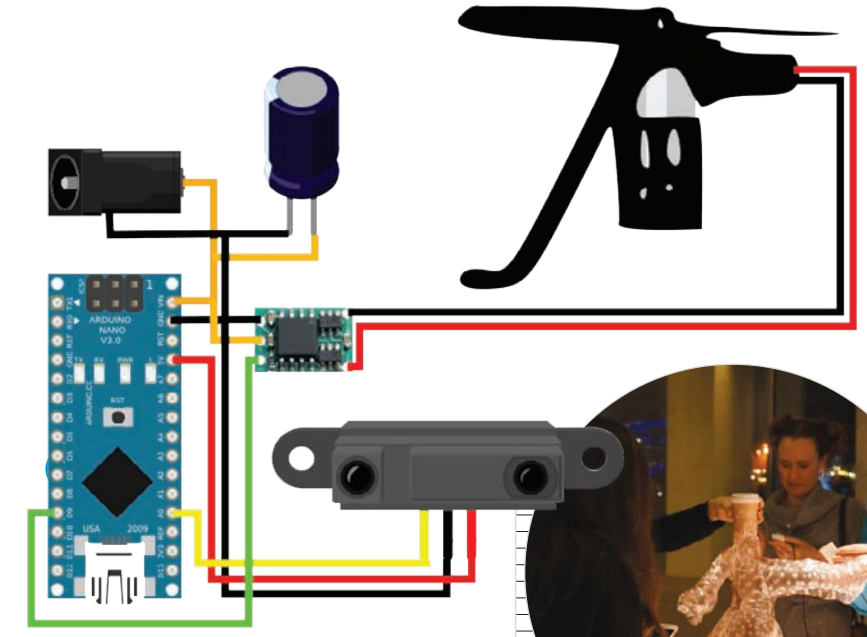
Cut a 30mm hole in the lid and bottom of the cup.

3. MOUNT THE FAN IN THE COFFEE CUP

A cardboard cutout and hot glue keep the fan centered in the cup (Figures A and B). That's it!

This fan is a nice solution for inflatable spikes, pillows, and collars —structures we've made by sewing kite fabric or by fusing layers of plastic bags using a clothes iron (instructables.com/id/Fuse-Plastic-Fabric-Technique). If you're feeling courageous, try converting your favorite 3D STL model into a sewable plan using Autodesk's 123D Make, like the "Video Game Plushies" project from *Make:* Volume 38 (makezine.com/projects/video-game-plushies).

To control the fan speed with Arduino, many solutions exist, from a single transistor (no reverse option), to a dedicated H-bridge board or a driver chip such as the L293D. Many suppliers ship small, dedicated boards taking a variety of input signals (I2C, pulse, serial) in different power categories. We ended up with the tiny ER100 board (Figure C) from German 1:87 scale model supplier Sol Expert (sol-expert-group.de). It's cheap, very small, (10mm×15mm), has awesome power characteristics (1.8A continuous, 8A peak), and takes just one wire as signal input, so it's compatible with Arduino Servo library PWM signals. You could find something similar (but not as tiny) at Pololu, SparkFun, Jameco, or Adafruit.



D

Edwin Dertien, Khiet Truong

Using this board, the electronics are pretty straightforward. In the diagram shown here (Figure D), we use an Arduino Nano, Sharp distance sensor, our InflataCup fan, ER100 speed controller, a large 1,000µF capacitor, and a DC power socket (taking 5V–6V, typically from a power bank or 4 AA batteries). Best of all, the control is proportional (like a servo) and you can both inflate and deflate your garment using the same fan!

All in all, it has been a great experience to test these building blocks during the workshops at Stanford and Twente. Thanks to all the participants, we've found some very interesting technology seeds for further development. In December we put the InflataCup to use in a new project, the *Inflatable Manifestation Dress* (see page 76). We can't wait to see what you'll inflate!

Build another project for inflatables — a pneumatic air muscle — and see more photos at makezine.com/go/inflatable-wearables.

COSPLAY FOR DAYS: Workshop participants used the InflataCup to create inflatable forms that look awesome for costumes, resembling trees, tentacles, serpents, or even an alien chest burster!

1-2-3 Mummify a Banana

Written by Frank E. Yost ■ Illustrated by Andrew J. Nilsen

WHY MOUNT A STINKY FISH ON THE WALL WHEN YOU CAN MOUNT A MUMMIFIED BANANA INSTEAD? HOW COOL IS THAT!

Some say Egypt is the birthplace of civilization with its architecture, hieroglyphics, and — even more famous — its mummies. *Mummification* is the process of drying and/or embalming a dead person, animal, or plant, mainly to preserve it from decay. Regular household baking soda is similar to salts the ancient Egyptians used for *desiccation* — drying out the body — and that's what you'll use on your banana.

1. DESICCATE YOUR BANANA

Cover the bottom of the box with baking soda, 1" deep or more. Place the banana on top, then cover it with a blanket of baking soda. Place the box in a warm, dry spot in the house.

Within a week, you'll notice the banana has started to shrink. Its moisture is being absorbed by the baking soda. Remove the banana from the hardened soda bed, break up the soda chunks, then cover with a new blanket of soda. Keep desiccating your banana this way for 6 months.

2. VARNISH IT

After 6 months the banana will be shrunken and black, wrinkly like a raisin and soft like leather. Gently brush and scrub away the soda, then use a heat gun or hair dryer to dry the banana even more.

Tie the stem to a wire coat hanger. Cover your banana with a thick coat of varnish. You want it to look glassy in appearance. Hang it to dry.

I made two banana mummies, one wrapped and one unwrapped. I like the unwrapped better. For the wrapped one, I cut ½" strips of an old bedsheet, soaked them in varnish, then wrapped the banana tightly from the bottom up.

3. MOUNT IT

Nail your banana mummy on a wooden plaque and mount it on the wall for all to see. If King Tut were alive today, he would be proud.

What else can you mummify? Share at makezine.com/go/123-mummify-a-banana.

FRANK E. YOST is an artist from Minnesota with interests in biking, drawing, woodcarving, bronze casting, welding, and R/C cars. Watch for his new book *The Giant Water Tower* on Kindle soon.

Time Required: 6 Months

Cost: $10–$15

You will need:

- **Banana, ripe** A little bit brown is good.
- **Small box** that your banana can fit in
- **Baking soda, large box (4lb / 1.81kg)**
- **Brush**
- **Scouring pad, soft**
- **Hair dryer**
- **Varnish**
- **Wooden plaque (optional)** A 6"×10" oval works well.
- **Hammer and nails**

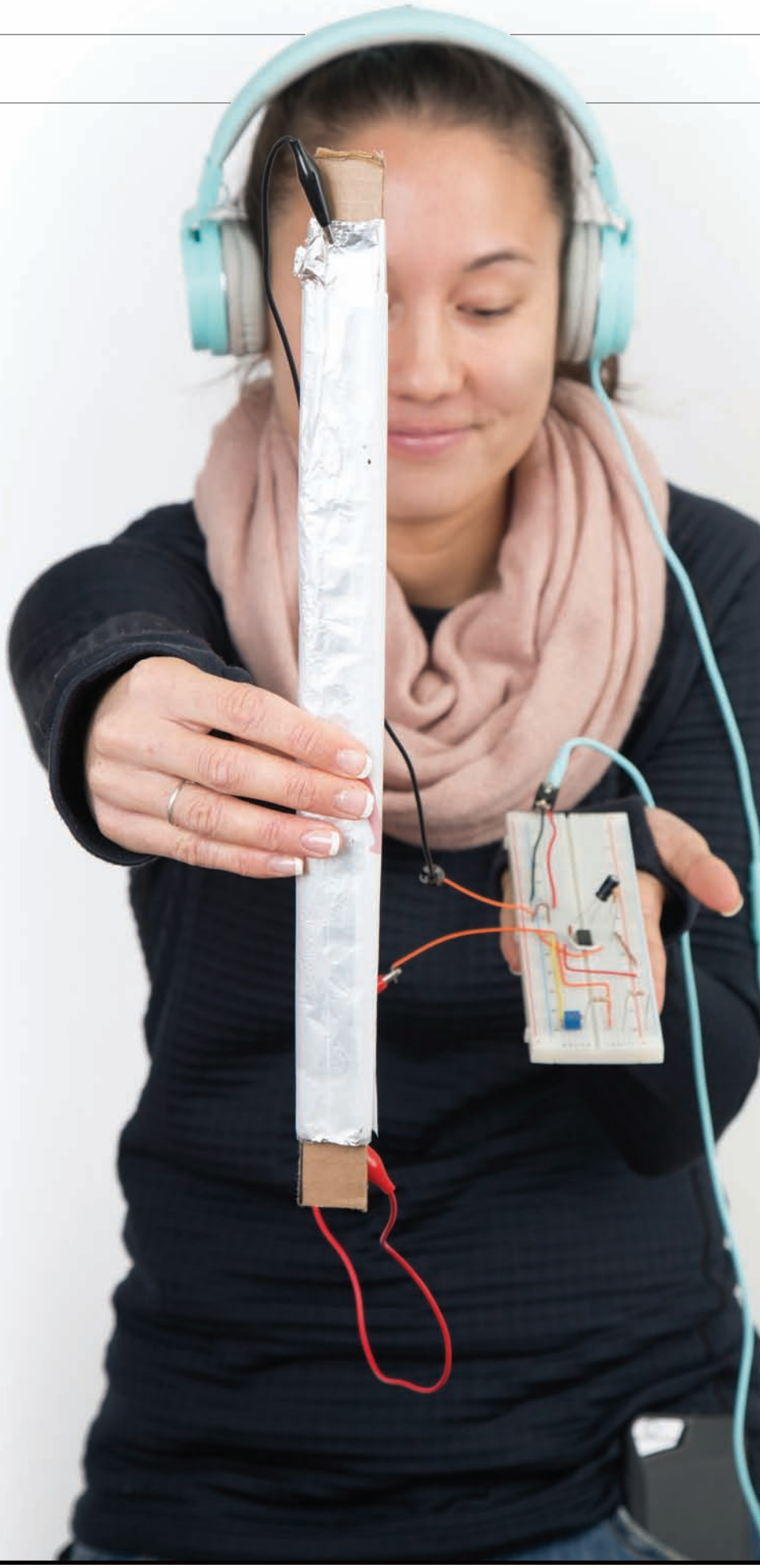
Frank E. Yost

The Sound Squeezer

Time Required: 30–60 Minutes
Cost: $10–$20

Entertain yourself with a homemade capacitor

Written by Charles Platt



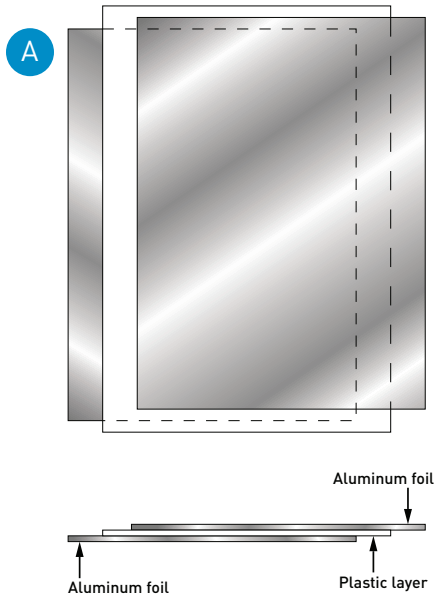
CAPACITANCE — THE ABILITY TO STORE A CHARGE — IS ONE OF THE STRANGEST ELECTRICAL PROPERTIES. Every object in the universe that can conduct electricity has capacitance with every other object in the universe. The only reason you don't notice this is that the effect is so small — unless the objects are extremely close together.

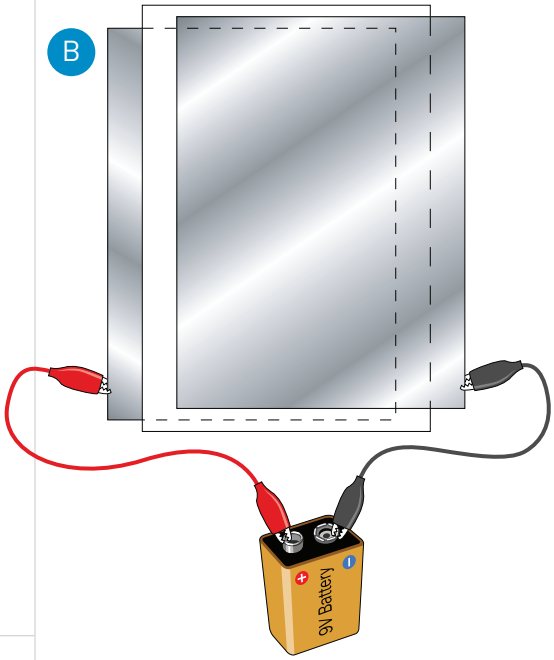
To construct a capacitor, all you need are two pieces of aluminum foil brought extremely close together, and an insulator between them. Add some voltage, and the capacitor stores it like a battery (although a tiny one). The opposite charges on the pieces of foil attract each other, holding themselves in place.

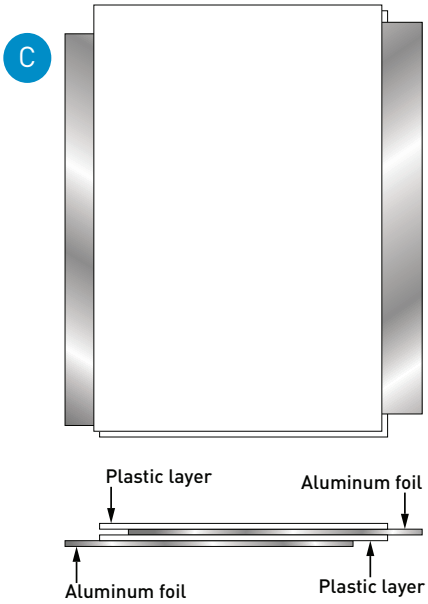
MAKE A DIY CAPACITOR

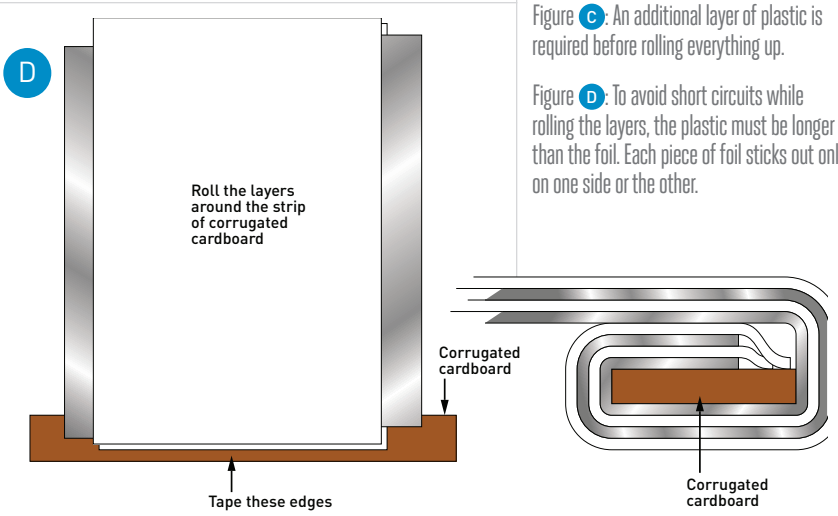
Start with a plastic supermarket shopping bag — the type that's so thin, it tends to fall apart if you try to carry a gallon of milk in it. I used a bag from my local Family Dollar.

Cut around 2 edges of the bag, trim away the









handles, and you should have a sheet measuring about 12"×18". Patch any holes in the bag with Scotch tape.

Cut 2 pieces of aluminum foil that are the same width as the plastic, but 2" shorter. Sandwich the plastic between the sheets of foil, which are offset from each other so they stick out at either side, as shown in Figures A and B. The sheets of foil must not touch each other. That's important!

This is your capacitor. If you have a meter that measures capacitance, attach one lead to each piece of foil. I got a reading of 3nF, which is 0.003µF. This may seem disappointingly low — but we can increase it by rolling up the layers to pack them closer together.

Lay another piece of plastic over the upper sheet of foil, so that the aluminum sheets won't touch when they are rolled around each other. (Figure C) shows what I have in mind.

Now cut a piece of corrugated cardboard about 15"×1", tape the bottom edge of your foil-and-plastic assembly to it, and roll the foil and the plastic around the cardboard, as shown in Figure D. Add more tape to prevent everything from unrolling.

CHARGE AND DISCHARGE

To check for short circuits, use a meter to measure the resistance between the 2 sheets of foil, which should be zero. If you have no meter, put a 9V battery in series with a 1K resistor and an LED, as in Figure E. Touch the LED to the battery and the resistor to the foil. The LED may flicker briefly, as the capacitor charges through it. After that, the LED should stay dark. If it lights steadily,

Materials

- **Roll of aluminum foil** thinnest available
- **Plastic shopping bags (2)** thinnest available
- **Corrugated cardboard, 1"×15"**
- **Adhesive tape**
- **Alligator patch cords (4)**
- **9V battery**
- **Generic red LED, low-current**
- **Resistors: 100Ω (1), 1kΩ (1), and 4.7kΩ (2)**
- **Trimmer potentiometer, 50kΩ**
- **Capacitors: 0.01µF ceramic (1), 100µF electrolytic (1)**
- **555 timer IC chip, TTL type**
- **Speaker, 8Ω, 3" or smaller**
- **Breadboard and hookup wire**

Tools

- **Scissors or utility knife**
- **Multimeter or capacitance meter (optional)**

CHARLES PLATT is the author of *Make: Electronics*, an introductory guide for all ages, and its sequel *Make: More Electronics*. makershed.com/platt

Figure A: A capacitor can consist of 2 layers of aluminum foil separated by a thin layer of plastic. The layers of foil must not touch each other.

Figure B: Charging the capacitor. A momentary connection is all you need.

Figure C: An additional layer of plastic is required before rolling everything up.

Figure D: To avoid short circuits while rolling the layers, the plastic must be longer than the foil. Each piece of foil sticks out only on one side or the other.

Charles Platt

Hep Svadja

you'll have to unroll your capacitor to find where the sheets of foil are touching each other.

My rolled-up capacitor had a value of 73nF. This still seems low compared with the physical size of the thing, but we can have some fun with it.

Charge your capacitor by touching the battery to it, as in Figure F. Now discharge the capacitor through your LED and the 1K resistor. If you watch carefully, and your room lighting isn't too bright, you'll see the LED flicker, proving that a roll of foil and shopping bags really can store and release electricity.

Next you can run a more counterintuitive test, shown in Figure G. First discharge the capacitor through the black wire at the bottom. Then touch the red alligator clip to the capacitor, and the LED will flash. You might wonder how this can happen, because the 1K resistor ensured that the right-hand end of the capacitor was at zero volts. So how did the right-hand side of the LED become positive enough to make it flash? Because even though a capacitor will not pass DC current, it will pass a brief pulse of current sufficient to light the LED. This is sometimes called displacement current, and I think it's so interesting, I added a section explaining it in the new edition of my book *Make: Electronics*.

SQUEEZABLE AUDIO

For added entertainment, use your capacitor to control the audio output of a 555 timer. The schematic is in Figure H, and a breadboard layout is in Figure I. Adjust the basic tone with the trimmer potentiometer, then press down hard on your rolled-up foil and plastic, and the tone should drop. This is what I call the Sound Squeezer. It gives you a source of instant vibrato.

The Sound Squeezer works because when you press the layers closer together, you increase their capacitance. And why does this happen? A simple formula describes it, but I don't have space to go into this here. You can find it online at makezine.com/go/sound-squeezer.

One last idea, suggested by my friend and collaborator Jeremy Frank: To achieve a higher capacitance value, forget about shopping bags and cooking foil and instead use a space blanket made of mylar film silvered with aluminum on one side. Two rectangles of that would be all you need.

In the meantime, the Sound Squeezer proves that capacitance is everywhere around you, if you take a moment to look for it.

See more step-by-step photos and share your build at makezine.com/go/sound-squeezer.

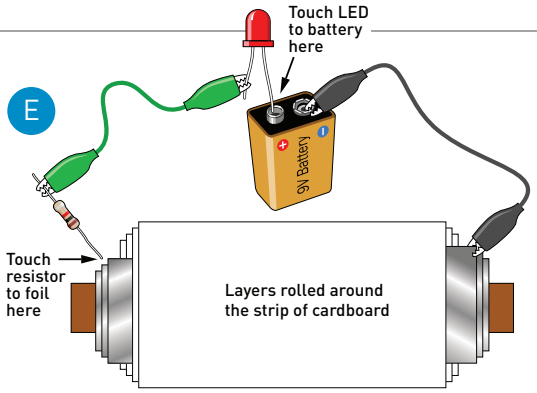


Figure E: Test for short circuits. The long lead of the LED is on the right. If the LED lights steadily, the layers of foil are touching each other somewhere.

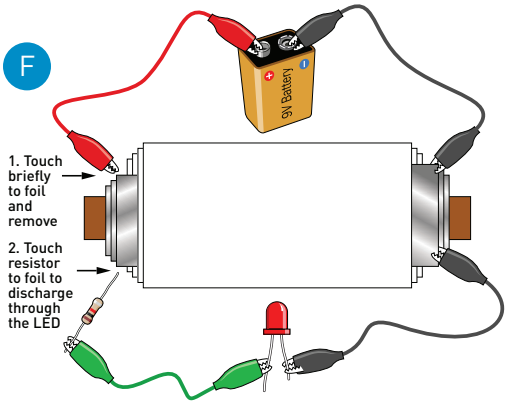


Figure F: Apply voltage momentarily to charge the capacitor. Then discharge the capacitor through the LED. The long lead of the LED is on the left.

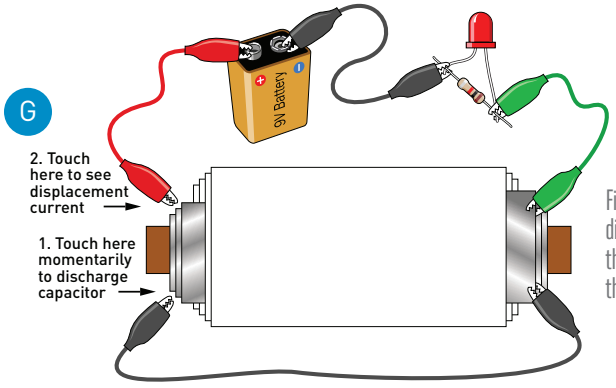
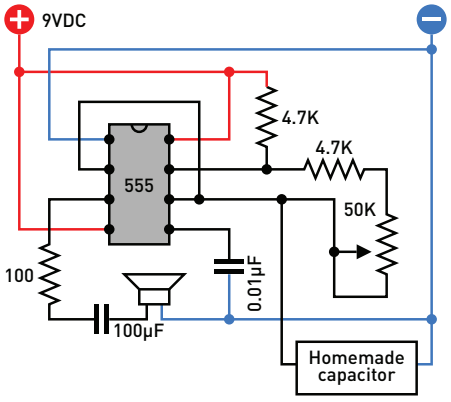
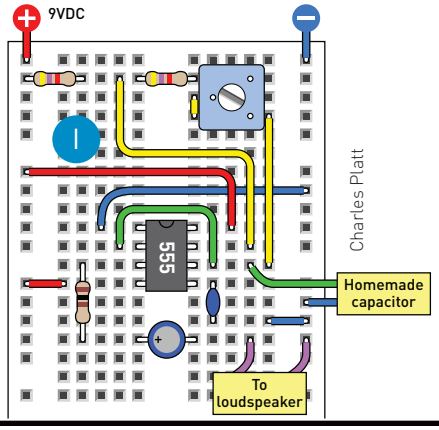


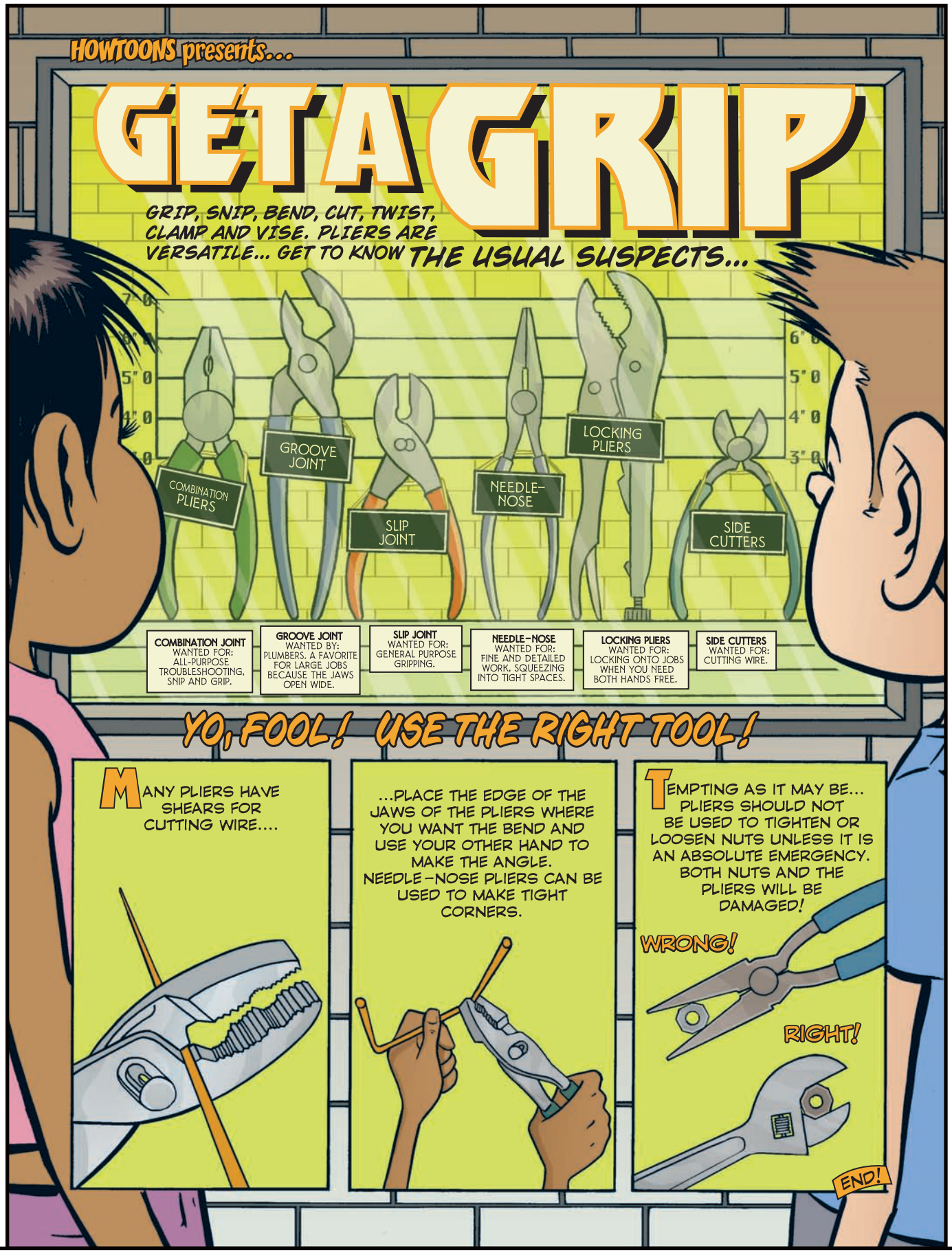
Figure G: Now you can witness displacement current, which passes through the capacitor. The long lead of the LED is on the right.

H Figure H: Schematic for generating squeezable audio.



I Figure I: Breadboard layout for squeezable audio.

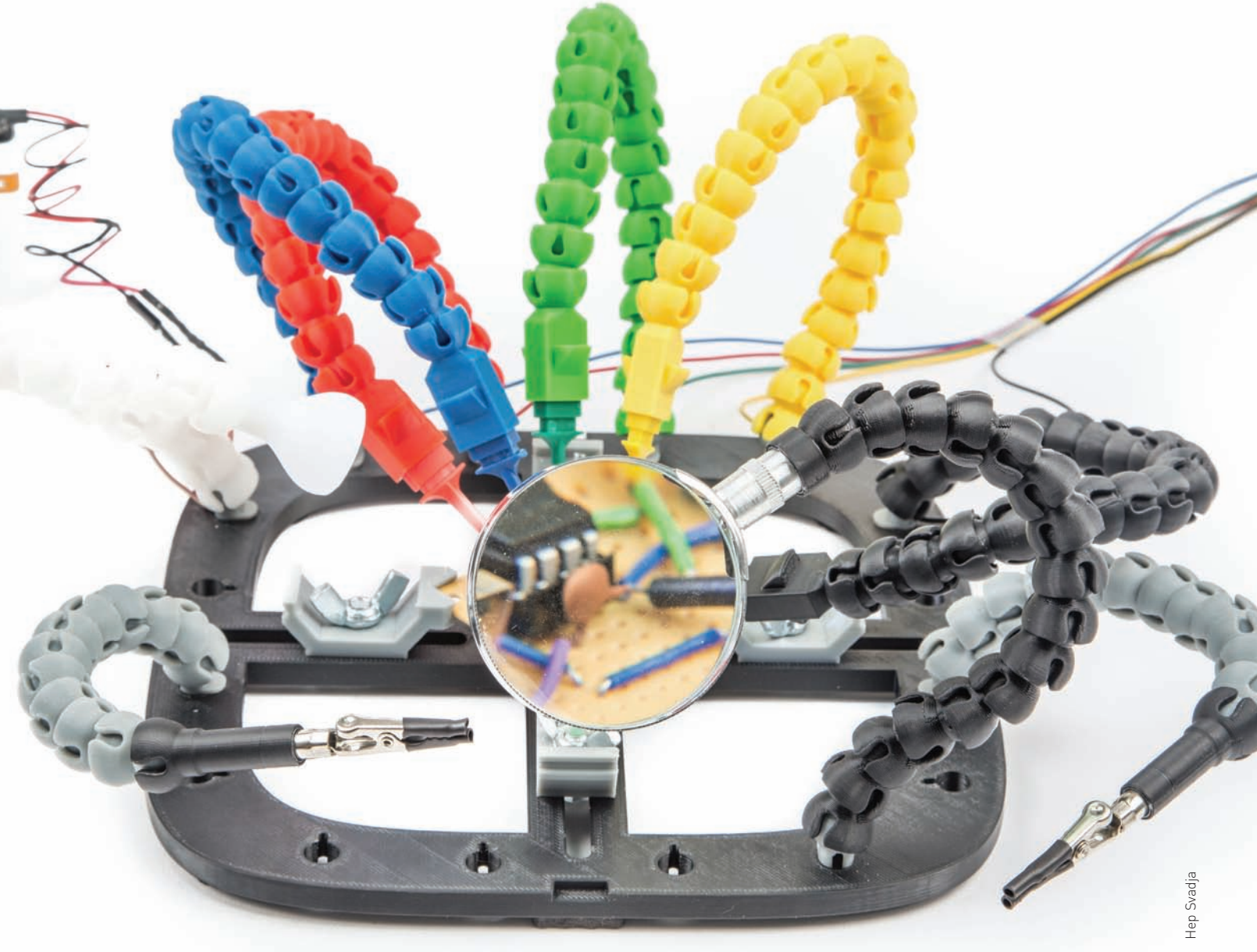



HOWTOONS presents...
GET A GRIP
GRIP, SNIP, BEND, CUT, TWIST, CLAMP AND VISE. PLIERS ARE VERSATILE... GET TO KNOW THE USUAL SUSPECTS...
COMBINATION PLIERS
GROOVE JOINT
SLIP JOINT
NEEDLE-NOSE
LOCKING PLIERS
SIDE CUTTERS
COMBINATION JOINT WANTED FOR: ALL-PURPOSE TROUBLESHOOTING, SNIP AND GRIP.
GROOVE JOINT WANTED BY: PLUMBERS. A FAVORITE FOR LARGE JOBS BECAUSE THE JAWS OPEN WIDE.
SLIP JOINT WANTED FOR: GENERAL PURPOSE GRIPPING.
NEEDLE-NOSE WANTED FOR: FINE AND DETAILED WORK, SQUEEZING INTO TIGHT SPACES.
LOCKING PLIERS WANTED FOR: LOCKING ONTO JOBS WHEN YOU NEED BOTH HANDS FREE.
SIDE CUTTERS WANTED FOR: CUTTING WIRE.
YO, FOOL! USE THE RIGHT TOOL!
MANY PLIERS HAVE SHEARS FOR CUTTING WIRE....
...PLACE THE EDGE OF THE JAWS OF THE PLIERS WHERE YOU WANT THE BEND AND USE YOUR OTHER HAND TO MAKE THE ANGLE. NEEDLE-NOSE PLIERS CAN BE USED TO MAKE TIGHT CORNERS.
TEMPTING AS IT MAY BE... PLIERS SHOULD NOT BE USED TO TIGHTEN OR LOOSEN NUTS UNLESS IT IS AN ABSOLUTE EMERGENCY. BOTH NUTS AND THE PLIERS WILL BE DAMAGED!
WRONG!
RIGHT!
END!

Doc Ock Work Dock

Create a custom PCB workstation for your electronic projects

Written by Giuseppe Finizia



Hep Svadja

I WORK IN A WELL-EQUIPPED LABORATORY DEALING WITH TECHNICAL INVESTIGATIONS ON SEIZED ELECTRONIC DEVICES. I needed a way to secure small printed circuit boards (PCBs) on my workbench and place multiple probes across the board for acquiring data from a circuit memory.

To create the perfect tool for my needs, I designed this 3D printable workstation with multiple articulated arms that allow me to connect any given board to the lab instruments for analysis.

1. PRINT THE PARTS

Find the files at thingiverse.com/thing:801279, and print the base platform and pieces of the PCB workstation with your 3D printer. Choose the base type that best suits your needs and your 3D printer dimensions.

I had great results using HIPS filament with a 0.19mm layer thickness (medium infill) for the base and 0.14mm (solid fill) for the rest. ABS also holds up well. PLA, however, tends to be too fragile for the arm joints.

2. MOUNT THE SILICONE BUMPERS

Apply 5 silicone bumpers beneath the base, one in each corner plus one in the center, so it will be more stable on your desk (Figure A).

3. ASSEMBLE THE PCB HOLDERS

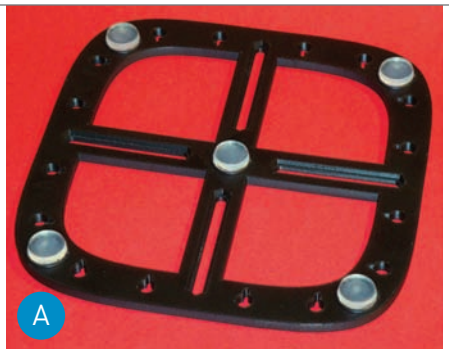
The base uses 4 sliding pieces arranged in a cross to anchor the PCB in place. Use the wing nuts and hex bolts to attach the holders to the base (Figure B). Each holder offers two faces — one for straight sides, the other for the corners.

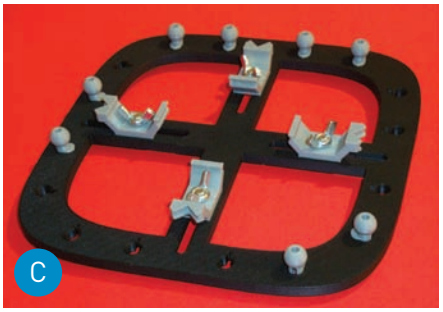
4. MOUNT THE BASE JOINTS

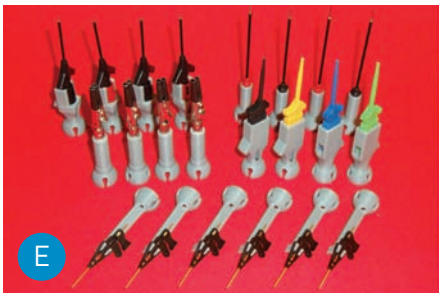
The base includes multiple holes where joints can be attached to hold the articulated arms. Base joints include a slot for passing an electrical cable through to the probe tip of your choice (Figure C).

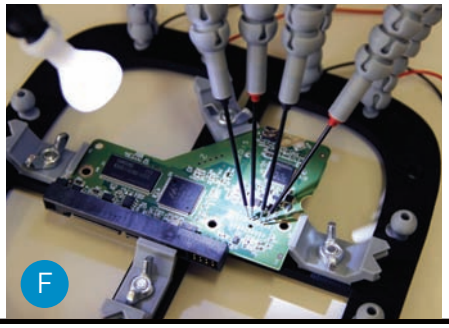
5. ASSEMBLE THE ARMS

Articulated arms are made to any length by assembling multiple ball and socket joints. In most cases, 20 elements should be sufficient. Within the arm is an internal duct for a probe cable.









GIUSEPPE FINIZIA is a computer engineer working as the Senior Analyst of the Electronic Forensics Unit of the Carabinieri. His colleagues call him "the inventor" because he often makes something new and original.

Time Required:
A Weekend
Cost:
$30–$50

Materials

- 3D printer filament (ABS or HIPS)
- Silicone bumpers (5)
- Heat-shrink tubing
- Wing nuts, 5mm (4)
- Hex bolts, 5×12mm (4)
- Test probe tips
- LED, super bright white (optional)
  Battery, 9V (optional)
- Resistor, 180 Ohm (optional)

Tools

- 3D printer

For a stiffer arm, I've designed a slightly smaller ball joint you can print that allows heat-shrink wrap to be applied to the ball portion of the joint (Figure D). I recommend a 0.27mm (270 micron) thick wrap, 9mm in diameter.

6. INSTALL CUSTOM TERMINALS

The terminal elements of the articulated arms are designed to accommodate different accessories and components. If you haven't already, print and attach the correct adapters for the probes you'll be using (Figure E).

GOING FURTHER

There are many ways to expand and adapt this workstation. I've created a base extension for mounting larger PCBs, or mounting them vertically. There's also an LED lamp arm that can be created with a single, super bright LED, 9V battery, and a 180 Ohm resistor (Figure F). Additional parts can be printed for adding a magnifying glass holder, or other specialized probe types. Better yet, create your own parts to adapt my design for exactly what you need.

View this project online by visiting makezine.com/go/3d-workstation.

Giuseppe Finizia

Pirate Radio Throwies

Written by David Scheltema and Tyler Winegarner
Illustrated by Jacob Thomas

Build magnetic micro-stations with the Raspberry Pi Zero

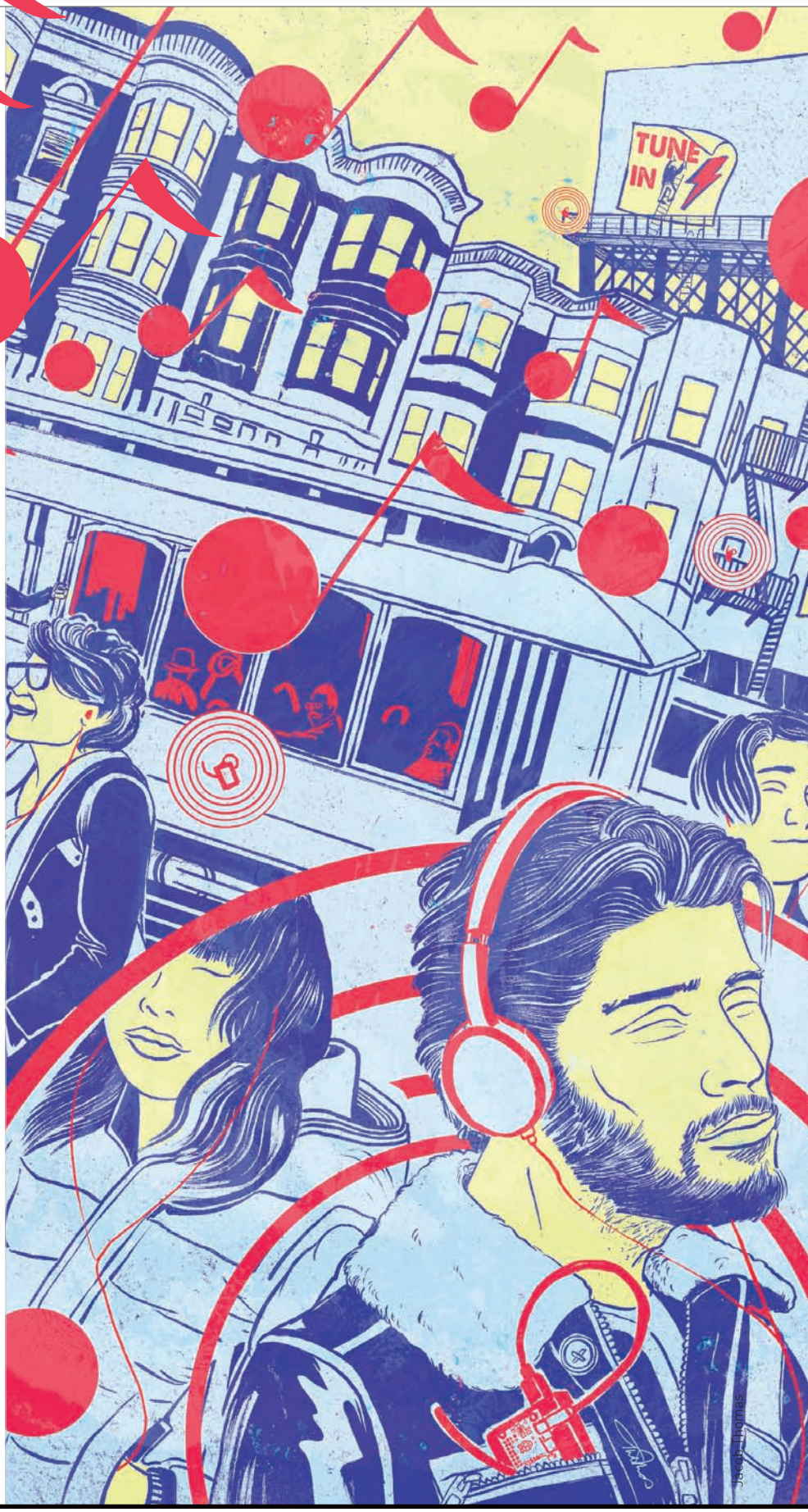
EVER WANTED YOUR OWN PIRATE RADIO STATION? HOW ABOUT A HANDFUL? Thanks to the new low-cost Raspberry Pi Zero computer — 5 bucks! — making your own pirate transmitter is so inexpensive you can make and deploy lots of them at once. And, because of the Pi Zero's small size, we were able to shrink our original Raspberry Pirate Radio project into a magnetic "throwie" form factor, so it can be simply tossed onto any available metal surface.

Like the original build (which used a Pi Model B), the throwie version runs two pieces of software called PiFM and MPG123, along with a Python script, to broadcast FM signals over a wire antenna soldered to pin 4 on the Pi. It's that simple! The Pi Zero is attached to a battery pack glued to strong magnets for ultimate sticking power.

TIP: For a cleaner FM signal, and to reduce any accidental broadcasts outside the FM band, build a simple bandpass filter for your Pirate Radio using just a few components at makezine.com/go/pirate-bandpass.

Broadcast range is a few hundred feet. Now you can blanket your home, school bus, cafe, or silent disco with your own private FM micro-stations! (Check local and federal laws first, of course.)

For step-by-step instructions and tips on safe broadcasting, check out the project online at makezine.com/go/pirate-radio-throwies.



Jacob Thomas

Toy Inventor's Notebook

ANAMORPHIC COLORING BOOK

Invented and drawn by Bob Knetzger

Time Required:
30–60 Minutes
Cost:
$5–$10

COLORING BOOKS ARE ENJOYING A BIG RESURGENCE, ESPECIALLY AMONG ADULTS. Here's a fun twist on coloring that uses anamorphic art. (*Anamorphic* means "without shape.") Color in the unrecognizable mystery shape, then view it as a reflection in a curved mirror: You'll see the image magically restored!

Making anamorphic drawings the traditional way involves mechanically distorting an image by transferring grid points from the original image onto a second, distorted grid, then drawing the lines to connect the points. Difficult and tedious! But the power of image editing software makes it a breeze. Draw or scan your image in Photoshop or GIMP, and place it on the bottom half of the canvas. Use *Transform→Flip Vertical* to make the image upside down and backward. Then use *Filter→Distort→Polar Coordinates* to instantly create the distortion.

Now roll a piece of mirrored mylar into a tube and place it beside your distorted image. Presto-change-o: Your original undistorted drawing appears like magic in the reflection! Color in your anamorphic art with crayons or markers.

Here's a sample image already distorted for you to color and view. Just place your mylar tube on the circle as shown.

Share your anamorphic art at makezine.com/go/anamorphic-coloring-book.

TOOLBOX

GADGETS AND GEAR FOR MAKERS

Tell us about your faves: *editor@makezine.com*

ALL IN ONE HOT AIR REWORK AND SOLDERING STATION

$230 xtronicusa.com

Not all soldering irons and stations are created equal. I personally own several, and I've found that X-Tronic produces consistently high quality products — so when I saw their 5040 all-in-one station, I had to get my hands on it. The unit is decked out with all the bells and whistles and well, let's just be honest, it looks really cool.

This set allows you to assemble or rework a board full of components. It includes a 70W soldering iron, 500W hot air gun, control station, and various bits and accessories that allow for a variety of applications while freeing up your hands. In fact, the entire rework station keeps workflow and ergonomics in mind.

— Emily Coker

ROCKLER SILICONE PROJECT MAT

$30 rockler.com

Whether you are a hard-core DIYer or a part-time home crafter, Rockler's silicone project mat is a welcome addition to any workshop. Not only can it handle the heat from glue guns, it also makes cleanup a snap no matter what kind of adhesive you use. Silicone, rubber cement, craft glue, and more all peel right off when it comes time to put everything away.

The 15"×30" mat is large enough to cover a decent-sized work area, and the ridged surface is also useful to corral loose screws and small hardware, while the silicone self-heals small cuts. It's also the perfect mat for photographers or videographers, as the unique slanted line pattern makes camera registration a breeze. *— Hep Svadja*

PALETTE GEAR MODULAR APP CONTROLLERS

$199+ palettegear.com

Every computer program is designed for keyboard and mouse control, but that doesn't make this the quickest, easiest, or most comfortable way to work.

Working with creative apps, such as Adobe's Lightroom, Photoshop, or Illustrator, can involve a lot of repetitive tasks, such as making the same mouse movements over and over again to tweak a RAW photo. This can be quite fatiguing.

Palette Gear has come out with a new controller system that consists of programmable sliders, dials, and buttons that can be set to control common Adobe tasks, such as adjusting the exposure level in photos.

I have found that, in addition to saving me some time and hand fatigue in a long photo editing session, Palette Gear switches allow for a finer level of control than I can usually achieve with just my mouse.

Their modular control system isn't just limited to Adobe programs — it can be set to a keyboard emulation mode, and there's also a Beta joystick mode, allowing you to map the controls to many of your other favorite programs. The latest software version allows for effortless setup and use.

Palette Gear could even potentially be used for controlling hardware, such as a tethered robot, but its benefits shine brighter when used for your favorite computer programs.

Sure, it's relatively easy to program an Arduino and a couple of buttons for keyboard shortcuts (such as `alt-shft-ctrl-W` for exporting images in Photoshop). But dials and sliders that can be reconfigured quickly and for different programs is a whole other story, which is why Palette Gear has quickly proven itself to be worth its place on my desk.

My only complaints are 1) I have to reconnect the Palette Gear module after a reboot or if I shutdown their program, and 2) I can use the dial in *Kerbal Space Program* to control thrust, but not the slider, which can only be set to an axis in Joystick mode. *— Stuart Deutsch*

Hep Svadja

SMARTSCOPE BY LABNATION

$229 lab-nation.com

LabNation's open source SmartScope is a relatively new offering in the world of USB oscilloscopes. Designed to be used with tablets, phones, and laptop/desktop computers, it's a perfect portable package for on-the-go circuit debugging. Its two channels capture 100MS/s each (at up to 30MHz), which is more than enough for troubleshooting the average microcontroller or single-board computer project.

In addition to its oscilloscope functions, the SmartScope can also act as an 8-input logic analyzer or a 4-output function generator, making it a great all-around device to carry in your portable kit. It can decode I2C, SPI, and UART signals, and can apply all of the traditional math and FFT functions that you'd expect in a modern digital oscilloscope.

The SmartScope software is incredibly intuitive, with a touch-based interface that leaves those fiddly benchtop scope knobs in the dust. The software runs on Android, iOS, Mac OS, Windows, and Linux, meaning you'd be hard-pressed to find a device it doesn't work with. From the interface, you can also export captured waveforms to Excel (.csv) or Matlab, and store the files in Dropbox. This tiny feature-rich oscilloscope is a perfect option for both beginner and advanced Makers alike.

— Jordan Bunker

NUGREEN LED DESK LAMP

$70 newertech.com

I've been using this excellent little task lamp all over the place. It has a low-profile head filled with 50 bright white (4,500K) LEDs, which, along with its adjustable gooseneck, makes it easy to light just the right angle on a project. I've had it illuminate the locks under a video camera during a lock picking class, light a 3D printer bed for build photos, and help me with some fine electronics soldering. I like the nifty capacitive switch at the base — a touch of the finger turns it on or off; a longer press activates the dimmer.

I honestly didn't expect it to be such a workhorse, but I really do grab it and take it from my garage workshop to my electronics workbench to the kitchen table, and elsewhere depending on where I'm working. Intriguingly, the cord running from the base of the lamp to the wall transformer has a barrel plug connector in line, meaning you could run it from a 12V battery source with ease, just in case you need to tinker on the go.

— John Edgar Park

UZEBOX STARTER KIT

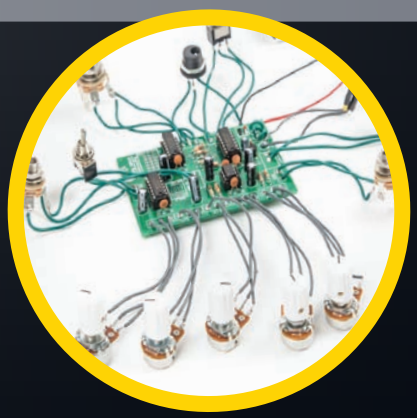
$75 adafruit.com

The Uzebox is an open source 8-bit game console that you build yourself. It's based on the AVR 8-bit general-purpose microcontroller by Atmel, and is designed with programmers in mind to help create and expand on their own games and demos. Your code will be kept clean while the audio and visuals run in real time on the operating system's background from the full-featured core.

Key features: 256 simultaneous output colors, 240×224 pixel resolution, tile and sprite support, two player ports for use with Super Nintendo controllers, and more. You can write game code for it in C, using fully open source tools on any platform.

The kit is best suited for people who are familiar with soldering and putting advanced PCBs together with various components including the pre-programmed chips. It'll take about 2 hours of soldering to fully assemble.

The Uzebox is perfect for those nostalgic gamers who love classic games. A preloaded SD card comes with *Space Invaders*, *Donkey Kong*, *Pac-Man*, and over 100 more. And the unit is completely mobile and plugs into anything with audio/video cables. *— EC*



SYNTHROTEK ATARI JUNK CONSOLE

$50 makershed.com

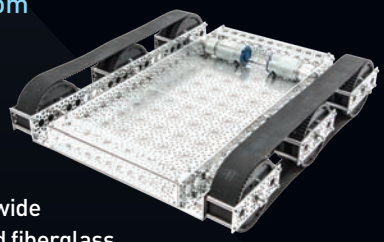
Beep, Zoom, Pow! No, this is not a Bjork song; it's the lovely sounds of the Synthrotek Atari Junk Console. Since 2009, Synthrotek has been making high-quality sound kits and products for geeks, musicians, and noise enthusiasts.

The Atari Junk Console takes everything from its cousin, the Atari Punk Console, and ramps it up a notch. The kit comes with all the materials you will need to build and solder it. Some of this gets a little tricky — it is recommended for those who are a little more advanced in their soldering and circuit skills. An optional case is sold separately, or you can make your own. *— EC*

ACTOBOTICS AGENT 390 TRACKED ROBOT KIT

$390 with motors, **$330** without

servocity.com



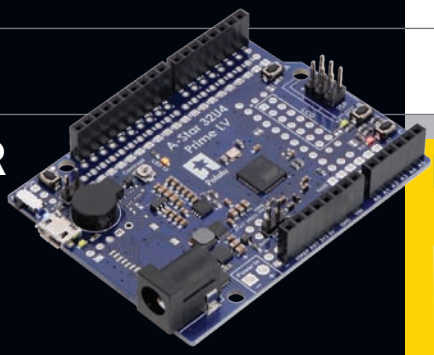
How strong a robot do you need? This 8lb, 18" long tank chassis rolls on 1.5" wide neoprene and fiberglass tracks running on 12 ABS pulleys, with three bearings on each quarter-inch steel axle. It's (optionally) powered with two 313-RPM, 416-oz-in., 12VDC planetary gear motors, and it's strong enough to slowly carry a child.

I followed Servo City's assembly video and built this in an afternoon. You'll need a 7/64" hex key to assemble it, as the connections are mostly #6 socket-head bolts. (A long T-handle hex key works well.) The kit doesn't come with electronics, so I hooked up a pair of Arduino-powered Turnigy 30W DC speed controllers. Actobotics clearly designed the tank treads for the model because they fit so snugly — my favorite detail.

If you need a strong, low-slung (1.25" floor clearance, max 37° ascent) robot chassis, the Agent 390 might be the solution.

— John Baichtal

POLOLU A-STAR 32U4 PRIME ARDUINO-COMPATIBLE BOARDS



$20–$35 depending on options pololu.com

There is no shortage of Arduino and Arduino-compatible boards for you to choose from, but you might want to pay close attention to Pololu's new A-Star 32U4 Prime offerings. Their new boards offer some very compelling features that set them apart from most of the other Arduino-compatible boards I've seen.

To start off, there are two versions — the A-Star 32U4 Prime SV (standard voltage), which can be connected to 5V–36V power sources, and the A-Star 32U4 Prime LV (low voltage), which can work with 2.7V–11.8V power sources. Robust onboard regulators allow for greater flexibility when designing your project.

You also get power distribution rails, a built-in power switch, three controllable LEDs, a switch for external power inputs, and reverse-voltage protection on external power inputs. And there are buzzer, microSD, and small character LCD options.

Pololu offers five flavors for both LV and SV boards, from bare minimum with no headers to fully featured with headers and all options included, making this one of the most versatile and Maker-friendly Arduino-compatible boards I've come across.

— SD

MAKEY MAKEY GO

$25 makeymakey.com

The $25 Makey Makey Go is a USB stick that allows any conductive object (a spoon, aluminum foil, even food) to mimic a single key on your computer's keyboard or a click of your mouse.

Where the Makey Makey Go becomes handy is as an accessory for teachers and students to bridge the digital world of custom code into the tangible world of custom hardware. For example, kids can trigger their Scratch code with whatever object feels appropriate. It could be a big red button, or maybe a cardboard sword wrapped in foil.

Unlike the original Makey Makey (which is still available for $50), the Go version is limited to only one input. That single-button limitation can be frustrating if you wanted to interact with software or a game with multiple controls. But once I came around to the idea of thinking of the device as an event trigger, and not so much a 1-button game controller, I could zero in on the kinds of applications that made sense.

There's something to be said for the elegant, compact design of the Go. With its price, features, and approachable design, I am certain that it will be a staple of science fair projects for years to come. It's a great way to compliment handmade software with a handmade interface.

— Donald Bell

BOOKS

THE FOOD LAB

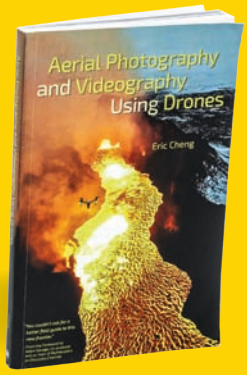
by J. Kenji López-Alt
$50 W.W. Norton & Company

At its core, cooking is making. Both activities use tools to assemble a variety of materials into something new and wonderful. And while cooking is even more widespread than building projects in the workshop, most of us only know how to follow a recipe, rather than understanding why the recipe works.

In *The Food Lab*, MIT-trained culinary scientist J. Kenji López-Alt explains that "why," breaking down his technical approach to cooking food perfectly while teaching the reader how to reproduce his results. He examines core concepts as simple as boiling pasta, disproving the advice of generations. He details the reason you want to cook your salmon skin-side-down. And it's likely the only cookbook that illustrates the ideal french fry thickness using a pair of calipers.

If there's one complaint, it's the lack of pizza — López-Alt's online pizza lessons are legendary — but at just shy of 1,000 pages, there's plenty of food-science knowledge to make up for that.

— Mike Senese



AERIAL PHOTOGRAPHY AND VIDEOGRAPHY USING DRONES

by Eric Cheng
$36 Peachpit Press

In his enlightening new book, author Eric Cheng, professional photographer and former DJI director of aerial imaging, helps guide novice pilots to becoming adept in the air, both flying and filming. He provides a variety of exercises designed to overcome the in-air directional confusion that plagues amateurs (and dooms many a drone), and details the mechanics of creating impressive video shots, including orbit and crane maneuvers. For beginning and intermediate drone pilots, these lessons are extremely valuable.

The book also includes a thick section of gorgeous full-color aerial photos from Cheng and other drone professionals, guaranteed to make you want to trek to your nearest erupting volcano and try to get similarly amazing images.

— MS

MELEPHANT

THIS MODDABLE SYSTEM SHOWS OFF A VERSATILE CONSTRUCTION PLATFORM

WRITTEN BY MATT STULTZ

IF YOU ARE LOOKING TO GET STARTED IN 3D PRINTING WITHOUT A LARGE INVESTMENT, the mElephant printer by Makeblock offers a decent starting point with lots of possibilities for improvements. While we found the print performance a bit lacking, the modularity of the system shows great potential.

A FAMILIAR HUE

The mElephant is based off of the extremely popular i3 printer design by Josef Prusa. However, the mElephant ditches the printed parts found in most i3 designs for the electric-blue anodized aluminum components that Makeblock is known for. The mElephant's frame lends stability to its prints thanks to the boxy design, which also nicely houses the sharp and clear OLED control screen.

SUPER EASY SETUP

Upon unboxing, you will find a cute little elephant test print already adhered to the bed of the machine. Don't toss this out — it's actually a fun little cellphone or tablet stand! Once we removed the elephant, setup was easy, especially since the mElephant features an auto bed-leveling sensor. This doesn't physically adjust the bed, but instead helps the printer to compensate for any irregularities during the print. The only portion of the printer you need to assemble is the included filament spool holder. This goes together quickly without the need for any hand tools. While the spool holder felt a little cheap to begin with, it actually worked quite well during our testing.

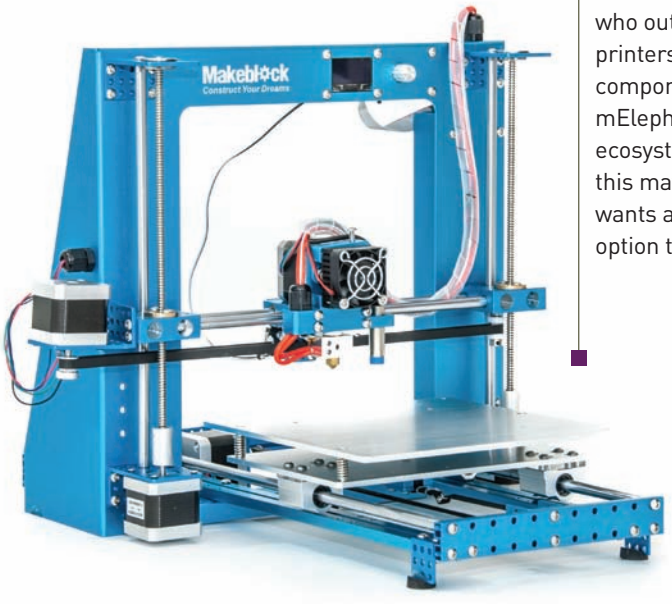
Makeblock recommends using Cura as the software interface. The two included printing profiles allow you to run the printer tethered if you wish, or to transfer the G-code it has created to the printer via SD card. The mElephant uses a microSD card and includes a small USB card reader with its other accessories.

PLA PREFERRED

The mElephant does not have a heated bed, so it's mostly a PLA-only machine. A print-cooling fan — sadly omitted — would greatly help the mElephant with PLA prints. The most significant shortfall in our tests was Z banding along the printed piece. This may be a mechanical issue, and hopefully will be fixed with future upgrades to the platform.

CONCLUSION

Looking at the mElephant, it's easy to dismiss it as a silly attempt at a 3D printer from a company that makes modern-day erector sets, but it actually shows the power of Makeblock's construction system. A user who outgrows or wants to repurpose most printers will only find themselves with a few components that they can reuse, while a mElephant owner is starting with an entire ecosystem of parts. At a penny under $600, this may be a great choice for someone who wants a fully assembled 3D printer with the option to tinker later.



PRINT SCORES

	0	1	2	3	4	5
Vertical Surface Finish						
Horizontal Finish						
Dimensional Accuracy						
Overhangs						
Bridging						
Negative Space						
Retraction						
Support Material						
Z Wobble						

TOTAL 22

MANUFACTURER Makeblock
PRICE AS TESTED $600
BUILD VOLUME 180mm×200mm×160mm
BED STYLE Non-heated aluminum
FILAMENT SIZE 1.75mm
OPEN FILAMENT? Yes
TEMPERATURE CONTROL? Yes, tool head (240°C max)
PRINT UNTETHERED? Yes (SD card)
ONBOARD CONTROLS? Yes (LCD with control buttons)
HOST/SLICER SOFTWARE Cura
OS Linux, Mac, Windows
FIRMWARE Open Marlin
OPEN SOFTWARE? Yes, both software and firmware
OPEN HARDWARE? Yes, Creative Commons Attribution ShareAlike 3.0
MAXIMUM DECIBELS 46.2

makeblock.cc

PRO TIPS

The machine's aluminum parts are pretty but soft; be careful moving it around and double-check that there are no bent pieces whenever you inspect it. If there are, you should be able to carefully bend them back into position.

WHY TO BUY

Based on the super-cool Makeblock construction system, this machine is very easy to redesign or upgrade as your needs evolve.

RESULTS

Matt Stultz is the 3D Printing and Digital Fabrication lead for *Make:*. He is also the founder and organizer of 3DPPVD and Ocean State Maker Mill, where he spends his time tinkering in Rhode Island.

Matt Stultz

The Fury Road: A Cormac McCarthy Fan Fiction

Written by James Burke

THE RUINOUS HORDES WORSHIPPED THE SUN BAKED CARNIVAL MACHINES. Oil churned and dripped like crimson sustenance to bones now crushed to dust. The heavy breathing of those sworn to Immortan Joe's loyalty syncopated to the rising howl of flames penetrating the fire breathing dunk tank called Flambé. Their cracked cancerous lips jerked gaudy and bruised while the machine engulfed the first occupant laden with protective gear all shine and chrome and they raised their hands in a violent triumph as if to suggest some cosmic specter of fate demanded them to bolster the sun up noonward. The flames rise at a barbarous tenor swinging circles inside the tank, still confined but radiant, baking the backs of the Boys now standing foot to foot up to fifty paces back. The warmth danced between the sweltering maze of pressed shoulders and shaken hands like a curious convection almost as if it too waited for its turn to throw the sand crusted ball.

What more certain validation of a man's worth can there be than this ball striking this target? The universe spent untold millennia placing the atoms of this ball in the same mote of dust as the Citadel just in reach of a black thumb named Kenny from the Two Bit Circus who built this macabre mechanization of crackling brimstone. Now in this swelteringly fatalistic inferno stands another Boy ready to deliver a satisfying throw.

The thrown ball had a perfect arc which quenched the thirst of chalky bloodlust. The dunk tank bellowed with flame and pushed and howled at another throw as the occupant flirted with immolation. They knew that only a battle could truly slake their thirst for Valhalla but they never ignore a whisper. That is the way it was and will be. That and not some other way.

In the distance Immortan Joe grinned beneath his horse-toothed mask. War Boys are born for games, he said. Nothing else. War Boys know the merit of game is not solely on the game itself but on the value of the hazard. These trials of chance or skill all aspire to the condition of war and a chance to glance at Valhalla and see my glory in that shiny reflection.

Into the night the Boys' fires danced for Immortan against god, against reason, with a clay grain and thunderous singing that he would never die. The War Rig's mission would be tomorrow and in the confines of the Boys and Joe were no divinations of the transgressions that Furiosa spun into fate. The cascading Citadel waters would no longer erode these sad stories and just as the Flambé burned carnal joys into the damned retinas there in the shadows welled the desire for freedom. They were not things, and they would not be silent.

Mike Senese